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SPATIO-TEMPORAL EVOLUTION OF ENVIRONMENTAL DYNAMICS IN GUARATIBA STATE BIOLOGICAL RESERVE AND ITS SURROUNDINGS, RIO DE JANEIRO, BRAZIL

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ABSTRACT

Mangrove is a coastal ecosystem that suffers from the growth of urban areas. We aim to study the environmental dynamics of the State Biological Reserve of Guaratiba-RJ and its surroundings, between 1990 and 2019, when there was great development in the region. Landsat images from 1990 and 2019, orthophotos from the Brazilian Institute of Geography and Statistics (IBGE), and field research were used. The methodology used the Normalized Difference Vegetation Index (NDVI), Normalized Difference Index on Built-up Areas (NDBI), and the Anthropic Transformation Index (ITA). The results showed that the mangrove area that was 16.07 km² in 1990 increased to 19.95 km² in 2019, the hypersaline areas went from 10.49 km² in 1990 to 7.08 km², and the built-up areas from 9.40 km² in 1990 to 24.73 km² in 2019. Variations occurred between mangrove areas (24.14%) and hypersaline areas (-32.51%), where there was migration of mangrove to these areas. The ITA was 4.13 in 1990 and 4.15 in 2019, varying 0.02, classified as Low Degraded. Geotechnologies showed good results in monitoring the reserve. The study showed the importance of the protection area, which mainly enabled the growth of the mangrove area and creation of barrier for built-up areas.

Keywords: Mangrove. Remote Sensing. Conservation Units. GIS.

EVOLUÇÃO ESPAÇO-TEMPORAL DA DINÂMICA AMBIENTAL NA RESERVA BIOLÓGICA DO ESTADO DE GUARATIBA E ENTORNO, RIO DE JANEIRO, BRASIL

RESUMO

O manguezal é um ecossistema costeiro que sofre com o crescimento das áreas urbanas. Objetiva-se estudar a dinâmica ambiental da Reserva Biológica Estadual de Guaratiba-RJ e seu entorno, entre 1990 e 2019, quando houve grande desenvolvimento na região. Utilizaram-se imagens Landsat de 1990 e 2019, ortofotos do Instituto Brasileiro de Geografia e Estatística (IBGE) e pesquisas de campo. A metodologia utilizou o Índice por Diferença Normalizada de Vegetação (NDVI), Índice por diferença Normalizada em Áreas Construídas (NDBI) e Índice de Transformação Antrópica (ITA). Os resultados mostraram que a área de mangue que era de 16,07 km² em 1990 passou para 19,95 km² em 2019, as áreas hipersalinas de 10,49 km² em 1990 para 7,08 km², as áreas construídas de 9,40 km² em 1990 para 24,73 km² em 2019. Ocorreram variações entre áreas de mangue (24,14%) e áreas hipersalinas (-32,51%), onde houve migração do manguezal para essas áreas. O ITA foi 4,13 em 1990 e 4,15 em 2019, variando 0,02, sendo classificado como Baixo Degradado. As geotecnológicas apresentaram bons resultados no monitoramento da reserva. O estudo mostrou a importância da área de proteção, que possibilitou, principalmente, o crescimento da área de manguezal e a criação de barreira para as áreas construídas.

Palavras-Chave: Manguezal. Sensoriamento Remoto. Unidade de Conservação. SIG

INTRODUCTION

The coastal regions can be considered one of the most threatened areas on the planet, because they are constantly undergoing anthropic transformations and used for natural resources (MELO, 2014). Approximately two thirds of the world's population live in these regions, where the main metropolises are established (KAWASHIMA et al., 2016). Coastal zones, including mangroves, are important areas of transition between terrestrial and marine environments that have significant social, environmental and ecological importance, providing fundamental environmental services (KRUG, LEÃO AND AMARAL, 2007; SOUZA, et al, 2018).

Melo (2014) could state that mangroves suffer from environmental degradation as a result of the frequent coastal occupation in the country. These environments are commonly associated with the margins of bays, coves, bars, river mouths, where the meeting of fresh and salt waters occurs (SOARES, 1997). They are characterized by several ecological processes that result in an intense production of organic matter. In addition, they also provide sediment stabilizer, coast line protector, source of income for riverside communities, habitat for crustaceans and ecological nursery (SCHÄFFER-NOVELLI, 1989). They present fine granulometry soil, muddy and unconsolidated consistency, with low oxygen content, rich in organic matter and, mainly, marked by extreme salinity variation due to their submission to the tidal regime (SOUZA et al., 2018).

According to the Food and Agriculture Organization (FAO) of the United Nations (2007), mangrove areas distributed around the world vary from 110,000 to 240,000 km². According to the study of GIRI (et al., 2011), their global extension is 137,760 km². Furthermore, Herz (1991) could state that over the year of his research, Brazil had 12% of the world's mangroves, reaching 25,000 km². More recent studies reported that these data can vary from 10,124 km² (FAO, 2007) to 13,000 km² (SOUZA et al., 2018). In Brazil, the mangrove swamp occurs all along the coast, with the northern limit of Cape Orange (04°30'N) and the southern limit of Laguna (28°30'S), in the state of Santa Catarina (SCHÄFFER-NOVELLI, MESQUITA AND CITRON; 1990).

Hypersaline areas (*apicuns*) are sandy areas found near, or inside, mangroves. Their limits are defined by tides of dizziness, and are much less frequently flooded than the adjacent mangroves (LENGIBRE, 2005; HADLICH AND UCHA, 2008; ALBUQUERQUE, et al, 2014). With this differentiated regime of flooding, associated with periods of high evaporation and low precipitation, the hypersaline areas are formed. The salinity found in these areas controls the species that colonize it (MELO, 2014). They are typically succulent herbaceous halophytes, instead of those typically found in mangroves. During the rainiest seasons, such areas may be colonized by typical mangrove vegetation, while in the driest seasons, mangroves may lose vegetation and become hypersaline.

The environmental services provided by this mangrove ecosystem are varied: Protection of coastal areas against storms and erosive tidal actions; retention of pollutants; retention of fine sediments carried by the waters; maintenance and conservation of fishing stocks in the estuary; recreation and leisure. They are essential for the maintenance of marine and terrestrial life, sheltering a fauna that uses it for feeding, reproduction, development and refuge area (NANNI et al., 2005).

As there is great proximity to urban areas, their degradation would be a great risk to the environment, generating great negative impact to the fauna and flora (MELO, 2014). Some authors affirm that this ecosystem will probably suffer from climate change, since its adaptive capacity is directly linked to its state of conservation (GIRI et al, 2011; LONG et al, 2014).

One of the main mangrove forest remnants in the municipality of Rio de Janeiro is located in Sepetiba Bay. In this location, it is composed of two features: the mangrove forest and hypersaline plains, better known as *apicuns* (SOARES, 2007). The study area is located in Barra de Guaratiba, a coastal neighborhood in the West Zone of the city of Rio de Janeiro. Its neighborhoods are Guaratiba, Vargem Grande, Recreio dos Bandeirantes and Grumari.

With the development of remote sensing and studies based on satellite images, it became possible to obtain good results, reducing time, mapping costs as well as detecting environmental, urban, agricultural and other changes. The spectral resolution in the study in question is also important, as the different spectral bands that are captured by the satellite help in the most varied discrimination of targets for a better verification of the area. For example, vegetation reflects a very low amount of electromagnetic energy in the red spectral range, as it is used in the process of photosynthesis. In the near-infrared range, vegetation reflects a lot of electromagnetic energy, due to its cellular structure. With this type of information, different types of information can be generated from band combinations and calculations. Geoprocessing, on the other hand, brings users closer to these data for processing and development of their applications, where they are provided with the tools for spatial analysis (CARVALHO et al., 2015; COSTA et al, 2006; GRIGIO, 2003).

The use of these tools for land use analysis becomes of great importance in terms of the possibility of observing the temporal variation of the region. With this, we have an important mechanism for studies focused on environmental analysis, management and planning of natural resources, understanding of hydrological processes, diagnosis of dynamism in coastal space, adaptation to climate change, among other purposes (SOARES, 2007; GILMAN et al, 2008; ALMEIDA, 2010; GIRI et al, 2011; SILVA AND MOREIRA, 2011; CHOW, 2018).

The main objective of this work is to follow the development of the study of the vegetation dynamics characteristic of the Guaratiba State Biological Reserve, with a 3 km buffer zone, as well as the urban occupation, among other characteristics in the years 1990 and 2019, consisting of a 29 year time interval. In this period, there was great industrial growth around Sepetiba Bay, intense urban expansion of the west zone and tourist movement in the region, justifying the changes that occurred in the areas.

The proposed research is based on satellite images/sensors of the Landsat series (5 TM and 8 OLI) for its long historical series, good quality and free availability and, as complementary information, orthophotos on the 1:25,000 scale of *Instituto Brasileiro de Geografia e Estatística* (IBGE). Normalized Difference Vegetation Index (NDVI) was used to identify vegetation coverage areas, whereas the Normalized Difference Construction Index (NDBI) and Anthropic Transformation Index (ITA) were used to assess the conservation status of the area.

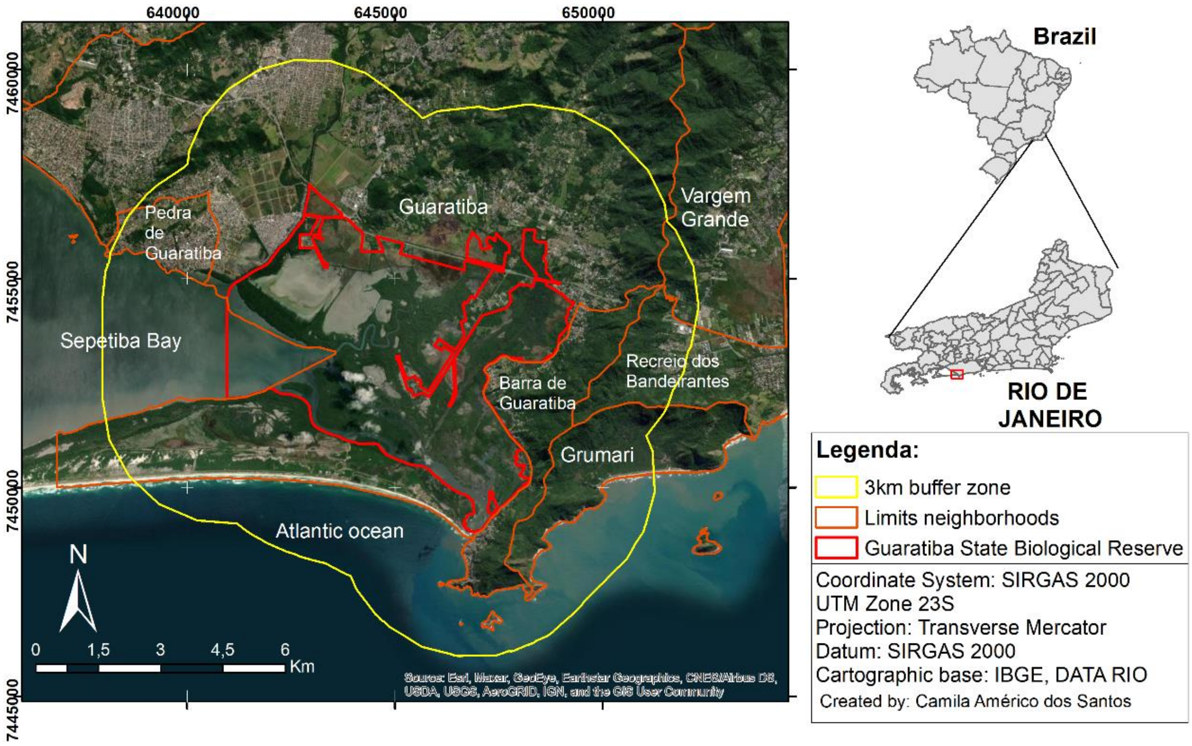
Results regarding the mapping of Guaratiba State Biological Reserve vegetation for the years 1990 and 2019 and a better understanding of the dynamics of occupation of the study area are expected, as well as data on land use and land cover, and preparation of the Index of Anthropic Transformation of the study area.

MATERIALS AND METHODS

Study Area

Guaratiba State Biological Reserve is located in the west zone of the city of Rio de Janeiro (RJ), in the district of Guaratiba, situated in the eastern portion of Sepetiba Bay (Figure 1). The headquarters is in an area outside the limits of the reserve (INEA, 2013). The reserve was created by State Decree No. 7,549, of November 20th, (RIO DE JANEIRO, 1974) with the objective of preserving the mangroves and archaeological sites in the region. It was previously called Biological and Archaeological Reserve of Guaratiba (RBAG) (Rio de Janeiro, 1974). Recently, State Law No. 5,842 of December 3rd, 2010, was recategorized, following the categories recommended by Law No. 9,985/2000, which established the National System of Conservation Units (in Portuguese *Sistema Nacional de Unidades de Conservação da Natureza* (SNUC)) (Rio de Janeiro, 2010; Brazil, 2000). It has 3,360 hectares and protects one of the most important remaining mangrove forests in the metropolitan region of Rio de Janeiro.

Figure 1 - Study area. Guaratiba State Biological Reserve and its surroundings with a 3 km buffer zone.



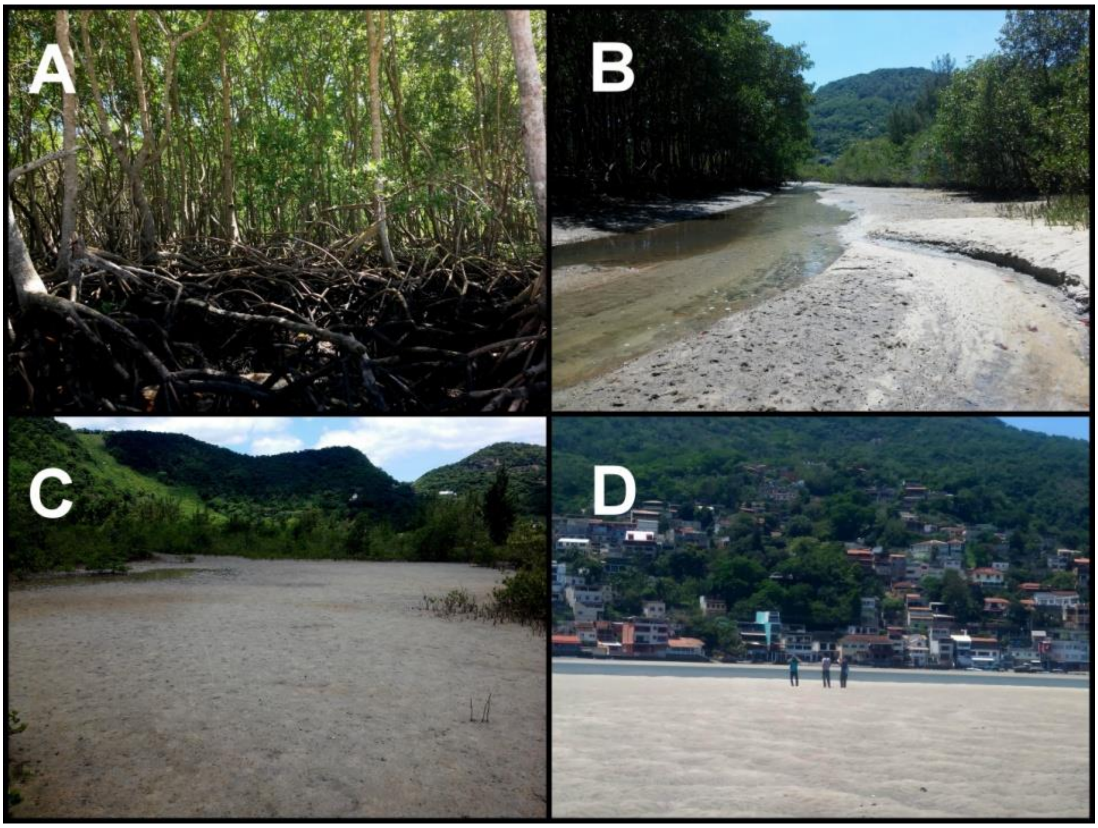
Sources - IBGE, DATA RIO. Elaboration or Organization: Camila Américo dos Santos, 2019.

Guaratiba State Biological Reserve presents three typical mangrove species: *Rhizophora mangle* (red mangrove), *Avicennia schaueriana* (black mangrove) and *Laguncularia racemose Laguncularia racemose* (white mangrove). Guaratiba region is characterized by an average annual rainfall of 1067mm, average annual temperature of 23.5 °C and microtidal regime with a range of less than 2m (ESTRADA et al., 2015; ESTRADA et al., 2008).

According to Almeida (2010), the region has been undergoing major changes, whether due to industrial growth around Sepetiba Bay, or the intense urban expansion in the West Zone, mainly in Barra da Tijuca and Recreio dos Bandeirantes neighborhoods. The districts of Guaratiba and Barra de Guaratiba have been growing quickly and in a disorganized way. An example mentioned by Soares (2007) is roads in specific places that cut large areas of the mangroves and hypersaline areas, dividing them in half, causing drainage obstacles and more tidal floods in these areas.

Guaratiba State Biological Reserve faces some problems, such as fishing, crab and “siri” species gathering that occur in its interior. According to Law No. 9.985/2000, in its art. 10, biological reserves aim to fully protect their biota and other natural attributes, with prohibition of direct human interference. It is possible to observe that there are irregular dwellings inside the reserve, but that the families ended up receiving documents of possession of the land, according to information obtained from park rangers who accompanied us on a field visit. There is an *in natura* sewage discharge from these houses and those built around the reserve, generating impact on the conservation unit. Allied to this, the urban expansion in the region (Figure 2) can compromise the dynamics of the mangrove forest and consequently the maintenance of its biodiversity. It is also necessary to highlight the problem with tourism, especially in summer, where tidal channels are used for navigation and water sports. In addition, Sepetiba Bay receives industrial waste with high levels of heavy metal contamination (INEA, 2013).

Figure 2 - Environments in Guaratiba State Biological Reserve – RBG registered in a field visit in 2018s. (A) Typical mangrove forest. (B) A tidal inlet at low tide. (C) The salt flat – apicum - without vegetation. (D) The urbanization around RBG.

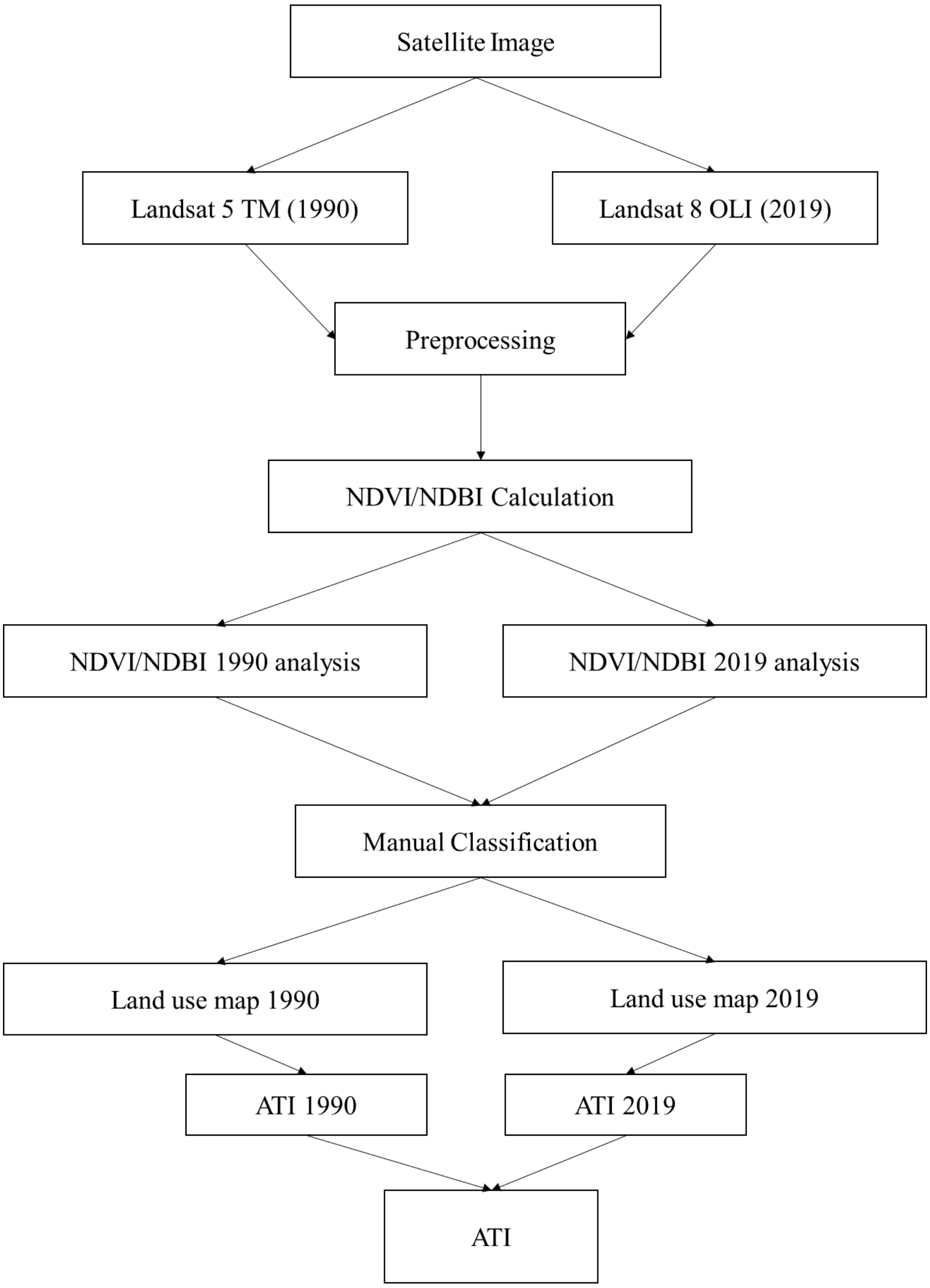


Source - Authors (2018).

Methodology

As can be seen in the flow chart (Figure 3), the Landsat series images for the present study were selected at Earthexplorer (https://earthexplorer.usgs.gov). Before vectorization of the land use classes, atmospheric corrections and processing were made to highlight the vegetation and the urban area. NDVI and NDBI indices were used for this purpose. After definition of the classes, the images were manually classified, generating land use maps on different dates. The final step consisted in the determination of the Anthropic Transformation Index.

Figure 3 - Flow chart of the methodology.



Source - Authors (2022).

Satellite images and pre-processing

Images obtained from Landsat 5 and 8 satellites (Collection 1 - level-1 data product) were selected for spectral indices calculation and subsequent land use mapping of mangrove vegetation, urban and salt flat areas. Different sensors were used: Landsat 5 Thematic Mapper (TM) from March, 12, 1990 (scene cloud cover 1%) and Landsat 8 Operational Land Imager (OLI) from February, 24, 2019 (scene cloud cover 0.13%). All images are orbit 217 and point 76 with UTM projection WGS84 and were acquired on earthexplorer website (https://earthexplorer.usgs.gov/), linked to the United States Geological Survey (USGS). However, the thermal bands were not considered in this study (Thermal Infrared Sensor – TIRS in Landsat 8). The general Landsat 5 images characteristics are shown in Table 1 and Landsat 8 images in Table 2. In addition, a field work was made to reconnoitre the area in November 2018.

Table 1 - Landsat 5 TM images' characteristics (USGS, no data).

Spectral band number	Wavelengths	Spatial resolution
Band 1 – Visible (Blue)	0.45 – 0.52 µm	30 m
Band 2 – Visible (Green)	0.52 – 0.60 µm	30 m
Band 3 – Visible (Red)	0.63 - 0.69 µm	30 m
Band 4 – Near Infrared	0.76 – 0.90 µm	30 m
Band 5 – Near Infrared	1.55 – 1.75 µm	30 m

Table 2 - Landsat 8 OLI and TIRS images characteristics (USGS, 2019).

Spectral band number	Wavelengths	Spatial resolution
Band 2 – Visible (Blue)	0.452 – 0.512 µm	30 m
Band 3 – Visible (Green)	0.533 – 0.590 µm	30 m
Band 4 – Visible (Red)	0.636 – 0.673 µm	30 m
Band 5 – Near Infrared	0.851 – 0.879 µm	30 m
Band 6 – Short wavelength infrared 1	1.566 – 1.651 µm	30 m

The images were pre-processed and transformed to Top-of-Atmosphere (TOA) spectral reflectance images, based on their metadata text files and on conversion expressions for Landsat 5 TM (Chander and Markam, 2003; USGS, undated) and for Landsat 8 OLI (USGS, 2019). The DOS1 atmospheric correction was applied, made automatically by the semi-automatic Classification plugin. First, they were reprojected for UTM projection zone 23 South and SIRGAS 2000 datum (Brazil official datum). The Landsat 5 TM bands were georeferenced to match the Landsat 8 OLI bands, as there was small displacement between the images of the two satellites. The Landsat 8 OLI bands themselves were used as the basis for this processing. All image processes were done on QGIS 2.18 software.
For transformation of Landsat 5 TM images into TOA spectral radiance, the following equation was used (Chander and Markam, 2003; USGS, no data):

$$L\lambda = ML * Qcal + Al \qquad \text{(Eq. 1)}$$

where $L\lambda$ is the TOA spectral radiance; *ML* is the radiance multiplicative scaling factor for a given band from metadata text file; *Qcal* is the pixel value in Digital Number; and *Al* is the radiance additive scaling factor for a given band from metadata text file.
Then, the following equation was used for transformation of Landsat 5 TM images into TOA reflectance images (USGS, 2019):

$$\rho\lambda` = \frac{\pi * L\lambda * d^2}{ESUN_\lambda * \cos\theta_s} \qquad \text{(Eq. 2)}$$

where ρλ` is TOA planetary reflectance; π is a constant, approximately 3.14; $L\lambda$ is the TOA spectral radiance; *d* is earth-sun distance in astronomic units from metadata text file; $ESUN_\lambda$ is mean solar exoatmospheric irradiance from metadata text file and θs is solar zenith angle in degrees from metadata text file.
For transformation of Landsat 8 OLI images to TOA spectral reflectance images, the following equation was used (Ganie and Nusrath, 2016; USGS, sd):

$$\rho\lambda = Mp * Qcal + Ap \qquad \text{(Eq. 3)}$$

where ρλ is TOA planetary reflectance without sun angle correction; *Mp* is reflectance multiplicative scaling factor for a given band from metadata text file; *Qcal* is the pixel value in Digital Number; and *Ap* is the spectral additive scaling factor for a given band from metadata text file.
For correction of TOA planetary reflectance of Landsat 8 OLI with sun angle, the following equation was used (Ganie and Nusrath, 2016; USGS, sd):

$$\rho\lambda` = \frac{\rho\lambda`}{\cos(\theta_{sz})} = \frac{\rho\lambda`}{\sin(\theta_{se})} \qquad \text{(Eq. 4)}$$

where ρλ` is TOA planetary reflectance with sun angle correction; θsz is the scene center sun elevation angle in degrees from metadata text file; θse is local solar zenith angle; $\theta sz = 90° - \theta se$.

Normalized Difference Vegetation Index (NDVI)

The vegetation indexes use combinations of radiometric measurements of satellite images to indicate the size and quality of green vegetation in a given location. The Landsat series of satellite sensors allow the use of a limited number of these indices due to their low spatial resolution of 30 meters (Zhang, 2016).
NDVI, from the values of grey levels for the red (R), near infrared (NIR) and medium infrared (MIR) bands, presented better responses for the ground cover represented in this work, where they could be spectrally differentiated, according to the study of Zha, Gao and Ni (2003). Abreu and Coutinho (2014) explained that in the region of red, vegetation absorbs energy, presenting as response in the images a darker color when the area is covered by dense vegetation, and a “lighter” response, close to white, if it is less dense. In the near infrared, the vegetation will present the opposite. With this contrast, new images can be generated, showing behaviors between exposed soil and vegetation. NDVI presents maximum reflectance in dense vegetation and maximum absorption in areas without vegetation (INSA, 2016), shown from spectral measures, quantitative and qualitative data of vegetation coverage, biomass and dynamics between soil and vegetation. It is a numerical indicator that varies between -1 and 1, where -1 means an area with leafless vegetation, suffering water stress due to soil water deficit The vegetation has leaves, with its metabolic and physiological functions in full operation, without hydric stress (Lourenço, Landim, 2004; Zhang 2016).
For the calculation of NDVI, the following expression was used (Eq. 5):

$$\mathrm{NDVI} = \frac{(NIR-RED)}{(NIR+RED)} \qquad \text{(Eq. 5)}$$

Where: NIR corresponds to the near infrared band and RED corresponds to the red band. Source: Adapted from Rouse et al. (1974).

Normalized Difference Build-up Index (NDBI)

In the case of NDBI, there is greater reflectance of constructed and sterile areas in the near infrared and middle infrared bands, while the values of ash levels for vegetation become less evident. The standardized difference of the two mentioned bands will result in positive values for constructed and similar areas, and negative values for vegetation, water bodies, etc (Zha, Gao, Ni; 2003).

He, et al. (2010), suggested improvement in the use of NDBI, ceasing to use an automatic classification method for a semiautomatic. However, they still have problems with the spectral responses of sterile areas, because they obtained responses similar to those of built urban areas, and to minimize this effect adoption of visual classification in digital environment is suggested, where the researcher uses his knowledge of the area and auxiliary materials, to distinguish the features.

For the calculation of NDBI, the following expression was used (Eq. 6):

$$NDBI = \frac{(MIR-NIR)}{(MIR+NIR)} \qquad \text{(Eq. 6)}$$

Where: MIR corresponds to the mid-infrared band and NIR corresponds to the near-infrared band. Source: Adapted from Zha, Gao, Ni, (2003).

Land use mapping

After processing NDVI with the near infrared bands and the red bands, applied to the formula in equation 1, two representative images of the vegetation coverage of the study area were obtained for the years 1990 and 2019. These NDVI bands were included in a false-color band composition, containing in the red filter (R) the band 5, in the green filter (G) the NDVI and in the blue filter (B) the band 3, for the 1990 image. For the 2019 image of Landsat 8 the composition used was to insert in the red filter (R) the band 5, in the green filter (G) the NDVI band and in the blue filter (B) the band 4.

In the processing of the NDBI, the bands of medium infrared and near infrared were used according to equation 2, obtaining images that highlight the areas built and without vegetation. To facilitate the interpretation a false-color band composition was made with the filters red (R) the band (NDBI), green (G) the band 4 and in the blue (B) the band 3 for the image of Landsat 5, 1990. For the Lansat 8 image of 2019 the false-color band composition was created by placing in the red filter (R) the NDBI band, in the green filter (G) the band 5 and in the blue filter the band 4.
After the NDVI, NDBI and the false-color band composition including the two indexes mentioned, the images were cropped to the Guaratiba State Biological Reserve area with a buffer of 3 km around it. This value was adopted in the study because it appears in the management plan (INEA, 2013) of the

reserve as an initial buffer for the buffer zone, based on the Methodological Roadmap for Preparation of Management Plans of the State Institute of Environment (INEA) (2010). However, the reserve has a buffer zone already delimited, where well defined and explicit criteria were adopted in the management plan. The RBG buffer zone occupies an area of 5,224.00 hectares, 2,765.42 ha in the continental portion and 2,458.57 ha in the marine portion.
The mapping classes were chosen from the features identified and of interest for the study. In all, nine classes were adopted as the main ones: constructed areas, hypersaline areas, areas without vegetation, sandbanks, tidal and river channels, mangrove swamps, *restinga*, beach and other types of vegetation. These classes were visually interpreted in satellite image color composite for each of the features, elaborating the polygons of each of the mapping themes. The manual classification was adopted in this study due to the presence of areas with similar spectral responses, which facilitates this differentiation. The interpretations of the images from different years made possible the construction of two land use and coverage mappings of the Biological Reserve of Guaratiba for the years 1990 and 2019, which in the development of the study determines the variation of the classes chosen in the twenty-nine years of interval between the images.

Anthropic Transformation Index (ATI)

With the end of Guaratiba State Biological Reserve land use and land cover mapping in both periods (1990-2019), it was possible to apply ITA to evaluate the conservation status of the area. This index uses the values of the total areas of land use and land cover map, with their respective weight (BEVEN, et al., 1988) (Equation 3). The weights were assigned from the multidisciplinary view of various specialists (MATEO RODRÍGUEZ, 1984; SCHWENK, CRUZ, 2008) and range from 0 to 10, where 10 indicates greater pressure (Table 1).

The weights established in this work for the map features were: Mangrove (1), Hypersaline Areas (5), Built-up Areas (10), Tidal and River Channels (1), Sand Banks (3), *Restinga* (2), Other Types of Vegetation (2), Non-Grove Areas (9), and Beach (1).

For ATI calculation, the following expression was used (Eq. 7):

$$\Sigma(\%USE * WEIGHT)/100 \qquad \text{(Eq. 7)}$$

Where: use = area in percentage values of the plant coverage class and use; weight = weight given to the different types of use and coverage as to the degree of anthropic changes. Source: adapted from Mateo Rodríguez, 1984.

Table 3 - Anthropic Transformation Index classification.

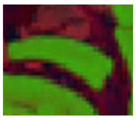
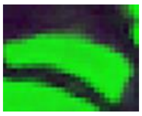
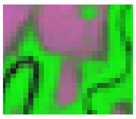
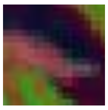
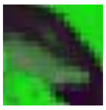
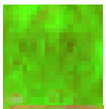
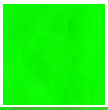
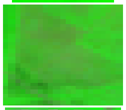
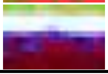
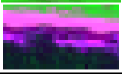
ATI CLASSIFICATION	VALUES
Little degraded	0 – 2.5
Regular	2.5 -5
Degraded	5 – 7.5
Very degraded	7.5 - 10

RESULTS AND DISCUSSION

NDVI, NDBI and Land Use Mapping

With the images resulting from NDVI and NDBI processing, four false-color band compositions were built, two concerning the NDVI, and two the NDBI in the years 1990-2019 for the areas of interest (Figures 3 and 4). With these compositions as partial results, it was possible to perform the visual classification in digital environment, where the features for each of the classes already mentioned were identified. In the composition with the NDVI in the years 1990 and 2019 (Fig.3), it was possible to visually distinguish the mangrove from other types of vegetation by the shade it assumes as a function of the moisture features when placed in a false-color band composition (Zha, et al., 2003). As it is a visual interpretation in digital media, an interpretation key was created for each specified class. Table 4 was based on the interpretation key provided by the website of the Laboratory for Image Processing and Geoprocessing (LAPIG) at the Federal University of Goiás (UFG).

Table 4 - Interpretation key of the study area.

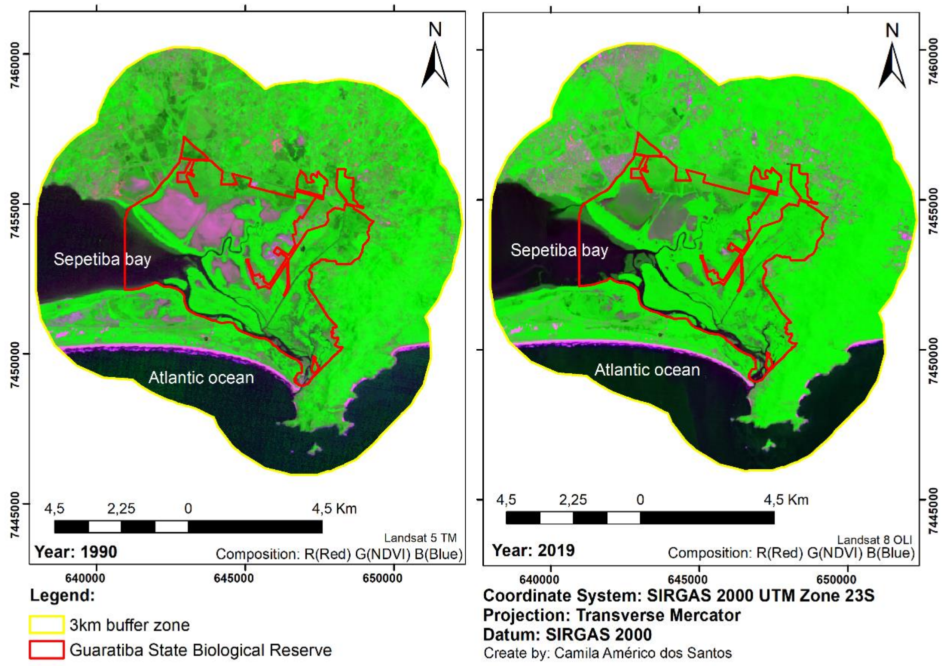
Classes	Texture	Tonality	Form	Location	False-Color Composition NDBI	False-Color Composition NDVI
Mangrove	Medium roughness	Dark tonality due to water present in the soil	Homogeneous /uniform area	Flat areas at low altitudes		
Hypersaline areas	No roughness	Light tonality	Exposed soil	In the middle of the mangrove, close to the tidal inlets		
Built-up areas	High roughness	Variable hue depending on the number of constructions	Great heterogeneity of targets (buildings, trees, etc.)	Variable		
Tidal inlets and rivers	Low/none roughness	Dark tonality	Meander form, may have been rectified by human action	Among the mangrove		
Sand banks	No roughness	Light tonality	Varied form	In or at the end of tidal channels and rivers		
Restinga	Low roughness	Light tonality	Varied form	Close to the beach, dunes.		
Others vegetation types	High roughness, except for NDVI	Dark tonality	Varied forms, by different types of vegetation	Various locations		
Area without vegetation	Low roughness	Light tonality	Exposed soil	Variable		
Beach	No roughness	High tonality	Sandy cord	Coast		

Sources - Based on Chave de Interpretação dos Biomas – LAPIG, UFG[1].

With the images resulting from the NDVI and NDBI processing, four false-color band compositions were built, two concerning the NDVI, and two the NDBI in the years 1990-2019 for the areas of interest (Figures 4 and 5). With these compositions as partial results, it was possible to perform the visual classification in digital environment, where the features for each of the classes already mentioned were identified. In the composition with the NDVI in the years 1990 and 2019 (Fig.4), it was possible to visually distinguish the mangrove from other types of vegetation by the shade it assumes as a function of the moisture features when placed in a false-color band composition (Zha, et al., 2003).

[1] Chave de interpretação dos Biomas. Laboratório de Processamento de Imagens e Geoprocessamento – LAPIG, Instituto de Estudos Socioambientais – IESA, Universidade Federal de Goiás. Available in: https://lapig.iesa.ufg.br/p/38948-chave-de-interpretacao-dos-biomas. Acessed on: 30 de Mar 2022.

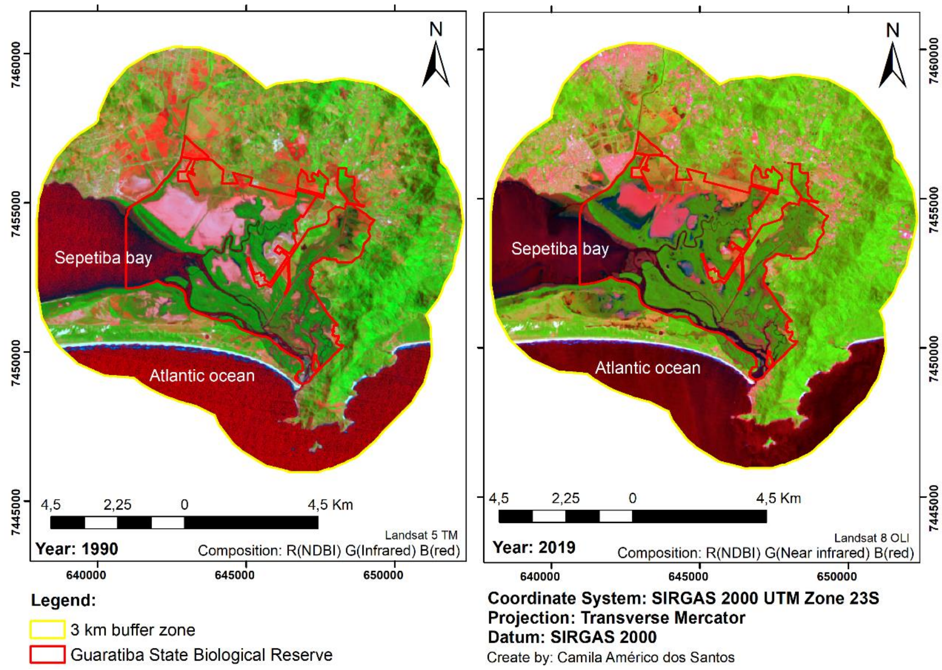
Figure 4 - False-color compositions from 1990s (left) and 2019 (right). The bands used were band red, NDVI and band blue.



Sources - DATA RIO. Elaboration or Organization: Camila Américo dos Santos, 2019.

In the composition with NDBI in the years 1990 and 2019 (Fig. 5), it was possible to visually distinguish the constructed and hypersalines areas that presented similar spectral responses, because these areas do not present any or almost any type of vegetation coverage. The doubts found regarding the classifications in the processing of the NDBI regarding false-color band compositions were compared with field works, orthophotos and auxiliary images.

Figure 5 - False-color compositions from 1990s (left) and 2019 (right). The bands used were NDBI, band infrared and band red.



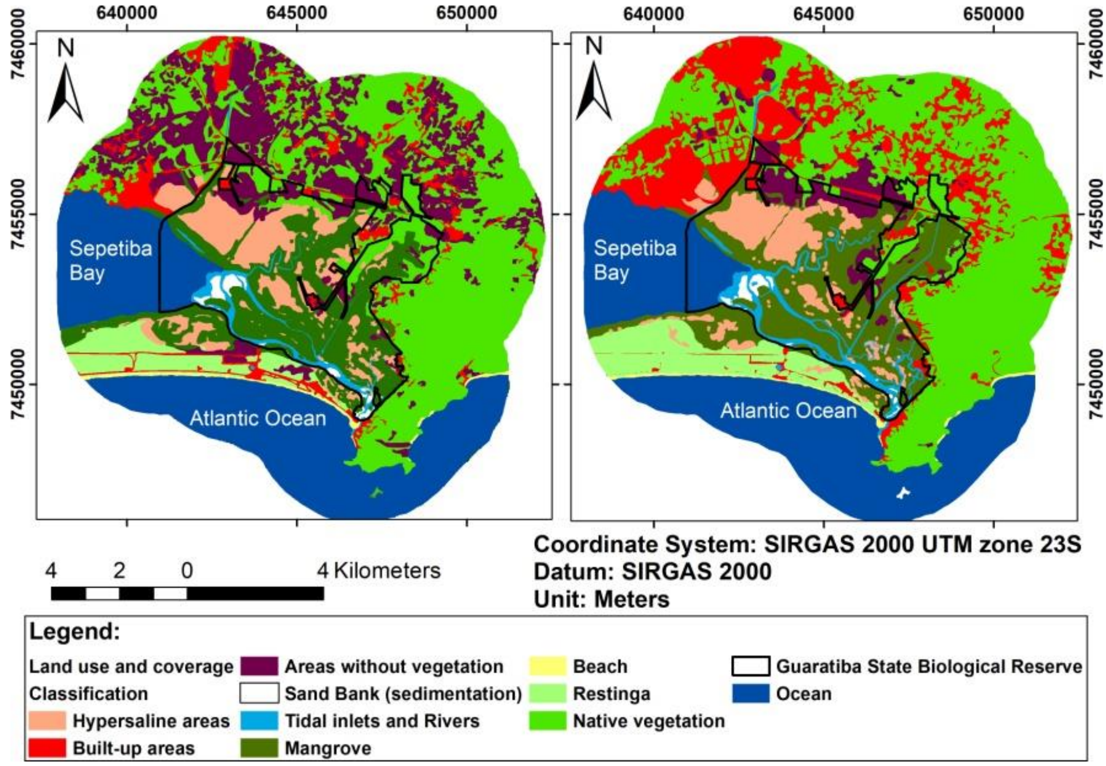
Sources - DATA RIO. Elaboration or Organization: Camila Américo dos Santos, 2019.

In the false color compositions with NDVI and NDBI for each of the years studied it could be noted that the results have already presented visual changes in the areas of interest, showing gradual decrease of hypersaline areas, consequently an increase in typical mangrove vegetation by invasion of hypersaline areas by the edges, and it is noted that some hypersaline areas disappeared from 1990 to 2015, characterizing a possible regeneration of mangrove vegetation in the period (Fig.4). The constructed areas show a significant increase in the research period (1990-2019) in the protection buffer around the Reserve (Fig.5). On the other hand, within the Reserve, there are no major changes, at least visually, but in field work the existence of constructions has been verified. Some of them have already been demolished, others, however, have been maintained, probably becoming illegal possession of land.

The NDVI and NDBI indexes proved to be very reliable in the application of the mapping of Land Use and Cover of the study area, facilitating the identification of features of the land. They highlighted with high quality the vegetation features, in the case of the NDVI and constructed areas, and hypersalines regarding the NDBI, without using very complex algebra and consisting of fast manipulation of the bands. The use of these indices in the thematic mapping of this area should be accompanied by some concerns such as: use of auxiliary documents (other images, photos and orthophotos available) and field trips to distinguish features that present difficulties in interpretation owing to similar spectral responses. It is also necessary to consider the possibility that the values for vegetation, in the case of NDVI, are not always positive, because their spectral response are different across several species, soil conditions, humidity and density (Zha, et al., 2003).

The maps of Land Use and Land Cover in the years 1990-2019, were elaborated based on the interpretations made by NDVI, NDBI and visual interpretation in digital media of the composition of the RBG images, with the captions defined for this study (Fig.6) One of the main objectives of the research can be considered to enable the separation of the features from the captions and comparison of the variation of the features in 29 years.

Figure 6 - Land use maps of Guaratiba State Biological Reserve and its surroundings in 1990s and 2019s.



Sources - DATA RIO. Elaboration or Organization: Camila Américo dos Santos, 2019.

With the results of the total areas regarding each classification (Table 5), we could see that the typical vegetation of the mangrove forest increased 24.14% to 19.95 km² at the end of the study period, however, a substantial decline of -32.51% in hypersaline areas was observed, and consequently, decrease of areas without vegetation, consisting of -68.58%. According to the study of Almeida, et al. (2008, 2011), there are usual variations of hypersaline and mangrove areas, with oscillations in these areas, where one gains or loses space to the other, over the years. This occurs due to low rainfall seasons in the site, affecting the entry of fresh water into the mangroves and *apicuns*, causing increase in salinity in the site. In addition, irregular constructions around the Reserve could be seen, totaling a variation of 163.09% in the period that also affects this regime of water exchange, because they obstruct the tidal channels, creating an artificial barrier in these places. With respect to the study of Soares (et al., 2007), there are reports that the region suffers from strong urban pressure, with irregular constructions of houses, and roads that cut through the mangrove forests. Constructions can be seen even inside the Reserve (CTEx - Army Technological Center).

Table -. Total areas for land use map in 1990s and 2019s.

CLASSES	**1990s (Km^2)**	**2019s (Km^2)**	**RATE CHANGE**
Mangrove	16.07	19.95	24.14 %
Hypersaline areas	10.49	7.08	-32.51%
Built-up areas	9.40	24.73	163.09%
Tidal inlets and rivers	2.72	2.92	7.35%
Sand banks	0.90	0.70	-22.22%
Restinga	5.80	6.95	19.83%
Others vegetation types	45.15	43.26	-4.19%
Area without vegetation	21.96	6.90	-68.58%
Beach	0.90	0.90	0%
Total	113.19	113.19	-

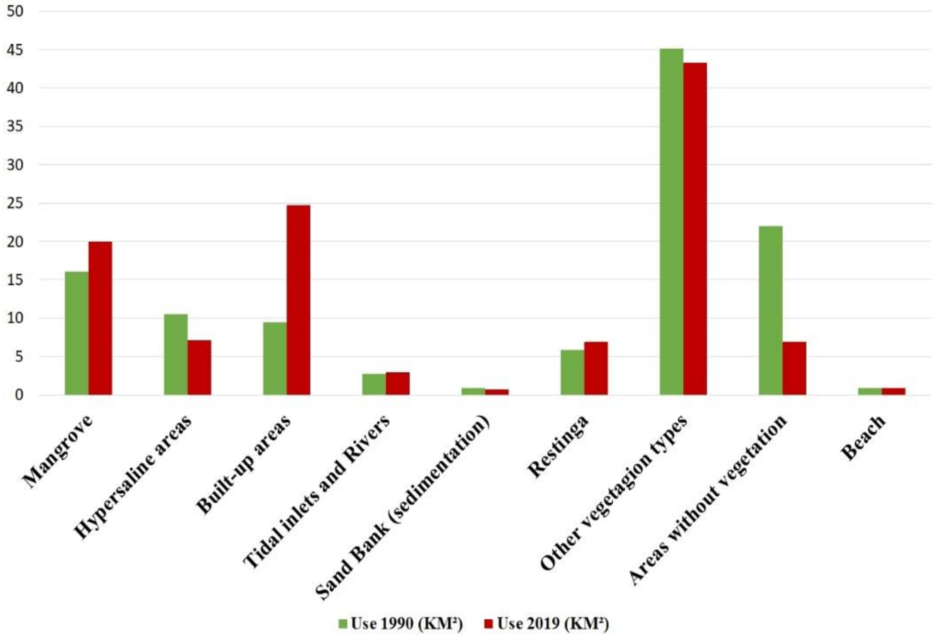
Sources - Authors, 2019.

Although the constructed areas have increased considerably during the study period, it can be seen that they increased along the buffer, whereas the interior of the Reserve has been preserved, which contributes to the conservation and growth of vegetation, shown in figure 6, table 5.

Corroborating these results, Godoy (2015) states in his studies that mangroves in the state of Ceará may suffer changes with climate change and rising sea levels, with migration of mangrove vegetation to areas where, earlier, there were no conditions for survival of such species. This would happen due to decrease in rainfall, the consequent decrease in river flow and increase in tidal volume within estuaries, raising the level of salinity in surface and underground waters. Thus, all these aspects may create a conductive environment to facilitate mangrove migration.

According to the study of Soares, et al., (2007), it could be reported that the study area consisted of mangrove forests that are well preserved, as well as their integrated systems: Ocean – estuary – rivers and mangrove forests – hypersaline plains – wetlands.

Figure 7 - Comparison of total areas in km² for land use classes in 1990s and 2019s.



Anthropic Transformation Index (ATI)

Table 6 of the ATI was generated from the map of Land Use and Cover, as well as the area features and their respective weights. This table shows the ATI values for the years 1990 and 2019 allowing an analysis of the data obtained in the two years proposed for the research in the reserve area and its buffer zone (Table 6).

Table 6 - ATI quantitative classification for each land use class in 1990s and 2019s.

CLASSES	LAND USE 1990 (%)	LAND USE 2019 (%)	WEIGHT	ATI (1990)	ATI (2019)
Mangrove	14.17	17.59	1	0,14	0,17
Hypersaline areas	9.25	6.24	5	0,46	0,31
Built-up areas	8.29	21.81	10	0,83	2,18
Tidal inlets and rivers	2.40	2.58	1	0,02	0,03
Sand banks	0.79	0.62	3	0,02	0,02
Restinga	5.12	6.13	2	0,10	0,12
Others vegetation types	39.82	38.15	2	0,80	0,76
Area without vegetation	19.37	6.09	9	1,74	0,55
Beach	0.79	0.79	1	0,01	0,01
Total	100	100	-	4,13	4,15

Sources - Authors, 2019.

With the percentage data obtained in the ATI (Table 3), it can be observed that even with the constructed areas growing approximately 13% from 1990 to 2019, the total result of the ATI remained classified as "regular" (2.5 - 5.0), consisting of small variation. This can probably be attributed mainly to the areas without vegetation in the study, which decreased by approximately the same amount. According to an overview of this topic, the vegetation areas in and around the reserve have increased, such as mangrove swamps and sandbanks. The hypersaline areas and the mangrove swamp also had the same dynamics as the areas without vegetation and constructed areas, where mangrove swamp grows by approximately 3%, while the hypersaline areas decrease this same value, probably owing to replacements under these conditions.

Supporting these results, Rocha and Cruz (2009) found similar results for Angra dos Reis and Paraty, which consist of similar features. They attribute this value, smaller than expected, in the spatial resolution of the sensor, for occurring in built-up areas closest to the reserve in the region of Barra de Guaratiba, for example. Other common feature of the areas is the existing tourist value, being evident that some areas should be preserved, although the tourist attraction also highlights the lack of urban planning, hence the management plan itself (INEA, 2013) states that there are sewage releases in natura in mangrove areas and irregular buildings.

The research highlighted the great importance of the availability of orbital images from a long time series of Landsat satellites, approximately 46 years old, free of charge, allowing access to information even by research with few financial resources. Using the images of the Landsat 5 TM (1990) and Landsat 8 OLI (2019) satellites, it was possible to construct the two indexes by normalized difference: NDVI and NDBI. With them, the creation of the map of land use and coverage was analyzed for the two years, showing the features of total areas of interest for the study. Even considering the 29 years of difference of the period between the first and the second image, the mangrove areas could grow, and this result shows the importance of the State Biological Reserve of Guaratiba with the preservation of the ecosystem of the region. The main proof is associated with the preservation of the area, i.e., the growth of the mangroves in the map of Land Use and Cover that varied from 16.07 km² to 19.95 km² in a significant percentage of 24.14%.

Regarding the constructed areas, it was possible to notice in the mapping that they increased significantly (163.09%) while the areas without vegetation lost space (-68.58%). This may be partially explained, since part of these areas without vegetation would already be reserved for areas destined for construction, such as condominiums or allotments, based on observations of the pattern of images in 1990 and 2019. The other areas did not show significant changes.

The ITA demonstrated that it has remained "regular" over the 29-year period. However, it was not possible to discriminate the large increase of constructed areas as a factor to be observed, and the next researches should be focused on this “wild” growth aiming to obtain relevant information for anthropic activities by ITA.

Finally, the importance of temporal studies developed in environmental protection areas, using orbital sensor images in the search for satisfactory responses that contribute to the mitigation of environmental impacts in the protection areas, should be highlighted.

REFERENCES

ABREU, K.M.P.; COUTINHO, L.M., 2014. Sensoriamento remoto aplicado ao estudo da vegetação com ênfase em índice de vegetação e métricas da paisagem. **Vértices**. 16, 173-198. https://doi.org/10.5935/1809-2667.20140012

ALBUQUERQUE, A.G.B.M.; FERREIRA, T.O.; CABRAL, R.L.; NOBREGA, G.N.; ROMERO, R.E.; MEIRELES, A.J.D.A.; OTERO, X.L., 2014. Hypersaline tidal flats (apicum ecosystems): the weak link in the tropical wetlands chain. **Environmental Reviews**. 22, 99-109. https://doi.org/10.1139/er-2013-0026

ALMEIDA, P.M.M.; SOARES, M.L.G.; KAMPEL, M., 2008. Monitoramento de uma Área de Manguezal na Região Metropolitana do Rio de Janeiro através de Técnicas de Sensoriamento Remoto. In: **III**

Congresso Brasileiro de Oceanografia–CBO, Fortaleza, Brasil. Available in: http://plutao.sid.inpe.br/col/dpi.inpe.br/plutao@80/2008/12.04.14.30.10/doc/Almeida_etal_2008B.pdf.

ALMEIDA, P.M.M., 2010. Análise espaço-temporal da área ocupada por florestas de mangue em Guaratiba (Rio de Janeiro, RJ) de 1985 até 2006 e sua relação com as variações climáticas. **Master**, Universidade Federal do Rio de Janeiro–UFRJ, Rio de Janeiro. Available in: http://objdig.ufrj.br/16/teses/772422.pdf.

BEVEN, K.J.; WOOD, E.F.; SIVAPALAN, M., 1988. On hydrological heterogeneity—catchment morphology and catchment response. **Journal of hydrology**. 100, 353-375. https://doi.org/10.1016/0022-1694(88)90192-8

BIRD, E., 2008**. Coastal geomorphology an introduction**, 2nd ed.; Wiley: England.

BRASIL. Lei Nº 9.985, de 18 de julho de 2000. Regulamenta o art. 225, § 1º, incisos I, II, III e VII da Constituição Federal, institui o Sistema Nacional de Unidades de Conservação da Natureza e dá outras providências. Available in: http://www.planalto.gov.br/ccivil_03/leis/L9985.htm. Accessed on: 16 dec. 2019.

CARNEIRO, A.S.L.; SANTOS, A.L.S.; BEZERRA, D.S.: AMARO, V.E.; COSTA, B.C.P.; BORGES, H.P.; AROUCHA, R.J., 2017. Análise multitemporal **da evolução de áreas de manguezais na ilha do Maranhão com dados de sensoriamento remoto. In: Anais do Simpósio Brasileiro de Sensoriamento Remoto Santos**, 18, 4918-4924. ISBN: 978-85-17-00088-1. Available in: http://marte2.sid.inpe.br/rep/sid.inpe.br/marte2/2017/10.27.13.58.44?ibiurl.backgroundlanguage=pt-BR&ibiurl.requiredsite=marte2.sid.inpe.br+802&requiredmirror=dpi.inpe.br/marte2/2013/05.17.15.03.08&searchsite=bibdigital.sid.inpe.br:80&searchmirror=sid.inpe.br/bibdigital@80/2006/04.07.15.50.13

CARVALHO, M.V.A.; SILVA, G.F.; CRUZ, C.B.M.; ALMEIDA, P.M.M., 2015. Avaliação do mapeamento de manguezais na Região Metropolitana do Rio de Janeiro através da integração entre GEOBIA e Mineração de Dados. In**: Anais do XVII Simpósio Brasileiro de Sensoriamento Remoto**, INPE, João Pessoa, Brasil, 3580 – 3587. ISBN 978-85-17-0076-8. IBI: <8JMKD3MGP6W34M/3JM4BRK>. Available in: ibi:8JMKD3MGP6W34M/3JM4BRK.

CHANDER, G.; MARKHAM, B., 2003. Revised Landsat-5 TM radiometric calibration procedures and postcalibration dynamic ranges**. in *IEEE Transactions on Geoscience and Remote Sensing*, vol. 41, no. 11, pp. 2674-2677.** https://doi.org/10.1109/TGRS.2003.818464

CHOW, J., 2018. Mangrove management for climate change adaptation and sustainable development in coastal zones**. Journal of Sustainable Forestry**. *37*, 139-156. https://doi.org/10.1080/10549811.2017.1339615

COSTA, M.R.P.; ALCÂNTARA, E.D.; AMORIM, A.D.J.E.; MOCHEL, F.R., 2006. Avaliação das potencialidades e fragilidades das áreas de manguezal para a implementação do ecoturismo usando ferramentas de sensoriamento remoto em Cururupu-MA, Brasil**. Caminhos de Geografia.** *22*, 237-243. Available in: https://seer.ufu.br/index.php/caminhosdegeografia/article/view/15409.

DIPSON, P.T.; CHITHRA, S.V.; AMARNATH, A.; SMITHA, S.V.; NAIR, M.H.; SHAHIN, A., 2015. Spatial changes of estuary in Ernakulam district, Southern India for last seven decades, using multi-temporal satellite data. **Journal of environmental management**. 148, 134-142. https://doi.org/10.1016/j.jenvman.2014.02.021

DUKE, N. C., MEYNECKE, J. 0., DITTMANN, A. M., ELLISON, A. M., AANGER, K., BERGER, U., CANNICCI, S., DIELE, K., EWEL, K. C., FIELD, C.D., KOEDAM, N., LEE, S. Y., MARCHAND, C., NORDHAUS, I. & DAHDOUH-GUEBAS, F., 2007. A world without mangroves**? Science**. 317, 41-42. https://doi.org/10.1126/science.317.5834.41b

ESTRADA, G.C.D.; CALLADO, C.H.; SOARES, M.L.G.; LISI, C.S., 2008. Annual growth rings in the mangrove *Laguncularia racemosa* (Combretaceae). **Trees**. *22*, 663-670. https://doi.org/10.1007/s00468-008-0224-9

ESTRADA, G.C.D.; SOARES, M.L.G.; FERNANDEZ, V.; ALMEIDA, P.M.M., 2015. The economic evaluation of carbon storage and sequestration as ecosystem services of mangroves: a case study from southeastern Brazil**. International Journal of Biodiversity Science, Ecosystem Services & Management** 11, 29-35. https://doi.org/10.1080/21513732.2014.963676

GANIE, M.A.; NUSRATH, A., 2016. Determining the vegetation indices (NDVI) from Landsat 8 satellite data. **International Journal of Advanced Research**. 4, 1459-1463. https://doi.org/10.21474/IJAR01/1348

GILMAN, E.L.; ELLISON, J.; DUKE, N..; FIELD, C., 2008. Threats to mangroves from climate change and adaptation options: a review. **Aquatic botany**. *89*, 237-250. https://doi.org/10.1016/j.aquabot.2007.12.009

GIRI, C.; OCHIENG, E.; TIESZEN, L.L.; ZHU, Z.; SINGH, A.; LOVELAND, MASEK, J.; DUKE, N., 2011. Status and distribution of mangrove forests of the world using earth observation satellite data. **Global Ecology and Biogeography**. 20, 154-159. https://doi.org/10.1111/j.1466-8238.2010.00584.x

GODOY, M. D., & LACERDA, L. D. D., 2015. Mangroves response to climate change: a review of recent findings on mangrove extension and distribution. In: **Anais da Academia Brasileira de Ciências**. 87, 651-667. https://doi.org/10.1590/0001-3765201520150055

Herz, R. 1991. Manguezais do brasil - 1988. São Paulo: Instituto Oceanografico da Usp/Cirm.

INSTITUTO ESTADUAL DO MEIO AMBIENTE – INEA, 2013**. Plano de Manejo da Reserva Biológica Estadual de Guaratiba**. Secretaria de Estado do Ambiente, Rio de Janeiro. Available online: http://www.inea.rj.gov.br/Portal/Agendas/BIODIVERSIDADEEAREASPROTEGIDAS/UnidadesdeConservacao/INEA_008603. Accessed on 01 Aug. 2020.

INSTITUTO NACIONAL DO SEMIÁRIDO – INSA*.* **Índice De Vegetação Por Diferença Normalizada.** Available online: http://www.insa.gov.br/ndvi/#.V4LMLlQrKUk. Acessed on: 10 jun. 2016.

KAWASHIMA, R.S.; GIANNOTTI, M.A.; ALMEIDA, C.M.D.; QUINTANILHA, J.A., 2016. Modelagem dinâmica espacial como ferramenta para simulação de cenários da paisagem na região portuária da Baixada Santista. **Boletim de Ciências Geodésicas**. 22, 703-718. https://doi.org/10.1590/s1982-21702016000400040

KRUG, L.A.; LEÃO, C.; AMARAL, S., 2007. Dinâmica espaço-temporal de manguezais no Complexo Estuarino de Paranaguá e relação entre decréscimo de áreas de manguezal e dados sócio-econômicos da região urbana do município de Paranaguá–Paraná. In: ***Anais do XIII Simpósio Brasileiro de Sensoriamento Remoto***, INPE, Florianópolis, Brasil. 2753-2760. ISBN 978-85-17-00031-7. (INPE-16402-PRE/10980). Available in: http://urlib.net/ibi/dpi.inpe.br/sbsr@80/2006/11.14.20.50.

LEBIGRE, J-M., 2015. Les marais à mangrove et lês tannes. Available in: https://www.futura-sciences.com/planete/dossiers/geographie-marais-mangrove-tannes-683/. Accessed on:12 Aug. 2020.

LONG, J.; NAPTON, D.; GIRI, C.; GRAESSER, J., 2014. A mapping and monitoring assessment of the Philippines' mangrove forests from 1990 to 2010. **Journal of Coastal Research**. 30, 260-271. https://doi.org/10.2112/JCOASTRES-D-13-00057.1

LOURENÇO, R.W.; LANDIM, P.M.B., 2004. Estudo da variabilidade do" índice de vegetação por diferença normalizada/NDVI" utilizando krigagem indicativa. **Holosenvironment.** 4, 38-55. ISSN: 1519-8634. Available in: http://leg.est.ufpr.br/lib/exe/fetch.php/disciplinas:geoesalq:artigo1.pdf.

MATEO, J., 1991. **Apuntes de Geografia de Los Paisajes**. La Habana: Universitaria, pp. 194.

MELO, J.G.S., 2014. Registro das dinâmicas espaciais dos manguezais no baixo curso do Capibaribe. **Master**, Universidade Federal de Pernambuco, Pernambuco. Available in: http://bdtd.ibict.br/vufind/Record/UFPE_c968b13a1b16fc423a29cbed3cea5bbc.

MOREIRA, M. V., CARDEMAN, R. G., TÂNGARI, V. R., 2017. Técnicas e métodos para análise urbana de áreas em expansão: estudo de caso de Guaratiba-RJ. São Paulo. **Anais do XVII ENANPU**, 17. Available in: https://anais.anpur.org.br/index.php/anaisenanpur/article/view/2286.

NANNI, H.C.; NANNI, S.M.; SIGNINI, R.C., 2005. A importância dos manguezais para o equilíbrio ambiental. In: **II simpósio internacional de ciências integradas da UNAERP** campus Guarujá, Brasil. Available in: https://www.unaerp.br/documentos/904-a-importancia-dos-manguezais-para-o-equilibrio-ambiental/file.

RIO DE JANEIRO (State). 1974. Decreto Estadual nº 7.549 – de 20 de novembro de 1974. Delimita a área da Reserva Biológica e Arqueológica de Guaratiba e dá outras providências. Available online: http://www.inea.rj.gov.br/cs/groups/public/documents/document/zwew/mdi2/~edisp/inea0026184.pdf. Accessed on: 16 Dec. 2019.

RIO DE JANEIRO. 2010. Lei nº 5842, de 03 de dezembro de 2010. Recategoriza a Reserva Biológica E Arqueológica Estadual De Guaratiba como Reserva Biológica Estadual De Guaratiba, redelimita sua área e dá outras providências. Available online: http://alerjln1.alerj.rj.gov.br/CONTLEI.NSF/f25571cac4a61011032564fe0052c89c/184767adad2aa28b832577fa006de757?OpenDocument. Accessed on: 16 dec. 2019.

ROCHA, S.P.; CRUZ, C.B.M., 2009. Aplicação do ITA na análise espaço-temporal do entorno da BR-101 nos municípios de Angra dos Reis e Parati. In: **Anais XIV Simpósio Brasileiro de Sensoriamento Remoto**, Natal, Brasil, 1505-1512. Available in: http://marte.sid.inpe.br/col/dpi.inpe.br/sbsr@80/2008/11.11.11.39/doc/1505-1512.pdf.

ROUSE, J. W.; HAAS, R.H.; SCHELL, J.A.; DEERING, D.W., 1974. Monitoring vegetation systems in the great plains with ERTS. **Proceedings of Earth Resources Technology Satellite-1 Symposium**, NASA, Washington, pp. 309-317. Available in: https://ntrs.nasa.gov/citations/19740022614.

SANTOS, C.S.C; DIAS, F.F.; FRANZ, B.; SANTOS, P.R.A.; FONSECA, R.T.; VARGAS, R.; SANTOS, C.A., 2019. Relative sea level rise effects at the Marambaia barrier island and Guaratiba mangrove: Sepetibabay (SEBrazil). **Journal of Sedimentary Environments**. 4, 249-262. https://doi.org/10.12957/jse.2019.44397

SCHAEFFER-NOVELLI, Y., 1989. Perfil dos ecossistemas litorâneos brasileiros, com especial ênfase sobre o ecossistema manguezal. **Publicação Especial do Instituto Oceanográfico**, pp. 1-16.

SCHAEFFER-NOVELLI, Y.; MESQUITA, H.S.L.; CINTRÓN-MOLERO, G., 1990. O sistema estuarino da lagoa de Cananéia, São Paulo, Brasil. **Estuários**. 13, 193-203. https://doi.org/10.2307/1351589

SCHWENK, L.M.; CRUZ, C.B.M., 2008. Conflitos socioeconômicos-ambientais relativos ao avanço do cultivo da soja em áreas de influência dos eixos de integração e desenvolvimento no Estado de Mato Grosso. **Acta Scientiarum Agronomy**. *30*, 501-511. https://doi.org/10.4025/actasciagron.v30i4.5305

SILVA, A. M.; MOREIRA, E. B. M., 2011. Avaliação espaço temporal do índice de vegetação (NDVI) no manguezal de Maracaípe–PE, através de imagens do satélite Landsat 5 TM. **XV Simpósio Brasileiro de Sensoriamento Remoto**–SBSR, Curitiba–PR, 1570. Available in: http://marte.sid.inpe.br/col/dpi.inpe.br/marte/2011/07.08.19.03/doc/p1334.pdf?metadatarepository=dpi.inpe.br/marte/2011/07.08.19.03.28&mirror=dpi.inpe.br/banon/2003/12.10.19.30.54.

SOARES, M.L.G., 1997. Estudo da biomassa aérea de manguezais do sudeste do Brasil-análise de modelos. **Thesis**, Universidade de São Paulo, São Paulo.

SOARES, M. L. G., 2007. Impactos das mudanças globais sobre manguezais do município do Rio de Janeiro. Núcleo de Estudos em Manguezais–Departamento de Oceanografia–Programa de Pós-Graduação em Meio Ambiente–UERJ.

SOUZA, C.A.; DUARTE, L.F.A.; JOÃO, M.C.A.; PINHEIRO, M.A.A., 2018. **Biodiversidade e conservação dos manguezais: importância bioecológica e econômica**. In: *Educação Ambiental sobre Manguezais;* Pinheiro, M.A.A.; Talamoni, A.C.B.; Orgs.; UNESP: São Vincente, Brasil, pp. 16-56. Available in: https://www.crusta.com.br/biblio/04.Capítulos/20-educacao_ambiental_manguezais_cap01_biodiversidade_conservacao.pdf.

UN FOOD AND AGRICULTURE ORGANIZATION, 2007. The World's Mangroves 1980–2005: a thematic study prepared in the framework of the Global Forest Resources Assessment 2005. **ISBN:**

978-92-5-105856-5. Available in: https://www.fao.org/3/a1427e/a1427e00.htm. U.S. GEOLOGICAL SURVEY – USGS, 2019. Landsat 8 (L8) Data Users Handbook. Version 4.0, South Dakota. Available in: https://d9-wret.s3.us-west-2.amazonaws.com/assets/palladium/production/s3fs-public/atoms/files/LSDS-1574_L8_Data_Users_Handbook-v5.0.pdf. Accessed on: 21 May 2020.

U.S. GEOLOGICAL SURVEY – USGS. Landsat Missions – Landsat 5. Available in: https://www.usgs.gov/landsat-missions/landsat-5. Accessed on: 21 May 2020.

U.S. GEOLOGICAL SURVEY – USGS. Landsat Missions – Using the USGS Landsat Level-1 Data Product. Available in: https://www.usgs.gov/land-resources/nli/landsat/using-usgs-landsat-level-1-data-product. Accessed in 21 May 2020.

ZHA, Y.; GAO, J.; NI, S., 2003. Use of normalized difference built-up index in automatically mapping urban areas from TM imagery**. International journal of remote sensing**. 24, 583-594. https://doi.org/10.1080/01431160304987

ZHANG, K.; THAPA, B.; ROSS, M.; GANN, D., 2016. Remote sensing of seasonal changes and disturbances in mangrove forest: a case study from South Florida**. Ecosphere,** 7. https://doi.org/10.1002/ecs2.1366

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