An Acad Bras Cienc (2023) 95(1): e20211079 DOI 10.1590/0001-3765202320211079
Anais da Academia Brasileira de Ciências | *Annals of the Brazilian Academy of Sciences*
Printed ISSN 0001-3765 I Online ISSN 1678-2690
www.scielo.br/aabc | www.fb.com/aabcjournal

ECOSYSTEMS

Effectiveness of Federal Protected Areas in the Preservation of Mangrove Forests on the Coast of the State of Paraíba, Brazil

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Abstract: This study evaluated the effectiveness of Federal Protected Areas on the coast of the state of Paraíba in northeastern Brazil with regard to the preservation of mangrove forests. The study area encompassed remaining mangrove forests distributed in four federal protected areas (PAs) located in Paraíba: Area of Relevant Ecological Interest (AREI) of Mangroves of the Mamanguape River, Environmental Protection Area (EPA) of the Mamanguape River, the *Restinga de Cabedelo* National Forest (NATFOR), and the Acaú-Goiana Extractive Reserve (EXTRES). The methods consisted of a spatiotemporal analysis considering the year of creation of each PA, with mapping and quantification as well as the assessment of impacts and effectiveness. NATFOR and EXTRES had the most conserved mangrove areas on the temporal scale, whereas AREI and EPA had the largest reductions in areas of mangrove forest. Urban expansion, sugarcane monoculture, and shrimp farming represented the main negative impacts spatially identified in these PAs. Based on the results of this study, the mangrove forests analyzed have continually suffered anthropogenic pressures since their creation as protected areas. The greatest effectiveness in the preservation of mangrove forests was found in Acaú-Goiana EXTRES and the least effectiveness was found in the AREI of Mangroves of the Mamanguape River.

Key words: Conservation, estuaries, mangrove, geotechnologies, negative impacts, protected marine areas.

INTRODUCTION

All human activities concentrated in coastal urban centers exert located on coastlines pressure on the flora, fauna, and other natural resources (Gerling et al. 2016). The northeastern Brazilian coast is one of the most dynamic in the country. Among the causes of this dynamism are rapid occupation by tourism activities, urban expansion, and shrimp farming, which have significantly altered local environmental conditions (Lacerda et al. 2006).

To mitigate such pressures, one management strategy implemented in Brazil has been the establishment of Protected Areas (PAs) (Figueiroa et al. 2016). Such areas are described as the designated space and its environmental resources, including jurisdictional waters, with relevant natural characteristics legally instituted by public authorities for the purpose of conservation and with defined limits under a special administration system to ensure adequate protection. These areas are divided in PAs under Full Protection and PAs under Sustainable Use (SNUC 2011).

The coast of Paraíba (northeastern Brazil) has four federal PAs under Sustainable Use. The Area of Relevant Ecological Interest (AREI)

of Mangroves of the Mamanguape River and Environmental Protection Area (EPA) of the Mamanguape River were created to ensure the conservation of endangered species on region basis, especially the manatee (*Trichechus manatus*), ensure the conservation of the remaining mangroves, the Atlantic Forest, and water resources. The *Restinga de Cabedelo* National Forest (NATFOR) was created to conserve the *restinga* vegetation, mangroves, and other ecosystems associated with the estuary of the Paraíba River. Finally, the Acaú-Goiana Extractive Reserve (EXTRES) was created for the conservation of natural resources.

The national conservation unit system defines the basic purpose of sustainable use units, which is to conserve nature while permitting the sustainable use of a portion of natural resources (SNUC 2011). Thus, the effectiveness of PAs with regard to the objectives of their creation is of utmost importance to the conservation of the ecosystems in these units.

The mangrove ecosystem is considered a permanent preservation area by Brazilian federal environmental law (Brasil 2012) and is found from the mouth of the Oiapoque River in the state of Amapá (northern Brazil) to the municipality of Laguna in of Santa Catarina (southern Brazil), in discontinuous areas with an extension of approximately 14,000 km^2 of the coast of Brazil (ICMBIO 2018) and constituting the second largest area of mangroves in the world (Gerling et al. 2016). This ecosystem serves as a biological filter, protects the coastline and is an important primary producer of the marine environment, sustaining the basis of coastal food webs and generating goods and services for local communities (Alves 2001). The main economic activities developed in this ecosystem are community-based tourism (ICMBIO 2018) and artisanal fishing (ICMBIO 2014). All such activities have considerable potential for the sustainable generation of income (ICMBIO 2018).

However, several factors threaten the mangrove ecosystem. Even mangroves in PAs are affected by disturbances, such as the removal of vegetation, silting, water pollution, and a reduction in river discharge (Paludo & Klonowski 1999, Fadigas & Garcias 2010, ICMBIO 2014). Such disturbances directly or indirectly promote significant losses to this ecosystem throughout the world (Maia et al. 2019).

The present study evaluated the effectiveness of federal protected areas on the coast of Paraíba with regard to the preservation of mangrove forests.

MATERIALS AND METHODS

Study area

The study area encompassed mangrove forests occurring in four federal PAs Sustainable Use which have mangrove conservation as one of their objectives, located on the coast of Paraíba and the extreme northern portion of Pernambuco in northeastern Brazil: AREI of Mangroves of the Mamanguape River situated between the municipalities of Rio Tinto and Marcação; EPA of the Mamanguape River in the municipalities of Lucena, Rio Tinto, Marcação, and Baía da Traição; the *Restinga de Cabedelo* NATFOR located in the municipality of Cabedelo; and the Acaú-Goiana EXTRES situated between the municipalities of Pitimbu and Caaporã in the extreme southern portion of Paraíba as well as the municipality of Goiana in the extreme northern portion of Pernambuco (Figure 1).

Acquisition and processing of satellite images

Landsat 5 TM sensor satellite images with 30 meters spatial resolution were obtained from the website site of the United States Geological Survey (USGS 2020). Images were selected based

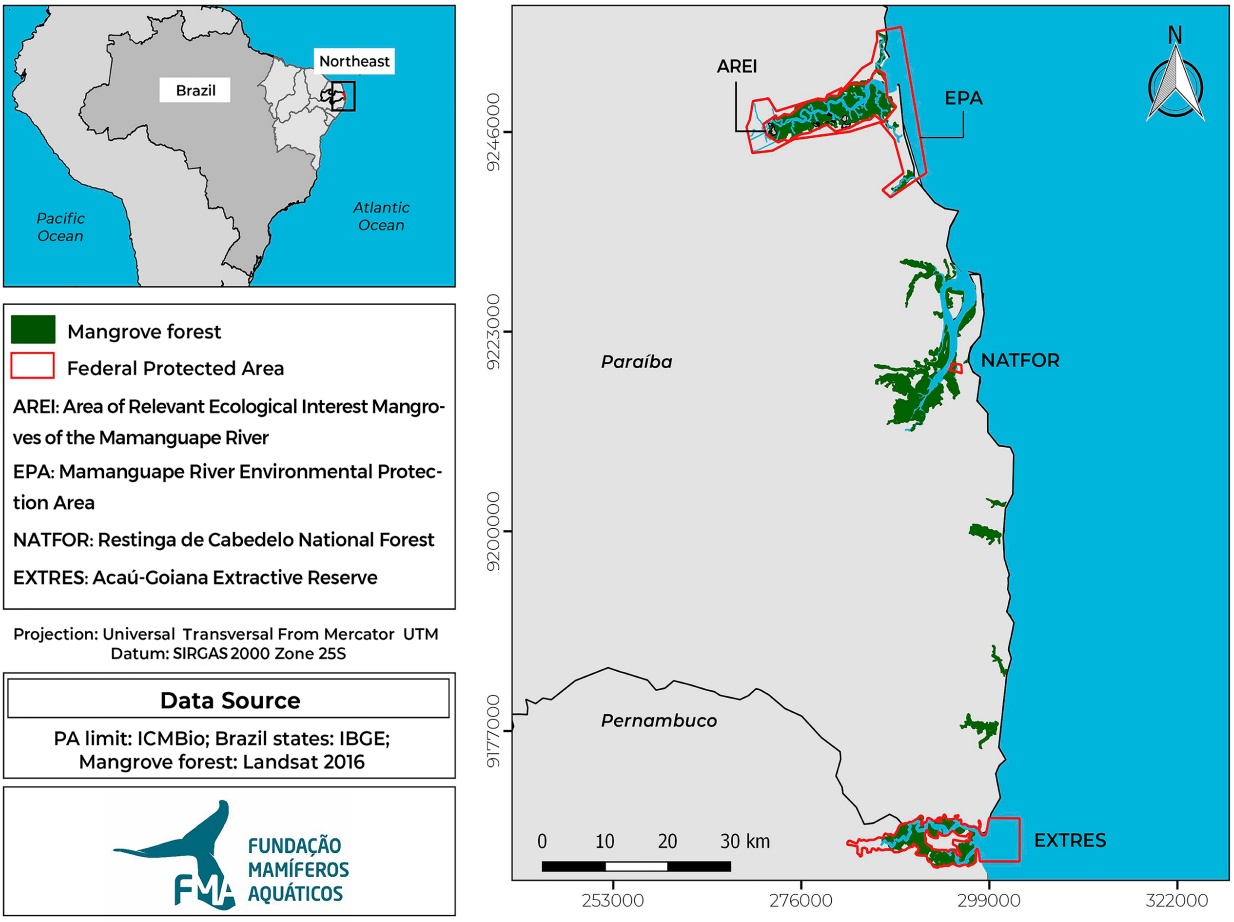


Figure 1. Federal Protected Areas distributed along the coast of the state of Paraíba in northeastern Brazil.

on date of establishment of PAs (before and after), cloud cover (preference was given to the dry season months August to April, with low rainfall) (Araújo et al. 2016) (Table I).

The method involved three steps. The first consisted of preprocessing with the reprojection of the images of the Southern Hemisphere and SIRGAS 2000 Datum and spectral composition using bands 3, 4, and 5. This composition highlights mangrove vegetation, favoring mapping for the obtainment of a more precise result (Boulhosa & Souza Filho 2009). The second step consisted of supervised classification and involved the processing of images using the maximum likelihood method to discriminate the targets (mangrove forests, clouds, and cloud shadows) (Crósta 1992). The third step consisted of post-processing to minimize possible classification errors by comparing the results to the high-resolution images from Google Earth. This method also enabled excluding some clouds and cloud shadows. All these procedures were performed in the ArcGIS 10.3.0 program with licensing conceded by the Aquatic Mammal Foundation (Fundação Mamíferos Aquáticos in Portuguese).

Assessment of impacts and effectiveness

To evaluate the possible negative impacts on the mangrove forests of the PAs, the same satellite images used for mapping were analyzed using the photointerpretation method (Panizza & Fonseca 2011). This enabled identifying elements of the landscape, such as the urban zone,

Table I. Period of image acquisition for each Protected Area.

Conservation unit	Decree of creation	Years of images
AREI of Mangroves of the Mamanguape River	Federal Decree Nº 91.890, November 5th, 1985	1984, 1995, 2005, and 2016
EPA of the Mamanguape River	Federal Decree Nº 924, September 10th, 1993	1991, 2005, and 2016
Restinga de Cabedelo NATFOR	Federal Decree w/n, June 2nd, **2004**	2003 and 2016
Acaú-Goiana EXTRES	Federal Decree w/n, September 26th, 2007	2005 and 2016

Abbreviations: AREI, Area of Relevant Ecological Interest; EPA, Environmental Protection Area; NATFOR, National Forest; EXTRES, Extractive Reserve; Nº, number; w/n, without number.

shrimp farming enterprises, and sugarcane plantations, both spatially and temporally. To evaluate the effectiveness of the PAs with regard to the preservation of mangrove forests, the year of creation of each PA was identified and spatiotemporal dynamics were used to divide the information into two scenarios: pre- and post-creation of the conservation units. Next, the quantification of the mapping was performed. This consisted on the calculation of the total area of each mangrove forest in hectares using the calculator in the ArcGIS 10.3.0 program. Finally, the percentage of retraction and expansion was calculated for each decade studied, for which 100% was considered the year before the creation of each PA (Brasil, unpublished data).

RESULTS

Spatialization and quantification of mangrove forests

The analysis of the spatialization of the mangrove forests in each PA revealed a change in plant cover in the AREI of Mangroves of the Mamanguape River throughout the period studied. After the creation of the AREI, the area of mangrove forest withdrew 5% in the 1990s, 10% in the 2000s, and 9% in the last decade analyzed (Figure 2).

The mapping of mangrove forests of the EPA of the Mamanguape River revealed retractions in areas of vegetation of 2% for the 2000s and 2010s. Despite some areas of expansion, areas of retraction prevailed in the EPA (Figure 3).

In *Restinga de Cabedelo* NATFOR, little variation (less than 1%) was found in the mangrove forests between the 2000s (before the creation of the PA) and 2010s (after the creation of the PA). The spatialization of the data revealed an area of retraction around the Jaguaribe River (tributary of the Paraíba River) in the last decade, which was found at low tide (DHN 2016) (Figure 4).

For Acaú-Goiana EXTRES, variations were found in the area corresponding to mangrove forest since the creation of the PA in the 2000s through to the last decade (post-creation). For the 2010s, an area of expansion (5%) prevailed (Figure 5).

Quantifying the mangrove forests of each PA analyzed in this study, the EPA of the Mamanguape River showed the largest area of mangroves and *Restinga de Cabedelo* NATFOR had the smallest area. In terms of expansion and retraction of the mangrove areas since the creation of each PA through to the last decade analyzed, Acaú-Goiana EXTRES had the greatest expansion, whereas the AREI of Mangroves of the Mamanguape River suffered the greatest retraction (Table II).

Identification and assessment of negative impacts on mangrove forests

Based on the satellite images used in this study, shrimp farming, urban growth, and sugarcane monoculture were identified as the most representative factors that caused negative

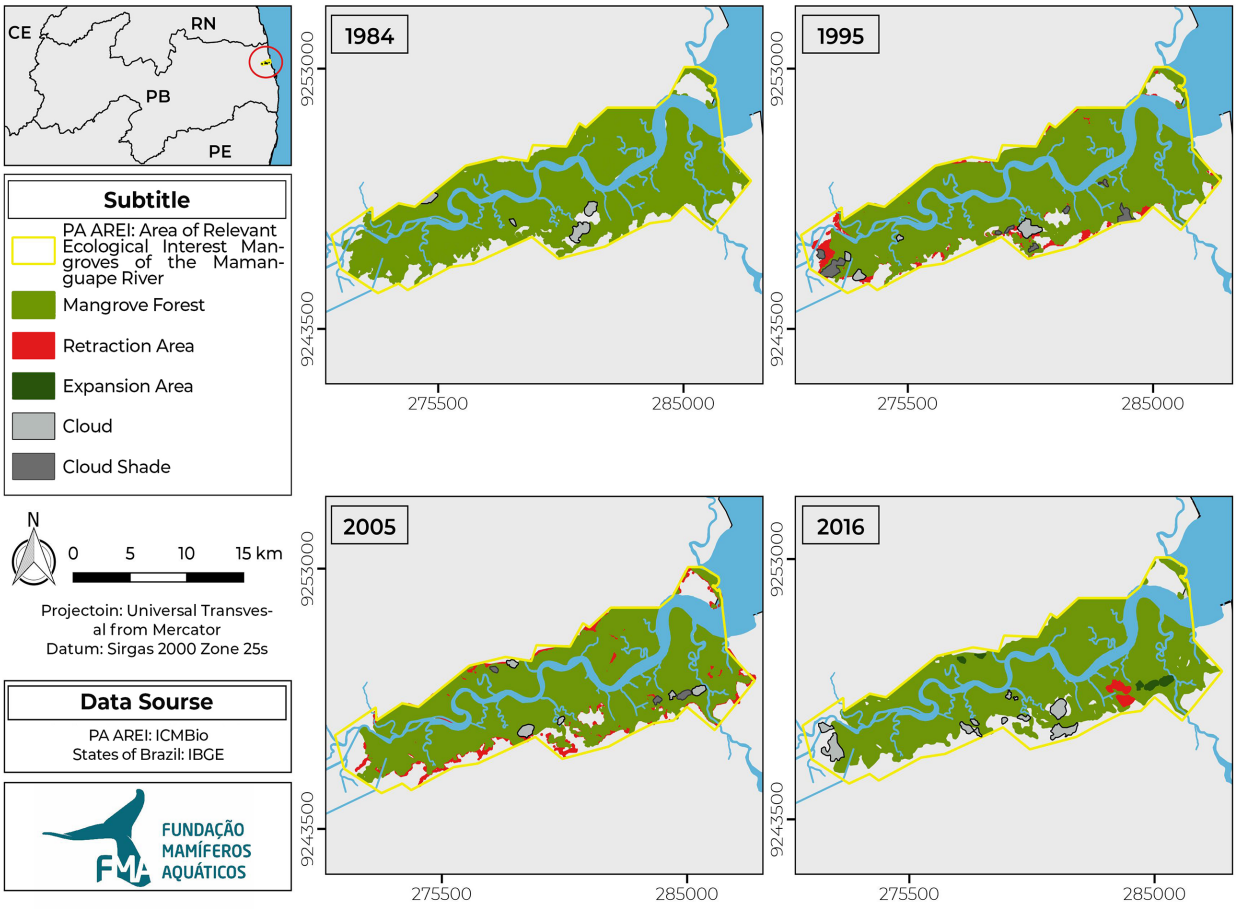


Figure 2. Spatiotemporal distribution of mangrove forests in Area of Relevant Ecological Interest (AREI) of Mangroves of Mamanguape River.

impacts either directly or indirectly on the mangrove forests in the PAs and surrounding areas.

In the AREI of Mangroves of the Mamanguape River, shrimp farming tanks, which were not found in the 1980s and 1990s (Figures 6-7). Beginning in the 2000s, shrimp farming tanks were found in the interior of this PA. Moreover, a flooded area was identified in 2010 with no mangrove plant cover (Figures 8-9).

Sugarcane monoculture activities had been found around the EPA of the Mamanguape River since the 1990s. No shrimp-farming tanks were found in that decade, however they have been observed in the 2000s with greater intensity and persisted into the following decade (2010s) (Figures 10-12).

Changes have also been found around the *Restinga de Cabedelo* NATFOR. Fragments of vegetation were found in the 2000s, whereas the same area corresponded only to the urban zone in the 2010s, revealing deforestation and urban growth (Figures 13-14).

Activities of potential impact such as shrimp farming in the center of the mangrove forest were found only in the surrounding areas of the Acaú-Goiana EXTRES. This activity was found in the 2000s (after the creation of the PA) and continues in this decade. Another perceptible impact was sugarcane monoculture in the municipalities of Pitimbu and Caaporã in the state of Paraíba as well as the municipality of Goiana in Pernambuco (Figures 15-16).

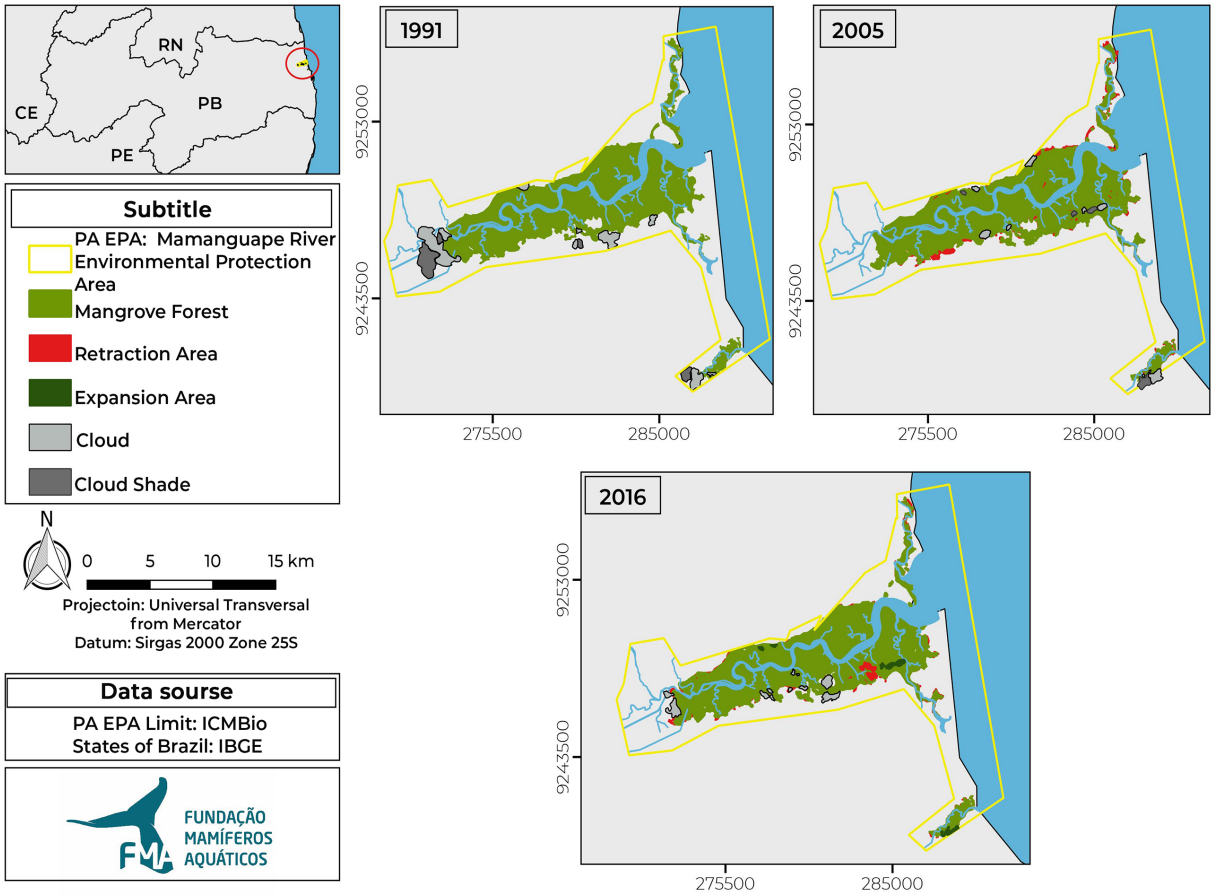


Figure 3. Spatiotemporal distribution of mangrove forests in the Environmental Protection Area (EPA) of Mamanguape River.

DISCUSSION

The present findings reveal an evident retraction of mangrove forests after the creation of the AREI of Mangroves of the Mamanguape River, with the extraction of wood between 1989 and 1993 having an important impact (Paludo & Klonowski 1999). According to these authors , the mangrove of the Mamanguape River was exploited for diverse uses, such as firewood, coal, and timber for constructing houses and boats.

Shrimp farming was another activity found in the AREI and was implemented by a private company in the southern portion of the PA. This activity is currently halted, as it was situated on an island with *restinga* vegetation located in the interior of the mangrove (ICMBIO 2018), causing an environmental impact. Besides the deforestation of mangrove vegetation, shrimp farming also caused pollution of the rivers due to the use of chemical products, the feed employed, discards from the activity itself (ICMBIO 2014), and changes in the configuration of the landscape, which contributed to the reduction in mangrove forests.

Another negative impact was the presence of an area of exposed soil (flooded) in the middle of the mangrove of the AREI. Such data are in agreement with findings described by Medeiros et al. (2018) in studies conducted in the same area analyzing satellite images and informal conversations with local residents. The authors state that this area had previously been covered with mangrove vegetation that was

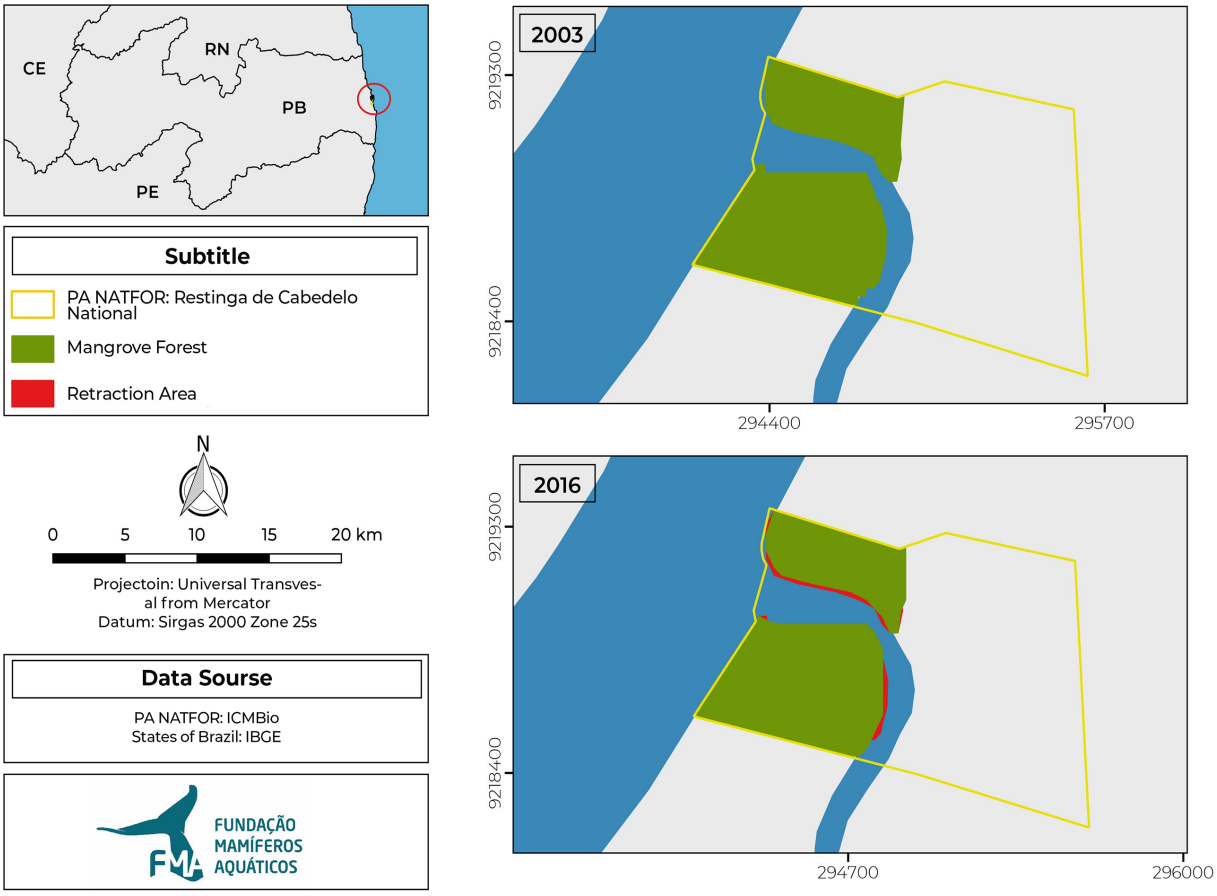


Figure 4. Spatiotemporal distribution of mangrove forests in *Restinga de Cabedelo* National Forest (NATFOR).

subsequently destroyed. The destruction of this riparian forest was reported to cause silting and a reduction in the amount of freshwater in the estuary and the input of pesticides by leaching of the soil because the CU is surrounded by sugarcane plantations (Pessoa et al. 2016).

The EPA of the Mamanguape River had the largest mangrove area among all CUs analyzed in this study. Assis et al. (2016) reported that mangrove class is the most representative among all landscape classes that make up this EPA. However, the largest loss of mangrove vegetation since the creation of the PA was also registered. Pessoa et al. (2016) reported the retraction of mangrove forests in the EPA of the Mamanguape River after the authors performed spatiotemporal analyses in this PA for the period 1985-2013, documenting the loss of dense vegetation (mangrove and Atlantic Forest) both in the EPA and its surroundings. Sugarcane monoculture, shrimp farming, real estate speculation, and mangrove wood extraction occur in these locations (ICMBIO 2014, Assis et al. 2016).

Sugarcane monoculture was reported to be the main agricultural activity in the region (Embrapa 2008), occupying large extensions of land and located in areas around the mangroves of the estuary of the Mamanguape River (B.C.D. Albuquerque, unpublished data). This activity began in the region in the 1970s with the expansion of sugarcane plantations through incentives of the Pro-Alcohol Program instituted by the federal government and the business community, causing considerable deforestation of the Atlantic Forest (Paludo & Klonowski 1999).

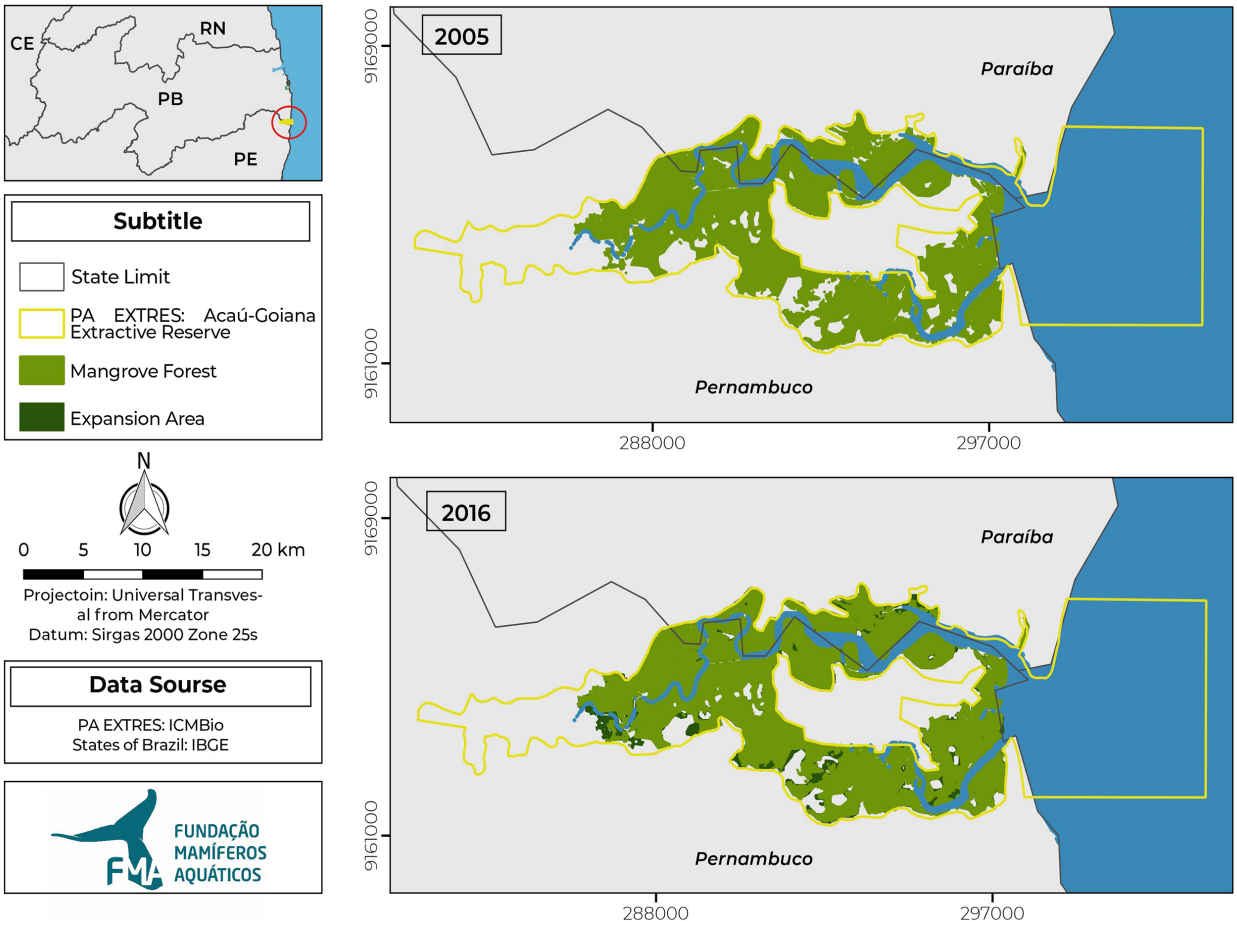


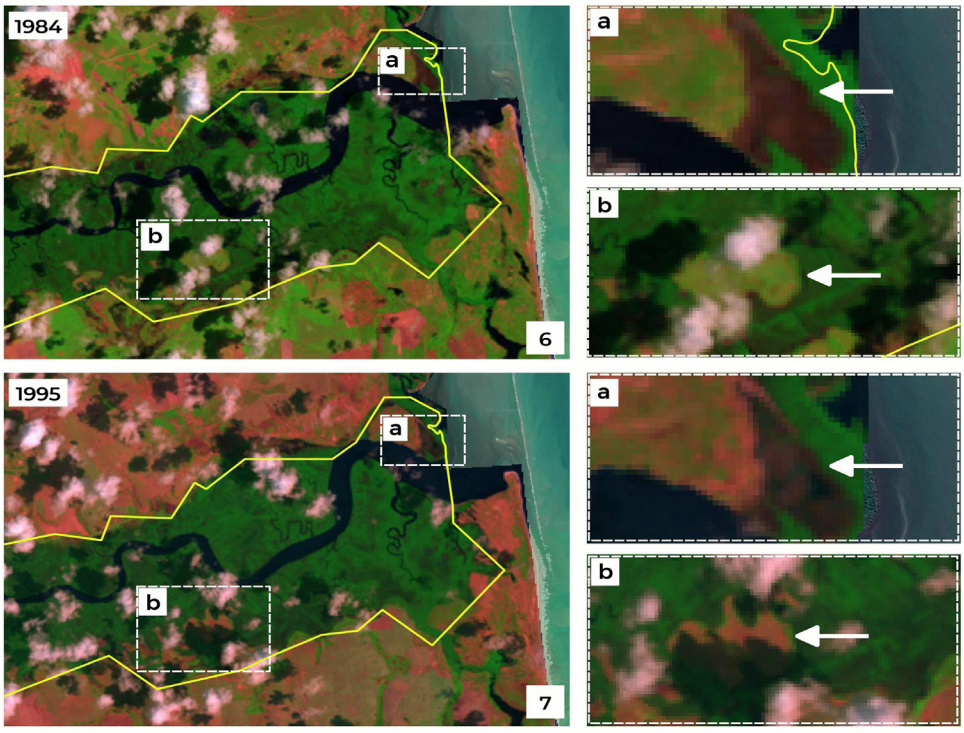
Figure 5. Spatiotemporal distribution of mangrove forests in Acaú-Goiana Extractive Reserve (EXTRES).

Table II. Quantification of mangrove forests in Protected Area.

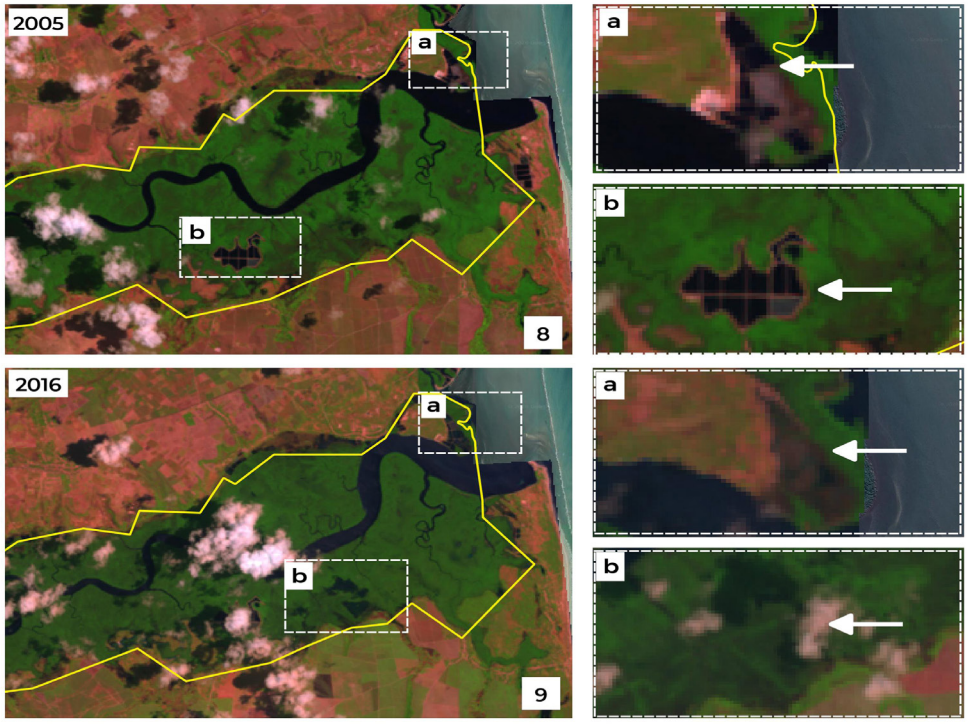
Protected Area	Decade/ year of acquisition of images	Temporal mark based on year of creation of CU	Mangrove forest (area in ha)	% of mangrove forest in total area of PA	Expansion/ retraction (% of area)
AREI of Mangroves of the Mamanguape River	1980/1984	Pre	4197.88	73	0
	1990/1995	Post	3902.33	68	-5
	2000/2005	Post	3641.56	63	-10
	2010/2016	Post	3656.14	63	-9
EPA of the Mamanguape River	1990/1991	Pre	4356.57	29	0
	2000/2005	Post	4009.43	27	-2
	2010/2016	Post	4086.75	27	-2

Abbreviations: AREI, Area of Relevant Ecological Interest; EPA, Environmental Protection Area; NATFOR, National Forest; EXTRES, Extractive Reserve; PA, Protected Areas; ha, hectare; %, percentage.

Besides the impacts on mangroves, there were negative impacts on the quantity and quality of the water, causing hydrological changes and increasing sedimentation, erosion, and silting (ICMBIO 2018).

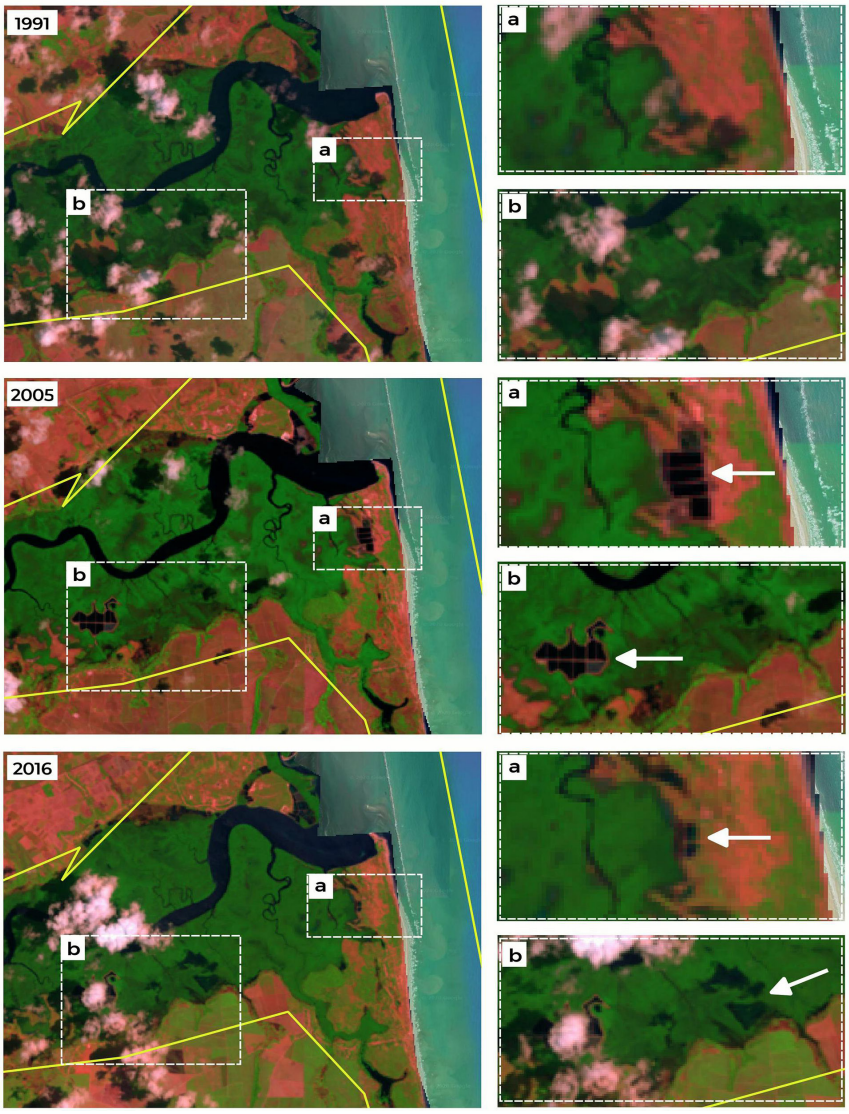


Figures 6-7. Evidence of transformation of landscape in AREI of Mangroves of Mamanguape River. Figures 6a (1984) and 7a (1995) show areas of wet soil with no vegetation. Figure 6b (1984) shows area of *restinga* vegetation in middle of mangrove and 7b (1995) shows the same area previously corresponding to *restinga* vegetation represented in 1995 by exposed soil.



Figures 8-9. Evidence of the transformation of landscape in AREI of Mangroves of Mamanguape River. 8a (2005) and 9a (2016) show area of shrimp farming tanks (northern portion of mangrove). 8b (2005) shows the area of shrimp farming tanks (southern portion of mangrove). 9b (2005) shows flooded areas with no mangrove vegetation.

Other incentives to the development of economic activities in the region occurred in the mid-1990s. According to Cardoso & Guimarães (2012), some indigenous families (Potiguara people) built shrimp nurseries in mangrove areas on the banks of the Mamanguape River with the incentive and investment of private companies. These nurseries were located to

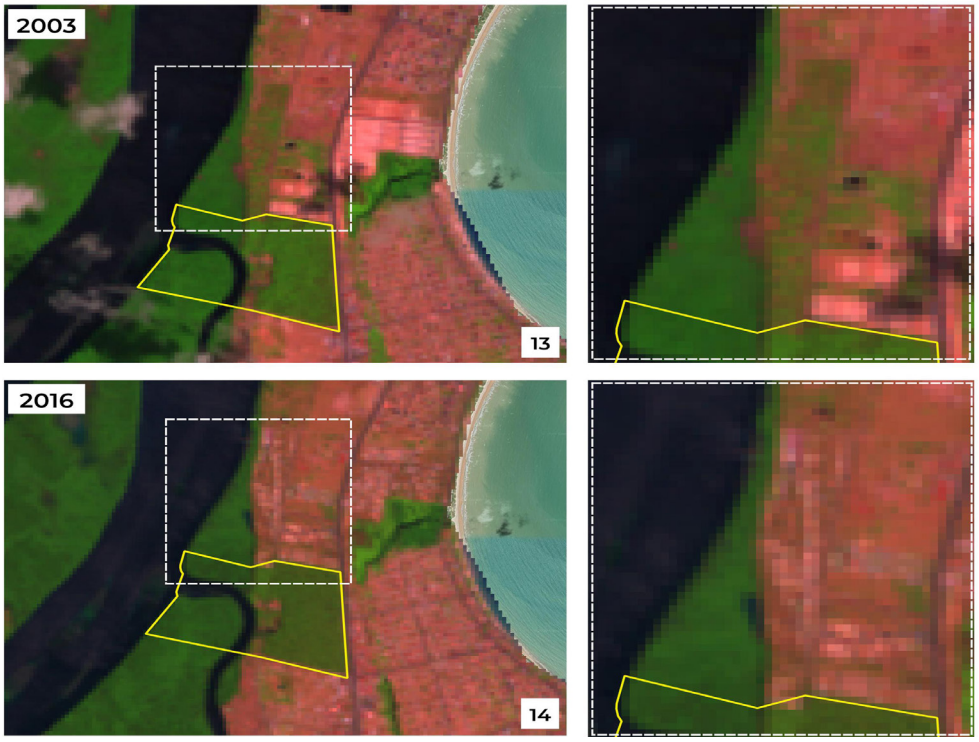


Figures 10-12. Evidence of transformation of landscape in EPA of Mamanguape River. 10a (1991) shows sugarcane plantations. 11a-b (2005) and 12a (2016) show shrimp-farming tanks installed on margins of mangrove. 12b (2016) shows flooded area.

the north in the villages of Brejinho, Tramataia, Camurupim, and Caieira, accounting for the largest portion of shrimp-farming tanks in the PAs (EPA of the Mamanguape River and AREI of Mangroves of the Mamanguape River). Shrimp farming activities were also identified in the communities of Barra de Mamanguape and Tavares in the southern portion of this estuary (ICMBIO 2014).

In *Restinga de Cabedelo* NATFOR, the small area of retraction of mangrove forests was situated on the banks of the Jaguaribe River (tributary of the Paraíba River). This retraction (less than 1%) may be a case of confusion in the classification of the image between the water and mangrove classes due to factors such as the fluctuation of the tide, which exerts an influence on the spectral response of the targets (Meneses & Almeida 2012).

Although the NATFOR did not exhibit a significant reduction of mangrove forest within its limits, the areas around the PA are impacted. A previous study on mangroves of the Paraíba River (of which *Restinga de Cabedelo* NATFOR is part) recorded a reduction in mangroves on the spatiotemporal scale caused by changes related



Figures 13-14. Evidence of the transformation of landscape in area around *Restinga de Cabedelo* NATFOR. Figure 13 (2003) shows fragments of vegetation. Figure 14 (2016) shows the same area but without vegetation (urban zone).

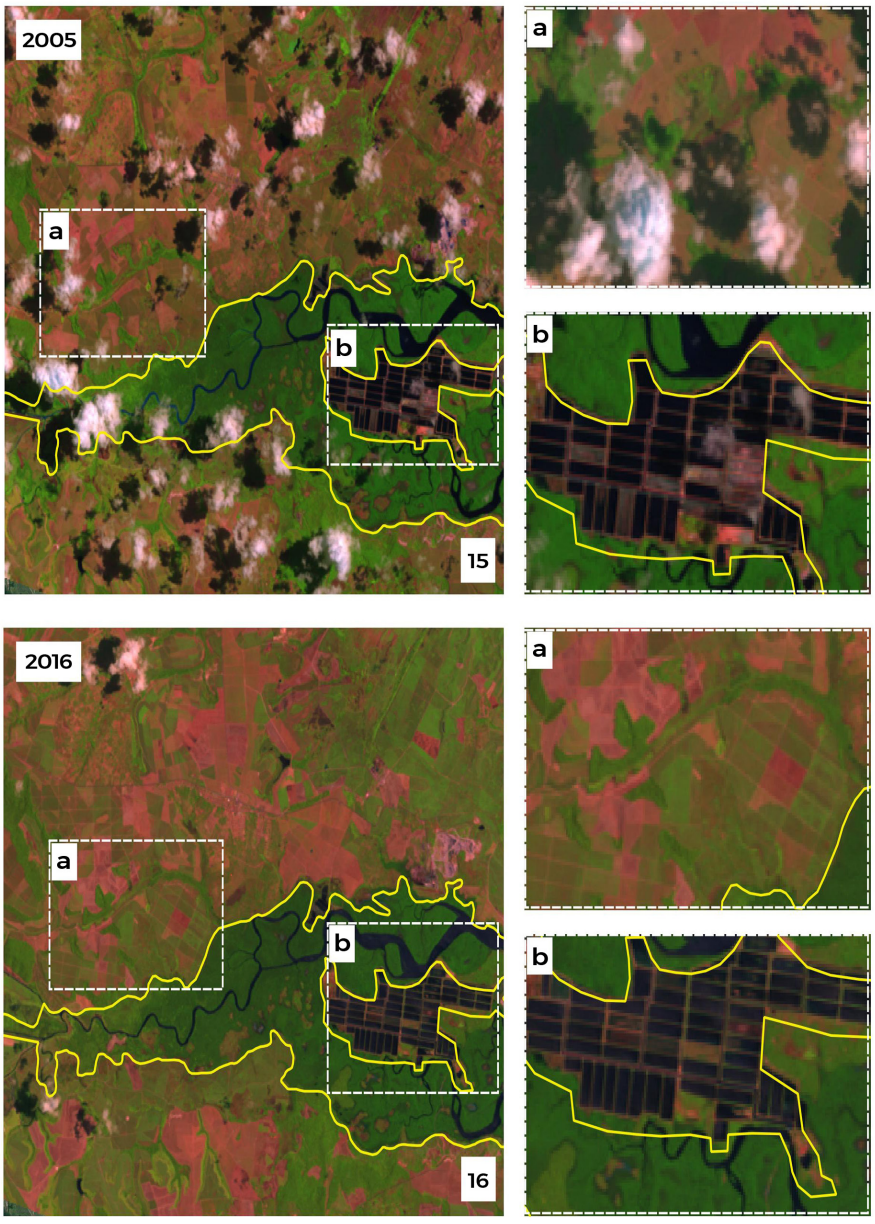
to human activities (Araújo & Bezerra 2018). The authors identified the replacement of areas of mangrove with shrimp farming activities and urban growth. However, no studies were found specifically on *Restinga de Cabedelo* NATFOR that analyzed the situation of the mangroves on a temporal scale, which makes the data of this study even more important to the management of this PA.

The NATFOR is situated within an urbanized matrix, the communities of which exert impacts on the mangrove ecosystem through the discharge of solid waste and untreated sewage directly into the mangrove (Araújo & Bezerra 2018) as well as deforestation and landfilling activities, resulting in mangroves highly altered by human activities (ICMBIO 2018).

The expansion of the mangrove forests in Acaú-Goiana EXTRES occurred mainly in the southern portion of the reserve, corresponding to the municipality of Goiana in the state of Pernambuco. In a spatiotemporal analysis of the estuary of the Itapessoca River in this municipality, Santana et al. (2011) identified an increase in areas of mangrove. The authors attributed this to the influence of saline waters that had advanced in the estuary, which favored the development of mangrove vegetation in more internal areas of the mangrove that had previously been occupied by sparse vegetation, exposed soil, and salt flats, with environmental conditions that did not permit this expansion.

This PA had a positive result regarding the preservation of mangrove forests, but this does not mean that the ecosystem is not being impacted. In the municipality of Goiana, the coastal region has experienced an intense process of urban growth for the past 30 years, with negative impacts on the mangrove ecosystem (Sousa et al. 2017). Urban growth in the surrounding areas has limited the expansion of the mangrove due to the lack of space for the development of this ecosystem (Santana et al. 2011).

Alongside urbanization, shrimp farming was found around the EXTRES. However, when



Figures 15-16. Evidence of the transformation of landscape in area surrounding Acaú-Goiana EXTRES. 15a (2005) and 16a (2016) show areas of sugarcane plantations. 16b (2005) and 17b (2016) show shrimp-farming tanks around the conservation unit.

this PA was created, areas occupied by shrimp-farming tanks were not part of the polygon that demarcated the protected area, although such activities are in the central area of the EXTRES and were installed before the creation of the PA (Cidreira-Neto & Rodrigues 2019).

Studies conducted by Silva et al. (2020) reported that shrimp farming activities located in the center of the EXTRES have increased since the 1990s and are situated in the northern portion of Pernambuco, which has had a rapid aquiculture growth (Guimarães et al. 2010). According to the ICMBIO (2018), shrimp farming has negatively affected mangroves due to the construction of shrimp tanks and dams, which have altered water flow. Thus, the shrimp nurseries around the EXTRES and located in the center of the mangrove have directly influenced this ecosystem.

Sugarcane monoculture was also found in the area around the EXTRES. According to Silva et al. (2020), this activity has drastically

altered the landscape of the region by replacing the Atlantic Forest with plantations, therefore interfering with the dynamics of fauna and flora populations in the PA.

In Brazil, 87% of the entire mangrove environment is located within protected areas, enabling greater effectiveness in the conservation of this ecosystem (ICMBIO 2018). However, the impacting activities cited in this paper constitute an imminent threat to the PAs studied. The present results show that these PAs have suffered anthropogenic pressures from the time of their creation to this day, causing changes in the size of the areas of the mangrove forests.

In conclusion, the present findings reveal that the greatest effectiveness in the preservation of mangrove forests was found in Acaú-Goiana EXTRES and the least effectiveness was found in the AREI of Mangroves of the Mamanguape River. It is fundamental to intensify monitoring activities to ensure the enforcement of all objectives proposed in the act of creation of each PA as well as the involvement of the populations in and around these protected areas through environmental education actions with the aim of mitigating the impacts of human actions and conserving the mangrove ecosystem. In addition, for the maintenance of this important biome, it is of fundamental importance that the Brazilian government promotes and executes programs of research, protection, preservation, as well as exercising the power of environmental police for the protected areas.

Acknowledgments

The authors are grateful to the *Programa de Pós-Graduação em Ecologia e Monitoramento Ambiental* (PPGEMA [Graduate Program in Ecology and Environmental Monitoring]), *Fundação Mamíferos Aquáticos* (FMA [Aquatic Mammal Foundation]), *Laboratório de Cartografia e Geoprocessamento* (LCG/UFPB [Cartography and Geoprocessing Lab]), Environmental Protection Area of the Mamanguape River (ICMBio), "Long Live the Manatee" project of the *Fundação Mamíferos Aquáticos* and sponsored by Petrobras through the Petrobras Socioenvironmental Program and the Manatee Conservation Program of the *Fundação Mamíferos Aquáticos* in partnership with the *Fundação Grupo Boticário de Conservação à Natureza* [Boticário Group Foundation for the Conservation of Nature]).

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How to cite

MEDEIROS IS, SANTOS SS, REBELO VA, ALMEIDA IC, VELOSO TMG, ALMEIDA NV & BORGES JCG. 2023. Effectiveness of Federal Protected Areas in the Preservation of Mangrove Forests on the Coast of the State of Paraíba, Brazil. An Acad Bras Cienc 95: e20211079. DOI: 10.1590/0001-3765202320211079.

Manuscript received on July 30, 2021;
accepted for publication on November 22, 2022

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