Research Article

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Anthropogenic environmental pressures in urban conservation units: a case study in Belém, Brazilian eastern Amazon

Abstract

Over 70% of the Amazon inhabitants live in cities. Moreover, the contest between urban and green areas is historically known. In this scenario, the green areas in the Eastern Amazon cities are now beneath constant pressure and some of its ecosystem services can be reduced because of environmental stress. Therefore, this study aimed to investigate environmental stressors in two urban conservation units in the Brazilian Eastern Amazon. To understand how the urbanisation affected both the eutrophication process and forest resilience in the study area, we investigated the literature about the urban sprawl in Belém city and analysed, through remote sensing techniques, the responses for vegetation and built-up indices in the last 30 years. The results showed that the city expansion had not considered sustainable criteria, which ultimately intensified the anthropic eutrophication of the Bolonha Lake. Despite anthropogenic and climate pressures in the last decades over the green areas of Belém, the forest within the park showed no signal of reduced resilience. Lastly, joint efforts are necessary to improve wastewater treatment in the Metropolitan Region of Belém, so the water quality of the reservoirs improve, and its macrophytes blooming reduce gradually.

Keywords: utinga state park, urban sprawl, eutrophication, forest resilience, remote sensing

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Vítor Abner Borges Dutra,[1] Paulo Amador Tavares,[2] Aline Maria Meiguins de Lima,[3] Hebe Morganne Campos Ribeiro[4]

[1]PhD/Doctoral Student in Environmental Sciences, Postgraduate Program in Environmental Sciences, Federal University of Pará (UFPA), Geosciences Institute – Federal University of Pará, Augusto Corrêa Street, 01 – Guamá. 66075-110, Belém, Pará, Brazil

[2]PhD/Doctoral Student in Environmental Sciences, Postgraduate Program in Environmental Sciences, Geosciences Institute – Federal University of Pará (UFPA), Augusto Corrêa Street, 01 – Guamá. 66075-110, Belém, Pará, Brazil

[3]PhD in Sustainable Development of the Humid Tropic, Professor at the Postgraduate Program in Environmental Sciences, Federal University of Pará (UFPA), Augusto Corrêa Street, 01 – Guamá. 66075-110, Belém, Pará, Brazil

[4]PhD in Electrical Engineering, Professor at the Postgraduate Program in Environmental Sciences, State University of Pará (UEPA), Doctor Enéas Pinheiro Street, 2626 – Marco. 66095-015, Belém, Pará, Brazil

Correspondence: Vítor Abner Borges DUTRA, PhD/Doctoral Student in Environmental Sciences, Postgraduate Program in Environmental Sciences, Federal University of Pará (UFPA), Geosciences Institute – Federal University of Pará, Augusto Corrêa Street, 01 – Guamá. 66075-110, Belém, Pará, Brazil, Tel +55 091 981764026,
Email abner_dutra_@hotmail.com, vitor.druidaum@gmail.com

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Introduction

The urbanisation is a complex socio-economic process that transforms the built environment, converting formerly rural into urban settlements, while also shifting the spatial distribution of a population from rural to urban areas. It includes changes in dominant occupations, lifestyle, culture and behaviour, and thus alters the demographic and social structure of both urban and rural areas.[1] According to Dye[2] urbanisation has positive and negative impacts. The first one being the economic growth and development, along with a range of beneficial social outcomes. The second one comprises the increased crowd, pollution and stress compared to rural areas. Furthermore, 55% of the world population was living in urban areas in 2018, and by 2050, 68% of the world's population is projected to be urban.[1]

Given the background, the Amazon counts with over 70% of its inhabitants living in cities.[3] Moreover, the Eastern Amazon comprises the last portion of the Amazon Basin; this estuary comprises river deltas, is a hotspot for human development, and has been under continuous pressure resulted from anthropogenic activities in the last centuries.[4] The human occupation in these areas was usually dispersed and scattered across the forest, dependent on river accessibility and the possibility of extractive activities.[2] Currently, the Amazon estuary is one of Brazil's last frontiers of development supported by the Brazilian government and is usually seen as a land of great opportunities for those pursuing new enterprises.[5,6]

In the framework of urbanisation, the city of Belém, Pará, stands out as being the biggest city in the Amazon delta and the second largest in Amazon. The often called "capital of the Amazon" also clusters up with six more municipalities (Ananindeua, Benevides, Castanhal, Marituba, Santa Bárbara do Pará, and Santa Izabel do Pará),[7] what originates the Metropolitan Region of Belém, comprising almost 2.5 million dwellers and being the major metropolitan region in the Eastern Amazon.

The competition for space in urban areas means smaller areas for nature, reducing the experience along with the natural world and, therefore, resulting in a reduced knowledge of (and support for) environmental issues.[8] In this sense, the Ecosystem Services (ES), such as disturbance regulation, water regulation and supply, recreation and cultural activities[9] are under constant pressure in urban areas.[10] Well-managed urbanisation can help maximise the benefits of agglomeration while minimising environmental degradation.[1] Therefore, it is fundamental not only to have green spaces in the cities but to manage them following sustainable criteria, such as the Sustainable Development Goals 11 (sustainable cities and communities) and 15 (life on land).[11]

Considering that green spaces are under continuous anthropogenic pressure in the cities (including the Amazon ones) and need to endure environmental disturbances, it is crucial to define both forest resilience and stability. The resilience determines the persistence of relationships within a system and is a measure of the ability of these systems to absorb changes of state variables, driving variables, and parameters, and yet persist (i.e., part of the ecosystem does not become extinct rapidly). Stability, on another note, is the ability of a system to return to an equilibrium state after a temporary disturbance (i.e., the more rapidly it returns, and with the least fluctuation, the more stable it is).[12] In this scenario, we opted for the resilience approach to investigate the environmental stress in two green areas within the Metropolitan Region of Belém. Despite forest resilience being considered a trendy environmental policy goal, it is still a challenging concept for land managers to interpret from a practical perspective.[13,14]

In the context of water regulation and supply in urban areas, one commonly noticed modification caused due to the urbanisation process is the increase of eutrophication in lentic water environments, such as reservoirs for public water supply. In these aquatic environments, the algae naturally expand its area of occupation depending on the availability of nitrogen, phosphorus, carbon dioxide and other substances resulted from the organic decomposition.[15] However, this phenomenon can be turned into an uncontrolled process, considering that the excessive release of nutrients inside the water ultimately results in the growth of water vegetation (also called macrophytes) inside and on top of the reservoir.[16] In this situation, the stated process receives another denomination: anthropic (or cultural) eutrophication, in which the natural environment characteristics are altered, affecting the multiple uses of water and consequently the ES provided by it, such as public water supply and preservation of the aquatic life.[16,17] Murphy et al.[18] argue that human beings have been influencing the global movement of macrophyte species and impacting inland aquatic habitats, and this need to be assessed considering its specificities, location, and intensity worldwide.

Some of the existing technological alternatives to monitor earth's natural areas are the Remote Sensing (RS) data and techniques.[19,20] Among the RS possibilities applications for ecological and urban purposes, the Land Use and Land Cover (LULC) change mapping[21] and the execution of radiometric indices to monitor vegetation health area are some of the most common possibilities.[22] In the last few decades, open access RS data had made the number of its applications increase.[23] For instance, some Amazon level works had been done in order to understand both its LULC[24] and the forest resilience throughout vegetation indices.[25] It is essential that methods and data quality for each study area are selected with transparency and according to the specificities of each region.[26]

In this sense, the study aimed to investigate environmental stressors in two urban conservation units in the Brazilian Eastern Amazon, specifically in the Metropolitan Region of Belém. To achieve this, we made a historical analysis, via RS, of three environmental aspects that are being altered in these green areas. Therefore, this research explores three objectives to i) investigate the urban sprawl process toward the Utinga State Park Conservation Unit; ii) interpret the water vegetation growth dynamics in the Bolonha Lake over the last 30 years; and iii) analyse the forest resilience in the study area.

Material and methods

Study area

The city of Belém is in the Eastern Amazon, State of Pará, Brazil. The city has a population of approximately 1,485,732 inhabitants, living in a total area of 1059 km^2.[27] In Figure 1, we present our study area and where each of the conservation units analysed is located.

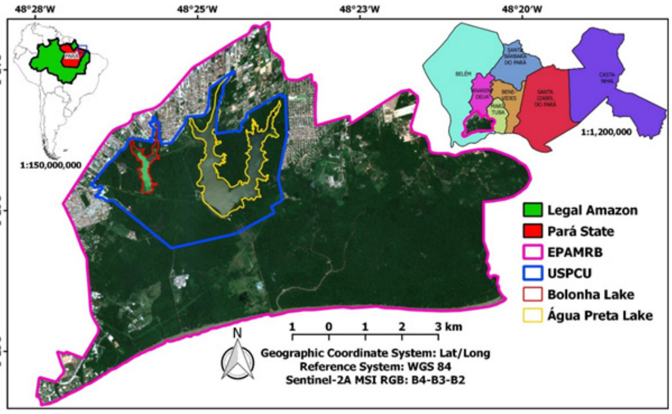

Figure 1 Map of the study area showing the geographic location of the Environmental Protection Area of the Metropolitan Region of Belém (EPAMRB), Utinga State Park Conservation Unit (USPCU) and both Bolonha and Água Preta Lakes. The coloured municipalities of the Metropolitan Region of Belém are supplied by the water of both lakes.

The Köppen-Geiger classification of Belém is Af, i.e., the climate is equatorial with a fully humid precipitation pattern.[28,29] The two main occurrences of vegetation fragments in the city are the Upland (or Mainland) and Floodplain Forests.[30] Their Brazilian phytophysiognomies classifications are a subgroup of Dense Ombrophilous Forests, called *Terra Firme* and *Várzea* (or *Inundável de Igapó*), respectively.[31]

The city is subdivided into Urban and Natural Environment Macrozones. The first one corresponds to urbanised areas, located predominantly in the continental portion of the city. The second one prioritises the preservation, protection, and recovery of natural resources in the municipality of Belém.[32]

The Natural Environment Macrozone is subdivided into three major areas. Nonetheless, we chose only the first zone, which includes the Utinga State Park Conservation Unit (USPCU) and the Environmental Protection Area of the Metropolitan Region of Belém (EPAMRB). Both USPCU and EPAMRB areas are essential for the public water supply of the city and the conservation of the remaining Amazon rich fauna and flora. However, the unorganised urban growth and severe environmental pollution are increasing threats for these areas.[33]

Utinga state park conservation unit

In 1993, the Pará State Government created the USPCU, whose aim is to secure public water supply through the management and recovery of degraded areas around both Bolonha and Água Preta Lakes. The total area of the USPCU is 1,393.088 ha, and its lakes handle up to 63% of the public water supply of the Metropolitan Region of Belém.[33]

The Brazilian Law classifies the USPCU as Conservation Unit of Integral Protection, which implies in the maintenance of the ecosystems free from the human interference, granted only the indirect use of the natural resources in the area.[34] Some of those indirect uses are the leisure to the community, the development of scientific research, cultural and educational activities, tourism, recreation and conservation of the fauna and flora.[33]

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Environmental protection area of the metropolitan region of belém

The damping zone around the USPCU is the EPAMRB. With 5,653.81 ha, this area is classified by the Brazilian Law as Conservation Unit of Sustainable Use, i.e., it has the compatibilisation of nature conservancy with the sustainable use of a portion of its natural resources.[34] One of the main objectives of EPAMRB is to ensure the land use order based on ecological and urbanistic criteria.[35]

Data acquisition

We obtained four optical satellite scenes and one digital elevation data (Table 1). Regarding the satellite scenes, three of them were Landsat 5 Thematic Mapper (L-5 TM), and the last one was a Sentinel-2 Multispectral Instrument (S-2 MSI). The L-5 TM data were acquired in surface reflectance level from the EarthExplorer platform of the United States Geological Survey, and the S-2 MSI data were acquired in the top of atmosphere level from the Copernicus Open Access Hub platform of the European Space Agency (ESA).

Table 1 Satellite data acquired for this study

Sensor Acronym	Sensor Type	Acquisition Date	Band Information	Spatial Resolution (m)
L-5 TM	Optical	6/7/1988	B3 – Red (660 nm)	30
		2/7/1998	B4 – NIR (830 nm)	30
		13/07/2008	B5 – SWIR (1650 nm)	30
S-2A MSI	Optical	14/08/2018	B4 – Red (665 nm)	10
			B8 – NIR (842 nm)	10
			B11 – SWIR (1610 nm)	20
SRTM	C-Band Radar	Feb-00	DEM	30

The Shuttle Radar Topography Mission's (SRTM) 1 arc-second Digital Elevation Model (DEM) was obtained directly from the software Sentinel Application Platform (SNAP) 6.0, through the function Add Elevation Band with bilinear interpolation resampling method. The projection of the SRTM DEM was WGS 84 Zone 22S to match both the L-5 TM and S-2 MSI data.

Data processing

The flowchart in Figure 2 represents the data processing steps adopted for this research. The first step implemented was the conversion of the data to surface reflectance, which is an essential step to apply to satellite data to retrieve trustworthy LULC information.[36] The seasonal variability of the main atmospheric constituents of the Amazon represents a challenge for optical RS, which manifests intense cloudiness regime, a high aerosol burden in the dry season and seasonal concentration of water vapour and ozone.[37]

The Sen2Cor atmospheric correction processor was developed by Telespazio VEGA Deutschland GmbH on behalf of ESA[38] and showed plausible statistical results compared to other atmospheric correction processors.[39] Thus, Sen2Cor v2.5.5 algorithm was applied to the S-2A Level-1C Top-Of-Atmosphere (TOA) data to achieve the Level-2A Bottom-Of-Atmosphere (BOA) reflectance product. Moreover, the L-5 TM data acquired were already available at BOA level.

After the atmospheric correction, the S-2 L2A data was resampled to 10 m spatial resolution through SNAP's S2 Geometric Resampling algorithm. The parameters used for interpolation and aggregation of the pixels' values were the bilinear upsampling and mean downsampling methods, respectively.

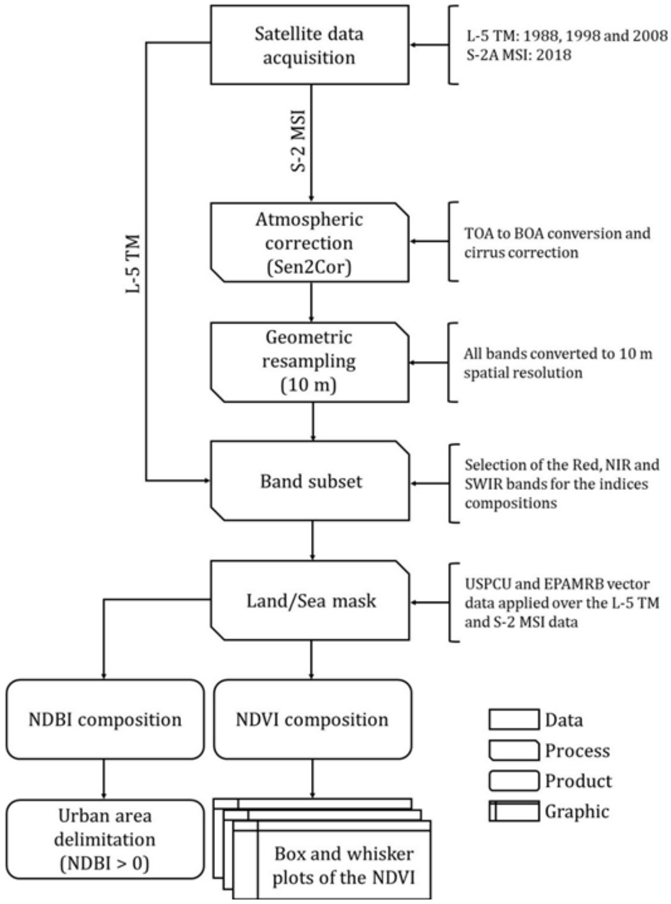

Figure 2 Process flowchart of the data analysis.

Vegetation classes and radiometric indices

Vegetation indices are designed to enhance the contribution of vegetation properties and allow reliable spatiotemporal comparisons of terrestrial photosynthetic activity and canopy structural variations.[40] In this sense, we evaluated four different classes for vegetation, considering the most prominent features in the study area, as follows: Water Vegetation (WVE), Mainland Forest (MLF), Igapó Forest (IGF) and Grassland (GSL) (Table 2).

In one previous analysis in the study area, Tavares, Dutra, et al.,[41] found that the Normalised Difference Vegetation Index (NDVI) could dissociate different types of vegetation better than other straight vegetation indices, such as the Normalised Difference Water Index (NDWI). For this reason, we adopted the NDVI to interpret the vegetation classes. The NDVI was produced through band algebra using the near-infrared (NIR) and the red bands of each satellite to create a quantitative measurement of vegetation conditions.[42] The expression is described in Equation 1.

$$NDV1 = \frac{\rho NIR - \rho \mathrm{Re}d}{\rho NIR + \rho \mathrm{Re}d} \quad (1)$$

We used SNAP's Pin Manager Tool to select 20 random pixel points for each vegetation class, using the key of interpretation in Table 2 as a base to distinguish each one of them. After that, we analysed the behaviour of each pixel for each year. It was ensured, when possible, that those sampled pixels were taken from across the entire scene to avoid any bias.

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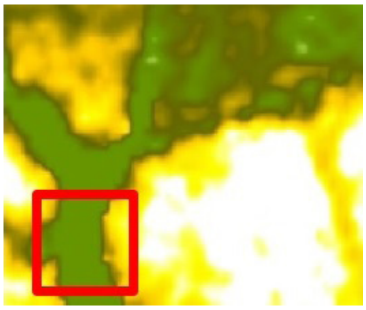
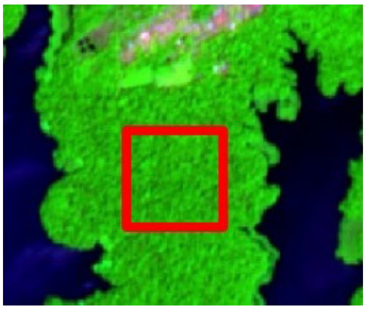
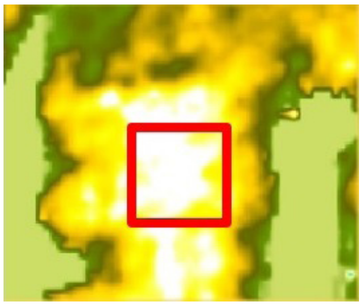
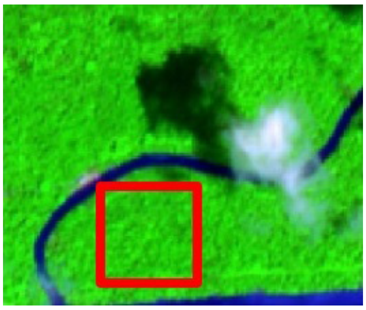
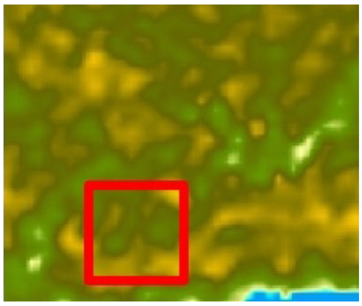
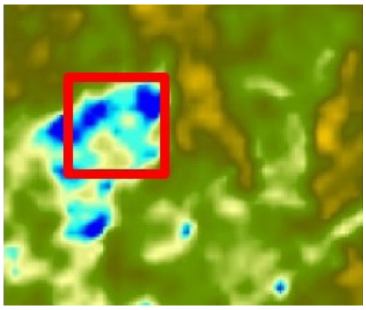
Table 2 Key of interpretation of the different vegetation classes (highlighted in red) in the study area

	S-2 MSI (B4; B3; B2)	S-2 MSI (B12; B8; B4)	SRTM DEM (C-Band Radar)
Water Vegetation (WVE)			
Mainland Forest (MLF)			
Igapó Forest (IGF)			
Grassland (GSL)			

Additionally, we applied the Normalised Difference Built-up Index (NDBI)[43] to the data to retrieve the urban sprawl values between 1988 and 2018. The NDBI combines the shortwave infrared (SWIR) and NIR bands of the satellite to retrieve pixel values of the built-up areas in the scene (Equation 2).

$$NDBI = \frac{\rho SWIR - \rho NIR}{\rho SWIR + \rho NIR} \qquad (2)$$

From the NDBI results, we select the values greater than 0, which should describe urban occupation, as they are supposed to exclude both the chlorophyll and the water spectral responses.[43,44] However, the amount of sediment in the Amazon waters can make it mistakenly respond as constructed areas.[45] For example, in the study of Trindade[46] the waters around Santarém city were confused with the built-up areas of the town. For this reason, after we found the values of NDBI greater than 0, we manually corrected the results to represent the urban area at our study site.

Results

Figure 3 illustrates the NDVI visual representation for the years 1988 (L-5 TM), 1998 (L-5 TM), 2008 (L-5 TM) and 2018 (S-2 MSI). Some variations in the NDVI results between L-5 TM and S-2 MSI may occur because of their different central wavelength values (as displayed in Table 1). Another important factor to be considered, in terms of vegetation and urban area change analysis, is the difference in the spatial resolutions between L-5 TM and S-2 MSI satellites. Despite these disparities, the urban expansion towards the USPCU is noteworthy. Another significant detectable stressor in the conservation unit is the macrophytes bloom inside the Bolonha Lake. In the 2018 scene, the lake was entirely covered by WVE, which is why the area was recognised by the NDVI.

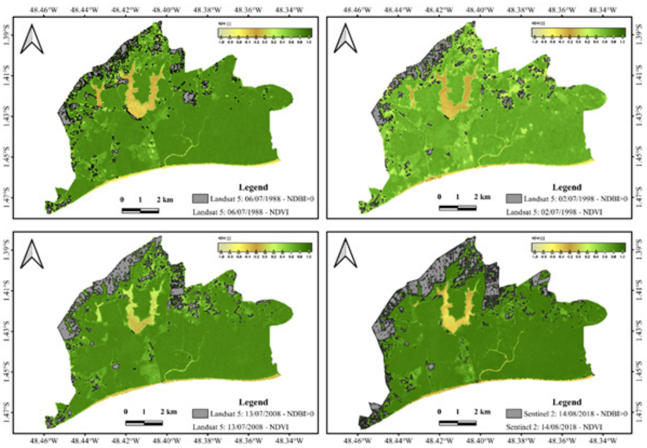


Figure 3 Normalised Difference Vegetation Index (NDVI) variation (-1 to 1) for the vegetation classes and Normalised Difference Built-up Index (NDBI) variation (> 0) for the urban area in the last 30 years in the study area. It is noticeable the urban growth toward the Utinga State Park Conservation Unit (USPCU) in the period and the aquatic macrophytes coverage of the Bolonha Lake in 2018 (note that it becomes entirely green in the last panel).

Regarding the different types of vegetation analysed, we identified no significant variation in the inland's NDVI response values, such as MLF and IGF (Figure 4). Nevertheless, a significant difference was noted in the WVE values. Although we identified NDVI values greater than 0 within Bolonha Lake since 1988 (which means positive response to chlorophyll), in none of the years the values were high, and constant, as in 2018. From this perspective, it is possible that a water pollutant stressor may be acting in this lake and might be intensified in the last decade. Also, it is important to highlight that there were chlorophyll responses inside the lake. This fact, by itself, already indicates that a certain amount of organic matter is being dumped into the lake and is causing algae to proliferate inside of it.

In Figure 3, it is possible to identify that the urban area is increasing inside the EPAMRB toward the USPCU. The data extracted from the NDBI calculation, when the results were greater than 0, shows that the urban area increased from 464.42 to 905.12 ha between 1988 and 2018 (Table 3). This result shows that the occupation of these natural areas almost doubled in the last 30 years. In 1998, the amount of clouds in the L-5 TM scene was worthy of attention, which might be one reason why, in this year alone, the urban area identified was smaller than in the previous decade.

Table 3 The urban area identified in the study site from 1988 to 2018, considering NDBI > 0

Year	1988	1998	2008	2018
Urban area (ha)	464.42	436.48	665.63	905.12

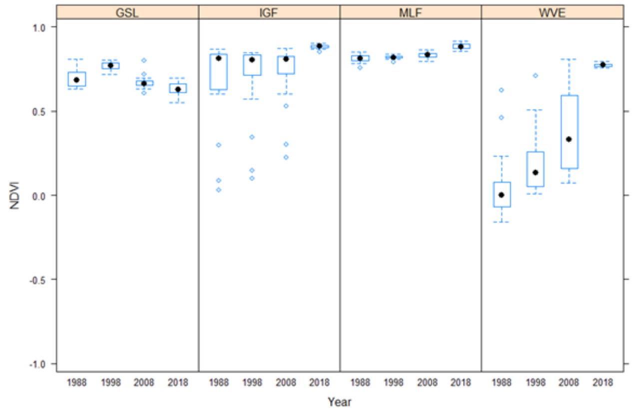


Figure 4 Box and whisker plots of the NDVI showing values for each (n = 20) vegetation class in 30 years (1988-2018). The WVE's NDVI values increased significantly in the period, pointing the worrisome consequence of pollution of the Bolonha Lake.

Discussion

Urban sprawl

In contrast with our results for the urban area among the selected years, Gutierrez et al.[47] found a total urban area of 1,950 ha in 2015 for the USPCU and EPAMRB. However, during their study, they used the old limits of these conservation units, in which they covered a higher portion of the urban areas of Belém and Ananindeua municipalities. Furthermore, these authors used a different type of LULC mapping method to define their study area.

To comprehend how this urban expansion occurred around and toward the USPCU, we assessed the historical occupation process of the city. Belém, according to Ponte[48] until the very end of the 19th century, was still profoundly bound to the hydrography in its economic activities, public equipment and means of territorialisation. This relationship denotes the connection of the city to the water, which is often called a waterfront model. Notwithstanding, in the mid to late 20th century, the urban growth of Belém has been influenced by an urban remodel, based on the European and North American strategy of consuming (street lighting, streetcar, telephone, water pipes, machines, among others). Additionally, the hygienist logic has imposed changes in the city infrastructure and overall urbanisation, where law established, in practical terms, the rationalisation of the urban layout and the suppression of water meanders of creek beds and small urban rivers, to accelerate the flow of wastewater away from the city.

Corroborating the aforementioned process, the Pará State Government signed in 1945 a contract with a private company to draw up a remodelling plan for the Belém water supply services. The constructions went from 1945 to 1951, including a pump house for the Utinga area. Afterwards, in 1966, the conclusion of the BR-316 highway construction quickly increased the human occupation around the Bolonha and Água Preta Lakes. This lead to various infrastructure works in the area to secure the public water supply and, in the '80s, both lakes were interconnected to ensure the water supply for the entire Metropolitan Region of Belém.[33] From the late '80s until nowadays, the local environmental laws have been trying to mitigate the effects of urban sprawl towards the USPCU.

Regardless of the environmental law effort, the occupation towards the park almost doubled in the last three decades, as seen in Table 3, which implies the higher pressure over the Bolonha and Água Preta

Lakes and their surrounding vegetations (mainly MLF). One reason for part of this urban sprawl within the conservation unit is the conflict over governance of parts of the territory on the border between Belém and Ananindeua.[49] Moreover, the Pará State Government started in 2013 a series of road constructions and interventions to improve both the traffic in the city and integrating the Metropolitan Region of Belém. Controversially, they allowed the construction of a bridge over the Bolonha Lake, going against the integral environmental protection principle of the USPCU. The infrastructure works of the bridge occurred between 2013 and 2015, upon the project entitled *Ação Metrópole*. The effects of this infrastructure work in the urban sprawl towards the USPCU are yet to be seen.

In this framework, Cardoso, Sobrinho, & Vasconcellos[50] argue that the environmental management of urban parks depends on land use planning and its surroundings. They assert that, in areas with an unorganised territory, it is possible to increase the pressure over the LULC of the green areas, which ultimately causes the depredation of its natural resources (and consequently, its ES). Some worrisome consequences of this unorganised urbanisation are the spread of WVE inside and on top of the reservoirs,[51] the modification of the forest resilience characteristics in the green areas,[25] and the increased effect of urban heat island.[52] Therefore, more investment in the environmental management of the green areas within the cities is required. For example, Baró et al.[53] investigated five European cities, and the research results revealed mismatches between ES supply and demand in their study area, suggesting that further protection and restoration of urban green infrastructure is needed if ES are to play a more relevant role in meeting environmental quality standards and policy goals in cities.

Water vegetation proliferation

As displayed in Figure 3, the WVE bloom happened throughout the last 30 years. In 2018, the values of NDVI for WVE were higher than GSL (Figure 4), showing a high photosynthetic activity of the macrophytes. Furthermore, according to the multitemporal analysis of Cardoso, Monteiro, Venturieri, & Campos[54] over the USPCU between 1984 and 2008, this happened sometime between 2004 and 2006, where the WVE class was detected in the L-5 scenes. However, in the year of 2008, we did not identify a high proliferation of macrophytes, this may have occurred because of a manual removal required by the local managers of the USPCU as a palliative strategy to reduce the impacts of this vegetation in the Bolonha Lake.[55]

Vasconcelos & Souza[56] presented in their paper that the water quality parameters of both Bolonha and Água Preta Lakes were above the recommended for a water supply lake in 2011. These elevated results can explain why WVE proliferation is high in these lakes. Another evidence of high chlorophyll values in these reservoirs was exposed by Dutra, Tavares, Trindade et al.[57] in an estimate RS analysis of the chlorophyll in the Água Preta Lake. In their paper, there was found a high concentration of chlorophyll in two parts the Água Preta Lake: the Guamá River pickup point and the adduction point for the Bolonha Lake. These pieces of evidence show that the Água Preta Lake is eutrophic but is not yet in the same state of WVE proliferation of the Bolonha Lake due to its coverage area and water flows characteristics. Comparatively, the Água Preta Lake total area is six times bigger than Bolonha Lake, being 268.67 and 45.06 ha, respectively. Thus, Água Preta Lake has a higher self-purging capacity than Bolonha Lake.

To better comprehend the state of degradation of these lakes, it is essential to appraise the wastewater treatment situation in Belém. According to the National System of Information about Sanitation, only 2.67% of the domestic sewage was being treated in the city until 2016.[58] This is one of the worst values between the 100 biggest cities in Brazil. As stated in the Management Plan of the USPCU, until 2012, there were at least 21 effluent release points inside Bolonha and Água Preta Lakes. The origin of these wastewaters is the urban areas in the EPAMRB around the USPCU.[33]

The estimated polluting load dumped daily inside both lakes, until 2012, was 2.2 tons of Biochemical Oxygen Demand (2.2 tons of BOD/day), being 1.16 and 1.03 for Bolonha and Água Preta Lake, respectively.[33] The dumping of wastewater inside the lakes, with no treatment, is one of the main stressors in the USPCU.

The aforementioned anthropic eutrophication affects the spatial distribution of WVE, increasing its growth and proliferation.[59,60] Therefore, this vegetation can be used as a long-term indicator of environmental conditions, especially water quality.[61,62,18,51] For instance, Haas & Ban[63] investigated urban LULC and ES changes in Beijing, China, based on L-5 TM and S-2 MSI data, and concluded that crucial ES, such as waste treatment, noise reduction and global climate regulation were significantly affected by landscape structural changes.

The macrophyte removal has regularly been occurring to improve the water pumping from Bolonha Lake towards the water treatment station to ensure the public water supply of the Metropolitan Region of Belém.[55] However, this is the only palliative method implemented, and it has a continuous cost for the Pará State Government, making it urgent to look forward to reliable solutions for Bolonha Lake.

Forest resilience

In order to identify if the primary vegetation (IGF and MLF) in the study area is losing its resilience, we captured the NDVI results from the 20 points (pixels) per class, described in the methodology (Figure 4). All of our scenes were acquired in average climatic years. Moreover, as mentioned by Anderson et al.[25] our study area is not located within one of the zones most affected by repetitive droughts in the Amazon. However, as mentioned by these authors, the forest resilience in Amazon is being reduced due to recurring droughts, and this is usually noticed in, or close to, years of extreme events, such as the El Niño and La Niña. These events are decreasing their reoccurrence time because of anthropogenic climate-changing activities.[64] In this sense, our results may be explained by two facts: i) we could not find enough L-5 TM scenes to test the hypothesis at the end of the dry and wet seasons in Belém, which is a persistent problem in this sort of historical analysis in the Amazon;[65] and ii) we did not test the hypothesis exhaustively in drought years.

Another difficulty related to forest resilience in the USPCU might be associated with the urban expansion in the buffer zone of the lakes. Historically, Belém has given its natural areas for urban development, and this is noted in areas such as the Cotijuba and Mosqueiro Islands, where some vast green areas have been converted into urban areas in the last 40 years.[66,24] Other natural areas in the city, such as the Gunnar Vingren Ecological Park, highly depend on social participation to ensure its conservation status.[50] Furthermore, the loss of the leading provider of ES in the city of Belém, which, as seen in Carvalho & Szlafsztein[67] work, is already reduced in densely populated areas of the city. McPhearson, Andersson, Elmqvist, & Frantzeskaki[68] study showed that the social-ecological resilience of an urban environment depends on the provision of ES through green areas. The existence of these green areas is also essential to the enhancement of the quality of life of the inhabitants of the city.[69]

Gutierrez et al.[47] who also studied the USPCU and EPAMRB, have noted the reduction of natural forests in the region as well. It is important to note that any anthropic modification in a natural area, in aggregation with the repetitive droughts, can cause uncountable (and unknown) problems in this same area. Some well-known complications are the loss of biodiversity[70] and the increase in tree mortality.[71] These problems are aggravated when these conservation units are the only significant green areas in the continental area of Belém.[72–75]

Conclusion

The urbanisation phenomenon is happening worldwide, and, in the Amazon, it is no different. However, this process occurred in an unorganised and ravenous way in the last decades in the region, and the remaining green areas in the cities are under constant anthropic pressure. For this reason, we investigated environmental stress aspects in two fundamental conservation units within the most populated cluster of cities in the Eastern Amazon, via remote sensing, in the last 30 years. The results showed that the urbanisation process and infrastructure work around USPCU did not consider environmental management criteria; this ultimately affected the aquatic ecosystem of the park, mainly Bolonha Lake. Another finding was that, despite the anthropic and climate pressures, the forest within the park showed no sign of reduced resilience in the period. Lastly, our findings have crucial implications for urban planning and management for the Metropolitan Region of Belém. Considering that the lakes within USPCU are accountable for 63% of water supply for almost 2.5 million urban dwellers in the Eastern Amazon, it is imperative to the local managers, along with academic institution and private initiative, to implement definitive solutions for Bolonha Lake eutrophication and macrophytes bloom. One viable solution is to improve the wastewater treatment in the city of Belém, which percentages are still very low compared to the biggest cities in Brazil.

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Conflicts of interest

The Authors declare no conflict of interest.

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