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Artigo de Investigação

LEGAL EVOLUTION OF LAND USE IN PERMANENT PRESERVATION AREAS IN TWO MUNICIPALITIES IN THE NORTHEASTERN BRAZILIAN COAST:
A PROPOSAL FOR REFORMULATING THE LEVEL OF PROTECTION OF COASTAL ECOSYSTEMS

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ABSTRACT – The preservation of coastal zones in tourist regions is essential for maintaining sensitive ecosystems and ensuring socioeconomic sustainability. Internationally significant destinations along the northeastern Brazilian coast face increasing anthropogenic pressures and legislative gaps that threaten their ecological integrity. This article examines the legal evolution of Brazil's Forest Codes (Laws 4.771/1965, 7.511/1986, and 12.651/2012), focusing on coastal areas, and compares two municipalities with distinct coastal dynamics and types of Permanent Preservation Areas (PPAs): Barreirinhas (Maranhão) and Valença (Bahia). The methodology included: (I) a theoretical review; (II) analysis of the legal framework; (III) PPAs mapping in accordance with legal criteria; and (IV) a comparative land-use analysis (1990-2023) using MapBiomas data. The results show divergent trends: in Barreirinhas, the PPAs reduced their area from 677.5km² to 649.6km² (-4%), while anthropogenic activities (agriculture, urbanization, and bare soil) increased from 27.7km² to 30.3km² (from 10% to 13.3%). In Valença, the PPAs expanded their area from 161.1km² to 228.6km² (42%); however, inadequate land uses within protected areas also increased, indicating weaknesses in conservation effectiveness. The study concludes that PPA delineation must integrate hydrological, ecological, and ecosystem-based criteria, including salt flats, saline areas, mobile dunes, and riparian zones at the national level. This approach, supported by global scientific evidence, is urgently needed to preserve critical coastal ecosystems, particularly in high-impact tourism regions.

Keywords: Tourist regions; protected areas; forest codes; conflicts.

RESUMO – EVOLUÇÃO LEGAL DO USO DA TERRA NAS ÁREAS DE PRESERVAÇÃO PERMANENTE EM DOIS MUNICÍPIOS DA ZONA COSTEIRA DO NORDESTE BRASILEIRO: UMA PROPOSTA DE READEQUAÇÃO DO NÍVEL DE PROTEÇÃO DE ECOSSISTEMAS COSTEIROS A preservação de zonas costeiras em regiões turísticas é fundamental para a manutenção de ecossistemas sensíveis e a sustentabilidade socioeconômica. Destinos de relevância internacional no litoral do Nordeste Brasileiro enfrentam pressões antrópicas crescentes e lacunas legislativas que ameaçam sua integridade ecológica. Este artigo examina a evolução legal dos Códigos Florestais (Leis n.º 4.771/1965, 7.511/1986 e 12.651/2012) com foco na zona costeira do Brasil, considerando dois municípios com diferentes dinâmicas litorâneas e tipos de Áreas de Preservação Permanente (APPs), Barreirinhas (Maranhão) e Valença (Bahia). A metodologia incluiu: (I) revisão teórica; (II) análise do marco legal; (III) mapeamento de APPs conforme critérios legais; e (IV) análise comparativa do uso do solo (1990-2023) com dados do MapBiomas. Os resultados revelam tendências divergentes: em Barreirinhas, as APPs reduziram sua área de 677,5km² para 649,6km² (-4%), enquanto atividades antrópicas (agropecuária, urbanização e solo exposto) aumentaram de 27,7km² para 30,3km² (de 10% para 13,3%). Já em Valença, as APPs expandiram sua área de 161,1km² para 228,6km² (42%), assim como os usos inadequados no interior das áreas protegidas também aumentaram, indicando fragilidades na efetividade da proteção. Conclui-se que a delimitação de APPs deve integrar critérios hidrológicos, ecológicos e ecossistêmicos, incluindo apicuns, salgados, dunas móveis e zonas ripárias em âmbito nacional. Essa abordagem, respaldada por evidências científicas globais, é urgente para conservar ecossistemas costeiros críticos, especialmente em regiões turísticas de alto impacto.

Palavras-chave: Regiões turísticas; áreas protegidas; códigos florestais; conflitos.

HIGHLIGHTS

- Innovative proposal to include coastal sub-ecosystems as new PPAs.
- Land use disrespects the law in PPAs of two coastal municipalities in NE.
- An innovative study proposes the recognition of salt flats, saline areas and mobile dunes as PPAs.
- Legal loopholes were traced in the management of PPAs in coastal areas of Brazil.

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1. INTRODUCTION

The notion of protecting areas that are representative of natural ecosystems in Brazil's territory dates back to the 1934 Forest Code (República Federativa do Brasil, 1934). This Code included preservationist aspects, regulating property use based on the type of forest present and defining categories such as protective forests, remnants, and protective models of agrarian production. The concept of Permanent Preservation Areas (PPAs), which is the main protected area established by law in Brazil, was only instituted by the Forest Code (Law. 4.771) in 1965 (Borges *et al*., 2011).

The legal evolution of the Brazilian Forest Code underwent implementations until 2012, becoming more explanatory, in an attempt to reduce dubious interpretations of the law, as well as imposing more restrictions on private property, addressing the need to maintain and protect PPAs and Legal Reserve areas. Before the publication of this Code, few regulations protected environmental resources on rural properties in the Brazilian territory.

However, despite a significant evolution of legal provisions, such as the National Council for the Environment (CONAMA) Resolutions (República Federativa do Brasil, 1986, 1997, 2002, 2007) that address specific aspects of environmental legislation and establish rules for its application and inspection, several environmental researchers, as well as politicians and governors who advocate the cause, argue for bills that indicate the need to establish more effective criteria for PPAs at the national level.

Theoretically, the issue that this work intends to address fits into an analysis of the level of protection of PPAs in the Brazilian coastal zone; notably, there is a discrepancy in the level of protection, to the detriment of the interior environments of the territory. Advocating authors such as Pinheiro *et al*. (2013), Pinheiro, Moura-Fé and Freitas (2013), Zanatta *et al*. (2014), Albuquerque *et al*. (2015), and Bonzanini and Lupinacci (2023), among others, argue that some ecosystem delimitation criteria in the current legislation are not sufficient to cover coastal environments considering their intense dynamics of change, areas of high international importance, in the ecological, economic and socio-cultural scope.

The studies by Pinheiro *et al*. (2013) and Pinheiro, Moura-Fé, and Freitas (2013) converge in highlighting a structural weakness in Brazilian environmental legislation regarding the protection of coastal ecosystems, especially the dune system. The authors emphasize that Law 12.651/2012, by not recognizing mobile dunes as PPAs and by fragmenting the dune ecosystem into isolated features, disregards its ecological, geomorphological, and landscape complexity. Based on detailed analyses of legal texts and consistent scientific evidence, the studies demonstrate that this regulatory gap favors processes of irregular occupation and environmental degradation, particularly in coastal areas subjected to intense anthropogenic pressures. As a result, the authors argue for the need to classify dunes as an integrated and legally protected ecosystem, under penalty of irreversible loss of this natural heritage.

This critique of legal fragmentation is also central to the study by Albuquerque *et al*. (2015), which addresses the mangrove ecosystem. Analogously to the case of dunes, the authors point out that the Forest Code protects only mangrove vegetation, allowing uses considered "ecologically sustainable" in salt marsh and salt flat areas, despite their functional interdependence. The analysis shows that such a legal distinction ignores the ecological dynamics of the mangrove as an integrated system, opening the door to uses incompatible with its conservation. The results indicate that sectoral protection compromises the effectiveness of environmental legislation, especially in historical and current contexts of intensive land use, contributing to the progressive degradation of these sensitive environments.

The works of Zanatta *et al*. (2014) and Bonzanini and Lupinacci (2023) further deepen the discussion by empirically demonstrating the effects of environmental legislation on continental areas, directly relating legal norms, land use, and environmental degradation. In the study of the Areia Dourada stream basin, it is evident that the 1965 Forest Code offered greater compatibility with natural dynamics, ensuring significantly broader territorial protection than that provided for in current legislation, whose reduction of PPAs exacerbates land use conflicts and environmental pressures.

Complementarily, the analysis of the upper Cabeça river basin reveals the recurring non-compliance with PPAs and Legal Reserves, with the replacement of native vegetation by agricultural activities, intensifying erosion processes, siltation, and loss of soil fertility. Taken together, these studies reinforce the idea that weakened regulations and ineffective enforcement of environmental legislation have directly contributed to the increased degradation of ecosystems, highlighting the need for a conceptual and practical review of environmental protection policies in Brazil.

Research on federal environmental legislation is not restricted only to Brazil; internationally, several scientific studies focus on this issue, including studying the impacts of tourism on nature. In Russia, Zazolína (2025) analyzed the current environmental legislation. In this study, the author emphasizes that the numerous legislative acts at various levels significantly complicate both the implementation of

environmental standards and legal enforcement practices. One of the main factors contributing to these challenges is identified as the absence of a unified codified legal act – i.e. the Environmental Code of the Russian Federation. It also notes the legislators' lack of attention to the natural and climatic specificities, among other factors, in the process of drafting environmental codes.

The study conducted by Díaz Duque *et al*. (2025) in Cuba followed the same premise of the aforementioned Russian author, emphasizing the deficiencies in several problems traced by specialists in issues such as the environmental documents that govern the country, the approach to sustainability in government management and legislation, among other issues related to environmental policy and management.

The concern about the pressure of tourism on natural resources was studied by Ziari and Mosleh (2025) in the northern region of Tehran, Iran. Similarly, to the objective of this article, these authors also resorted to a multi-temporal analysis (1985-2022) to show the environmental changes and degradations resulting from land use. By tracing key factors contributing to environmental degradation, such as irregular construction and changes in land use, the research provided practical insights for policymakers. In the study conducted by Abbas (2023) in Pakistan, the author emphasized the strong relation between tourism development and environmental deterioration in that country.

As an example, a significant challenge in protecting the Brazilian coast is posed by the exclusion of ecosystems that are strategic in the regulation of coastal environments – such as mobile dunes, sandspits, salt flats, leached soils, and saline areas – from the regime of PPAs, which is justified by the lack of significant vegetation cover. Considering this regulatory gap, this study offers substantive contributions toward the advancement of scientific knowledge in coastal environmental management. The proposed approach demonstrates potential to redefine PPAs delimitation criteria, incorporating geomorphological and ecological parameters compatible with the dynamics of protection of coastal systems.

Therefore, the objective of this study is to trace the legal evolution of the Forest Codes (Law 4.771/1965, Law 7.511/1986 and Law 12.651/2012), focusing on the coastal zone of Brazil's Northeast region, by comparing two municipalities with different dynamics of coastal functioning and different types of PPAs. After tracing the legal evolution aspects, we compared two land cover contexts in the PPAs of said laws, in the contexts of 1990 and 2022, to understand the impact of changes in the dynamics of land use and determine the legal status of use in PPAs in relation to changes in environmental legislation in different coastal environments.

2. METHODOLOGY

2.1 Characterization of study areas

We selected two tourist municipalities in the coastal zone of northeastern Brazil (fig. 1). Brazil's northeastern coast is a region of major geographical relevance, characterized by a diversity of coastal formations that vary in their different units of the federation. Notably, these include Maranhão and Bahia, which, in addition to having the largest coastlines in Brazil's Northeast region, have distinct environmental characteristics. Maranhão, located on the northern coast of Brazil, has a coastline marked by extensive areas of dunes, deltas, tablelands, mangroves and restingas, reflecting a geomorphological environment of transition between the equatorial climate and the tropical zone (Lima *et al*., 2023). In turn, Bahia, which is part of the Eastern Coast, has a coast characterized by ample environments of mangroves, reefs, beaches with extensive coasts and cliffs, with a strong influence of the humid tropical climate (Silva & Silva, 2007).

The physical and hydrographic dynamics of these two regions are different due to the variations in rainfall regime, characteristics of sea currents and behavior of tides. The Northern Coast of Brazil is strongly influenced by sediment deposition processes, resulting from low wave energy, which favors the development of large estuarine systems and mangroves, with water dynamics that is characteristic of areas with low slope. The coastal zone of Maranhão has a low coast domain, configuring an intense and prolonged sedimentary deposition, from the Cretaceous, followed by the continuous remobilization of this same material by morphogenetic agents, a phenomenon that is still regular with high frequency throughout its length, which originated three gradually differentiated coastal segments, namely: rectilinear, sandy coast, to the east that surrounds the municipality of Barreirinhas; coast of recesses, mud, to the west; and mixed coast, exhibiting aspects of the two systems, in the recess of the Golfão Maranhense (Feitosa & Souza, 2015).

The municipality of Barreirinhas, located in the state of Maranhão, Brazil, is known for being the gateway to Lençóis Maranhenses, one of the most important National Parks in the country, famous for its

vast dunes without vegetation cover, white sand and crystal-clear water lagoons that form during the rainy season, whose local economy is strongly influenced by tourism, in addition to fishing and agriculture.

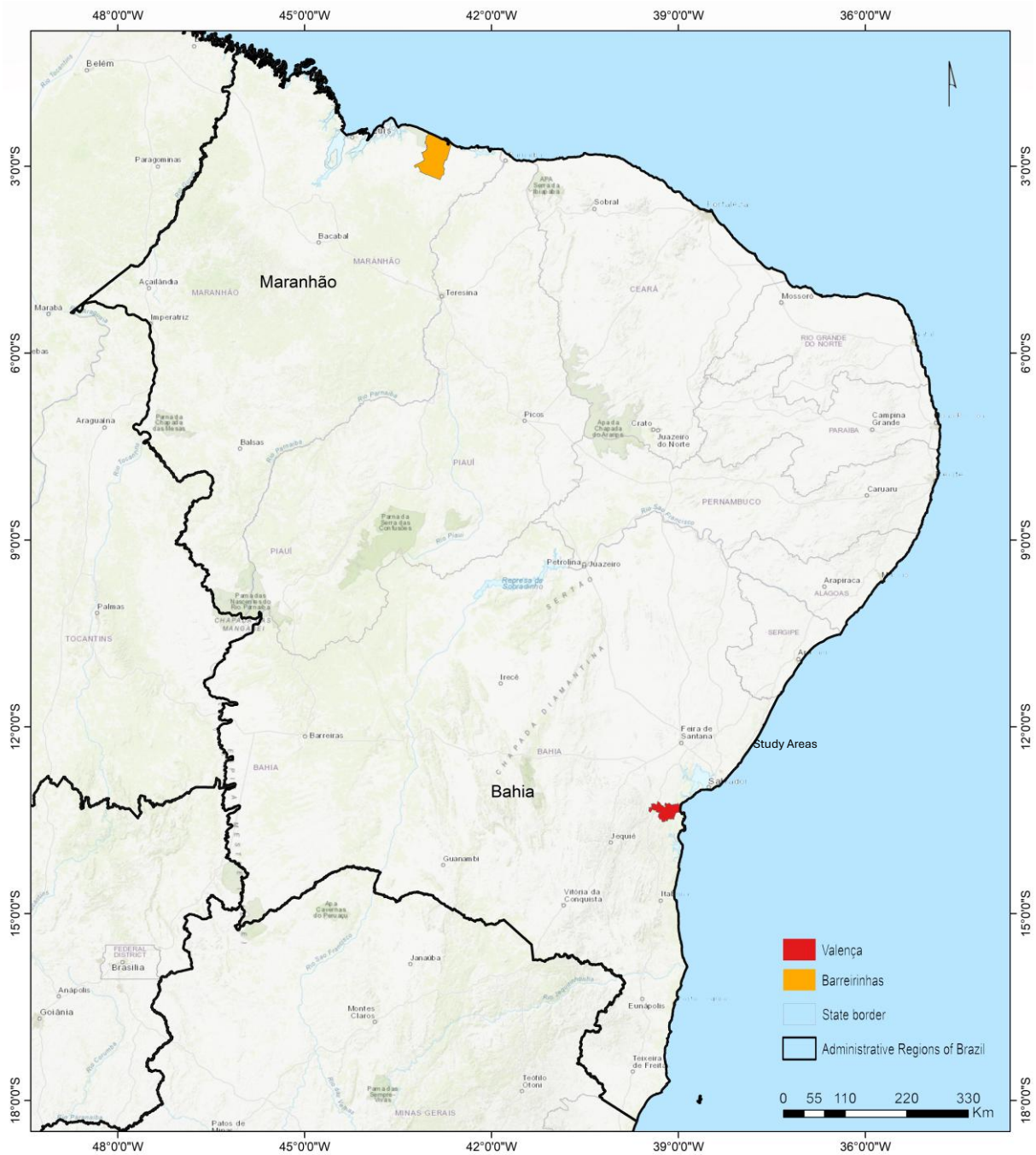

Fig. 1 – Study areas: Municipalities of Barreirinhas (MA) and Valença (BA).

Fig. 1 – Áreas de estudo: Municípios de Barreirinhas (MA) e Valença (BA).

Source: IBGE (2022)

Due to the remarkable, internationally recognized scenic beauty of Lençóis, the municipality of Barreirinhas has received a significant number of tourists in recent years, which has impacted the local infrastructure and economy, since it has a relatively small population, with 65 589 inhabitants in a territorial area of 3 046 308km² (Instituto Brasileiro de Geografia e Estatística [IBGE], 2022a).

The municipality of Barreirinhas, the main gateway to the Lençóis Maranhenses National Park, recorded 76 666 visitors in September 2025, according to the Informative Bulletin of the Maranhão Tourism Observatory (Obstur-MA), representing an increase of 56.28% compared to the same period in 2024, thereby consolidating the destination as one of the most sought-after in the state of Maranhão and a symbol of the advancement of tourism planning in the region (Maranhão, 2025).

Given its physical aspects, it is worth mentioning that Barreirinhas has its territory drained predominantly by the Preguiças river basin and is located in the *Cerrado* biome, where characteristic vegetation cover can be identified, such as the wooded and forested savannas in the rural area of the municipality (IBGE, 2023a).

As it is located in the region of the Maranhão coast, it has specific vegetation and geomorphological features such as restingas, mangroves, salt flats, and mobile dunes. The climate type is humid tropical, with a rainy season beginning in January and ending in June and drought from July to December. The average annual temperature is above 27°C and total rainfall ranges between 800 and 2 000mm (Instituto Maranhense de Estudos Socioeconômicos e Cartográficos, 2020).

Such characteristics enable diverse economic activities, in addition to tourism in Barreirinhas. Agriculture is practiced itinerantly, focused on subsistence, being one of the main economic activities of the municipality. In addition, there is fishing, plant extraction, and extensive livestock farming.

The other municipality analyzed in this work is located on the Eastern Coast of Brazil, in the state of Bahia, and due to this factor has some aspects that are different from Maranhão. Due to the greater energy of the waves and greater intensity of upwelling, in this part of Brazil, which presents a more active dynamic, the coastal behavior favors erosion and the formation of cliffs and reefs (Tessler & Goya, 2011).

These geomorphological contrasts, in addition to the different climatic and hydrographic conditions, characterize the coasts of Maranhão and Bahia with particularities that influence not only their landscape and the formation of the coastal ecosystems that compose them, but also their environmental and socioeconomic dynamics.

For comparative analysis in this study, the municipality of Valença is located in the state of Bahia. It has a population of 85 655 inhabitants, and has a territorial area of 1 123 975km² (IBGE, 2022b). Located in the Lower South region of the state, this municipality has singularities in its coastal formation, characterized by its rich biodiversity and proximity to significant ecological areas, including ample mangrove environments bordered by salt flats, and sedimentary marine deposits forming extensive coastal spits.

Such coastal formations, economic activities and ways of life are made possible by the climatic conditions in the region, with predominance of the super-humid tropical climate type (Köppen & Geiger, 1948), but without a defined dry season, unlike Barreirinhas, with the average temperature of the hottest month exceeding 18°C. The total rainfall of the driest month is above 60mm, with higher rainfall from March to August, exceeding the total of 2 000mm per year. In the warmer months (December to February) the average temperature is 24 to 25°C, easily exceeding 30°C in the summer (IBGE, 2002).

As for the hydrographic network present in Valença, the municipality is bordered to the south by the Engenho river and to the north by the Jiquiriçá river, belonging to the Recôncavo Sul hydrographic basin, located in the Central East region of the State of Bahia, which occupies an area of 6 900km², distributed over 25 municipalities. The large mountains to the west of the municipal territory feed a considerable number of springs, which form the main river channels present in the municipality. Among them, the Una and Piaú rivers are the most important (Bahia, 2015). Valença is also bordered to the west by the Taperoá channel fluviomarine system, with an expressive formation of estuarine environments.

Located in the Lower South region of the state, this municipality presents unique features in its coastal formation, characterized by its rich biodiversity and proximity to important ecological areas, including extensive mangrove forests bordered by salt flats, as well as marine sedimentary deposits that form broad coastal sandbars. Its economic activities are distributed among agriculture, tourism, fishing, and mariculture, supporting a wide network of family-based production.

However, informality in labor relations and in the supply of goods and services permeates the main economic drivers of Valença, which have significant relevance in the regional economy of Bahia and Brazil. In economic terms, the Gross Domestic Product (GDP) is led by the service sector (R$750 509.94), followed by public administration, defense, education, public health, and social security (R$380 048.98), while agriculture (R$133 284.54) and industry (R$129 033.74) play a secondary, but relevant, role in the local economy (IBGE, 2020). These data reflect a context of informality in productive spaces, which may be closely associated with economic and, consequently, social and cultural devaluation (Sheikh, 2019), differing from the scenario of greater formalization of tourism activities observed in Barreirinhas, Maranhão. Unlike Barreirinhas, whose economy is more focused on the primary sector, with activities of extraction of natural resources and agriculture, in Valença, in addition to the relevance of these activities, the industrial sector is also considerable.

In shrimp farming, one of the industrial activities present in Valença, the municipality stands out as the largest shrimp producer in Bahia and the tenth in Brazil, and also occupies the ninth position in the

production and processing of rubber, with a predominance of extractive activities with low implemented technology (IBGE, 2022b).

Such physical, economic and social characteristics give the municipalities analyzed different forms of occupation of their territories, hence different forms of appropriation of natural environments, whether legally protected or not. Such understanding of socio-spatial differentiation is essential in the comparative analysis of the legal evolution and land use occupation over the decades, proposed in this work.

2.2. Methodological procedures

This study was developed in four operational stages: (I) theoretical foundation in bases with research on the theme, analysis and choice of legislation to be compared and selection of the most effective mapping methodologies for the proposed objectives; (II) preparation of cartographies of PPAs in accordance with the selected legislation; (III) organization of cartographic data on Land Use and Occupation for the two proposed municipalities; (IV) stage of comparative analysis of PPAs in each of the legislations and of the spatial dynamics of the types of land uses adopted within these areas, for the two municipalities.

The thematic map of PPAs of the municipalities of Barreirinhas-MA and Valença-BA were produced based on Law 7.511 of July 7, 1986, which amends provisions of Law 4.771 of September 15, 1965. We also produced the PPAs map referring to what is recommended by the new Forest Code (Federal Law 12.651/2012). Thus, we prepared a map based on the previous code (Laws 4.771/1965 and 7.511/1986) and other map based on the current code for both areas of study.

As a reference, a guiding framework was developed for each municipality studied to compare the diversity of types of PPAs identified, according to the forest codes mentioned (table I).

The production of two maps of PPAs has a comparative purpose to identify which of the forest laws in terms of area provides greater protection of water resources and biodiversity (flora and fauna) in the municipalities. It should be noted that Law 4.771/1965 has undergone changes and received additions over time, one of which was instituted by Law 7.511 of July 7, 1986, which changed the width of PPAs for the marginal strips of watercourses.

However, there was a new amendment based on Law 7.803 of July 18, 1989. In it, new PPAs distances were established.

In the stage of determining the PPAs, there was delimitation of the water bodies of the municipalities. To this end, there was acquisition of orbital images of the *Landsat*-5 satellites, Thematic Mapper (TM) sensor with orbits/point: 219/62 and 220/62 with a passage date of Jul 10, 1990 for Barreirinhas and Oct 23, 1990 referring to Valença, and the *Landsat*-8 images, Operational Land Imager (OLI) sensor, orbits/points: 220/62 and 220/63, dated 07/18/2023 and 07/11/2023, respectively, for Barreirinhas, and orbits/points: 216/069 and 070, dated 08/20/2023 for Valença.

The use of land use and land cover data from the *Landsat* satellite, referring to the year 1990, is methodologically justified by the objective of analyzing environmental conditions within the legal framework prior to the enactment of Law 12.651/2012. Images from other satellites, such as *Sentinel,* although more suitable for detailed analyses in PPAs due to their higher spatial resolution, are only available from 2016 onwards, a period already covered by the current Brazilian Forest Code.

Therefore, their use would not be consistent with the temporal scope necessary to assess land use patterns associated with the previous legislation. Given the absence of higher-resolution orbital images for earlier periods, the cartographic scale was standardized to 30 meters, compatible with the *Landsat* data, which proved sufficient for the proposed comparative analysis. Thus, the approach adopted ensures methodological and temporal coherence, aligning data availability with the legal context under investigation.

After obtaining the images, they were imported into *QGIS v.3.8.23* with reprojection of the data and mosaic in color composition of type 5(R), 4(G), 3(B) for *Landsat*-5 and 4(R), 8(G), 3(B) for *Sentinel*-2A. Then, a polygon vector layer was created, which enabled the delimitation of the water bodies of the study areas for the years 1990 and 2023. Soon after the mentioned procedures, the tributaries were separated with the break features tool, and, to determine the width of the channels, the line measurement tool was used, then the buffer of the river channels was created. For this purpose, the Fixed Distance Geoprocessing > Buffer algorithm was used. The distances were established, according to article 2 of Law 7.511 for water bodies mapped in 1990 and article 4 of Law 12.651 for courses delimited in 2023. For the PPAs of all channels, the following algorithms were applied: merge vector layers, dissolve and difference. The latter was aimed at eliminating the filling of the buffer that would correspond to the river channels. It is noted that the springs of the courses were covered in the application of the buffer

Table I – Legal comparison of the types of PPAs in the coastal municipalities analyzed.
Quadro I – Comparação jurídica dos tipos de PPAs nos municípios costeiros analisados.

PPAs	Law 7.511, of July 7, 1986 (Previous Law)	Law. 12.651, of May 25, 2012 (Current Law)	Municipalities	
			Barreirinhas	Valença
River Channels	Art. 2 – The following are considered as subject to permanent preservation, by the sole effect of this Law: forests and other forms of natural vegetation located: 1. within 30m for rivers less than 10m wide; 2. within 50m for watercourses that are 10 to 50m wide; 3. within 100m for watercourses that measure between 50 and 100m wide; 4. within 150m for watercourses that are between 100 and 200m wide; within a distance equal to the distance between the banks for watercourses that are more than 200m wide; 5 – within 500m for watercourses that are more than 600m wide.	Art. 4. I – The marginal strips of any perennial and intermittent natural watercourse, excluding ephemeral ones, from the edge of the regular bed channel, in a minimum width of: a) 30m, for watercourses less than 10m wide; b) 50m, for watercourses that are 10 to 50m wide; c) 100 m, for watercourses that are 50 to 200m wide; d) 200m, for watercourses that are 200 to 600m wide; e) 500m, for watercourses that are greater than 600m wide.	Yes	Yes
Springs	Art. 2. c) in the springs, even in the so-called "water eyes," whatever their topographic situation.	Art. 4. IV – the areas around the springs and perennial water springs, whatever their topographical situation, within a minimum radius of 50m.	Yes	Yes
Dunes	There is no specificity. Art. 2 The following are considered as subject to permanent preservation, by the sole effect of this Law: forests and other forms of natural vegetation located: in the restingas, as dune fixers or mangrove stabilizers. (Dunes without vegetation cover would not be protected in any legislation).		Yes	No
Restinga in dunes	Art. 2. f) in restingas, as dune fixers or mangrove stabilizers. (There is no conceptualization). There is no specificity for areas with no dunes, only sandspits. It acts for the municipality of Barreirinhas-MA, but there is no influence for the municipality of Valença-BA	Art. 4. VI – restingas, as dune fixers or mangrove stabilizers; Art. 3. For the purposes of this Law, the following are defined as: XVI – restinga: sandy deposit parallel to the coastline, in a generally elongated form, produced by sedimentation processes, where different communities that receive marine influence are found, with mosaic vegetation cover, found on beaches, sandspits, dunes and depressions, presenting, according to the successional stage, herbaceous, shrub and arboreal stratum, the latter more interiorized.	Yes	No
Restinga in sandspits			No	Yes
Mangroves	There is no specificity.	Art. 4. VII – mangroves, in all their extension.	Yes	Yes
Surroundings of natural lakes and lagoons	There is no specificity. Art. 2. b) around lagoons, lakes or natural or artificial water reservoirs.	Art. 4. II – the areas surrounding the natural lakes and lagoons, in strip with a minimum width of: a) 100m, in rural areas, except for the body of water with up to 20ha of surface, whose marginal strip will be 50m; b) 30m, in urban areas.	Yes	Yes
Declivity	Art. 4. V – slopes or parts thereof with a declivity greater than 45°, equivalent to 100% on the line of greatest slope.		No	Yes

Source: Authors

In order to identify the other PPAs of the municipalities and illegal use and occupation of these areas, we used land use and cover data for 1990 and 2022 from MapBiomas collection 9 (table II). The classes proposed by MapBiomas were grouped according to the characteristics that were most effective for the objectives of the study. This collaborative project produces an annual mapping of land cover and use with data starting from 1985 (MapBiomas Brasil, 2023).

The MapBiomas raster land use and cover data obtained from the website through the Google Earth Engine platform were converted into *QGIS* for the vector structure, then the vector for the year 1990 was clipped with the drainage PPAs as a mask layer, based on Law 7.511/1986, while for 2022 the same was done, however, based on the PPAs obtained based on Law 12.651/2012. The land covers (table I), in turn, established as PPAs were represented on the maps as determined by the laws analyzed.

Finally, the types of use and occupation included in the PPAs were considered in order to identify the quantity of area and their type of change in the dynamics of use in the context of each legality system of the Forest Codes. By identifying these characteristics, it is possible to understand which type of use underwent expansion or reduction in relation to legal change in recent decades. To identify the PPAs associated with slopes, we used the Digital Elevation Model (DEM) of the Brazilian Geomorphometric

Database (TOPODATA) of the National Institute for Space Research (Instituto Nacional de Pesquisas Espaciais, 2011), with a spatial resolution of 30 meters. These data correspond to the sheets: 02S435_ZN and 03S435_ZN for Barreirinhas and 13S405_ZN and 13S39 for Valença. The scenes were downloaded from the TOPODATA website and then imported into *QGIS*.

Table II – Characterization of land use and land cover classes (MapBiomas level 4) in Valença and Barreirinhas *(1990 e 2022)*.

Quadro II – Caracterização das classes de uso e ocupação do solo (MapBiomas nível 4) em Valença e Barreirinhas (1990 e 2022).

	Class	Description		Legality of use (PPA)
Land cover	Forest Formation	Forest	Types of vegetation with a predominance of tree species, with continuous canopy formation (Riparian Forest, Gallery Forest, Dry Forest and Cerradão [Ribeiro & Walter, 2008]), in addition to semideciduous seasonal forests.	ADEQUATE
		Savanna	Savannas with defined tree and shrub-herbaceous strata (Restricted Sense *Cerrado*: dense *Cerrado*, typical *Cerrado*, sparse *Cerrado* and rocky outcrop *Cerrado*).	
		Grassland	Grasslands with a predominance of herbaceous stratum (dirty field, clean field and rocky outcrop field) and some areas of savanna such as the rocky outcrop *Cerrado*.	
		Tree Restinga	Forests established on sandy soils or dunes in the coastal zone.	
	Mangrove	Mangrove	Dense, evergreen forests, often flooded by the tide and associated with the coastal ecosystem of Mangrove.	
	Non-Forest Natural Areas	Salt flat	Salt flats or leached soils are formations mostly devoid of arboreal vegetation, being associated with a higher, hypersaline and less flooded zone of the mangrove, in general, in the transition between mangrove and mainland.	
		Flooded Field and Wetland Area	Vegetation with predominance of herbaceous stratum subject to seasonal flooding (e.g., Wet Field) or under fluvial/lake influence (e.g., Swamp). In some regions, the herbaceous matrix occurs in association with arboreal species of savanna formation (e.g., Parque de *Cerrado*) or palm trees (Vereda, Palmeiral).	
		Beach, Dune and Sandy Beach	Sandspits, bright white in color, with no predominance of vegetation of any kind.	
		Herbaceous Restinga	Herbaceous vegetation with fluviomarine influence.	
		Shrub Restinga	Dominant vegetation type of pioneer areas (*restinga*), occurring in the dunes and dominated by nanophanerophytic communities.	
	Continental Waters	Continental Waters	Rivers, lakes, dams, reservoirs and other bodies of water.	
Land use	Urbanized Area	Urbanized Area	Areas with significant density of buildings and roads.	INADEQUATE/ UNDER LEGAL PERMISSION
	Aquaculture	Aquaculture	Area referring to artificial lakes, with predominance of economic activities of fish, seafood or crustacean farming.	
	Bare soil	Mining	Areas referring to industrial or artisanal mineral extraction (mining), with clear soil exposure by anthropic action.	
		Other areas with no vegetation	Areas with non-permeable surfaces (infrastructure, urban expansion or mining) not mapped in their classes and regions of bare soil in natural areas or in off-season crop areas.	
	Agriculture Forestry	Agriculture	Areas occupied with short- or medium-term agricultural crops, usually with a vegetative cycle of less than one year, which after harvest require new planting to produce; Forestry: Tree species planted for commercial purposes. Pasture; mixed use areas where it was not possible to distinguish between pasture and agriculture, areas with non-permeable surfaces (infrastructure, urban expansion or mining).	
		Soy	Areas cultivated with soybean crop.	
		Pasture	Predominantly planted pasture areas, directly associated with agricultural activity. Natural pasture areas, in turn, are predominantly characterized as grassland or wetlands, and may or may not be subjected to grazing practices.	
		Other Temporary Crops	Areas occupied with short- or medium-term agricultural crops, usually with a vegetative cycle of less than one year, which after harvest require new planting to produce.	
		Mosaic of uses	Agricultural use areas where it was not possible to distinguish between pasture and agriculture.	
		Forestry	Tree species planted for commercial purposes (e.g., pine, eucalyptus, araucaria).	

Source: Authors

In the Geographic Information System (GIS), data were processed, namely: mosaic of the DEM; reprojection; correction of negative values by applying a formula in the raster calculator of the System for Automated Geoscientific Analyses (*SAGA GIS*); pixel filling without data based on the Fill without Data tool; removal of spurious (closed) depressions of the DEM through the Fill Sinks (Wang & Liu, 2006) algorithm in *SAGA GIS*; clipping. Finally, we applied the declivity algorithm expressed in degrees.

3. RESULTS AND DISCUSSION

When studying the types of land use and land cover in the two municipalities analyzed, in the reference timeframes, we found a significant increase in the agricultural classes of mechanized use, especially in Barreirinhas, with the implementation of soybean cultivation.

In 1990, Agriculture occupied 91.62km² of the municipality, while in 2022 it started to occupy an area of 159.74km², that is, an increase of 74.34%; in contrast, Forest Areas were reduced approximately by 3.81% and Non-Forest Natural Areas had a loss of 0.43% in 2022 (fig. 2 and 3).

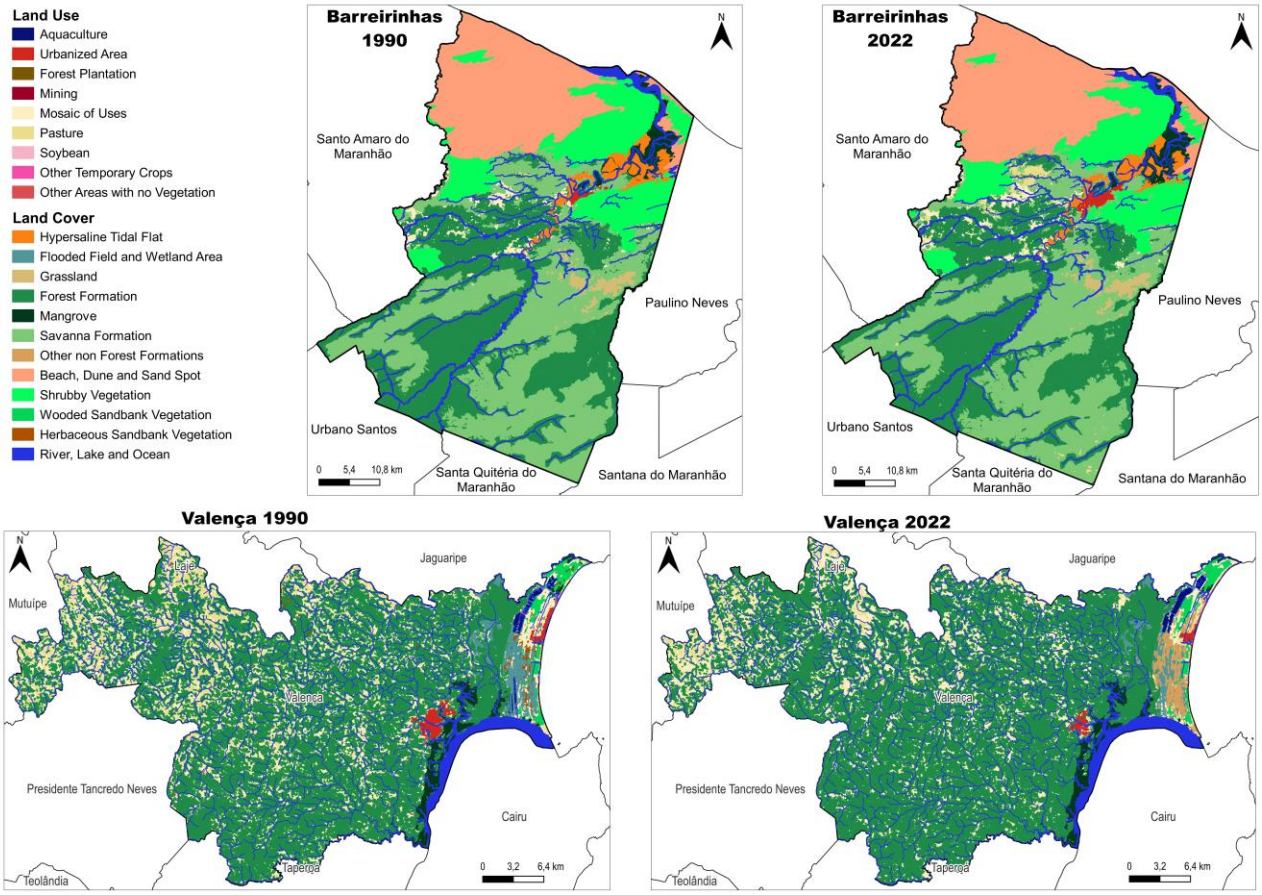

Fig. 2 – Land use and land cover scenarios in the municipalities of Barreirinhas and Valença organized according to MapBiomas data (1990 and 2022).

Fig. 2 – Cenários de uso e ocupação do solo nos municípios de Barreirinhas e Valença, organizados de acordo com os dados do MapBiomas (1990 e 2022).

Source: MapBiomas (1990,2022)

The mangrove area also underwent a 2.5% reduction between 1990 and 2022, however, this change in cover is associated with natural dynamics identified in the advance of mobile dunes over this feature. In this sense, the dune area had an increase of 2.3% in 2022, with the wind action being the main factor responsible for the change. In 1990, the bare soil formed only by Other Areas with no Vegetation increased by about 2.3% in 2022, this change was due to the introduction of mining, which contributed to the growth in terms of occupied area.

For the same reference period, there was an increase in the Urbanized Area, which in 1990 had an area of 5.1km², while in 2022 it started to have 14km², that is, a growth of 172.8% in the last 32 years. This is mainly due to the tertiary sector of Barreirinhas, which underwent an advance due to tourism in the Lençóis Maranhenses region. This tourism has contributed to the entry of capital into the municipality and creation of employment and income for the local population. The activity of this economy sector ranges from the handicrafts practiced by residents of the city and villages, sale of meals in restaurants, lodging in inns and hotels, rental of quadricycles, and transport of tourists to Lençóis Maranhenses, among others.

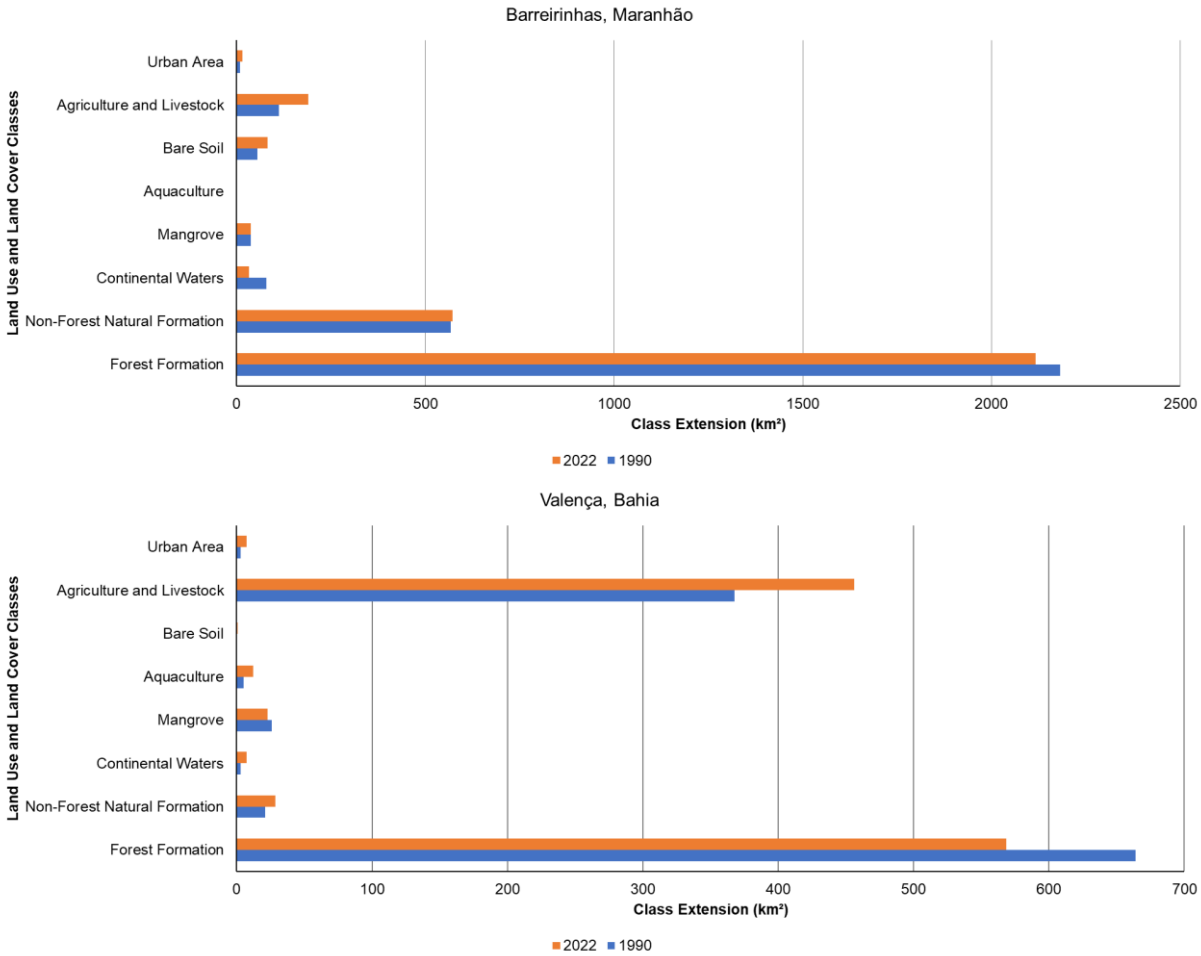

Fig. 3 – Surface area of the land use and land cover classes present in the analysed coastal municipalities (1990 and 2022).

Fig. 3 – Superfície das classes de uso e ocupação do solo existentes nos municípios costeiros analisados (1990 e 2022).

Source: Mapbiomas (1990, 2022)

The GDP of Barreirinhas in 2021 was R$635 796 million, according to IBGE municipal GDP data (2022a). The primary sector of the economy characterized by extensive agricultural activities, fishing, mining and plant extraction has a substantial importance in obtaining income in Barreirinhas.

However, the advance of agriculture in Barreirinhas and the consequent loss of native vegetation in recent decades is a negative aspect of this activity, as it is associated with deforestation and fires in the region. Pasture is the land use associated with the growth of municipal agriculture; in 1990, it occupied an area of 5.5km², while in 2022 it represented about 63.8km², which implies an exacerbated increase of 1 056%.

In Valença, the dynamics of evolution of land use and occupation is, to some extent, similar to that of Barreirinhas. There was a significant decrease in forested environments (with a 14% reduction in covered area) and in mangroves (with an almost 11% reduction in area), with growth of environments for agricultural activities and urban areas (whose classes doubled the cover area in three decades) (fig. 3).

Other economic activity that showed significant growth is Aquaculture (with more than 120% increase in covered area). Aquaculture activities involve producing fish (fish, molluscs, algae, shrimp and others) in captivity.

According to Municipal Livestock Production data (IBGE, 2023b), in 2023, the municipality of Valença rose as the 10th largest shrimp producer in Brazil (with more than 2 650 tons produced). The central problem of captive fish farming is the transformation of natural ecosystems, such as mangroves and salt flats, into shrimp ponds, causing the destruction of habitats that are essential for the reproduction of marine species, in addition to causing the reduction of biodiversity in the region.

In addition, for the development of industrial activity, there is adoption of intensive use of chemicals, such as pesticides and antibiotics, thus contaminating the water (García *et al*., 2019). And, among the social impacts, the expansion of aquaculture activities is associated in Valença with the loss of traditional fishing territories. In order to trace the level of protection of PPAs and which land uses are directly associated with this evolution, we carried out a comparative cartographic analysis of the size of the protected areas provided for in the two environmental legislations.

According to the legal analysis applied to the cartographies, the PPAs covered by Laws 4.771/1965 and 7.511/1986 (previous Law) occupied an area of 677.5km² in Barreirinhas and in Law 12.651/2012 (current Law) this value becomes 649.6km², which means a reduction of 4% of the areas protected by the Forest Code (table III).

Table III – Area of the PPAs delineated in environmental legislation in 1990 and 2022 for the analysed municipalities.
Quadro III – Área das APP delimitadas na legislação ambiental de 1990 e 2022 para os municípios analisados.

Permanent Preservation Areas	**Barreirinhas-MA**		**Valença-BA**	
	Area in km² in 1990	**Area in km² in 2022**	**Area in km² in 1990**	**Area in km² in 2022**
River channels and springs	287.53	225.49	channels with a width of 30 and 100m: 160.98km²	channels with a width of 30 and 100m: 160.98km²
Dunes	Not applicable	Not applicable	Not applicable	Not applicable
Restinga in dunes	390.05	374.4	Not applicable	Not applicable
Restinga in sandspits	Not applicable	Not applicable	There is no specificity in the current law	37.13
Mangroves	There is no specificity in the previous law	48.47	There is no specificity in the current law	25.75
Surroundings of natural lakes and lagoons	There is no specificity in the previous law	1.32	There is no specificity in the current law	4.65
Declivity	Not applicable	Not applicable	0.13	0.13
TOTAL	**677.58**	**649.68**	**161.11**	**228.64**

Source: Authors

This is mainly due to the reduced protection of River Channel and spring areas, and the reduced resting vegetation cover in dunes due to anthropogenic alteration. This leads to considerable environmental consequences due to the destruction of these ecosystems.

In Valença, there was an increase in the cover of PPAs, which represented 161.1km² and expanded to an area of 228.6km², which represents an increase of 42% of the total area previously protected. Considering that restinga environments in sandspits, mangroves and around natural lakes and lagoons had no legal restrictions in 1990 and started to have them from 2012, this increase is justified (table III).

However, not only was the environmental legislation changed, but the types of land use and occupation in these two municipalities compared also underwent significant changes, including the cover within the PPAs, focal areas of analysis in this present study.

Figures 4 and 5 show the spatialization of this change, considering the contexts of legal inadequacy of land use in the PPAs of the municipalities under analysis between 1990 (considering Law 4.771/1965) and 2022 (according to the new Forest Code), and table IV shows the sizes of areas and types of uses assumed by the old PPAs.

Regarding the inadequate uses in the PPAs in Barreirinhas, the results indicate that 9% of them were occupied by Agriculture (pasture and mosaic of uses), the Urbanized Area class (0.7km²) and Bare Soil (0.2km²), in turn, they were also associated with a conflict in relation to environmental legislation. They involved 0.3% of the PPAs. These results show that 27.7km² (approximately 10%) of the banks of the municipality's hydrographic network were occupied irregularly, as determined by the mentioned forest code (table IV).

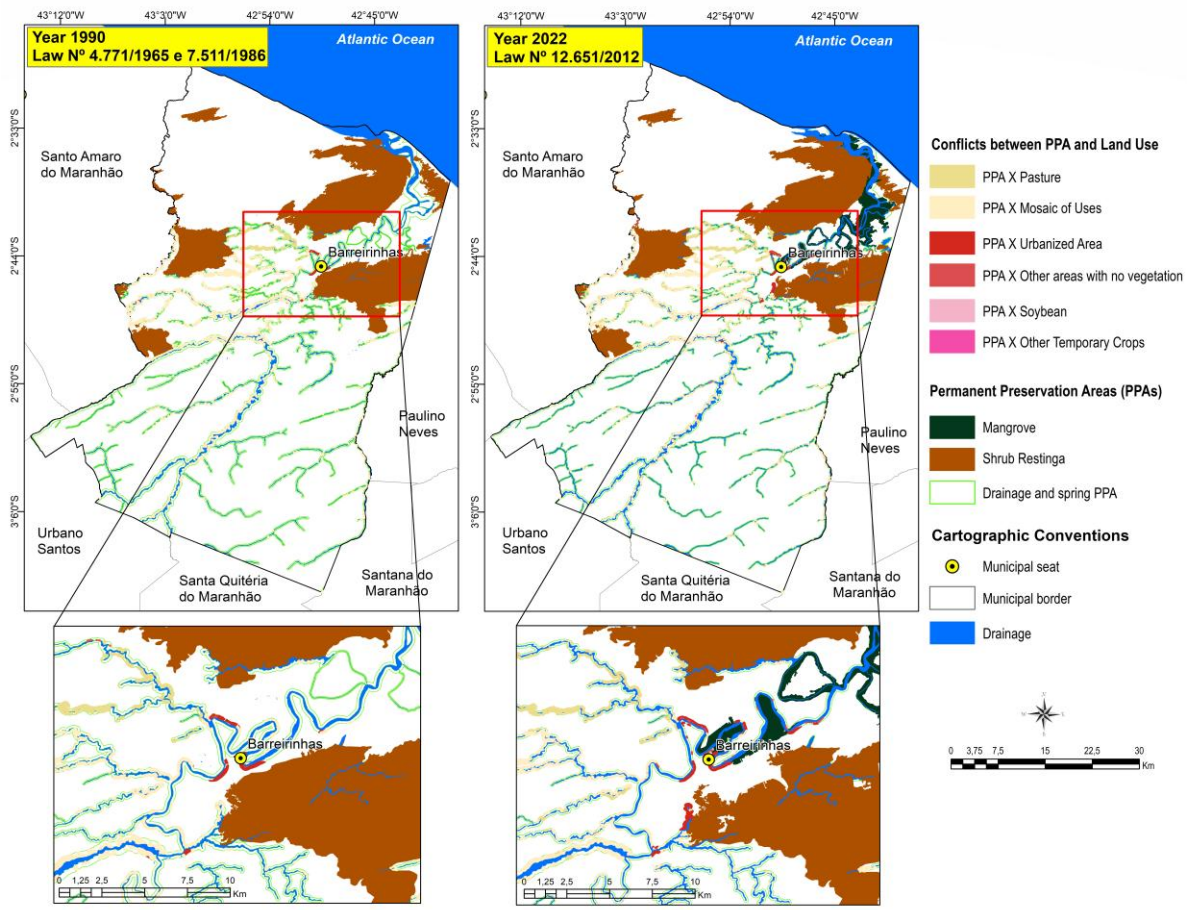

Fig. 4 – Legal inadequacy of land use in the PPAs of the municipality of Barreirinhas between 1990 and 2022.

Fig. 4 – Inadequação legal do uso do solo nas APP do município de Barreirinhas entre 1990 e 2022

Source: MapBiomas (1990; 2022); USGS (1990; 2022); ZEE-MA (2021); IBGE (2022)

Table IV – Comparison with the size of areas and types of uses assumed by the old PPAs.

Quadro IV – Comparação com a dimensão das áreas e os tipos de uso assumidos pelas antigas APPs.

Land Use and Cover	Permanent Preservation Areas (km²)			
	Barreirinhas, Maranhão		Valença, Bahia	
	Law 4.771, of September 15, 1965 and Law 7.511, of July 7, 1986 (Previous Law)	Law 12.651, of May 25, 2012 (Current Law)	Law 4.771, of September 15, 1965 and Law 7.511, of July 7, 1986 (Previous Law)	Law 12.651, of May 25, 2012 (Current Law)
Inadequate Use (Aquaculture, Bare Soil, Agriculture and livestock and Urbanized Area)	27.71	30.31	38.92	55.38
Forest	191.85	138.19	105.82	112.0
Non-Forest Natural Formation	34.94	28.27	1.61	17.99
Mangrove	—	27.58	—	25.54

Source: Authors

The vegetation cover that involves the Forest, Non-Forest Natural Formation and Mangrove classes concentrate 86% of the drainage PPAs for the year 1990, while to the north of the municipality, specifically in the Preguiças River, mobile dunes (8.4km²) occupy 2.9% of the banks and 0.6% (1.7km²) are small areas of water bodies.

In 2022, the conflict situation is aggravated by agricultural activity, totalling 12.8% of inadequate use in the protection areas, while the Urbanized Area (just over 1km²) and Bare Soil (0.14km²) total 30.3km² (13.3% of the occupation of the PPAs). While the plant species grouped in the Forest, Non-Forest Natural Formation and Mangrove occupy about 82.5% of the banks protected by law, while mobile dunes (6.8km²) 3% and water bodies (2.4km²) only 1%.

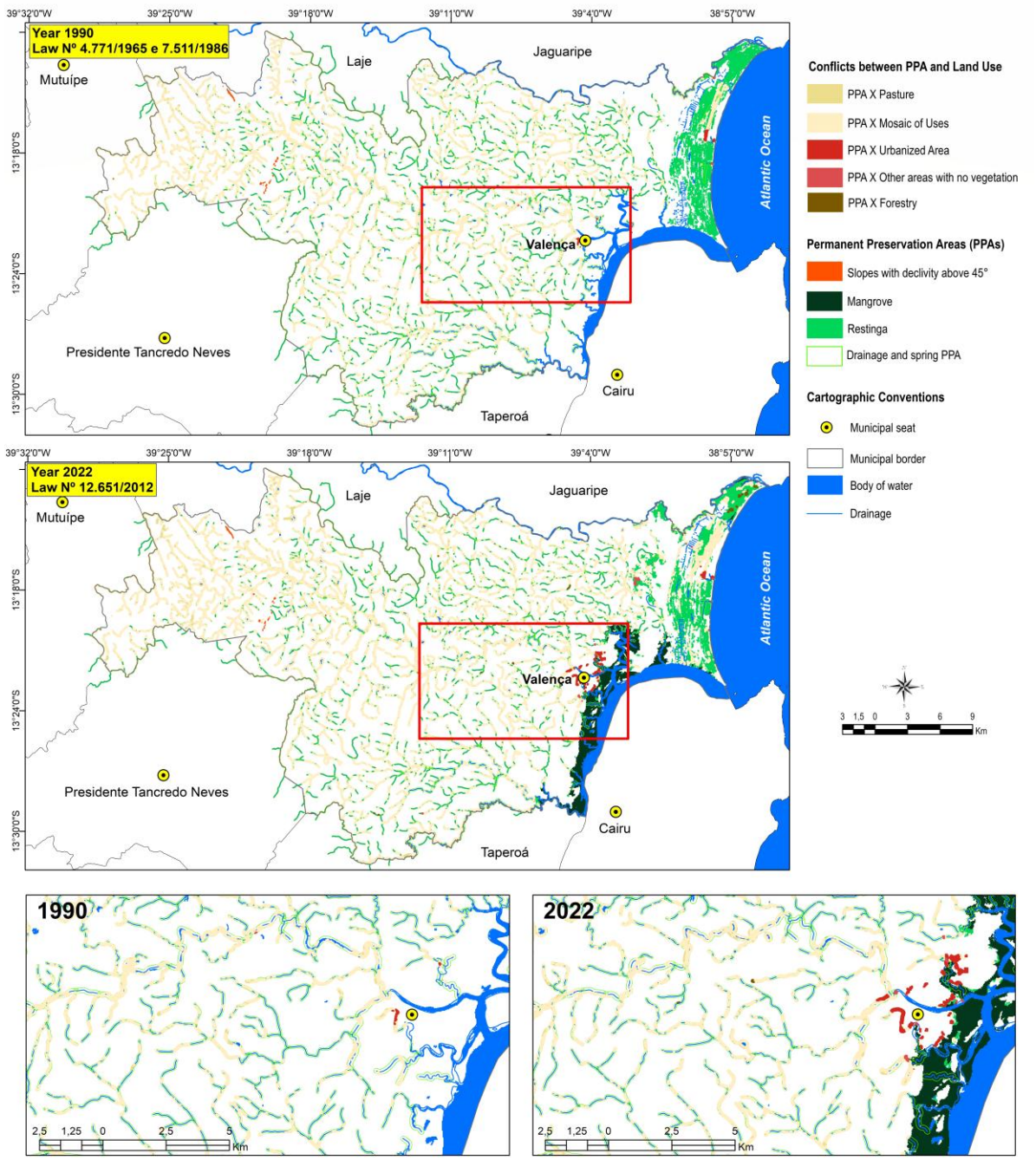

Fig. 5 – Legal inadequacy of land use in the PPAs of the municipality of Valença between 1990 and 2022.

Fig. 5 – Inadequação legal do uso do solo nas APP do município de Valença entre 1990 e 2022.

Source: MapBiomas (1990; 2022); USGS (1990; 2022); IBGE (2022)

In the current legislation, the protection associated with water bodies was unfavorable compared to the previous law; the results for the GIS mapping show that the loss of PPAs was approximately 21%. Considering all the PPAs in Barreirinhas, the situation of greater protection of vegetation is identified in the previous law, as the new forest code for this application scenario presents a decrease of 4%.

In the municipality of Valença, although the PPAs had their cover expanded with the updated Forest Code, the inadequate land uses and occupation within these areas were also expanded. As an example, the activities of Aquaculture, Agriculture, Urbanized Areas and Bare Soil, which occupied approximately 39km², started to occupy 55.3km² within the PPAs in this municipality. This indicates a lack of robust inspection in the PPAs, which, in turn, can lead to serious environmental damage, such as illegal deforestation, the release of pollutants into water bodies and the irregular occupation of protected areas. This occurs, for example, when landowners invade or use in an inadequate manner these areas for activities such as agriculture and livestock farming, or illegal construction.

Although the previous Forest Code has a protective character, there are flaws associated with the absence of a more specific and clear delimitation of PPAs. This same conclusion was noted by Santos Filho *et al*. (2015) in relation to the first Brazilian forest code of 1934. In addition to methods for inspecting PPAs more efficiently. According to Santos Filho *et al*. (2015, p. 279):

> Over the decades after 1930, the Forest Code underwent several changes until the introduction of the new Code in 1965, and, among the changes in relation to the revoked Code of 1934, it is worth mentioning the creation of the Legal Reserve and Permanent Preservation Areas.

The 2012 Forest Code has greater clarity regarding the delimitation of PPAs compared to the previous one, with this difference being the main aspect responsible for the current law providing greater protection of vegetation cover; however, in relation to the protection of vegetation on the banks of watercourses, Law 7.511/1986 is more favourable toward preservation. This change occurs in what is determined in article 2, paragraph "a" and item 4 of said law: "within 150m for watercourses that are between 100 and 200m wide; within a distance equal to the distance between the banks for watercourses that are more than 200m wide". This is consistent with Zanatta *et al*. (2014, p. 205), who noted that the Forest Code update represented a setback in the preservation of water bodies, since "it does not meet the vegetation efficiency ranges necessary for the conservation of water resources, significantly reducing the functions and, consequently, the services provided by nature to man".

The Brazilian Forest Code was created at the beginning of Brazil's industrialization process in the 1930s, aiming to standardize the use of raw material from forests. This objective is fundamental, as it is necessary to establish rules for the use of forest resources. However, what is found in the study area is non-compliance with what is prescribed by law until the present moment. The growth of agriculture in Barreirinhas and Valença, for example, was followed by increased pressure on water resources, soil and consequently forest biodiversity.

PPAs are intended to protect environmentally vulnerable sites, such as riverbanks, hilltops and slopes, which should not be deforested so as not to cause erosion, river silting and mass movements, in addition to protecting springs, fauna, flora and biodiversity, etc. Thus, the lack of native vegetation cover in PPAs cause erosive processes with greater intensity and "triggers the loss of surface layers of soils, with consequent loss of fertility, transforming areas with major potential for food production or preservation into degraded sites with low agricultural productivity" (Bonzanini & Lupinacci, 2023, p. 24).

While, in Valença, in addition to the problems in drainage PPAs that are similar to what occurs in Barreirinhas, the economic activities of aquaculture also gradually appropriate the areas of mangroves and salt flats. That is, the theory is not in line with the practice in relation to the areas that should mandatorilly be protected.

With a focus on the physiognomy of salt flats, part of the mangrove ecosystem, as well as the saline areas, are not covered by the previous law or by the current law, as a PPAs:

> Salt flats [*Apicuns*] are flat areas with high salinity, devoid of vegetation or with sparse vegetation, located in the innermost portion of the mangroves, especially between mangroves and slopes, at the mid-supralitoral interface. Its vegetation is composed of herbaceous plants that grow in the sand. (Hadlich *et al*., 2016, p. 69)

The definition itself shows the relation between them; both the mangrove and the salt flat are formed by the interaction of tidal dynamics, developing vegetation with capacity to adapt to brackish environments with high salinity.

The Federal Law in force, in its article 4, determines as PPAs in paragraph VII "mangroves, in all their extension." Thus, item seven leads to the understanding that the entire ecosystem is being legally protected; however, this law dissociates the treatment for salt flats and saline areas. Thus, there is a protection of some features rather than others that are not considered as PPAs, although they all are part of the same system (Albuquerque *et al*., 2015).

Salt flats are covered by the new Forest Code in chapter III-A, entitled: "Ecologically Sustainable Use of Salt Flats and Saline Areas", and this chapter was added by Provisional Measure 571, of May 25, 2012, later converted into Law 12.727, of Oct 17, 2012. Paragraph 1 clarifies that salt flats and saline areas can be used in shrimp farming and saline activities.

It is understood that not considering salt flats and saline areas as part of the mangrove system and the possibility of their use for the aforementioned activities constitute an obstacle to the very protection of the mangrove, as both physiognomies are part of the same ecosystem. In this sense, Albuquerque *et al*. (2015, p. 129) ratify that "although mangroves and their correlated and interdependent features are characterized by intense dynamics and close interrelation, the current Brazilian environmental legislation at the federal level does not seem to understand or disregard the relevance of such characteristics". This exclusion would necessarily result in the violation of PPAs because they are connected areas, which makes it difficult for environmental agencies to inspect them.

Another important element in studies related to the application of the forest code concerns riparian vegetation, which corresponds to plant formations near water bodies, thus addressing the concept of distance and also water (Kobiyama, 2003). In these works, the terms riparian zone and riparian ecosystem are common. The first refers to a three-dimensional physical space that includes vegetation (tree, grass, etc.), soil and river (body of water). "Its extension is horizontally up to the reach of the flood and vertically from the regolith (below) to the top of the forest canopy (above)" (Kobiyama, 2003, p. 5). While the second term should be used when referring to the system, processes, mechanisms, among others; it is appropriate to use the term riparian ecosystem, which is an open system. "Therefore, it is considered an ecotone between terrestrial and aquatic ecosystems through the movement of surface water and groundwater" (Kobiyama, 2003, p. 6).

Riparian vegetation has several functions, namely: stabilization of slants and slopes, maintenance of river morphology and protection from flooding, retention of sediments and nutrients, mitigation of water and soil temperature, provision of food and habitat for aquatic species, maintenance of ecological corridors, landscape and recreation, fixation of carbon dioxide, interception of rocky debris (Silva, 2003).

In this context, Silva (2003) presented a list of recommended widths for riparian strips according to the functions performed. Such widths are the same as those presented in Connecticut River Joint Commissions (CRJC, 1998). Thus, the ideal widths for riparian zone functions are 10 to 15 meters for slant stability, 15 to 30 meters (fish habitat), +30 meters (nutrient removal), 30 to 45 meters (sediment control), +60 meters (flood control), +90 meters (wildlife habitat).

As clarified by Zanatta *et al*. (2014, p. 206): "According to the studies of CRJC (1998) and the survey carried out by Silva (2003), more than 180m (90+m on each bank) of PPA are necessary in order to effectively protect water bodies, soil and biodiversity".

Based on the riparian zone's systemic characteristics and important functions, it is proposed that the PPAs of watercourses, lagoons and lakes consider the riparian zone for their delimitation, since considering only the width of a water body to define the areas to be protected and not the dynamics, exchange of matter and energy, interactions between landscape components, in addition to the natural function of the systems, is detrimental to the very environmental sustainability goal of the legislation. Accordingly, it is also suggested the inclusion of salt flats and saline areas as PPAs associated with the mangrove ecosystem or, alternatively, the reduction of the areas available for use by these economic activities.

Another significantly studied issue – derived from the same sense of ecosystem protection and not from the functioning and dynamics of the environments, questioned by Brazilian researchers, since before the new Forest Code – is the exclusion of mobile dunes as PPAs. As only the restinga ecosystems, which fix the dunes, are considered, only the fixed dunes end up being protected. While dune environments, without floristic cover, become targets for urban expansion, implementation of large eolian projects, among other related issues, derived directly from this loophole in environmental legislation.

In article 2 and item VIII of CONAMA Resolution 303, of March 20, 2002, dunes are defined as "a geomorphological unit with predominantly sandy constitution, with the appearance of a comorum or hill, produced by the action of winds, located on the coast or inside the continent, which may or may not be covered by vegetation". Thus, in Barreirinhas there are mobile and fixed dunes.

Coastal dunes provide habitats for plants, animals and microorganisms, help protect beaches, coasts and interior areas from various disturbances, such as extreme weather conditions, storms and sea level rise; in addition, dunes and beaches provide ecosystem services, such as coastal protection, acting as natural barriers against storms, minimizing damage caused by erosive processes and flooding (Lustig, 2023; Silva *et al*., 2024).

When dunes are removed or replaced with anthropogenic activities in low-altitude areas, "environments become more susceptible to flooding processes during storms, triggering damage to

infrastructure, economic losses in seaside developments, and potentially affecting other ecosystem services." (Silva *et al*., 2024, p. 2).

Given the ecological importance of dunes (fixed and mobile) and because they are areas with remarkable scenic beauty, high complexity and natural vulnerability resulting from deflation processes, it is also suggested their inclusion as PPAs in the current forest code; it should be noted that CONAMA resolution 303/2002 in article 3 and item V establishes dunes as PPAs.

4. CONCLUSIONS

The findings of this study indicate that environmental conditions afford different types of ecosystem formation in the coastal zone of Northeast Brazil. Comparing both municipalities, one located on the Eastern Coast and the other on the Northern Coast of the Brazilian territory, it is understood that the legal applications of environmental protection also differ from each other. These municipalities have major international tourist relevance due to the proximity to Lençóis Maranhenses and Morro de São Paulo, which represent icons of Brazilian tourism; however, their inefficient legal protection jeopardizes not only the ecological integrity, but the very sustainability of tourism activities in the medium and long term. The inadequate appropriation of the soil, given the economic and environmental potential of these territories, shows a contradiction between tourism development and environmental conservation, urgently requiring: the harmonization of PPA legislation with coastal geomorphological particularities; and integrated management mechanisms that make ecosystem protection compatible with sustainable economic activities.

In short, in the municipality of Barreirinhas, located in the state of Maranhão, the update of legislation focusing on PPAs indicated a loss of legally protected areas. Such areas were quickly altered, occupied by expansion of urbanized areas, bare soil and agricultural activities, to the detriment of forests, especially in environments close to the banks of rivers and in dune environments.

In the analysis of the municipality of Valença, in the state of Bahia, considering the different existing ecosystems, the same update of the legislation focusing on PPAs indicated an increase in legally protected areas. With the addition of restinga ecosystems in sandspits, mangroves and around natural lakes and lagoons, the new Forest Code now covers almost double the previously protected areas. However, inappropriate uses within PPAs have also increased, such as the introduction of aquaculture, forestry, bare soil, agriculture and urbanized areas.

Another research finding is that the delimitation of PPAs must follow the environments' hydrological, ecological functioning behavior, dynamics and processes. The delimitation of PPAs only by ecosystem characteristics excludes other ecological formations with high importance that do not have the same classification regarding dominant type of vegetation. For example, the ecosystems included in the fluviomarine plain: salt flats, leached soils and saline areas, which have a water and ecological dynamics that is similar to that of mangroves. Due to this legal loophole, potentially polluting projects are installed in unprotected ecosystems, in the center and edges of mangroves, such as shrimp farming and aquaculture, which have shown significant growth in occupied area in the last three decades.

Similarly, there are insufficient legal concepts for protection of riparian zones and their important functions, when it is proposed that the PPAs of watercourses, lagoons and lakes consider only the width of water bodies to define the areas to be protected and not the dynamics, exchange of matter and energy, interactions between landscape components, in addition to the natural function of the systems; thus, disregarding these aspects is detrimental to the very environmental sustainability goal of the legislation.

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AUTHOR`S CONTRIBUTIONS

Idevan Gusmão Soares: Writing – original draft preparation, Data curation, Formal analysis, Visualization. **Sarah Andrade Sampaio:** Writing – original draft preparation, Formal analysis, Visualization. **Regina Célia de Oliveira:** Supervision, Writing – review and editing, Project administration.

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