

Temporal Analysis of the Mangrove Forest at the Mocajuba River Hydrographic Basin-Pará

Juliane da Costa Cavalcante¹ 
Aline Maria Meiguins de Lima¹ 
Jéssica Cristina Conte da Silva² 
Bruno Silva de Holanda¹ 
Crislayne Azevedo Almeida¹ 

Abstract

Mangrove forests are ecosystems naturally susceptible to environmental stresses, such as rising sea level and coastal erosion. However, the anthropic stresses, such as real estate speculation, deforestation and water pollution, put at risk this environment's stability, interfering with its balance. The present work's aim is to perform a temporal analysis of the mangrove forest that is a part of the Mocajuba river hydrographic basin and its buffer zone, as well as identifying natural and anthropic stresses to which the mangroves are susceptible. It was verified that the mangrove forest areas presented a substantial reduction between 1984 and 1999, and a small loss between 1999 and 2018. Thus, in the mangrove forest buffer zone, the anthropized areas increased while the forest areas decreased, demonstrating the deforestation in these areas. It can be concluded that the mangrove forest in the study region present a regression.

Keywords: Conservation units, spatial analysis, remote sensing.

1. INTRODUCTION

The mangrove forest is a phanerophytic community of brackish environment, located at the mouth of rivers and streams that reach the sea, presenting muddy soil (manguito) with the vegetation adapted to salty water (fluvio-marine), such as the red mangrove (*Rhizophora mangle*), black mangrove (*Avicennia sp.*) and white mangrove (*Laguncularia racemosa*) (IBGE, 2012).

The mangrove biome is typically found in coastal environments of tropical and subtropical zones presenting high salinity, muddy soil rich in organic matter, limited oxygen and a diversity of trees and shrubs constantly submerged. This ecosystem provides food and shelter to many species, as well as an income source to the inhabitants of such areas and the surroundings (MATIAS; SILVA, 2017).

Mangrove forests represent 8% of the Earth's shoreline, amounting to a total of 181,077 km², from which Brazil has the second largest area with 13,400 km² of mangrove forest (SPALDING et al., 1997). In the northeast of the

Pará state, mangrove forests cover an area of 2,176.78 km² (SOUZA FILHO, 2005). These areas are protected by 15 Conservation Units (UC), from which 13 are Extractive Reserves (RESEX) (MMA, 2019).

Even if those areas are legally protected by the Brazilian Law n. 12651/2012 (Brazilian Forest Code), the mangrove forests face constant anthropic impacts, such as substantial crab capture, real estate pressure, and also the land use substitution to develop agriculture and livestock activities. These anthropic threats interfere in the ecosystem's resilience when facing natural impacts, such as climate change, rising sea level and dunes progression over the mangrove areas (CARVALHO; JARDIM, 2019).

The mangrove forest at the Mocajuba river basin is inserted in this perspective, facing threats caused by the expansion of anthropic occupation, such as urban areas, crops and pastures (TELES; PIMENTEL, 2015). Aiming to restrain the expansion of such activities and protect the mangrove areas, the Conservation Units for Sustainable Use were created in the RESEX category, considering that the Mocajuba river basin encompasses a portion of three

¹ Universidade Federal do Pará, Programa de Pós-graduação em Ciências Ambientais, Belém, PA, Brasil

² Universidade Federal do Pará, Programa de Pós-graduação em Engenharia Civil, Belém, PA, Brasil

of such units: RESEX São João da Ponta (unnumbered decree from 13 December 2002), RESEX Mãe Grande de Curuçá (unnumbered decree from 13 December 2002), and RESEX Mocapajuba (unnumbered decree from 10 October 2014).

Considering the need for studies focused on the behavior of mangrove ecosystems that face anthropic and natural pressures, the present work aims to perform a temporal analysis of the mangrove forest that are a part of the Mocajuba river hydrographic basin and its buffer areas.

2. MATERIALS AND METHODS

2.1. Study area

The study (Figure 1) area comprises the mangrove forest at the Mocajuba river hydrographic basin, that is a part of the municipalities of São João da Ponta, Curuçá and Terra Alta, located in northeastern Pará, Brazil. The mangrove forest areas are protected by three extractive marine reserves: São João da Ponta, Mãe Grande de Curuçá and Mocapajuba.

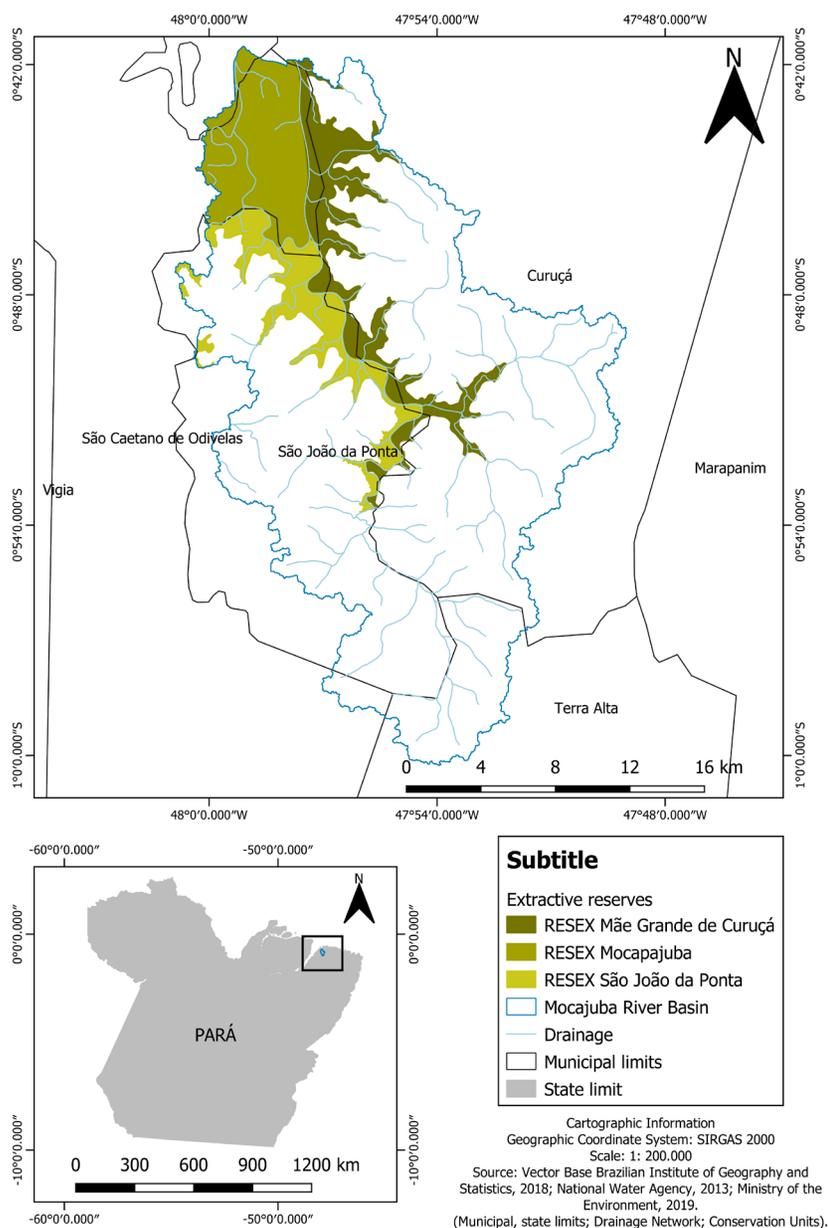


Figure 1. Location of the Mocajuba river hydrographic basin and the extractive reserves.

2.2. Platform and data processing

Google Earth Engine (GEE) platform provides various satellite imagery datasets and other geospatial data that can be exported or processed in the platform. To elaborate land use and cover maps and to quantify mangrove forest areas at the Mocajuba river basin, images were collected from Landsat-5 TM (LANDSAT/LT05/C01/T1_TOA) for 1984, Landsat-7 ETM+ (LANDSAT/LE07/C01/T1_RT_TOA) for 1999, and Landsat-8 OLI-TIRS (LANDSAT/LC08/C01/T1_RT_TOA) for 2018. The imagery datasets were obtained and processed on the GEE platform.

Using a GEE script, a filter was applied to remove cloud pixels from the imagery datasets between 1st January and 31 December of 1984, 1999 and 2018, with the Quality Assessment (QA) band to exclude pixels that were either too shiny or too dark (clouds and shadows). Lastly, to generate only one image to represent the study years, a median reducer was applied. This methodology intends to generate a final image free of clouds, with “clean” pixels, considering all the images from 1984, 1999 and 2018 (DINIZ et al., 2019; ROSA, 2018).

2.3. Classification and sampling class

Using the selected images, the calculation was done for the following spectral indexes:

- Normalized Difference Vegetation Index (NDVI) (eq. 1) uses the red (RED) and near-infrared (NIR) wavelengths (ROUSE et al., 1973).

$$NDVI = \frac{NIR - RED}{NIR + RED} \quad (1)$$

- Normalized Difference Water (or Moisture) Index (NDWI or NDMI) (eq. 2) is derived from the near-infrared (NIR) and short-wave infrared (SWIR) bands (GAO, 1996).

$$NDMI = \frac{NIR - SWIR}{NIR + SWIR} \quad (2)$$

- Modified Normalized Difference Water Index (MNDWI) (eq. 3) uses green (Green) and short-wave infrared (SWIR) bands (XU, 2006).

$$MNDWI = \frac{Green - SWIR}{Green + SWIR} \quad (3)$$

After calculating the spectral indexes, the Random Forest classifier, available at the GEE platform, was used to perform decision-making based on random variables subsets, generating various classifiers groups, such as tree

(bootstrap), that is, decision trees arrangement (bagging or bootstrap aggregating) (GISLASON et al., 2005). The imagery spectral bands and spectral indexes generated were used for the decision-making.

The collection of samples started with the classes to be mapped: (1) water, that encompasses all water classes, such as oceans, rivers, natural and artificial lakes, and others; (2) mangrove forest, vegetation influenced by fluvial and marine water (IBGE, 2012); (3) forest formation, dense ombrophilous vegetation, primary or secondary, and also areas in the initial stage of recovery (IBGE, 2012); (4) non-forest, land cover with various anthropic uses, such as urban areas, pasture, agriculture, highways and exposed soil.

The choice to merge the subclasses that constitute “forest formation” and “non-forest” was made to reduce classifier confusion. Furthermore, quantifying forest formation and non-forest classes allows to observe the expansion and regression of natural vegetation and anthropic occupation.

2.4. Accuracy calculation

Classifications accuracy was calculated using the Kappa coefficient. In equation 4, K is the Kappa coefficient, $\sum_{i=1}^c x_{ii}$ is the sum of the main diagonal matrix elements; [c] is the number of lines; [x_{ii}] is the value in line [i] and column [i]; [x_{i+}] is the sum of line [i] elements, and [x_{+i}] is the sum of column [i] elements in the confusion matrix; and [n] is the total number of samples (COHEN, 1960; VALE et al., 2018).

$$Kappa = \frac{n \sum_{i=1}^c x_{ii} - \sum_{i=1}^c x_{i+} x_{+i}}{n^2 - \sum_{i=1}^c x_{i+} x_{+i}} \quad (4)$$

According to the Kappa coefficient, the quality of the classification may be analyzed using the values: 0 (poor); 0.01 - 0.2 (slight); 0.21 - 0.4 (fair); 0.41 - 0.6 (moderate); 0.61 - 0.8 (substantial); 0.81 - 1.0 (almost perfect) (LANDIS AND KOCH, 1977; COHEN, 1960).

The points chosen to the accuracy calculation were selected using Random Points tool, a simple random sampling technique available at Qgis 3.6.2 software.

The synthesis of the methodology to quantify mangrove forest areas and generate the land use base: (1) PLATAFORM - Google Earth Engine; (2) DATA - landsat 5, 7 and 8 for 1984, 1999 and 2018, respectively; (3) CLOUDS FILTER - cloud detection and removal; (4) SPECTRAL DATA - NDVI, NDWI and MNDWI; (5) CLASSIFIER - Random Forest; (6) CLASSES - water, mangrove forest, forest formation and non-forest; (7) RESULTS - land use base and mangrove forest areas regression and expansion

3. RESULTS AND DISCUSSION

The classifications obtained accuracy values of 0.86, 0.92 and 0.80 for the years 1984, 1999 and 2018, respectively. According to Table 1, it is observed that between 1984 and 1999 there was an increase of 3,48% in the forest formation class and a decrease of 13,26% in the non-forest class. Between 1999 and 2018, there was a reduction of 23,55% in the forest formation class and a growth of 115% in the non-forest class.

Table 1. Quantification of mapped classes.

Classes	1984	1999	2018
Water	19.17 km ²	21.55 km ²	23.15 km ²
Mangrove forest	62.98 km ²	59.97 km ²	59.95 km ²
Forest formation	165.65 km ²	171.42 km ²	131.04 km ²
Non-forest	38.74 km ²	33.60 km ²	72.40 km ²
Total		286.54 km ²	

Source: Author.

These results are similar to the ones found by Teles and França (2014), at São João da Ponta, between 1984 and 1995, which showed a growth in secondary forest areas, and a reduction in anthropic areas (mining and agriculture). Between 1995 and 2004, Teles and França (2014) found a reduction in secondary and primary forest areas and a growth in anthropic areas, although they found a slight increase in the mangrove forest areas, different from what was detected in the present study.

The Mocajuba river basin comprises an area of approximately 406 km², from which 70% can be considered as buffer zone, contemplating the 3 km distance from the boundaries of the Conservation Unit, according to the National Environmental Council resolution n. 428, from 2010 (CONAMA 428/2010). However, the mangrove forest influence area extends beyond the basin's boundaries because of the buffer distance (Figures 2, 3 and 4).

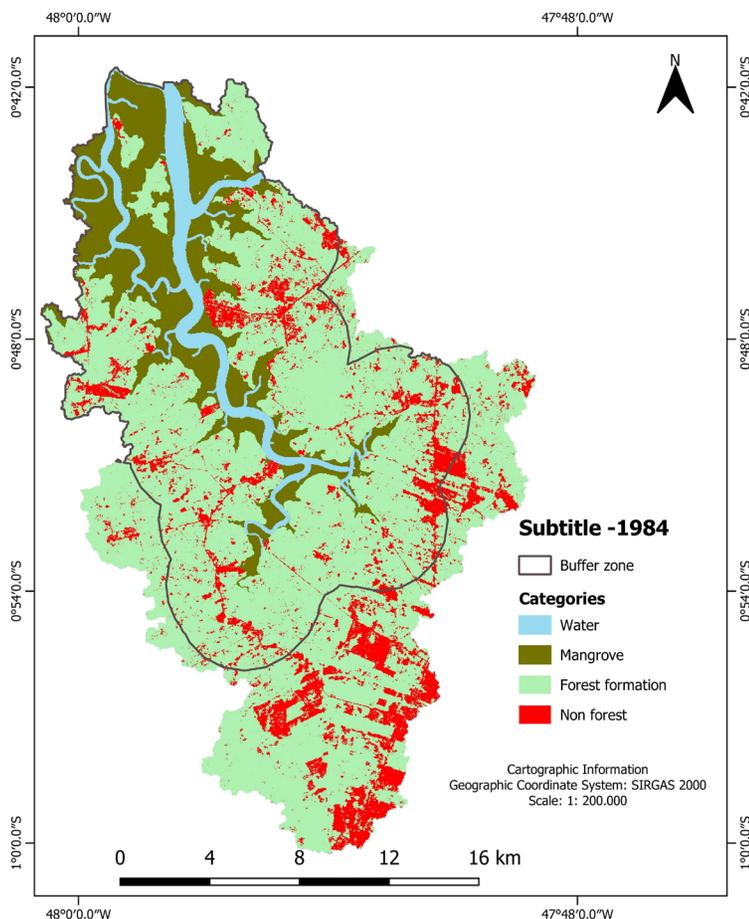


Figure 2. Map of land use and cover on the study area – 1984.

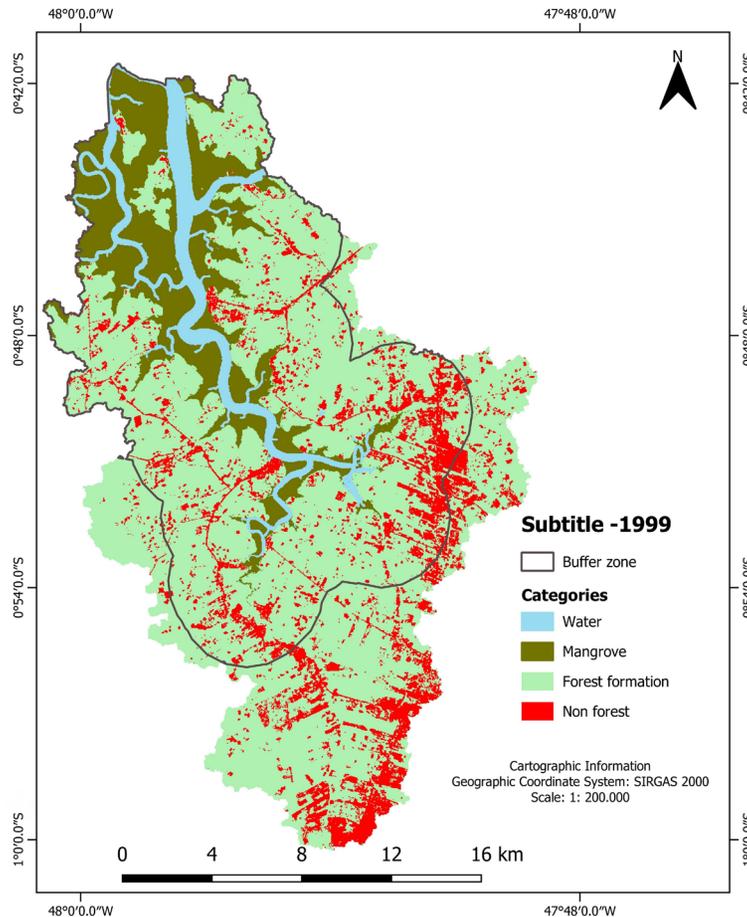


Figure 3. Map of land use and cover on the study area – 1999.

The results show that in 1984 the mangrove forest surroundings were already taken by anthropic activities, even if there was a slight reduction of anthropization in 1999 and a substantial growth seen in 2018. Figures 2, 3 and 4 show the land use dynamic at the study area.

It was observed, during field visits, that mangrove forests in the region face threats due to the expansion of human activities, mainly urban settlements, agriculture and pastures. This was also observed by Teles and Pimentel (2015), who perceived scarce fragments of primary vegetation and extensive areas in various regeneration stages, which indicates that the region has been densely occupied by humans.

The threats in the surroundings of the mangrove forest at the Mocajuba river basin negatively impact the ecosystem's balance. According to Eni et al. (2012), the balance between biotic and abiotic environments safeguard

the characteristics of natural environments, such as soil and vegetation aspects. The authors concluded that there is a connection between vegetation and soil parameters, as the vegetation protects the soil from various climate conditions, preventing erosion and maintaining soil moisture, and the soil provides organic matter and nutrients, supporting the vegetation. Thus, the variables are related, sustaining the natural environment's stability and regeneration ability.

In this perspective, studying the composition and development of mangrove forests is essential to connect the ecosystem's response to the existing environmental conditions. Furthermore, it can establish the similarities of these environment's responses to many natural and anthropic interventions, aiding in predicting other environmental responses to conservation and recuperation actions (SOARES, 1999).

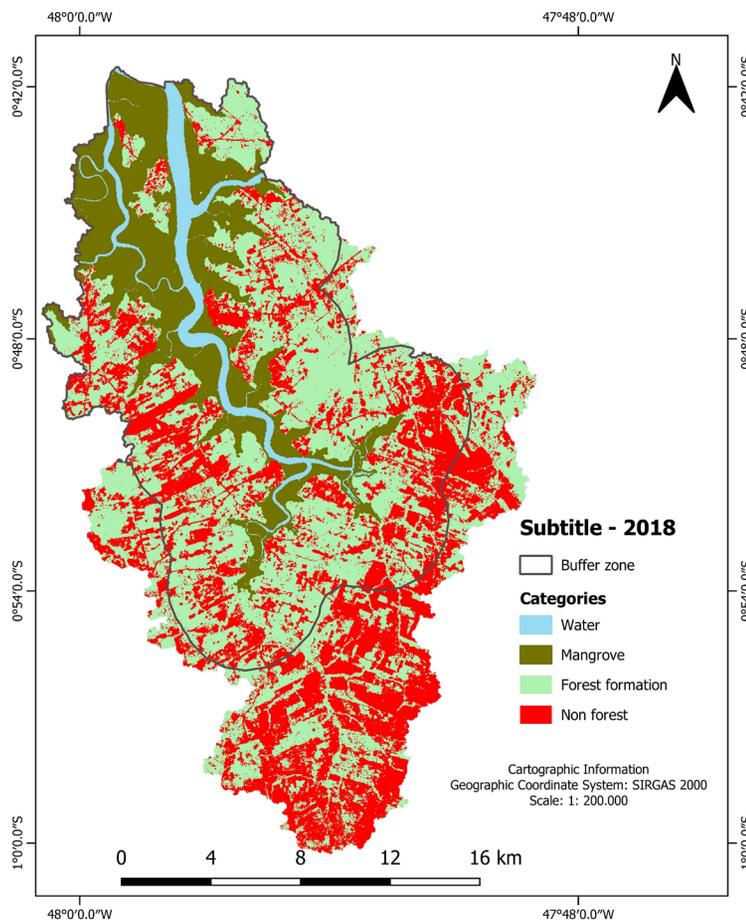


Figure 4. Map of land use and cover on the study area – 2018.

Framework 1 presents secondary data for the composition of flora species of mangrove forests at northeast Pará sites, as well as the environmental and anthropic stresses this ecosystem is susceptible to.

Framework I. Flora composition and structure, environmental and anthropic stresses.

	Flora composition and structure (secondary data)	Environmental stresses (secondary data)	Anthropic stresses (secondary data)	Actions and advices
MARAPANIM	<p>Main tree species: <i>Rhizophora mangle</i>, <i>Avicennia germinans</i> and <i>Laguncularia racemosa</i>. <i>Spartina brasiliensis</i> in accretion zones (LOUBRY; PROST, 2013; PROST et al., 2013).</p> <p>Height: 10 – 15 m; diameter: 10 – 45 cm (<i>Rhizophora mangle</i>); Height: 10 – 20 m; diameter: 40 cm (<i>Avicennia germinans</i>); Height: 8.5 – 13 m; diameter: 9 cm (<i>Laguncularia racemosa</i>) (SALES et al., 2009).</p>	<p>Erosion processes (sea tide currents); mangroves buried by sandbanks; biological threats on the vegetation (plagues) (<i>Hyblaea</i>) (PROST et al., 2013).</p>	<p>Artisanal fishing; urbanization (PROST et al., 2013)</p>	<p>Artisanal fishing inspection to respect species' reproduction period; inspection and police authority in the installment of urban structures that do not comply with legislation.</p>

Framework 1. Continuation...

	Flora composition and structure (secondary data)	Environmental stresses (secondary data)	Anthropic stresses (secondary data)	Actions and advices
SÃO CAETANO DE ODIVELAS	<p>Prevailing species found: <i>Avicennia germinans</i> L. in 59.6% and <i>Rhizophora mangle</i> L. in 32.06%. Less prevailing species: <i>Avicennia schaueriana</i> Staff and <i>Leech</i>; <i>Laguncularia racemosa</i> Gaertn (PROST et al., 2013).</p> <p>Diameter: 17.5 – 22.5 cm (<i>Rhizophora mangle</i>), considered younger forest; Diameter: 17.5 – 32.5 cm (<i>Rhizophora mangle</i>), considered stable forest (RIBEIRO JÚNIOR, 2017).</p>	Erosion processes (sea tide currents); mangroves buried by sandbanks; biological threats on the vegetation (plagues) (<i>Hyblaea</i>) (PROST et al., 2013).	Real estate speculation and solid waste littering (PINHEIRO, 2014).	Restrains on the implementation of real estate developments at Permanent Preservation Areas (mangrove forests and riparian vegetation); inspection and establishment of a waste collection system to serve the local population.
SÃO JOÃO DA PONTA	<i>Rhizophora</i> sp. (red mangrove), <i>Avicennia</i> sp. (black mangrove), <i>Laguncularia</i> sp. (white mangrove) and <i>Acrostichum</i> sp. (mangrove fern) (FRANÇA et al., 2016).	Erosion processes (FRANÇA et al., 2016).	Extractive activities, crops, small livestock herds (FRANÇA et al., 2016).	Environmental education focused on the local population to encourage sustainable agriculture.
CURUÇÁ	<i>Rhizophora mangle</i> , <i>Avicennia germinans</i> and <i>Laguncularia racemosa</i> (ALMEIDA, 1996).	Erosion processes (sea tide currents) (LIMA et al., 2014).	Real estate speculation, solid waste littering, inordinate constructions, invasion of mangrove forest for shrimp farming, deforestation of riparian vegetation near rivers who feed the mangrove forest (PINHEIRO, 2014).	Restrains and inspection on the implementation of real estate developments so they comply with environmental legislation; police authority on areas with inordinate settlements at the mangrove forest and riparian vegetation.
SOURCE	<i>Rhizophora mangle</i> , <i>Rhizophora racemosa</i> <i>Avicennia germinans</i> (CARVALHO; JARDIM, 2017). Height: 11.6 m; diameter: 23.27 cm (CARVALHO; JARDIM, 2017).	Rising sea level, advancing dunes over the mangrove forest (CARVALHO; JARDIM, 2019).	Predatory techniques and intensive shellfish capture; mangrove forest cut for wood (CARVALHO; JARDIM, 2019).	Inspection to respect aquatic species' reproduction period; environmental education to encourage sustainable agriculture.
SALINÓPOLIS	<i>Rhizophora mangle</i> , <i>Avicennia germinans</i> and <i>Laguncularia racemosa</i> (CARVALHO; JARDIM, 2017). Height: 10.8 m; diameter: 21.45 cm (CARVALHO; JARDIM, 2017).	Rising sea level; coastal erosion; changes in temperature in dry and wet seasons (MENDES, et al., 2013 CARVALHO; JARDIM, 2019).	Solid waste littering, sewage disposal, deforestation, intensive shellfish capture, real estate speculation, tourism, roads construction and housing allotments at the Biological Reserve (CARVALHO; JARDIM, 2019; MENDES, et al., 2013).	Inspection of domestic sewage treatment and solid waste destination to comply with environmental legislation, environmental studies to implement projects focused on social and environmental impacts mitigation.
ALGODOAL	<i>Rhizophora mangle</i> (75%), <i>Avicennia germinans</i> (23%) and <i>Laguncularia racemosa</i> Gaertn (2%) (CARVALHO; JARDIM, 2017; BASTOS; LOBATO, 1996). Height: 9.5 m; diameter: 21.60 cm (CARVALHO; JARDIM, 2017).	Shoreline erosion (recession of 150 to 200 m over the decade) (MENDES et al., 2013)	Solid waste littering, sewage disposal, deforestation, intensive shellfish capture and sand extraction for construction sites (CARVALHO; JARDIM, 2019; MENDES et al., 2013).	Inspection to identify sewage disposal; respect aquatic species' reproduction period; identification of illegal activities.
BRAGANÇA	<i>Rhizophora mangle</i> and <i>Avicennia germinans</i> (SEIXAS et al., 2006). - Height: 8.6 – 11.3 m; diameter: 10 – 45 cm (<i>Rhizophora mangle</i>). - Height: 10.5 – 11.9 m; diameter: 40 cm (<i>Avicennia germinans</i>) (SEIXAS et al., 2006).	Shoreline erosion (recession of 50 m observed in one year 1998/1999); changes on the coastal vegetation due to sand banks advancing over mangrove forests (SOUZA FILHO 2013).	Road construction; disruption of drainage networks where roads serve as barriers for the sea tides flow; inordinate occupation of beaches; solid waste littering (SOUZA FILHO 2013).	Environmental studies to implement projects focused on mitigation of social and environmental impacts; protection of mangrove forests and riparian vegetation by banning new anthropic settlements; inspection of domestic sewage treatment and solid waste destination to comply with environmental legislation.

Several species observed at the Mocajuba river basin are common in mangrove forest environments, according to Framework 1, such as *Rhizophora mangle* and *Avicennia germinata*.

As well as the mentioned sites, the mangrove forests located on the whole study area are exposed to various anthropic stresses, threatening their stability. According to Prost et al. (2013) anthropic stresses are site specific, so they have low intensity, frequency and magnitude. Therefore, these stresses do not affect the energy input and do not cause significant alterations on the structure and diversity that may lead to mangrove forest regression.

In contrast, stresses are localized interventions that influence species behavior when facing changes on the natural environment. An example is the case of the highway PA 458 (Bragança - Ajuruteua) whose construction was started in 1973 opening a road 45 km long from the center of Bragança to Ajuruteua beach, covering a part of the mangrove forest on its way. Currently this forest is slowly recovering and adapting, but the crab population was severely reduced, which affected the people who traditionally captured them as an economic subsistence activity (OLIVEIRA, HENRIQUE, 2018).

In the location where the basin land cover transition from mangrove forest to mainland, there is secondary vegetation and exposed soil. The secondary vegetation area might be a way for the forest species to adapt when facing environmental changes, that is, as a way to maintain the balance, mangrove species, which occupied these areas before and were suppressed by anthropic intervention, were replaced through secondary succession. According to Bastos and Lobato (1996), anthropic stresses cause long term responses that result in alterations and losses in the vegetation structure at certain environments.

On the other hand, exposed soil areas interfere in the sediments transport and in the water contribution from the basin to the river's mouth. Mochel et al. (2013), in the study of mangrove forest at São Luís, Maranhão, conclude that deforesting the terrestrial ecosystems surrounding the mangrove swamps intensify the erosion process, increasing the sediments deposition on the swamps. In this situation, indirect impacts, such as mainland deforestation, might negatively affect the mangrove forests, as is the case of the buffer zone at the Mocajuba river basin, where 25% of the area is occupied by anthropic activities (Table 1).

Table 2. Mangrove forest transition matrix.

	1984	1999	2018
Total mangrove forest (km²)	62.98	59.97	59.95
	1984 - 1999	1999 - 2018	1984 - 2018
Unaltered mangrove forest (km²)	59.51	57.53	58.56
Regression (km²)	3.475	2.44	4.42
Mangrove forest to Water	1.9	1.94	3.6
Mangrove forest to Forest formation	1.56	0.48	0.8
Mangrove forest to Non-forest	0.015	0.02	0.02
Expansion (km²)	0.46	2.42	1.39
Water to Mangrove forest	0.12	0.48	0.28
Forest formation to Mangrove forest	0.3	1.93	1.05
Non-forest to Mangrove forest	0.04	0.01	0.06

Source: Author.

Considering this perspective, even if the anthropic stresses are considered site specific, human's long-term interferences over the environment might make it difficult for mangrove forests to survive, affecting their adaptation and responses when faced with natural impacts. That was proved by Thomas et al. (2017) in the quantification of mangrove forest areas between 1996 and 2010 in South, Central and North America, Middle East, Southeast Asia and Oceania. The mangrove forest's area loss caused by anthropic action totalized 38%, from which 16% was due to agriculture. The untouched mangrove forest area was 45% of the total global mangrove forest area.

Aside from anthropic impacts, oscillations on the natural environment also interfere on the mangrove forests survival. According to Charron et al. (2013), the mangrove forests evolution is intrinsically dependent on shoreline morphosedimentary modifications. The alternance of erosion processes and coastal progradation is followed by the progression and regression of mangrove forests that face the sea. In contrast, according to Bezerra et al. (2013), climate change and, consequently, rising sea level directly affect mangrove forests, with the extension of such impacts depending on local characteristics. Therefore, it is not possible to state that the variations in the Mocajuba river mangrove forests are caused only by the expansion of human settlements without taking into consideration the natural conditions that also affect these environments.

Considering the environmental and anthropic impacts to which the mangrove forests are susceptible, the Mocajuba river basin's mangrove forest suffered modification on its extension between 1984 and 2018 (Figure 5). As shown in Table 2, between 1984 and 1999 the region suffered a loss, and between 1999 and 2018, the decrease was less significant.

According to Table 2, from the total area of mangrove forests in the basin in 1984, 94.49% remained until 1999, resulting in an alteration of 5.51%. In the transition between 1999 and 2018, from the total area remaining from 1984, approximately

95.93% remained, thus 4.07% suffered alterations. This way, summing the numbers from 1984 until 2018, approximately 10% of the total area of mangrove forests suffered some type of transformation. The map demonstrates that part of this alteration (6.6%) implicates that those areas became part of the riverbed because they are related to deforestation actions, which caused riparian erosion and an increase in the river cross-section. The remaining 3.4% correspond to a definitive alteration, either to secondary vegetation or non-forest areas.

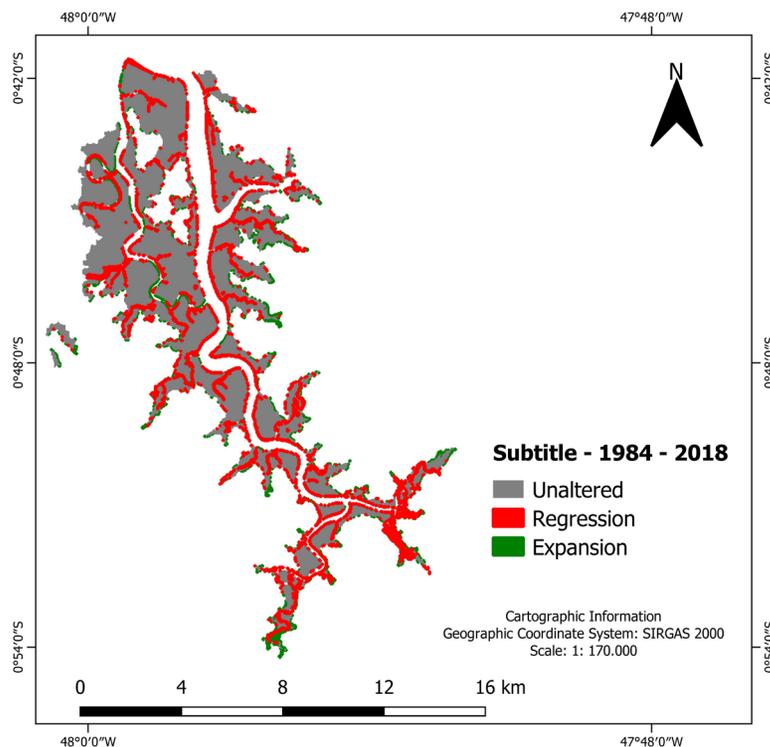


Figure 5. Regression and expansion of mangroves between 1984 and 2018.

This result diverges from other authors, such as Diniz et al. (2019), who observed a regeneration tendency on Brazilian mangrove forests over the last three decades. However, when performing a timeframe comparison, the authors observed a growth on mangrove forest areas between 1985 and 1999, and a small reduction between 1999 and 2018, that last one similar to the result found on the present study. Between 1986 and 1995, Faure (2013) observed an increase on mangrove forest areas at São Caetano de Odivelas and Marapanim, Pará. In addition, Nascimento Júnior et al. (2013) also observed an increase on mangrove forest areas between 1996 and 2008, in the states of Pará

and Maranhão. In Table 2, it is noted that the mangrove forest areas are expanding in the Mocajuba river basin, even if the expansion rates are lower than the regression rates.

Thomas et al. (2018) researched 16 areas in an attempt to represent the global range of mangrove forests. They observed a growth tendency between 1996 and 2010 mostly at the mangrove forest in Bragança, Pará, but also a reduction tendency at the mangrove forests in São Luís, Maranhão, and in the state of Amapá on the same years.

Thus, it is possible to understand that the dynamic of mangrove forests changes depending on the region, the natural characteristics, the environment's oscillations, the

anthropic interferences and, mostly, the forest's resilience and behavior when facing these issues.

Once more analyzing Table 2, it is observed that the expansion and regression of mangrove forests occurred mainly with the classes Water and Forest formation. That is, the mangrove forests substituted or were substituted mostly by Water or Forest. The variations between Mangrove forest and Non-forest were inferior, concluding that the anthropic settlements are not yet interfering considerably in the survival of mangrove forests in the region and that the Extractive Reserves are protecting mangrove forests from the expansion of anthropization.

According to Table 2, the dynamic of the mangrove forests at the Mocajuba river basin tends to regression. Therefore, mangrove forest areas that suffered regression were bigger than the areas regenerated on each of the three studied years. The areas that receded were mainly replaced by erosion processes (Mangrove forest to Water) and changes in the natural environment (Mangrove forest to Forest formation).

The mangrove forest areas that became secondary forest (Table 2) might have suffered anthropic or natural impacts, changing the ecosystem's characteristics and, consequently, inhibiting the survival of mangrove species and creating an environment suitable for secondary succession.

Rovai et al. (2012) concluded that restoring mangrove species into impacted areas is compromised by residual stresses, therefore sowing mangrove species might be ineffective if the local characteristics were not taken into consideration. In this case, the consequences of impacting mangrove forests may run deeper, making it difficult to ensure their survival and favoring their substitution to more resilient species, such as the secondary forests at the Mocajuba river basin.

The fact that water invaded areas that previously were mangrove forests proves the occurrence of erosion processes in the basin, as well as in anthropized areas near rivers and

mangrove forests. Faure (2013) also claims that this region is characterized by small erosion sites associated with anthropic factors. Likewise, the rising sea level causes the displacement of the influence area of sea tides, flooding and eroding the mangrove forest areas (GILMAN et al., 2006).

According to Prost et al. (2013), at the Marapanim and São Caetano de Odivelas mangrove forests were observed the same patterns for succession gradients as the ones at the Mocajuba river basin. The succession gradient called "Stick Pattern" (Padrão Paliteiro) is specific to areas eroded by the sea tides, presenting adult species of *Avicennia sp.* and *Rhizophora mangle* on the boundaries, because all other younger mangrove trees were affected and removed by erosion (Figure 6).

In contrast, the rising sea level also favors the migration of mangrove trees towards the mainland in case there are no barriers to their colonization (GILMAN et al., 2006), such as the water and secondary forest areas that were substituted for mangrove forests. In the same way, according to Faure (2013), the sediments carried by the Mocajuba river tend to be partially imprisoned on the estuarine perimeter, forming fine sand deposits, small barriers and sand islands, where the mangrove trees can migrate to, representing a specific vegetation succession.

Similar to the "Stick Pattern" observed by Prost et al. (2013), the study area also presented the "Stair Pattern" (Padrão Escada) (Figure 7), characterized by mixed trees of *Rhizophora mangle*, *Avicennia germinas* and other species, and associated with mangrove forest's progradation zones where there is fine sediments accumulation and, consequently, the establishment of tidal muddy plains.

The mangrove forest areas substituted with non-forest areas were very small if compared with other classes. However, it is a change that requires attention due to the fragility of mangrove forests when facing anthropic interventions, as well as the forest's potential to recover with favorable environmental factors, as explained before.



Figure 6. Stick pattern (paliteiro).



Figure 7. Stair pattern (escada).

Matias and Silva (2017) performed the temporal analysis of mangrove forests at the south of Alagoas between 2004 and 2016, noting expansion and regression in various areas. Mangrove forests protected by Conservation Units and in areas with higher saltwater input expanded, while mangrove forests pressured by anthropic activities regressed. Thus, if the Conservation Units administrations do not initiate the actions to ensure conservation, management and sustainability on the extractive reserves, the mangrove forests will continue to have their survival threatened.

Summarizing, mangrove forests in the Mocajuba river basin had a regression behavior due to both natural and anthropic factors aforementioned. The Extractive Reserves (RESEX), created to contain the expansion of human occupation and protect mangrove forests, are fulfilling their objectives. As observed, a few mangrove forest areas were replaced by anthropized areas. However, the area considered as Buffer Zone is anthropized, which might negatively interfere in the mangrove forests long term dynamic.

Also, the RESEXs do not have a Management Plan, which difficult initiatives to conserve and manage these Conservation Units (UC), aiding the anthropization stress over the mangrove forests in the whole basin and in the buffer zone.

4. CONCLUSION

The results show that the mangrove forest lost area between 1984 and 2018, presenting a regression behavior. However, this forest has a recovery potential (expansion), but with a lower intensity compared to the suppression (regression).

The region's mangrove forest is susceptible to human intervention, such as urban settlements expansion, agriculture and pasture areas. Those encompass the non-forest class, that presented an increase between 1984 and 2018 on the RESEX buffer zone. Besides the anthropic stresses, the mangrove forest is also subject to natural stress, such as rising sea level.

The changes in mangrove forest areas occurred mainly converting them to Water and Forest formation, considering that a greater amount of water substituted or was substituted by mangrove forests. The opposite occurred between the classes Mangrove forest and Non-forest, concluding that the expansion of anthropic activities in the basin still interfere very little with the mangrove forest dynamics, and that area transformations in the region happen mainly between mangrove forests, water and other forest areas.

Approximately 90% of the total mangrove forest areas in the basin remained unaltered during the period studied by the present work. Around 10% of the mangrove forest areas were altered, becoming part of riverbeds due to erosion processes, or suffered changes in their structure when occupied by other secondary vegetation and by non-forest areas.

In this context, the mangrove forests located at the northeast of the Pará state are susceptible to conditions that come from natural changes, such as coastal erosion, and to anthropic stress. That stress puts a pressure on the stability of the mangrove forest at the Mocajuba river basin, where the anthropic activities may affect this ecosystem's long-term resistance when facing natural stresses.

Therefore, the purpose of the Marine Extractive Reserves, to protect and conserve mangrove forests that face the expansion of anthropic activities, is being fulfilled. Even with the expansion of these activities along the main river in the Mocajuba river basin, the RESEX are protecting the mangrove forests borders. However, the Buffer Zones are occupied by anthropic activities, which, if extended to the whole basin, might interfere in the mangrove forests dynamic.

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CORRESPONDENCE TO

Juliane Costa Cavalcante

Universidade Federal do Pará, Rua Augusto Corrêa, 01, CEP 66075-110, Belém, PA, Brasil
e-mail: julianecosta63@gmail.com

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