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Source: Tropical Conservation Science, 12(1)

Published By: SAGE Publishing

URL: https://doi.org/10.1177/1940082918822411

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Research Article

Coastal Land Use in Northeast Brazil: Mangrove Coverage Evolution Over Three Decades

Tropical Conservation Science
Volume 12: 1–15
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DOI: 10.1177/1940082918822411
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Abstract

It is essential to monitor both the mangrove coverage and the encroachment of anthropogenic activities to assess the evolution of these highly valuable and threatened ecosystems. Using the grid technique, Landsat images of three estuaries in Pernambuco, northeast Brazil, were analyzed to track changes in land use over the past three decades. This study is the first time the grid technique has been used as a precise method to quantify and localize the mangrove coverage changes at local scale. We found that the technique was a synthetical and cost-effective way of observing land-use changes over the study period, and its precision was evident for local-scale study. An increasing trend of mangrove coverage was observed and can be related to the salinization. This increase in salinization is a result of anthropogenic activities and climate change. We also found that differences in geometrical properties influenced the spatiotemporal patterns of mangroves. To mitigate adequately the negative impacts induced by anthropization and climate change, the characteristics of mangrove forest configuration and human activities should therefore both be considered.

Keywords

mangrove, Landsat, grid technique, anthropic threats, land use, remote sensing

Introduction

Mangroves are of great socioeconomic and environmental importance globally. They provide raw materials and food and contribute greatly to coastal protection, erosion control, water purification, carbon sequestration, tourism, recreation, and education (Barbier et al., 2011). They also contribute to the maintenance of fisheries by providing nursery habitats and increasing marine productivity. This makes them of central importance to local culture and traditional knowledge (Walters et al., 2008). These forests of salt-tolerant species allow the development of complex food webs (Valiela, Bowen, & York, 2001), and because mangrove ecosystems carry out essential ecological functions, any significant loss of mangrove forests will have significant consequences on these food webs as well as on biodiversity and abundance.

Yet, mangrove wetlands are being threatened by the growth of anthropogenic activities. Moreover, climate change, the increase of CO_2 emissions, rising sea levels, and alterations in precipitation regimes are having a great impact on these ecosystems (McKee, Rogers, & Saintilan, 2012; Ward & Larcombe, 2010). Indeed, more than one third of the world mangrove disappeared in the past 60 years, and since the beginning of the 21st century, mangroves continue to be lost at a rate of about 0.2% of their total area per annum (Hamilton & Casey, 2016). Despite these threats, only 6.9% of mangroves worldwide come under any form of protected area legislation (Giri et al., 2011). Mangrove forest management is thus a great challenge for biodiversity preservation, particularly in the estuaries where human activities are encroaching (Alongi, 2002;

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Received 31 July 2018; Revised 30 November 2018; Accepted 9 December 2018

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De Souza-Machado, Kloas, Toffolon, Zarfl, & Spencer, 2016; Kennish, 2002).

Mangrove vegetation grows in a relatively narrow fringe between the land and the sea, between latitudes 25°N and 30°S (Valiela et al., 2001).The fact that mangroves are mostly found in developing regions of Asia, Africa, and South America adds additional challenges to their monitoring (Li, Mao, Shen, Liu, & Wei, 2013; R. O. Santos, Lirman, & Serafy, 2011). There is also a lack of precision over the definition of mangrove forests, and this contributes to a lack of clarity regarding the state of mangrove forests globally. For example, mangroves are often defined as intertidal communities of trees, but this can sometimes also refer to muddy sediments and other herbaceous vegetation. Therefore, it is impossible to establish whether the worldwide extent of mangrove ecosystems is 100,000 km^2 or 200,000 km^2 (Wilkie & Fortune, 2003).

The Brazilian coast has the second largest mangrove area in the world, distributed between the Oiapoque River on the French Guyana border (04°30′N) and Sonho Beach in the state of Santa Catarina (28°53′S; Kjerfve & Lacerda, 1993). There was approximatively 10,124 km^2 of mangrove in Brazil in 1983, but by 2000, the estimated area had shrunk to 9,630 km^2 (Giri et al., 2011). In the past three decades, the Brazilian mangrove has been severely impacted by harbor expansions, the development of tourism infrastructure, and the growth of agriculture and industry, especially along the northeastern and southeastern coasts (Schaeffer-Novelli, Cintrón-Molero, Soares, & De-Rosa, 2000). The destruction of mangrove areas for the installation of shrimp farms has been identified as a particularly important factor for mangrove loss in the northeast region of Brazil (Guimarães, Travassos, Souza Filho, Gonçalves, & Costa, 2010).

The Brazilian state of Pernambuco has significant mangrove coverage because its geographical position and low altitude is conducive to mangrove growth (Silva, Galvíncio, Brandão Neto, & Morais, 2015). Along the 187 km of coast, there are 15 estuaries with mangroves. This habitat is important for fauna biodiversity (e.g., fish, birds, mollusks, and crustaceans) in the area. Indeed, more advanced larval stages were observed in the mangroves in Pernambuco compared with adjacent habitats, indicating strategic ontogenic migration to this zone (Silva-Falcão, Severi, & De Araújo, 2013).

Biodiversity and fisheries are closely related, and many anthropogenic activities depend on a healthy mangrove ecosystem. There are 34 riverine communities in Pernambuco subsisting on fishing and gathering mollusks and crustaceans (Lessa, Monteiro, Duarte-Neto, & Vieira, 2009). Some 13,000 fishermen are involved in small-scale artisanal fishing (Silva et al., 2015). Collecting data describing the condition of mangrove coverage in the area should, therefore, be considered a top research priority, as an entire socioeconomic system depends on it.

To understand mangrove transformation trends, historical data on land use are required. Integrating geographic information systems (GIS) and remote sensing enables the generation of data that can accurately record landcover changes (Rawat & Kumar, 2015). Maps generated through this approach illustrate the ecological properties of the studied areas and can thus be used as tools to guide environmental managers and policy makers (Schmidt et al., 2004). Maps of anthropic activities must be used to implement concrete conservation strategies (Tulloch et al., 2015). Vulnerable areas need to be identified to enable efficient planning and prioritization of conservation measures (Groves et al., 2002). Several vegetation indices have shown the benefits of separating the detected vegetation into small grids that allow meaningful spatial and temporal comparisons of vegetation dynamics and enable research to be conducted with the precision necessary to characterize local variations (Huete et al., 2002).

The aim of this study was to provide information on the evolution of mangrove cover in three of the main estuaries of Pernambuco, over a period of three decades. These three systems have suffered from different forms of land exploitation, and we expected them to show different trends in their vegetation patterns. Our main hypothesis was that each type of landscape alteration (harbor expansion, aquaculture, urbanization, and agriculture) threatens the mangroves and has a quantifiable structural impact. The grid technique has never been applied to investigate mangrove coverage changes at a local scale, and this study is the first to test if this application is effective. It is assumed that dividing mangroves into small cells will aid with the precise identification and quantification of drastic spatiotemporal modifications.

Methods

Study Area

Three estuaries—the Santa Cruz channel, Sirinhaém, and Suape—were chosen because of the differences in their geomorphology and in the human activities being conducted within their areas (Figure 1).

The Santa Cruz Channel is a 20-km long coastal estuarine complex located in the north of Pernambuco and comprising a U-shaped area of 22 km^2. The Santa Cruz Channel circles Itamaracá Island and has two accesses to the Atlantic Ocean (Schwamborn et al., 2001). The mangrove composed by *Rhizophora mangle* (red mangle), *Avicennia shaueriana* (black mangle), and *Laguncularia racemosa* (white mangle; Medeiros, Kjerfve, Araujo, & Neumann-Leitão, 2001) is distributed all along the

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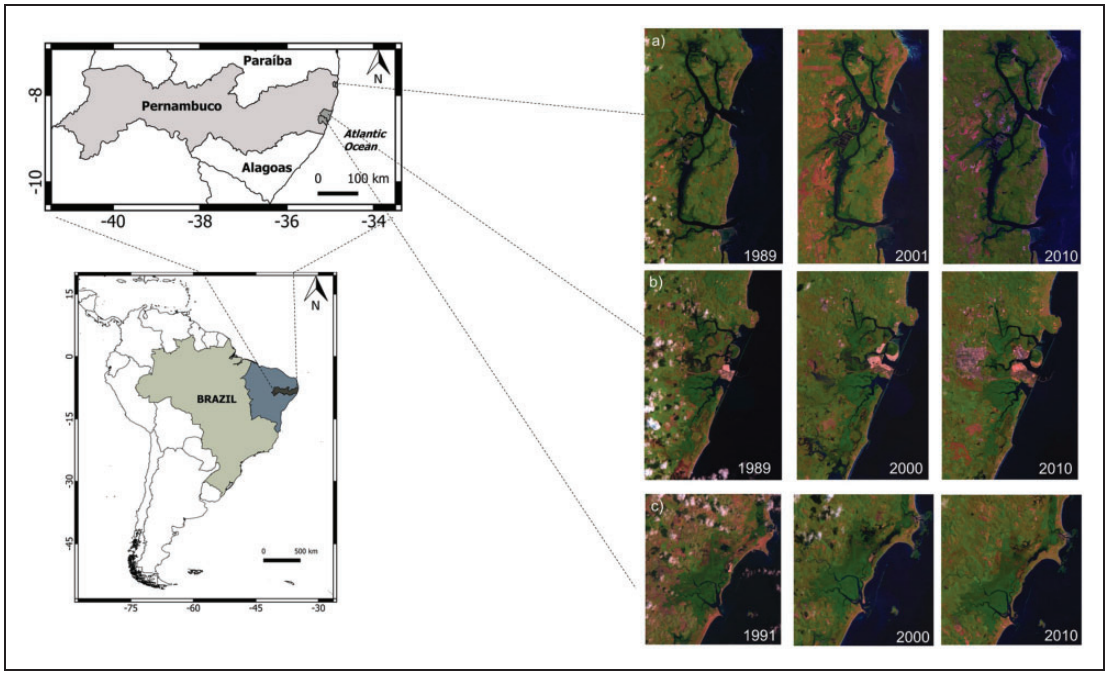


Figure 1. Location of the three estuaries of interest along the coast of Pernambuco with Landsat satellite images.

channel, particularly on its eastern borders (Gomes, Santos, Alves, Rosa-Filho, & Souza-Santos, 2002). Situated at the center of the channel, the city of Itapissuma is Pernambuco's main fishing hub and one of the region's best known tourism destinations (Quinamo, 2006). Aquaculture, artisanal fishing, industry, and agriculture are all important anthropogenic activities in the area (De Moura & Candeias, 2009).

The second estuary, in the Suape estuarine complex, has a watershed of 3,800 km^2 and is located approximately 40 km south of the city of Recife, between 8°15′–8°30′S and 34°55′–35°05′W (Koening, Leça, Neumann-Leitão, & Macêdo, 2003; Souza & Sampaio, 2001). The region has a flattened geomorphological shape, medially divided by the outcrops of the fractured volcanic masses of the cape of Santo Agostinho (M. A. Santos & Costa, 1974; Silva et al., 2015). Before the construction of a port in 1979, four rivers—the Massangana, Tatuoca, Ipojuca, and Merepe—drained into the Suape estuary, itself partly isolated from the ocean by an extensive sandstone reef line (A. P. Silva, Neumann-Leitão, Schwamborn, & Gusmão, 2004). The construction of the port altered the geomorphological and hydrodynamic conditions of these rivers (Muniz, Neto, Macêdo, & Filho, 2005). Indeed, landfills blocked the flow of both the Ipojuca and Merepe rivers, causing the retention and accumulation of water, which led to the inundation of the mangroves. The mangroves of the Suape complex are characterized by four genera belonging to three families: *R. mangle*, *L. racemosa (L.) c.f. Gaertn.*, *A. germinans*, *A. schaueriana Stapf & Leechman ex Moldenke*, and *Conocarpus erectus L*, as well as a variety of peripheral and generalist species (Silva et al., 2015).

The mangrove forest of the third study area, situated in Barra de Sirinhaém district in the southern coast of Pernambuco, is characterized by *R. mangle*, *L. racemosa*, and by species from the genera *Avicennia* (Maciel & Alves, 2009). In addition to artisanal fishing, agroindustry, services, and trade are important socioeconomic activities in the zone. A sugarcane plantation was established there in the 19th century, and Sirinhaém plays an important role in national sugar production.

GIS Analysis

To obtain the grid cells for our analysis (Figure 2), the following methods were used.

Satellite images. Satellite images of the three estuaries over the past three decades were analyzed to describe the evolution of the mangrove area. Optical images between 1989 and 2016 from the following satellites and sensors were used: Landsat 5/Thematic Mapper, Landsat 7/Enhanced Thematic Mapper Plus, Landsat 8/Operational Land Imager/Thermal Infrared Sensor (Table 1).

These images were acquired from the Landsat collection of the United States Geological Survey site (https://www.usgs.gov/). Different compositions of Red (R),

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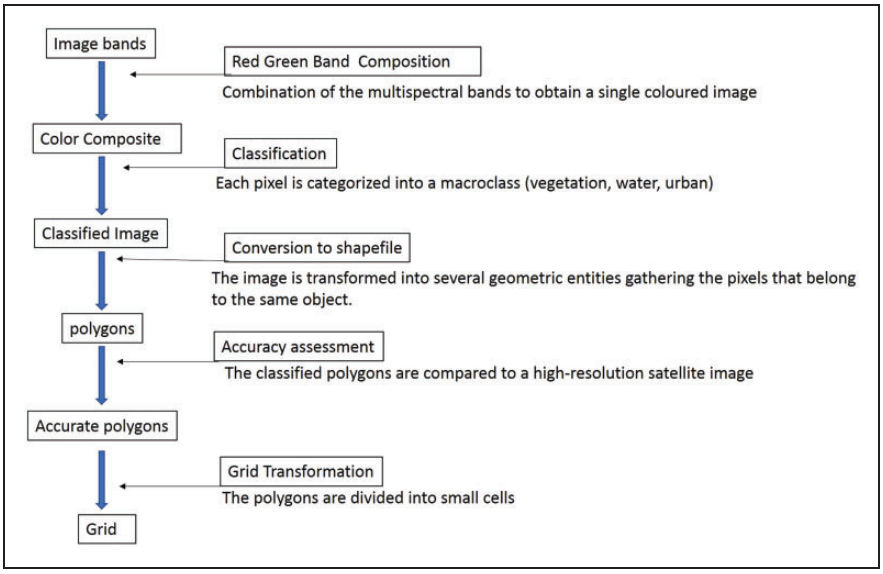


Figure 2. Flowchart of the GIS analysis.

Table 1. Characteristics of the Collected Images.

Estuary	Date	Satellite	Instrument	Orbite	Point
Santa Cruz Channel	12/09/1989	Landsat5	TM	214	65
	13/11/1994	Landsat5	TM	214	65
	04/08/2001	Landsat7	ETM+	214	65
	29/10/2006	Landsat5	TM	214	65
	08/10/2010	Landsat5	TM	214	65
	08/02/2015	Landsat8	OLI/TIRS	214	65
Suape	04/03/1989	Landsat5	TM	214	66
	14/08/1996	Landsat5	TM	214	66
	26/09/2000	Landsat5	TM	214	66
	26/08/2006	Landsat5	TM	214	66
	06/09/2010	Landsat5	TM	214	66
	20/07/2016	Landsat8	OLI/TIRS	214	66
Sirinhaém	20/10/1991	Landsat5	TM	214	66
	14/08/1996	Landsat5	TM	214	66
	26/09/2000	Landsat5	TM	214	66
	26/08/2006	Landsat5	TM	214	66
	06/09/2010	Landsat5	TM	214	66
	20/07/2016	Landsat8	OLI/TIRS	214	66

Note. TM = Thematic Mapper; ETM+ = Enhanced Thematic Mapper Plus; OLI = Operational Land Imager; TIRS = Thermal Infrared Sensor.

Green (G), and Blue (B) bands were realized to create false color images: Landsat 5 (bands 547), Landsat 7 (bands 543), and Landsat 8 (bands 654; Figure 1).

Image processing. To map different anthropogenic activities and identify features in the landscape, a semiautomatic (or supervised) image processing classification technique was applied to the satellite images which enabled the identification of landcover through its spectral signature (Congedo, 2016). Macroclasses of objects with similar spectral signatures were determined to create manual training spectral signatures to overlay pixels belonging to the same landcover class. Two algorithms were then applied to assign each pixel to a class: the minimum distance and the maximum likelihood. The minimum distance algorithm calculates the Euclidean distance between spectral signatures of image pixels and training spectral signatures and assigns, for each pixel, the closest class of spectral signature (Mather & Tso, 2016). The maximum likelihood algorithm was used to categorize a pixel using the probability distributions for the landcover classes, following Bayes' theorem (Munyati, 2004).

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The supervised classification was carried out in Quantum GIS (QGIS 2016) using the Semi-Automatic Classification Plugin (Congedo, 2016). Ten macroclasses were established (water, urban area, mud bank, mangrove, vegetation, cloud, exposed soil, cloud shadow, port, and aquaculture). For each estuary, maximum likelihood and minimum distance algorithms were applied. Then, the accuracy of the classification was checked by looking at the satellite image to see if the class attributed to most of the pixels was valid. Moreover, the image classes were compared with a high-resolution satellite image from a similar date (http://www.google.com/earth/download/ge/). The algorithm that gave the most pertinent result was chosen: maximum likelihood for the Santa Cruz Channel and minimum distance for Suape and Sirinhaém. As the images were taken during different tide conditions, the mud flats that were exposed at low tide were classified as water to obtain the same pattern for high tide images.

Polygon processing. The classified raster images were converted into polygons and exported to a shapefile format. Manual cleaning was then applied using QGIS editing tools. The polygons that did not belong to the preestablished class were removed using the satellite image of the corresponding year as a visual reference. This hand editing method is often necessary after a supervised classification (Guimarães et al., 2010; Li et al., 2013).

Spatiotemporal patterns of changes in mangrove coverage. Using ThemaMap software (https://themamap.greyc.fr/), the mangrove polygons were converted into a grid to precisely and accurately identify the areas that have undergone change. The use of a grid allows changes to be monitored at a local scale and enables observations of how, when, and where these changes occurred, at a spatial resolution finer than polygons. For each year, the grid and the mangrove polygons were intersected, and a unique grid for all the years was obtained with a binary code representing the presence or absence of mangrove in each cell. The grid cells were 0.1 km by 0.1 km, which was considered to be an appropriate unit given our study scale and the resolution of the satellite image used for the polygons. The spatiotemporal patterns of coverage mangrove modifications were analyzed mapping the mangrove that was lost, gained, and remained stable over the three decades.

Anthropogenic encroachment on mangroves. The encroachment of anthropogenic activities on mangroves was investigated, and the polygons corresponding them were mapped. Anthropogenic activities considered to constitute the most direct threat to the mangrove forest were quantified: aquaculture, urbanization, the commercial port, and agriculture. The vegetation and the exposed soil polygons in a radius of 1 km around mangrove polygons were used as a proxy to represent agricultural expansion. Industries were classified as urban because their spectral signatures were similar. To determine which activity had the greatest impact on mangrove, the intersection between the mangrove area at the beginning of the study (1990) and the area of each anthropic activity at the end of the study (2015) was calculated. The polygons generated by this intersection enabled us to estimate the overlap between the anthropic activities and the initial mangrove, being able to quantify mangrove substitution.

Results

Spatiotemporal Patterns of Mangrove Coverage

Measuring the mangrove areas for each estuary in each image (Figure 3) helped assessing the spatiotemporal variations along the past three decades.

The Santa Cruz Channel mangrove area increased between 1989 and 1994 and then decreased between 1994 and 2001. A stable period is noticeable between 2006 and 2010, followed by a decrease between 2010 and 2015. An increase of the Sirinhaém mangrove coverage can be observed between 1991 and 2000. After 2000, the coverage area remained relatively stable. A sharp increase in Suape mangrove was observed between 1989 and 1996. After this, fluctuations were minor, but an increase between 2000 and 2006 can be seen, followed by a decrease between 2006 and 2010.

The mangrove areas that were lost, gained, and those which remained stable were mapped to see if the variations were localized in preferential areas (Figure 4).

The three estuaries exhibit different spatial patterns in terms of mangrove coverage changes over the three decades. Mangrove appearances and disappearances in Sirinhaém occurred in the outermost mangrove ecosystem, and mostly in the north. The appearances consist in a large patch of mangrove in the northeast and few dispersed cells, whereas the disappearances are insignificant over the three decades (see Appendix Figure A3).

By contrast, the appearances in the Santa Cruz Channel are scarce and border the stable mangrove. A relevant area of mangrove disappeared in the center of the estuary and a substantial mangrove withdrawal is observable on the north and south edges (see Appendix Figure A2).

Concerning Suape, the appearances of mangrove occurred mainly in the north and to a lesser extent in the south. A vast central area of new mangrove is noticeable, whereas significant areas of mangrove were lost on the coastal side of the estuary (see Appendix Figure A4).

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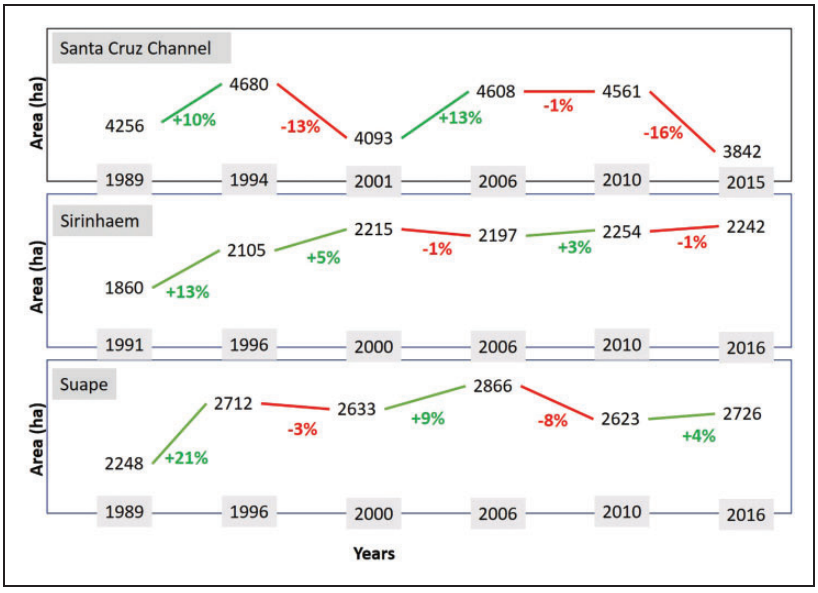


Figure 3. Slopechart of the mangrove areas of the three estuaries for each collected year and the evolution in percentage between two successive years.

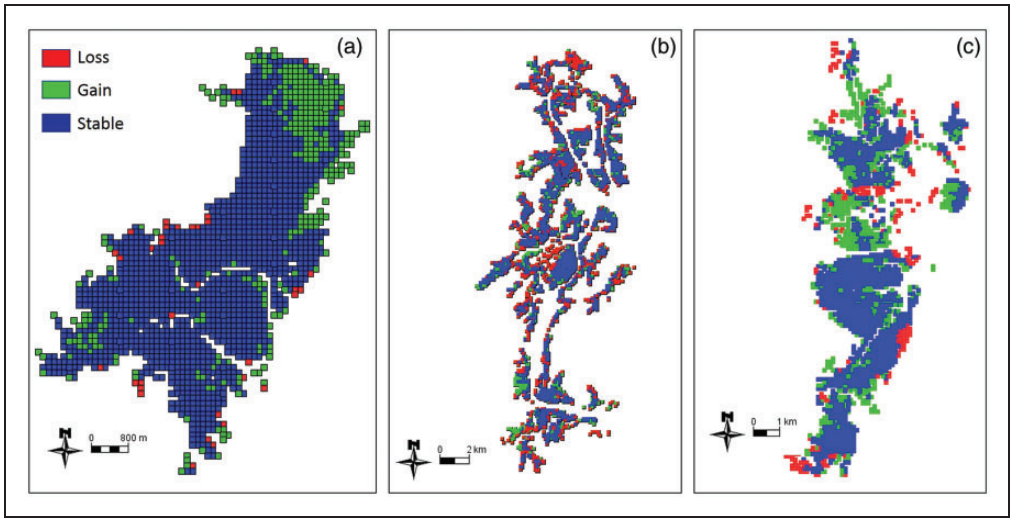


Figure 4. Maps of the mangrove areas that appeared, disappeared, and remained stable in (a) Sirinhaém, (b) the Santa Cruz Channel, and (c) Suape over the studied period.

Human Encroachment on Mangrove Forests

Maps of human activity and mangrove spatial occupation over the past three decades were produced (Figure 5; see Appendix Figure A1), enabling us to analyze the human impact on mangrove forests. Three years were chosen in each estuary to show landscape modification over time.

These images enabled a visualization of the impact of three main human activities that encroached on mangrove: aquaculture in the Santa Cruz Channel, the port in Suape, and agriculture in Sirinhaém. For the Santa Cruz Channel (Figure 5(a)), the conversion of mangrove into aquaculture has occurred in several zones distributed over the whole estuary but is more apparent in two major areas in the center. In Sirinhaém (Figure 5(b)), the entire edge of the mangrove forest is bordered by agriculture activity, leaving only a compact core of mangrove without direct exposure to this activity. In Suape, the encroachment of human activity is confined to a specific area in the central northern part of the estuary, where there has been gradual deforestation due to the construction of the industrial port (Figure 5(c)).

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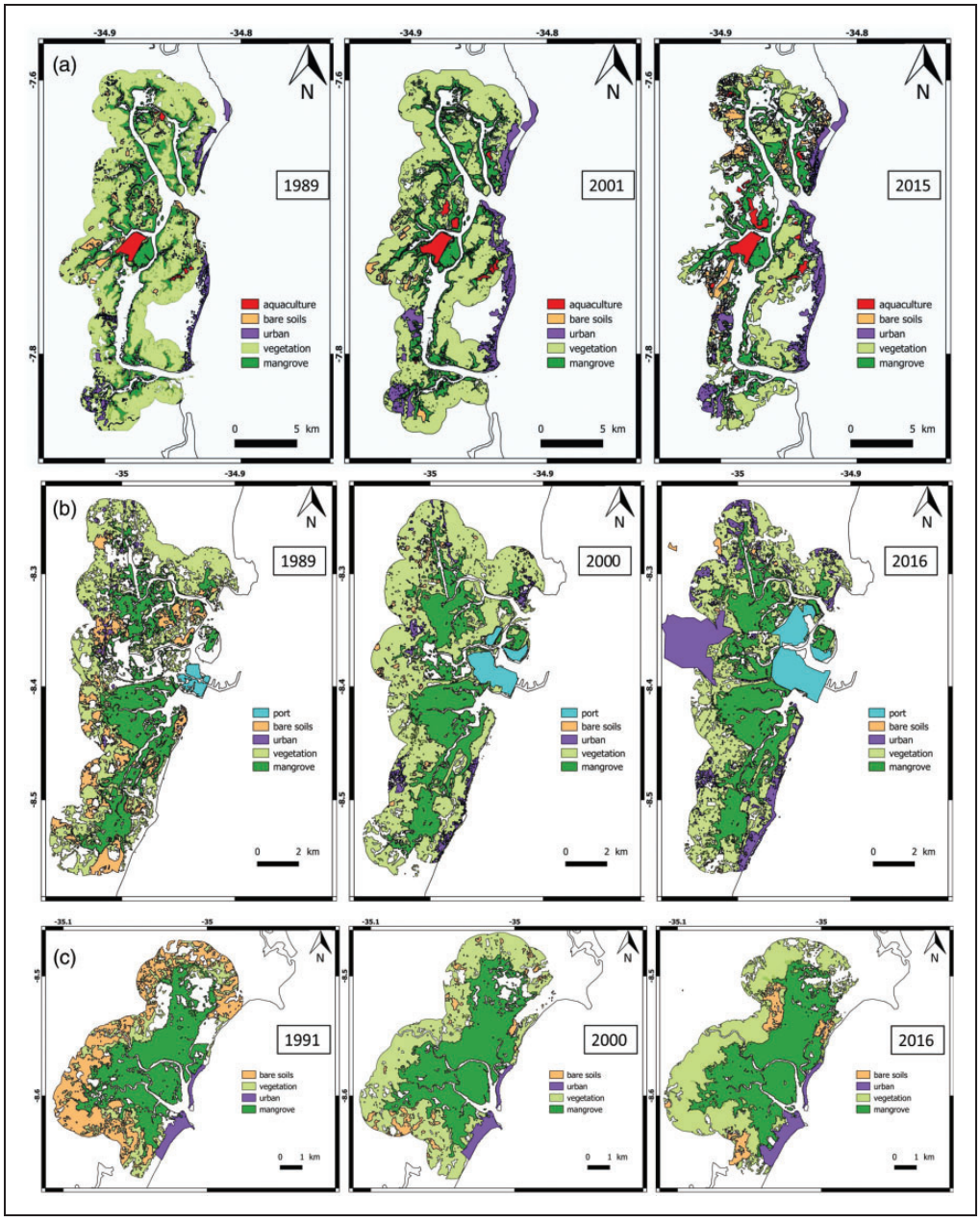


Figure 5. Evolution of mangrove areas and anthropic activities spatial occupation over the past three decades in (a) the Santa Cruz Channel, (b) Suape, and (c) Sirinhaém.

However, even if the other human activities did not replace the mangrove, a general trend of anthropization is observable in the three estuaries and is more pronounced in Suape and the Santa Cruz Channel. Indeed, the urban area has increased significantly in both estuaries during these years, and the Suape industrial complex, situated in the west of the mangrove forest, represents the anthropic activity which extended the most over the studied period.

The areas of the different land uses were measured over the three decades in the three estuaries (Table 2) to quantify the evolution of both the human activities and the mangrove coverage. It appears that the only estuary that suffered a mangrove reduction is the Santa Cruz channel with a 10% decrease of its mangrove area, whereas in both Suape and Sirinhaém, a 20% mangrove coverage increase occurred. An expansion of the human activities settled in the three estuaries is noticeable.

The aquaculture area, in the Santa Cruz Channel, increased by 92% over the three decades, with the expansion beginning most noticeably after 1994.

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Table 2. Areas in Hectares of Each Land Use for the Three Estuaries, Their Total Evolution Over the Three Decades, and the Proportion of Mangrove That Was Removed for the Benefit of Each Land Use.

Estuary	Land use	1990	2000	2015	Total change		Mangrove removal (%)
					ha	%	
Santa Cruz Channel	Aquaculture	345	474	662	+317	+92	3
	Bare soils	812	279	2,486	+1,674	+77	0
	Mangrove	4,256	4,093	3,842	−414	−10	—
	Urban	4,690	7,413	7,432	+2,742	+58	0
	Other vegetation	12,276	13,796	5,399	−6,877	−56	0
Sirinhaém	Bare soils	803	212	249	−554	−69	1
	Mangrove	1,860	2,215	2,241	+381	+20	—
	Urban	145	145	199	+54	+37	0
	Other vegetation	1,323	275	2,091	+768	+58	2
Suape	Port	118	355	683	+565	+479	2
	Bare soils	489	153	47	−442	−90	0
	Mangrove	2,248	2,633	2,726	+478	+21	–
	Urban	79	299	1,220	+1,141	+1,454	0
	Other vegetation	2,916	4,576	3,521	+605	+21	0

This activity had the greatest impact on mangrove in the estuarine complex, spreading over 3% of the initial mangrove. The area dedicated to aquaculture increased sharply after 1994 but has remained stable since 2010, while the mangrove coverage gradually declined (Table 2). Furthermore, an increase of the urban area by 58%, in this estuary, was accompanied by a decrease in vegetation and an increase of bare soils.

Meanwhile, in Sirinhaém, 3% of the mangrove was removed for the benefit of agriculture (2% by other vegetation and 1% by bare soils). Thus, the total area of exposed soils underwent an abrupt reduction after 1991 and was replaced by vegetation, while the total mangrove coverage increased. After this period, the areas of exposed soil, vegetation, and mangrove remained relatively stable.

During the period of the study, the port in Suape substituted 2% of the initial mangrove. The most significant expansion of the port area occurred between 1996 and 2000, increasing from 159 ha to 355 ha along with a reduction of the mangrove. Meanwhile, the urban/industrial area sharply raised by 1494%, becoming the most significant human activity in the area. Nevertheless, even if Suape was the estuary where the anthropization was the most striking, the mangrove area still increased 21% from 2,248 ha to 2,726 ha.

Discussion

Protection measures for a mangrove area can only be pertinent if it is known how, where, and when mangrove coverage has changed. This study is the first application of the grid technique for local-scale monitoring of mangrove, and it was effective for synthesizing changes in mangrove cover which can help implement conservation strategies. It is a parsimonious way to map the spatio-temporal patterns as they can be seen in two maps, one for the appearances and one for the disappearances. Unlike the gain–loss maps generated through the polygons overlapping technique, the grid technique enables to assess the modification rates for the overall period. Moreover, grids are more precise than polygons as the unit of study consists in smaller cells. They are therefore more adaptable for local-scale monitoring. The ability to alter cell sizes also allows a good way to see modifications at different scales, which can then be attributed to processes operating at different scales. Further research is needed to test whether or not this technique can effectively determine scales of threats.

The grid technique is appropriate for spatially representing landscape processes and has previously been used for integrated river basin models (Rathjens, Oppelt, Bosch, Arnold, & Volk, 2015). The precision of the technique, coupled with in situ data, allows to model several spatial aspects of animal or vegetation population structure (Royle, Fuller, & Sutherland, 2018). However, few studies are using this approach.

On another level, the distribution of different biotic elements is key to establishing connectivity, which is an omnipresent theme in current studies (Olds et al., 2017). The grid technique could therefore bring powerful insights to seascape ecology as the hypothesis of coastal habitats being separate is giving way to the concept of an interconnected mosaic of habitats (Nagelkerken, Sheaves, Baker, & Connolly, 2015).

Mangrove coverage in the three estuaries fluctuated noticeably over the three decades of the study. An overall increase can be noted in Suape and Sirinhaém,

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whereas after a similar initial increase, the Santa Cruz channel mangrove has decreased during the past 5 years. Mangroves in all three estuaries are strongly influenced by salinization, and the phases of mangrove increase can be linked to this. Salinization can stimulate mangrove growth by enabling its development in areas that were previously colonized only by freshwater plants (Teh et al., 2008). Wetland salinization is a process occurring at a global scale (Herbert et al., 2015; Nachshon, Ireson, Van Der Kamp, Davies, & Wheater, 2014; Williams, 2001) and is related to climate change (Meiggs & Taillefert, 2011). During droughts, alterations in soils properties enable mangrove landward expansion (Rogers, Wilton, & Saintilan, 2006). Sea level rise also causes salt water intrusion into the estuaries (Church & White, 2006). In regions close to our study sites, such as the Metropolitan region of Recife, a 5.6-mm/year increase in sea level was observed between 1946 and 1988 (Neves & Muehe, 1995), which was above the mean world annual sea level rise at that time (Hay, Morrow, Kopp, & Mitrovica, 2015).

Furthermore, an increase in salinity can also be directly linked to anthropogenic activities (Cañedo-Argüelles et al., 2013). This secondary salinization occurred in the Santa Cruz Channel between 1989 and 1994 due to extensive damming leading to the spread of mangroves (Lacerda & Marins, 2002). Another example of human-induced salinization is the establishment of the port in Suape, which altered the geomorphological and hydrodynamic conditions of the area, particularly in the Ipojuca River estuary (Koening et al., 2003). Muniz et al. (2005) sampled parameters including salinity, pH, dissolved oxygen, transparency, and temperature from three fixed stations in this estuary. They compared summer and winter before (1978) and after (1986–1987) the port's construction, to analyze the effects of port-induced changes. A general increase of all the chemical parameters was observed postconstruction, with an increase in salinity having the greatest ecological impact. This increase is due to the Ipojuca river being diverted toward the ocean, causing a reduction in river-flow speed, sedimentation, and a diminution in the circulation and depth. As a result, the mouth of the river has been transformed into a coastal lagoon where evaporation and consequently salinity were high. This increase in salinity is likely to have favored mangrove development and enhanced the appearance of a recovery zone (Souza & Sampaio, 2001).

Because spatial patterns in each estuary are different, conservation measures must also take into account specific localized conditions within each of the three zones. Differences in mangrove dynamics between the estuaries can be explained by differences in anthropogenic activities and by the morphological shapes of the estuaries.

The Santa Cruz Channel is the only estuary that has suffered a loss in mangroves over the three decades. It is thus important to understand the evolution of land use in this estuary. The mapping anthropogenic activities demonstrated that aquaculture between 1994 and 2001 was significant in the center of the estuary. It adversely affected mangroves not just through direct encroachment leading to deforestation but also by induced physicochemical changes (Naylor et al., 2000). Toxic effluent and the alteration of sediment rates are two possible reasons for mangrove disappearance in zones that were not directly exposed to aquaculture.

The mangrove diminution observed in the Santa Cruz Channel between 2010 and 2015 could be attributed to pollution. Mercury contamination was already registered in the area as a consequence of the effluent from a chlorine and caustic soda plant which settled in 1963 and released between 22 and 35 tons of mercury by 1987 (Meyer, 1996). However, high mercury concentrations were encountered recently in the sediment of the Santa Cruz Channel (De Moura & Candeias, 2009). The values were higher than those found in 1981 by the Companhia de Tecnologia de Saneamento Ambiental. Those results indicate recent inputs or a recent movement of the accumulated mercury toward the Santa Cruz Channel. As mercury is accumulated in sediment, its transport depends on environmental factors. As a consequence, the aquatic system can remain contaminated for many years after any mercury input in the area (De Moura & Candeias, 2009). Yet, mercury can prevent the survival of mangrove seedlings (Huang & Wang, 2010) and can also affect mangrove growth by causing a depletion of nutrients, as high concentrations threaten the microorganisms that guarantee the biological conversion of minerals (Ravikumar et al., 2007).

The port construction is the main driver in the spatial dynamic of the Suape mangroves, whether through direct deforestation, salinization, and sedimentation that would explain the fast recovery of the mangrove. The other drastic anthropic landscape modification during the studied period is the growth of urban areas and the concomitant removal of other vegetation. Indeed, urban area is currently the predominant land use around the mangrove. This constitutes an additional chemical threat, as more and more urban effluent will be discharged near the mangroves. A recovery area in the center and the instability of the coastal zone were observed, emphasizing that the modifications were localized. This configuration enables priority zones for protective measures to be determined.

Mangrove forest shapes could also, in part, explain the differences observed in mangrove spatiotemporal coverage patterns as the stability of a forest, and its susceptibility to external pressures, depends on its geometrical features (Hessburg, Agee, & Franklin, 2005).

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Mangrove appearances and disappearances in the Santa Cruz Channel were distributed all along the estuary and formed several small aggregates. This is possibly due to its geometrical properties, which presented as elongated shapes that could increase its vulnerability to salinization, resulting in the appearance and disappearance of areas suitable for mangrove growth. This highlights a lack of stability in this zone and suggests that the protection of targeted zones might be inappropriate: Conservation measures need to be implemented at the estuary scale.

Mangrove stability in Sirinhaém could also be related to mangrove structural characteristics. Patch size and proximity to mangrove cells influence mangroves' ability to resist habitat loss because where the core forest is sizable, the stand as a whole is less vulnerable (Harper, Steininger, Tucker, Juhn, & Hawkins, 2007). Hence, the important patch size of Sirinhaém mangrove can confer a resistance to anthropogenic threats because the main part of the forest is not exposed–unlike in a more parceled landscape. The compactness of Sirinhaém's mangroves thus explains their overall growth, despite surrounding threats, as the survival of the vegetation is a function of the density of the initial forest (Kéfi et al., 2007).

Implications for Conservation

In this study, the spatiotemporal patterns of changes in the mangrove cover were mostly determined by anthropic activity. Aquaculture, agriculture, urbanization, and harbor construction caused deforestation, released toxic effluents inhibiting mangrove growth, and induced salinization enhancing mangrove development. Despite of all these threats, our results showed a trend of mangrove growth in two of the three estuaries over the past three decades. Therefore, it seems that their resilience to disturbance was linked to their geometrical properties and to a favorable change of salinity conditions.

Indeed, salinization, mostly induced by port construction, damming, and sea-rise level, had a positive effect on mangrove. Nevertheless, it could endanger the nursery function of mangrove because freshwater or estuarine fish can be adversely affected by increases in salinity. This physiological stress could force them to migrate toward less saline areas (Nielsen, Brock, Rees, & Baldwin, 2003). Salinization could also constitute an ecological threat, decreasing inorganic processes of nitrogen removal, reducing carbon storage, and increasing the release of toxic sulfides which impact nutrient cycles and climate regulation (Herbert et al., 2015). Because the secondary salinization that occurred in our study area could have an impact at individual, population, community, and ecosystem levels (Cañedo-Argüelles et al., 2013), mitigation measures should be contemplated.

Moreover, before the implementation of any conservation measures or, indeed, any further anthropogenic activities, the geometrical properties of the mangrove should be considered to evaluate future impacts. Although our study among others discussed the importance of geometrical features, few works on wetlands have focused on their implications for conservation planning to date (Boström, Pittman, Simenstad, & Kneib, 2011). Mangrove spatial configurations (patch size and patch dispersion) can also determine faunal distribution (Pittman, McAlpine, & Pittman, 2004); therefore, alterations to those features could impact biodiversity.

As these habitats are important for artisanal fisheries, our results can be used to elaborate concrete conservation strategies. Our mapping of the landscape modifications can indeed be useful because the anthropization had a relevant impact on the mangrove patterns. Aquaculture, agriculture, and port construction were established as three anthropogenic modifications that directly threaten the mangrove. The expansion of the activities that do not encroach on the mangrove was quantified, and in Suape, the urbanization was identified as a potential threat. Avoiding the spatial expansion of these activities should be a priority.

The grid technique was an effective method to investigate mangrove coverage changes at a local scale. Its precision helped to follow adequately spatiotemporal cover changes and relate them to anthropogenic activities. Hence, this method appears to be useful for conservation planning and future remote sensing work at local scale.

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Appendix

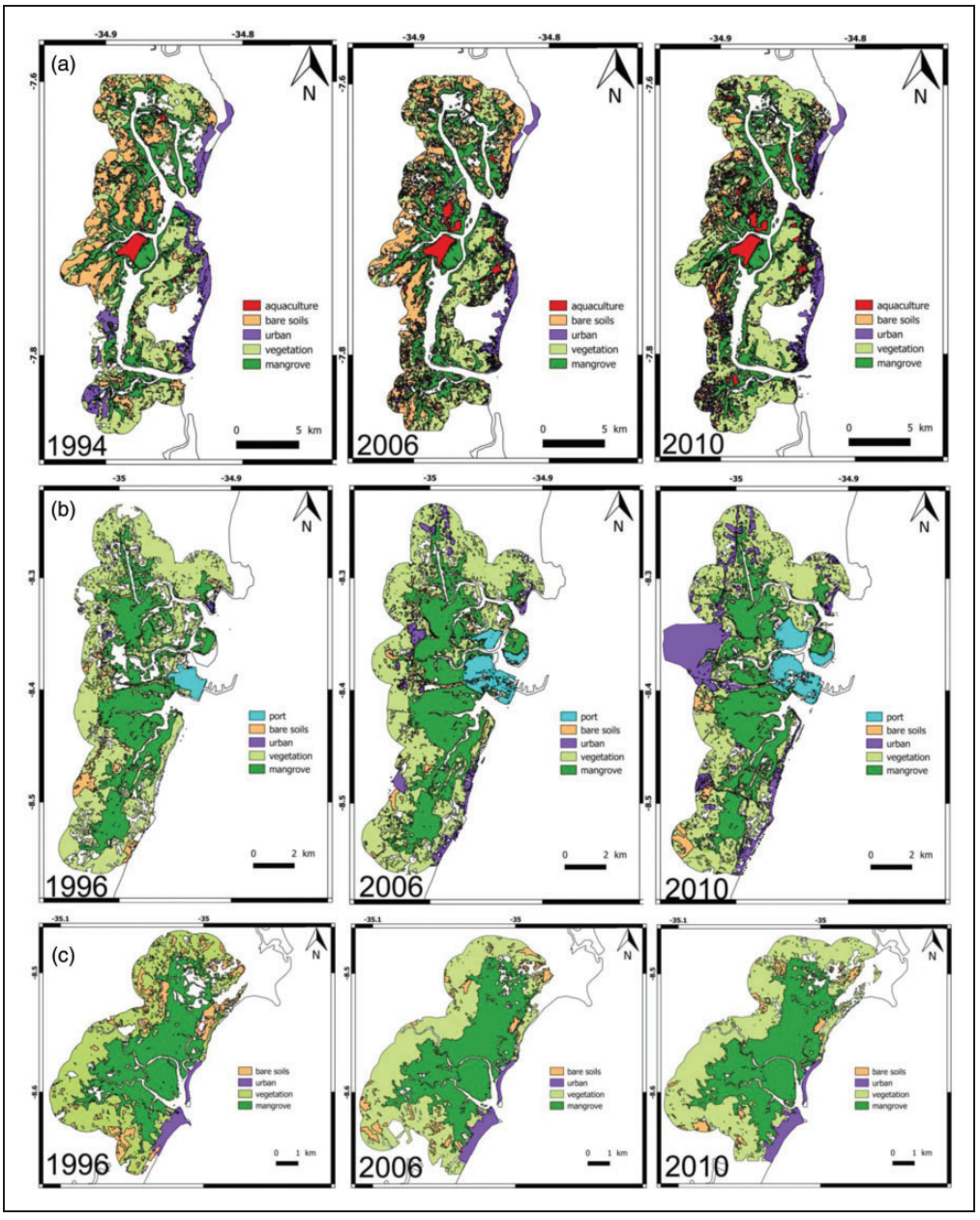


Figure A1. Evolution of mangrove area and anthropic activities spatial occupation for the images that were not presented in the results in (a) the Santa Cruz Channel, (b) Suape, and (c) Sirinhaém.

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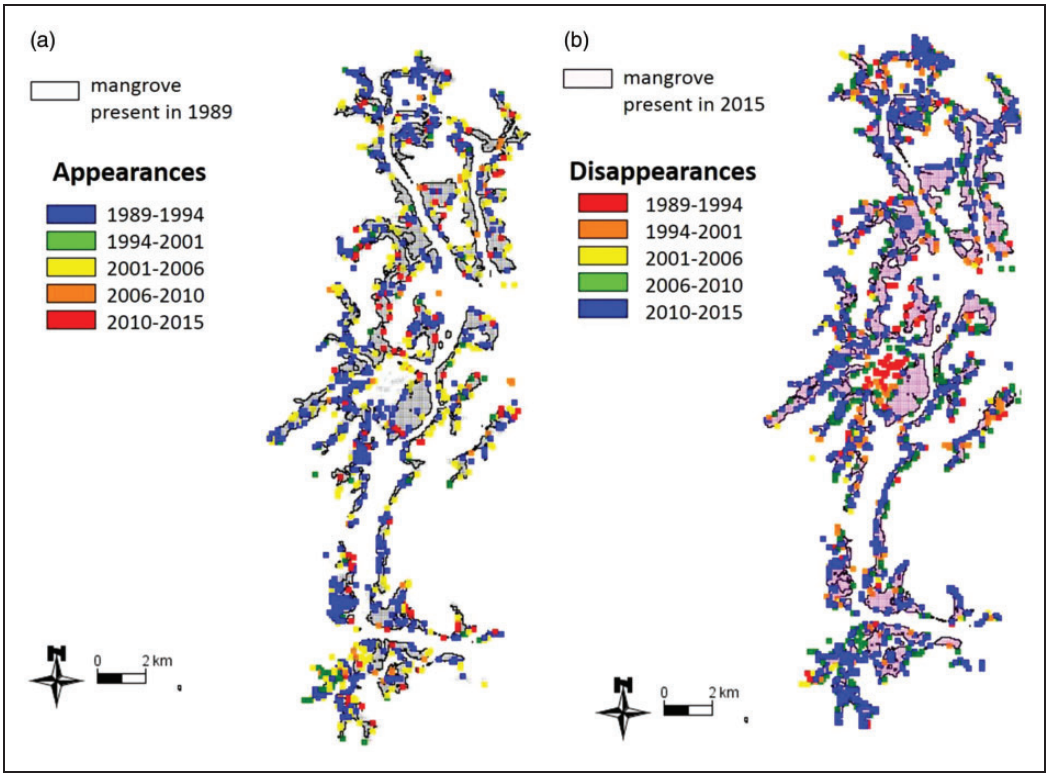


Figure A2. Maps of the mangrove areas that (a) appears and (b) disappears for each period in the Santa Cruz Channel.

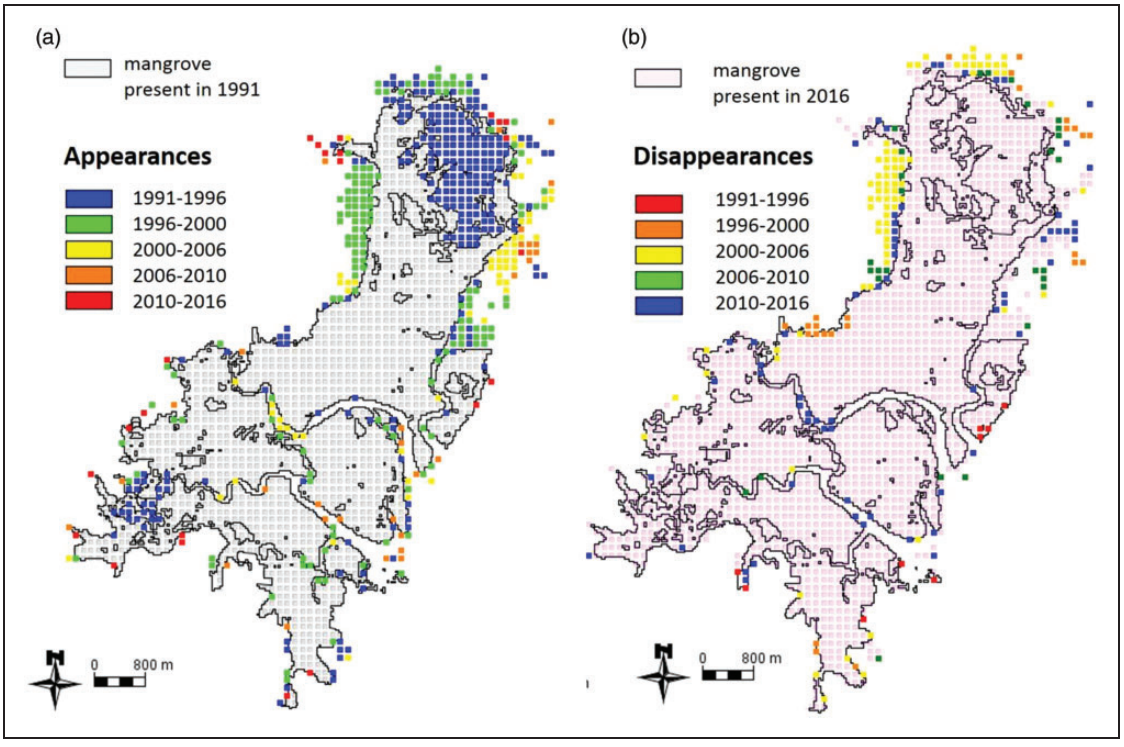


Figure A3. Maps of the mangrove areas that (a) appears and (b) disappears for each period in Sirinhaém.

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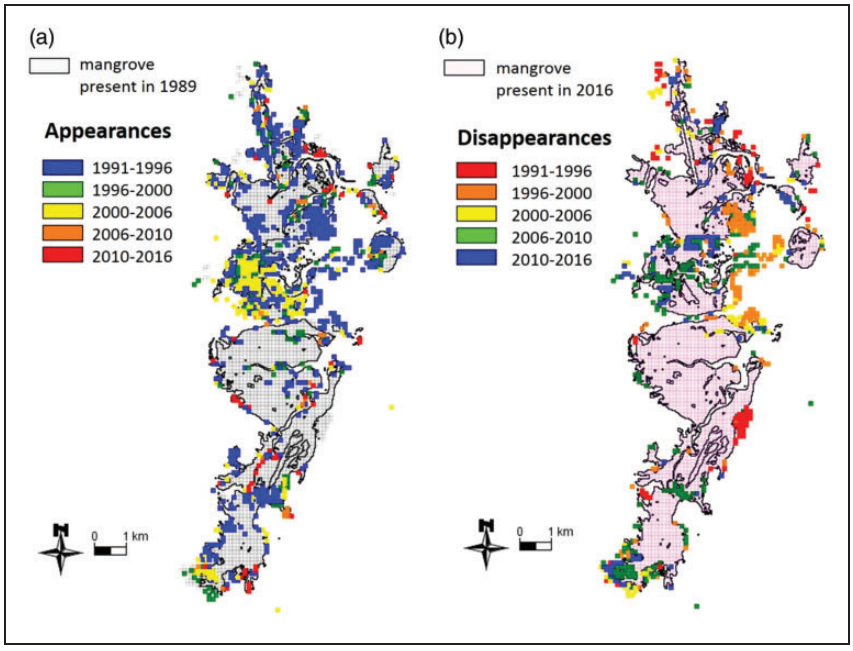


Figure A4. Maps of the mangrove areas that (a) appears and (b) disappears for each period in Suape.

Acknowledgments

We are grateful to Dr. Monique Simier for reviewing of the article.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This work was carried out under the National Institute on Science and Technology in Tropical Marine Environments—INCT-AmbTropic. We also thank the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) for the PhD scholarship of Latifa Pelage. This study is a contribution to the LMI TAPIOCA and PADDLE project (funding by the European Union's Horizon 2020 research and innovation program—grant agreement no. 73427).

References

Alongi, D. M. (2002). Present state and future of the world's mangrove forests. *Environmental Conservation*, *29*(03), 331–349.

Barbier, E. B., Hacker, S. D., Kennedy, C., Koch, E. W., Stier, A. C., & Silliman, B. R. (2011). The value of estuarine and coastal ecosystem services. *Ecological Monographs*, *81*(2), 169–193.

Boström, C., Pittman, S. J., Simenstad, C., & Kneib, R. T. (2011). Seascape ecology of coastal biogenic habitats: Advances, gaps, and challenges. *Marine Ecology Progress Series*, *427*, 191–218.

Cañedo-Argüelles, M., Kefford, B. J., Piscart, C., Prat, N., Schäfer, R. B., & Schulz, C.-J. (2013). Salinisation of rivers: An urgent ecological issue. *Environmental Pollution*, *173*, 157–167.

Church, J. A., & White, N. J. (2006). A 20th century acceleration in global sea-level rise. *Geophysical Research Letters*, *33*(1), ■. doi:10.1029/2005GL024826

Congedo, L. (2016). Semi-automatic classification plugin documentation. *Release*, *4*(0.1), 29.

De Moura, A. R. L. U., & Candeias, A. L. B. (2009). A multitemporal remote sensing and gis based inventory of the mangroves at itamaracá estuarine system, Northeastern Brazil. *Tropical Oceanography*, *37*(1–2), ■. doi:10.5914/tropocean.v37i1-2.5154

De Souza-Machado, A. A., Kloas, W., Toffolon, M., Zarfl, C., & Spencer, K. (2016). Metal fate and effects in estuaries: A review and conceptual model for better understanding of toxicity. *Science of the Total Environment*, *541*, 268–281.

Giri, C., Ochieng, E., Tieszen, L. L., Zhu, Z., Singh, A., Loveland, T., Duke, N. (2011). Status and distribution of mangrove forests of the world using earth observation satellite data. *Global Ecology and Biogeography*, *20*(1), 154–159.

Gomes, C. A. A., Santos, P. J. P., Alves, T. N. C., Rosa-Filho, J. S., & Souza-Santos, L. P. (2002). Variação temporal da meiofauna em área de manguezal em Itamaracá-Pernambuco [Temporal variation of meiofauna in mangrove area in Itamaracá-Pernambuco]. *Atlântica*, *24*(2), 89–96.

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Groves, C. R., Jensen, D. B., Valutis, L. L., Redford, K. H., Shaffer, M. L., Scott, J. M., Anderson, M. G. (2002). Planning for biodiversity conservation: Putting conservation science into practice: A seven-step framework for developing regional plans to conserve biological diversity, based upon principles of conservation biology and ecology, is being used extensively by the nature conservancy to identify priority areas for conservation. *AIBS Bulletin*, *52*(6), 499–512.

Guimarães, A. S., Travassos, P., Souza Filho, P. W. M. E., Gonçalves, F. D., & Costa, F. (2010). Impact of aquaculture on mangrove areas in the northern Pernambuco Coast (Brazil) using remote sensing and geographic information system. *Aquaculture Research*, *41*(6), 828–838.

Hamilton, S., & Casey, D. (2016). Creation of a high spatio-temporal resolution global database of continuous mangrove forest cover for the 21st century (CGMFC-21). CGMFC-21 Poster. *Global Ecology and Biogeography*, *25*(6), 729–738. doi:10.13140/2.1.2677.0726

Harper, G. J., Steininger, M. K., Tucker, C. J., Juhn, D., & Hawkins, F. (2007). Fifty years of deforestation and forest fragmentation in Madagascar. *Environmental Conservation*, *34*(4), 325–333.

Hay, C. C., Morrow, E., Kopp, R. E., & Mitrovica, J. X. (2015). Probabilistic reanalysis of twentieth-century sea-level rise. *Nature*, *517*(7535), 481–484.

Herbert, E. R., Boon, P., Burgin, A. J., Neubauer, S. C., Franklin, R. B., Ardón, M., Gell, P. (2015). A global perspective on wetland salinization: Ecological consequences of a growing threat to freshwater wetlands. *Ecosphere*, *6*(10), 1–43.

Hessburg, P. F., Agee, J. K., & Franklin, J. F. (2005). Dry forests and wildland fires of the inland Northwest USA: Contrasting the landscape ecology of the pre-settlement and modern eras. *Forest Ecology and Management*, *211*(1–2), 117–139.

Huang, G.-Y., & Wang, Y.-S. (2010). Physiological and biochemical responses in the leaves of two mangrove plant seedlings (Kandelia candel and Bruguiera gymnorrhiza) exposed to multiple heavy metals. *Journal of Hazardous Materials*, *182*(1), 848–854. doi:10.1016/j.jhazmat.2010.06.121

Huete, A., Didan, K., Miura, T., Rodriguez, E. P., Gao, X., & Ferreira, L. G. (2002). Overview of the radiometric and biophysical performance of the MODIS vegetation indices. *Remote Sensing of Environment*, *83*(1–2), 195–213.

Kéfi, S., Rietkerk, M., Alados, C. L., Pueyo, Y., Papanastasis, V. P., ElAich, A., & De Ruiter, P. C. (2007). Spatial vegetation patterns and imminent desertification in Mediterranean arid ecosystems. *Nature*, *449*(7159), 213.

Kennish, M. J. (2002). Environmental threats and environmental future of estuaries. *Environmental Conservation*, *29*(01), 78–107.

Kjerfve, B., & Lacerda, L. D. (1993). Mangroves of Brazil. *Mangrove Ecosystems Technical Reports ITTO TS-13*, *2*, 245–272.

Koening, M. L., Leça, E. E., Neumann-Leitão, S., & Macêdo, S. J. D. (2003). Impacts of the construction of the Port of Suape on phytoplankton in the Ipojuca River estuary (Pernambuco-Brazil). *Brazilian Archives of Biology and Technology*, *46*(1), 73–82.

Lacerda, L. D., & Marins, R. V. (2002). *River damming and changes in mangrove distribution*. *ISME/GLOMIS Electronic Journal*, *2*, 1–4.

Lessa, R. P., Monteiro, A., Duarte-Neto, P. J., & Vieira, A. C. (2009). Multidimensional analysis of fishery production systems in the state of Pernambuco, Brazil. *Journal of Applied Ichthyology*, *25*(3), 256–268.

Li, M. S., Mao, L. J., Shen, W. J., Liu, S. Q., & Wei, A. S. (2013). Change and fragmentation trends of Zhanjiang mangrove forests in southern China using multi-temporal Landsat imagery (1977–2010). *Estuarine, Coastal and Shelf Science*, *130*, 111–120.

Maciel, D. C., & Alves, Â. G. C. (2009). Conhecimentos e práticas locais relacionados ao aratu Goniopsis cruentata (Latreille, 1803) em Barra de Sirinhaém, litoral sul de Pernambuco, Brasil [Local knowledge and practices related to Goniopsis cruentata (Latreille, 1803) in a coastal village in the State of Pernambuco, Northeast Brazil]. *Biota Neotropica*, *9*(4), 29–36.

Mather, P., & Tso, B. (2016). *Classification methods for remotely sensed data*. Boca Raton, FL: CRC Press.

McKee, K., Rogers, K., & Saintilan, N. (2012). Response of salt marsh and mangrove wetlands to changes in atmospheric CO2, climate, and sea level. In B. A. Middleton (Ed.), *Global change and the function and distribution of wetlands* (pp. 63–96). New York, NY: Springer.

Medeiros, C., Kjerfve, B., Araujo, M., & Neumann-Leitão, S. (2001). The Itamaracá estuarine ecosystem, Brazil. In U. Seeliger & B. Kjerfve (Eds.), *Coastal marine ecosystems of Latin America* (pp. 71–81). Berlin/Heidelberg, Germany: Springer.

Meiggs, D., & Taillefert, M. (2011). The effect of riverine discharge on biogeochemical processes in estuarine sediments. *Limnology and Oceanography*, *56*(5), 1797–1810.

Meyer, U. (1996). On the fate of mercury in the northeastern Brazilian mangrove system, Canal de Santa Cruz, Pernambuco. *ZMT Contribution*, *3*, 105.

Muniz, K., Neto, B. D. B., Macêdo, S. J., & Filho, W. C. P. (2005). Hydrological impact of the port complex of Suape on the Ipojuca River (Pernambuco-Brazil). *Journal of Coastal Research*, *21*, 909–914.

Munyati, C. (2004). Use of principal component analysis (PCA) of remote sensing images in wetland change detection on the Kafue Flats, Zambia. *Geocarto International*, *19*(3), 11–22.

Nachshon, U., Ireson, A., Van Der Kamp, G., Davies, S. R., & Wheater, H. S. (2014). Impacts of climate variability on wetland salinization in the North American prairies. *Hydrology and Earth System Sciences*, *18*(4), 1251–1263.

Nagelkerken, I., Sheaves, M., Baker, R., & Connolly, R. M. (2015). The seascape nursery: A novel spatial approach to identify and manage nurseries for coastal marine fauna. *Fish and Fisheries*, *16*(2), 362–371.

Naylor, R. L., Goldburg, R. J., Primavera, J. H., Kautsky, N., Beveridge, M. C., Clay, J., Troell, M. (2000). Effect of aquaculture on world fish supplies. *Nature*, *405*(6790), 1017.

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Neves, C. F., & Muehe, D. (1995). Potential impacts of sea-level rise on the metropolitan region of Recife, Brazil. *Journal of Coastal Research*, *14*, 116–131.

Nielsen, D. L., Brock, M. A., Rees, G. N., & Baldwin, D. S. (2003). Effects of increasing salinity on freshwater ecosystems in Australia. *Australian Journal of Botany*, *51*(6), 655–665.

Olds, A. D., Nagelkerken, I., Huijbers, C. M., Gilby, B. L., Pittman, S. J., & Schlacher, T. A. (2017). Connectivity in coastal seascapes. In S. J. Pittman (Ed.), *Seascape ecology* (pp. 261–292). Hoboken, NJ: John Wiley & Sons Ltd.

Pittman, S. J., McAlpine, C. A., & Pittman, K. M. (2004). Linking fish and prawns to their environment: A hierarchical landscape approach. *Marine Ecology Progress Series*, *283*, 233–254.

Quinamo, T. D. S. (2006). Pesca artesanal e meio ambiente em áreas de manguezais no complexo estuarino-costeiro de Itamaracá, Pernambuco: O caso de Itapissuma [Artisanal Fishing and Environment in Mangrove Areas in the estuary-coast complex of Itamaracá, Pernambuco: the case of Itapissuma] (Master's dissertation) (pp. 1–221). Dissertação (Mestrado em Desenvolvimento e Meio Ambiente): Universidade Federal da Paraíba, João Pessoa.

Rathjens, H., Oppelt, N., Bosch, D. D., Arnold, J. G., & Volk, M. (2015). Development of a grid-based version of the SWAT landscape model. *Hydrological Processes*, *29*(6), 900–914.

Ravikumar, S., Williams, G. P., Shanthy, S., Gracelin, N. A. A., Babu, S., & Parimala, P. S. (2007). Effect of heavy metals (Hg and Zn) on the growth and phosphate solubilising activity in halophilic phosphobacteria isolated from Manakudi mangrove. *Journal of Environmental Biology*, *28*(1), 109–114.

Rawat, J. S., & Kumar, M. (2015). Monitoring land use/cover change using remote sensing and GIS techniques: A case study of Hawalbagh block, district Almora, Uttarakhand, India. *The Egyptian Journal of Remote Sensing and Space Science*, *18*(1), 77–84.

Rogers, K., Wilton, K. M., & Saintilan, N. (2006). Vegetation change and surface elevation dynamics in estuarine wetlands of southeast Australia. *Estuarine, Coastal and Shelf Science*, *66*(3–4), 559–569.

Royle, J. A., Fuller, A. K., & Sutherland, C. (2018). Unifying population and landscape ecology with spatial capture–recapture. *Ecography*, *41*(3), 444–456.

Santos, M. A., & Costa, W. D. (1974). Complexo industrial de Suape: Estudo hidrogeológico preliminar. In *Simpósio de geologia do Nordeste* (pp. 49–69). Recife, Brazil: Sociedade Brasileira de Geologia Do Nordeste.

Santos, R. O., Lirman, D., & Serafy, J. E. (2011). Quantifying freshwater-induced fragmentation of submerged aquatic vegetation communities using a multi-scale landscape ecology approach. *Marine Ecology Progress Series*, *427*, 233–246.

Schaeffer-Novelli, Y., Cintrón-Molero, G., Soares, M. L. G., & De-Rosa, T. (2000). Brazilian mangroves. *Aquatic Ecosystem Health & Management*, *3*(4), 561–570.

Schmidt, K. S., Skidmore, A. K., Kloosterman, E. H., Van Oosten, H., Kumar, L., & Janssen, J. A. M. (2004). Mapping coastal vegetation using an expert system and hyperspectral imagery. *Photogrammetric Engineering & Remote Sensing*, *70*(6), 703–715.

Schwamborn, R., Neumann-Leitão, S., de Almeida, T., Silva, A. P., Werner, E., & Saint-Paul, U. (2001). Distribution and dispersal of decapod crustacean larvae and other zooplankton in the Itamaracá estuarine system, Brazil. *Tropical Oceanography*, *29*(1), 1–18.

Silva, A. P., Neumann-Leitão, S., Schwamborn, R., & Gusmão, L. M. D. O. (2004). Mesozooplankton of an impacted bay in North Eastern Brazil. *Brazilian Archives of Biology and Technology*, *47*(3), 485–493.

Silva, E., Galvíncio, J. D., Brandão Neto, J. L., & Morais, Y. C. B. (2015). Space-time analysis of environmental changes and your reflection on the development of phenological of vegetation of mangrove. *Journal of Agriculture and Environmental Sciences*, *4*(1), 245–253.

Silva-Falcão, E. C., Severi, W., & De Araújo, M. E. (2013). Spatial–temporal variation of Achirus larvae (Actinopterygii: Achiridae) in mangrove, beach and reef habitats in north-eastern Brazil. *Journal of the Marine Biological Association of the United Kingdom*, *93*(2), 381–388.

Souza, M. M. D. A., & Sampaio, E. V. (2001). Changes on the vegetation structure of mangroves after the construction of the Suape port (PE, Brazil). *Acta Botanica Brasilica*, *15*(1), 1–12.

Teh, S. Y., DeAngelis, D. L., Sternberg, L. D. S. L., Miralles-Wilhelm, F. R., Smith, T. J., & Koh, H.-L. (2008). A simulation model for projecting changes in salinity concentrations and species dominance in the coastal margin habitats of the Everglades. *Ecological Modelling*, *213*(2), 245–256.

Tulloch, V. J., Tulloch, A. I., Visconti, P., Halpern, B. S., Watson, J. E., Evans, M. C., Chadès, I. (2015). Why do we map threats? Linking threat mapping with actions to make better conservation decisions. *Frontiers in Ecology and the Environment*, *13*(2), 91–99.

Valiela, I., Bowen, J. L., & York, J. K. (2001). Mangrove forests: One of the world's threatened major tropical environments: At least 35% of the area of mangrove forests has been lost in the past two decades, losses that exceed those for tropical rain forests and coral reefs, two other well-known threatened environments. *Bioscience*, *51*(10), 807–815.

Walters, B. B., Rönnbäck, P., Kovacs, J. M., Crona, B., Hussain, S. A., Badola, R., Dahdouh-Guebas, F. (2008). Ethnobiology, socio-economics and management of mangrove forests: A review. *Aquatic Botany*, *89*(2), 220–236.

Ward, I., & Larcombe, P. (2010). A geochemical comparison of modern and holocene mangrove sediments, Townsville region, North Queensland. *Wetlands Australia Journal*, *15*(1), 10–21.

Wilkie, M. L., & Fortune, S. (2003). *Status and trends of mangrove extent worldwide*. Forest Resources Assessment Working Paper No. 63. Food and Agriculture Organization of the United Nations: Rome.

Williams, W. D. (2001). Anthropogenic salinisation of inland waters. In *Saline lakes* (pp. 329–337). Kluwer Academic Publishers: Springer. Available at: https://doi.org/10.1023/A:1014598509028.

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