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Loss of vegetation cover in a tropical island of the Amazon coastal zone (Maranhão Island, Brazil)

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ABSTRACT

Coastal zones are valuable environments for humankind and have been used for urban settlements, recreation, harbours, mining and the gathering of natural resources. However, human occupation and usage of coastal ecosystems is threatening their diverse natural vegetation. The aim of this study was to analyse the changes in coastal vegetation cover of Maranhão Island in the face of urban development over the last 20 years through remote sensing imagery. Our results reveal a loss of vegetation for four of the five beaches studied. The most extensive loss occurred at the beaches of São Luis Municipality (accounting for 146 ha), which is highly urbanized. Vegetation loss also occurred at sites protected under national environmental legislation, most of which was due to illegal human activity. The results were discussed in the light of the literature which pointed out to a deterioration in the urban environment coinciding with the loss of vegetation, mainly in terms of domestic sewage pollution and erosion. We present for the first time an estimate of the vegetation loss for Maranhão Island, which contribute to the knowledge of Atlantic Forest deforestation, specifically the restinga vegetation that is yet poorly studied.

1. Introduction

Coastal zones are transitional sites where the landmass, the sea and the atmosphere interact (Leewis et al., 2012). These zones are valuable environments for humankind and have been used since ancient times for human settlements, harbours, mining and the gathering of natural resources. Moreover, historically, coasts are of cultural and religious importance, recreation and sightseeing (Thompson and Schlacher, 2008; Defeo et al., 2009). Coasts are among the most productive ecosystems, providing proportionally more services and goods for humans than other ecosystems, even those that cover greater areas (Millennium Ecosystem Assessment, 2005). These services include coastal protection, erosion control, water purification, carbon sequestration, provision of natural resources, and biodiversity maintenance (Barbier et al., 2011; Taylor et al., 2015). Coastal vegetation is a biologically productive component of coastal ecosystems and plays an important role in their ecology (Feagin et al., 2005; Nicholls and Cazenave, 2010; Martins et al., 2013). However, anthropogenic uses of coastal zones are jeopardizing these natural habitats (Neumann et al., 2015; Feist and Levin, 2016) and causing loss of their vegetatio..

The great economic value of coastal zones has resulted in settlement of their urban centres and rapid expansion of anthropogenic activities. Consequently, at present, c.a. 50% of the world's population (3.7 billion inhabitants) live within 100 km of a coast, which only represent less than 20% of all land (United Nations Environment Program-UNEP, 2016). In the tropics, about 1.36 billion people live on the coast (Nicholls et al., 2007; Sale et al., 2014). Climate change is one of the main challenges faced by humans and coastal human populations are particularly vulnerable to events of coastal erosion and sea level rise promoted by increased global temperatures. There is evidence that the deforestation of rainforests could influence climate at local, regional and global scales, with negative consequences for agricultural productivity among other impacts (Lawrence and Vandecar, 2015). Deforestation and degradation of vegetation represent a significant proportion (6–17%) of the anthropogenic CO_2 emissions contributing to global warming, mostly from tropical vegetation (Seto et al., 2012). In Brazil, uncontrolled occupation of coastal zones since the country's discovery by Europeans has promoted considerable loss of vegetative cover, particularly of the Atlantic Forest (Tabarelli et al., 2010; Lapola et al., 2014), of which only between 12 and 16% of the original cover remained by 2010 (Ribeiro et al., 2009).

Considering the increasing rate of urbanization and environmental

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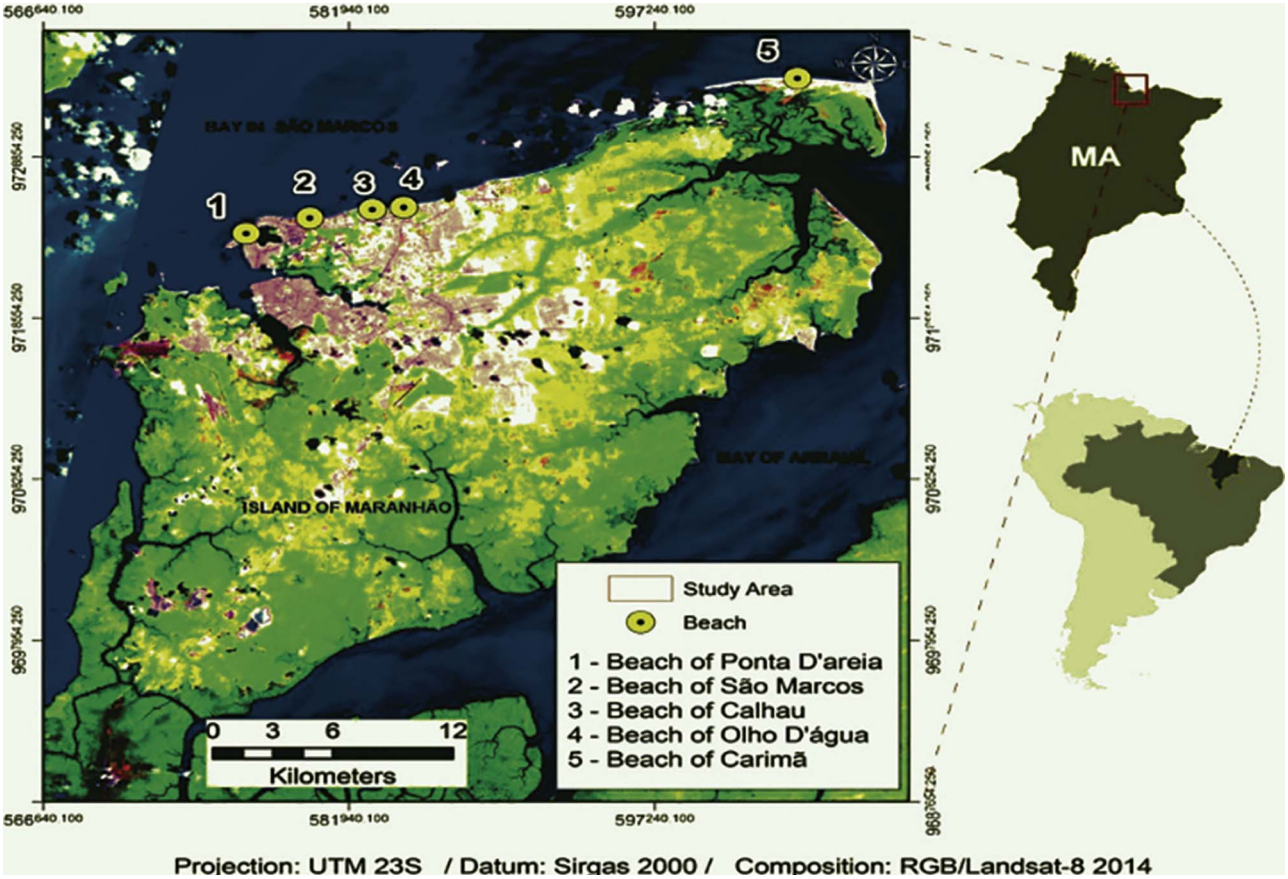

Fig. 1. Map of the study area with the location of sampling sites.

degradation, it is important to quantify the present state of degradation and to identify its consequences to establish solutions. To get an environmental baseline, mapping can provide information on vegetation cover that is crucial for protection and restoration programs (Xie et al., 2008; Lai et al., 2017). Among mapping techniques, satellite imaging is a powerful tool to understand the dynamics of loss of vegetation cover since it provides both spatial and multi-temporal analysis. Thus, processing of remotely sensed images is very useful for mapping a territory and for the management of risks and problems (Saatchi et al., 2001). The increasing use of these technologies is driven by the availability of several approaches and the possibility of rapid and efficient production of accurate results. Among other applications, remote sensing has been used to map and understand changes in spatial dynamics due to natural disasters and anthropogenic activities (Dahdouh-Guebas, 2002; Heuman, 2011; Nandy and Kushwaha, 2010).

Considerable urbanization and population increase have been observed on Maranhão Island over the last 20 years as a consequence of industrial projects and growing tourism. The island, located in an ecotone (a transition zone between two ecosystems), is considered to have high plant biodiversity. Anthropogenic pressures threaten the island's environment, leading to changes in geomorphology, hydrology, and sedimentary processes. An analysis of the processes related to loss of vegetation cover on the island could guide stakeholders and decision-makers in future planning and highlight the current environmental situation to citizens. Moreover, research into land alteration is crucial to understanding global environmental change (Turner et al., 2007) and case studies such as this one are essential to comprehending landscape dynamics (Santana-Cordero et al., 2017).

This study aims to analyse the changes in coastal vegetation cover of Maranhão Island, Northern Brazil, in light of urbanization over the last 20 years by means of geoprocessing and remote sensing imagery.

2. Methods

2.1. Study area

Maranhão Island, also known as São Luís Island, located in Maranhão State, is part of the Amazonian sector of the northern Brazilian coastline. This sector represents ca. 35% of the Brazilian coastline and is characterized by low relief, a broad coastal plain and a wide neighbouring continental shelf (Szlafsztein, 2012). The coastline of Maranhão State extends along a transitional zone between the tide-dominated Amazon-Pará coast of the North and the wind-dominated coast of Ceará State in the South. The coastline can be divided into Western, Central and Eastern sectors. The Central sector corresponds to Maranhão Gulf, wherein Maranhão Island is located (Pereira et al., 2016). There are 144 beaches distributed along the 490 Km of the Maranhão Gulf coastline, of which 60 are on Maranhão Island. The beaches are dissipative or ultradissipative (*sensu* Short, 2006), tide-dominated and primarily composed of fine quartz sands. The tidal regime is semidiurnal, with an extreme high water spring tide of approximately 7.0 m and a high neap tide of about 2.5 m. The local climate presents two well-defined seasons; a rainy season from January to June, and a dry season from July to December. Annual precipitation is in the order of 2200 mm. Mean air temperature is 27 °C, with no marked differences across the year (Pereira et al., 2016; INMET, 2016).

According to Freire and Monteiro (1993), Maranhão Island is located in a transition zone between the Amazon and Northeast vegetation. This transitional feature results in a rich local flora of about 260 species belonging to 78 families, the most frequent being the Fabaceae, Mimosaceae, Caesapiniaceae, Myrtaceae, Poaceae and Cyperaceae. Recently, Serra et al. (2016) reported 19 new species for the local vegetation. The herbaceous, shrub and tree vegetation that occur near the littoral zone and occupy the coastal sandy soils, such as the foreshore,