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Evaluation of changes in vegetation cover and their correlations with the surrounding area through geotechnologies: a case study of Brasília Botanical Garden[1]

Avaliação das alterações da cobertura vegetal e sua correlação com o entorno através de geotecnologias: estudo de caso do Jardim Botânico de Brasília

Evaluación de cambios en la cobertura vegetal y su correlación con el entorno mediante geotecnologías: estudio de caso del Jardín Botánico de Brasília

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Abstract: This study evaluated the phytomass variation in Brasília Botanical Garden (BBG) from 1984 to 2017 and its interaction with the surrounding area. Phytomass quantitative analysis was conducted using 35 images of the LandSat TM/ETM+/OLI series, obtaining the variation of vegetation indexes by Normalized Difference Vegetation Index (NDVI). Vegetation suppression was identified and proved the effectiveness of the preservation of BBG and BBG's Ecological Station (BBGES), adjacent to BBG. It was also observed a higher variation of the NDVI near the edge of contact with the urban grid, which suggests the negative influence of the urbanization process, and the importance of BBGES' proximity to its preservation. Discrepancies between environmental protection and urban land use show the very need to create mechanisms allowing the dialogue between urbanization and the protection of green areas.

Keywords: urban management, vegetation index, remote sensing.

Resumo: Este estudo avaliou a variação da fitomassa no Jardim Botânico de Brasília (BBG) de 1984 a 2017 e a relação interativa com o entorno. A análise quantitativa da fitomassa foi realizada utilizando 35 imagens da série LandSat TM/ETM+/OLI, obtendo-se a variação dos índices de vegetação por diferença normalizada - Índice de Vegetação por Diferença Normalizada (NDVI). Foi identificada a supressão da vegetação no entorno e comprovada a eficácia da preservação do BBG e da Estação Ecológica do BBG (BBGES). Também foi observada uma maior variação do NDVI do BBG próximo à borda de contato com a malha urbana, o que sugere a influência negativa do processo de urbanização e simultaneamente a importância da proximidade do BBGES para a preservação da área do BBG. Discrepâncias entre a proteção ambiental e o uso da terra apontam para a premente necessidade de criar mecanismos de diálogo entre urbanização e proteção de áreas verdes.

Palavras-chave: planejamento urbano, índice de vegetação, sensoriamento remoto.

Resumen: Este estudio evaluó la variación de la fitomasa en el Jardín Botánico de Brasilia (BBG) de 1984 a 2017 y la interacción en el entorno. El análisis cuantitativo de fitomasa se realizó utilizando 35 imágenes de la serie LandSat TM / ETM + / OLI, obteniendo la variación de los índices de vegetación por diferencia normalizada - Índice de Vegetación por Diferencia Normalizada (NDVI). Se identificó la supresión de vegetación en el entorno y se comprobó la efectividad de la preservación de BBG y la Estación Ecológica BBG (BBGES). También hubo una mayor variación en el NDVI de BBG cerca del borde de contacto con la red urbana, lo que sugiere la influencia negativa del proceso de urbanización y simultáneamente la importancia de la proximidad de BBGES para su preservación. Discrepancias entre la protección del medio ambiente y el uso de la tierra apuntan a la necesidad urgente de crear mecanismos de diálogo entre la urbanización y la protección de las áreas verdes.

Palabras clave: gestión urbana, índice de vegetación, teledetección.

INTRODUCTION

Botanical gardens face challenges and opportunities in response to urbanization and climate change (Heywood, 2011), therefore, public management will have to reevaluate their conservation policies for plants currently grown, as changes in climatic conditions will force them to reorient and strengthen their conservation policies and increase its participation in programs for the recovery of critically endangered species. In addition, botanical gardens will face an unprecedented opportunity to develop their role as centers of introduction and play an important role in the evaluation of new germplasm, both from ornamental plants and other economically important plants (Heywood, 2011).

The Botanical Garden of Padova, built Italy in 1545, was considered the first with a modern botanical garden concept, and today there are about 2,500 botanical gardens in the world (Golding et al., 2010; Chen & Sun, 2018). All these botanical gardens together cultivate more than 6 million plant species, representing about 80,000 taxa, or about a quarter of the estimated number of vascular plant species in the world (Jackson, 2001; O'Donnel & Sharrock, 2017; Chen & Sun, 2018). These gardens, therefore, play a central role in the conservation and exploitation of global plant biodiversity (Mounce, Smith & Brockington, 2017), as one of the goals of the Global Plant Conservation Strategy (GSPC) is to maintain 70% of endangered plant species of the world conserved ex situ (Callmander, Schatz & Lowry, 2005; Huang, 2011).

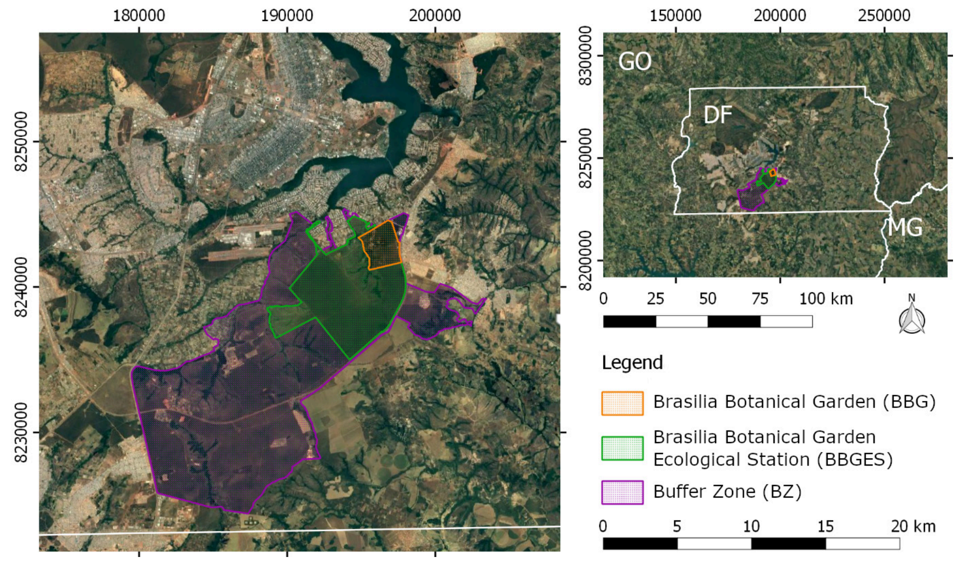
The understanding of existent limitations in the relations among different space-changing modifier agents is essential to reach an effective transformation. The assumption of the current intense and diffuse correlations between the spatial entity and the environment implies recognizing their respective responsibilities. Once assumed this interference, the aim of this study is to show the effect of urbanization on vegetation cover through the Brasilia Botanical Garden (BBG) case study. Therefore, to evaluate its phytomass variation it is indispensable the comprehension of limits and factors that produced it. The analysis of the interaction between BBG and its surroundings made it possible to diagnose their relation. Several botanical gardens are currently created as a strategy to protect the remaining autochthonous vegetation, which sometimes, represents the last natural cover fragments in a context of intense urbanization. The indicators generated results may be useful to feed delineate the discussions regarding about the effectiveness of its preservation. The objectives of this study are to evaluate the phytomass variation of Brasília Botanical Garden (BBG), to analyze BBG's interaction with its surroundings, and to point out aspects that contribute to the discussions regarding the effectiveness of its preservation. The results are useful to feed discussions about the effectiveness of its preservation.

MATERIALS AND METHODS

Study area

Based on technical criteria, the Brazilian Resolution 339/03 (Brasil, 2003) classifies and defines the requirements of botanical gardens in three categories, "A", "B", and "C". These categories observe technical criteria that consider infrastructure, qualifications of the technical staff and researchers, objectives, location, and operational expertise (Brasil, 2003). For the purpose of this study, only the included in category "A" were considered, once this category implies more restrictive requirements (Fig. 1).

Figure 1: Brasília Botanical Garden localization.



Source: QGIS (2018); Superintendência Técnico-Científica (SUTEC, 2018); Distrito Federal (2009a); Instituto Brasileiro de Geografia e Estatística (IBGE, 2018); Google image (2018).

Perimeter Definition

Information regarding the BBG official perimeter was requested to the Technical-Scientific Superintendency. A shapefile containing information about either BBG and Brasília Botanical Garden Ecological Station (BBGES) was sent to the authors. The perimeter used for the change analysis in this study was based on the legislation and were compared with data from BBGES and National Registry of Conservation Units (CNUC) - Cadastro Nacional de Unidades de Conservação - which presented lower precision, but through them, it was possible to identify the expansion area in the year of 1996 (Fig. 2).

Figure 2: Perimeter evolution of BBG (orange), BBGES (green), and BBGES's BZ (purple).

Source: Adapted from CNUC (BRASIL, 2018); SUTEC (2018) (BBG and BBGES limits).

Identification of Protected Units (UCs) surroundings

CNUC was consulted to identify the CUs that were directly connected with BBG and BBGES. Both areas are fully protected by Environmental Preservation Areas (APA) under federal and state administration. Two Areas of Relevant Ecological Interest (ARIE) were identified in the perimeters' surroundings. APAs and ARIEs were classified by the National System of Conservation Units (SNUC - Sistema Nacional de Unidades de Conservação) as areas less restrictive, of Sustainable Use (SU). Only the Botanical Garden's Ecological Station is under Full Protection (FP), a more restrictive UC (Tab. 1).

Table 1: Relation of CUs that include BBG, BBGES and its respective immediate surroundings, its administrative scopes and categorization.

Conservation Unit	BBG	BBGES	Around BBG	Around BBGES	Administrative Sphere	Category
APA Ribeirões do Gama e Cabeça de Veado Basin	X	X	X	X	State	US
APA Planalto Central	X	X	X	X	Federal	US
APA Bacia do Rio São Bartolomeu Basin			X	X	Federal	US
APA Lago Paranoá			X		State	US
ARIE Capetinga/Taquara				X	Federal	US
ARIE Cerradão Biological Reserve			X		State	US
Jardim Botânico Ecological Station	X	X			State	PI

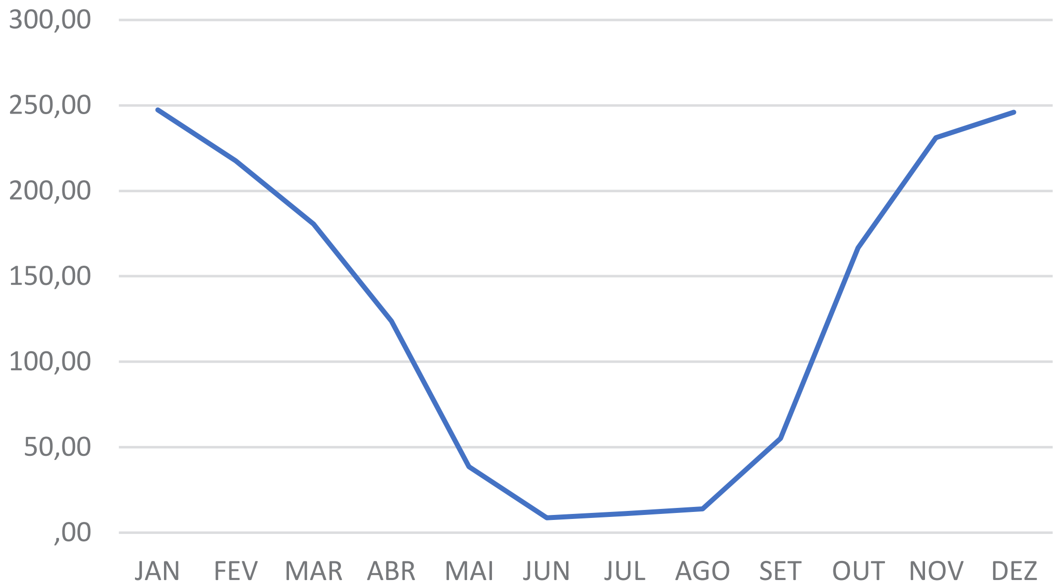
Source: adapted from CNUC (Brasil, 2018).

Criteria to define the temporal frame and image selection

The selection of images for multitemporal compositions using vegetation indexes should be selected at the same annual period, respecting the phenological stage from the local biome. In the dry season, phytophysiognomies present more differentiation, so this choice is determinant for an analysis close to reality since it reduces possible interferences caused by variations in vegetation humidity.

The Instituto Nacional de Meteorologia website (INMET, 2018) was consulted to identify the more favorable period for the selection of images. The collection of information proceeded with data on rainfall, individualized by month. The months that presented lower accumulated rainfall during the period of 1961 to 1990 were June, July, and August (Chart 1).

Chart 1: Monthly accumulated rainfall (mm) of Brasília Station (83377) from 1961 to 1990.



Source: INMET (2018).

This research chose images by Landsat series (Land Remote Sensing Satellite): Landsat 5, Thematic Mapper (TM) sensor; Landsat 7, Enhanced Thematic Mapper Plus (ETM+) sensor; and Landsat 8, Operational Land Imager (OLI) sensor. The spatial resolution of scenes in all sensors is of 30 meters and its temporal resolution is of 16 days, which results in an average of two scenes per month (Paranhos Filho et al., 2016).

The scenes were selected in the electronic address of the United States Geological Survey (USGS)[2], Earth Explorer (US Geological Survey, 2018a), which provides images of the whole globe from different sensors, satellites, and temporal scales. During the period from June to August, between the years 1984 and 2018, in the orbit/point 221/071, it was identified a total of 255 scenes.

The phytophysiognomies analysis of the Botanical Garden and surroundings was based on the variation of vegetation indices by normalized difference – Normalized Difference Vegetation Index (NDVI). This index can be manually calculated, however, USGS provides this material already processed, orthorectified, and with atmospheric correction through the electronic address ESPA (US Geological Survey, 2018b).

From this initial selection, 44 NDVIs were acquired by ESPA of which 9 were considered duplicated. The following analysis filtered the duplicated images to select the ones that could be discarded. One of them still presented clouds, one presented a defect, one had been influenced by the rainfall pattern of the previous month, and six were discarded using the selection criteria of proximity to the second half of July. The total was 35 scenes distributed as follows: 28 from Landsat 5, one from Landsat 7, and six from Landsat 8.

2 https://earthexplorer.usgs.gov

Normalized Difference Vegetation Index (NDVI) and multitemporal composition

To observe the variation in the BBG vegetation cover, was used the NDVI vegetation index. The scenes obtained from ESPA presented values that varies from -10000 to 10000, and this variation was corrected for calculations. The comparative analysis was conducted in annual periods. For multitemporal analysis, the free software QGIS (QGIS Development Team, 2018), a Geographic Information System (GIS) able to process images, was used.

The multitemporal false-color composition was produced in the QGIS' Raster calculator to generate the comparative images among scenes, by simply subtracting the newest from the oldest. The positive values indicate the increase and the negative decrease of NDVI values. The oscillation of values in each scene is of -20000 and 20000.

The option made for visualization was the rendering type "Simple band false-color" with linear interpolation and chromatic variation red-blue (RdBl), in order to distinguish the visualization of annual NDVIs. The value of white was adjusted to zero to explicitly distinguish where there was an increase and decrease. The interval limit of numerical variation was assumed between -5000 and 5000 for visual enhancement. On a scale of 0 (white) there was no increase in vegetation; negative scale (red) loss of vegetation; positive scale (blue) vegetation gain.

RESULTS AND DISCUSSION

Multitemporal analysis and NDVI variation

The comparative variations were systematized considering the years of alteration of BBG's perimeter. Seven multitemporal compositions showed NDVI variation. In this analysis, the focus was on BBG and BBGES. The analysis of BBGES' BZ was limited to its Northeast portion, which includes both institutions. The intervals established were:

- 1984-1985 – Previous situation to the occupation of BBG
- 1985-1987 – BBG first perimeter
- 1987-1992 – BBG perimeter expansion
- 1992-1996 – Dismemberment of BBG and creation of BBGES
- 1996-2009 – BBGES expansion
- 2009-2018 – Approval of the BZ of BBGES
- 1984-2018 – Interval between the oldest scene and the newest scene.

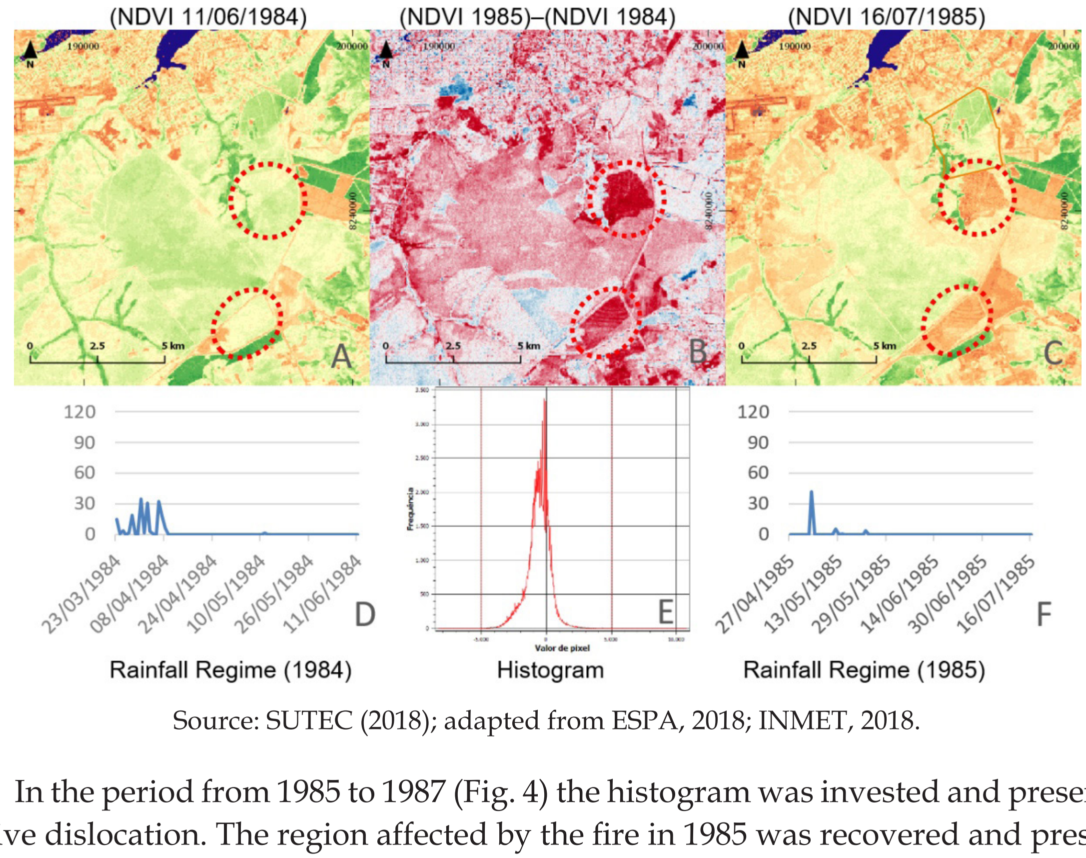
For each of these multitemporal compositions it has been made a cut to evaluate the histogram of the visible portion of plotted image. As the product of the frequency distribution of NDVI values it was possible to observe a gaussian curve. The oscillation at left characterizes a decrease in NDVI values, while at right characterizes an increase.

When the curve presented a variation close to zero, the subtle increase or decrease in NDVI value resulted in a white image, with coloration in tones of light blue and pink, respectively. On the other hand, the image presented intense tones of red and blue when NDVI variation was steeper. In these cases, it was searched to identify the cause of variations.

To assist the reading, the figures were systematized with the presentation of the oldest NDVI (RdYlGn), followed by the multitemporal composition (RdBl) and the newest NDVI (RdYlGn) of the period. Below each of the NDVI, it was inserted a table with the previous rainfall patterns to the scene imaging, to explicit a possible variation occasioned by rainfall. The variation histogram was inserted below the multitemporal compositions.

In the period from 1984 to 1985 (Fig. 3) the histogram curve presented negative dislocation, which indicates a decrease in NDVI values, besides a negative asymmetry due to its intense reduction. In the image's central portion, it is possible to identify a homogeneous decrease. The spot identified it in the BBG surroundings, in the scene from 1985, related to a fire-scar. It is highlighted that this fire did not exceed BBG limits. The area identified in the South portion of the image indicates the presence of activities related to agriculture, which justifies the significant variation.

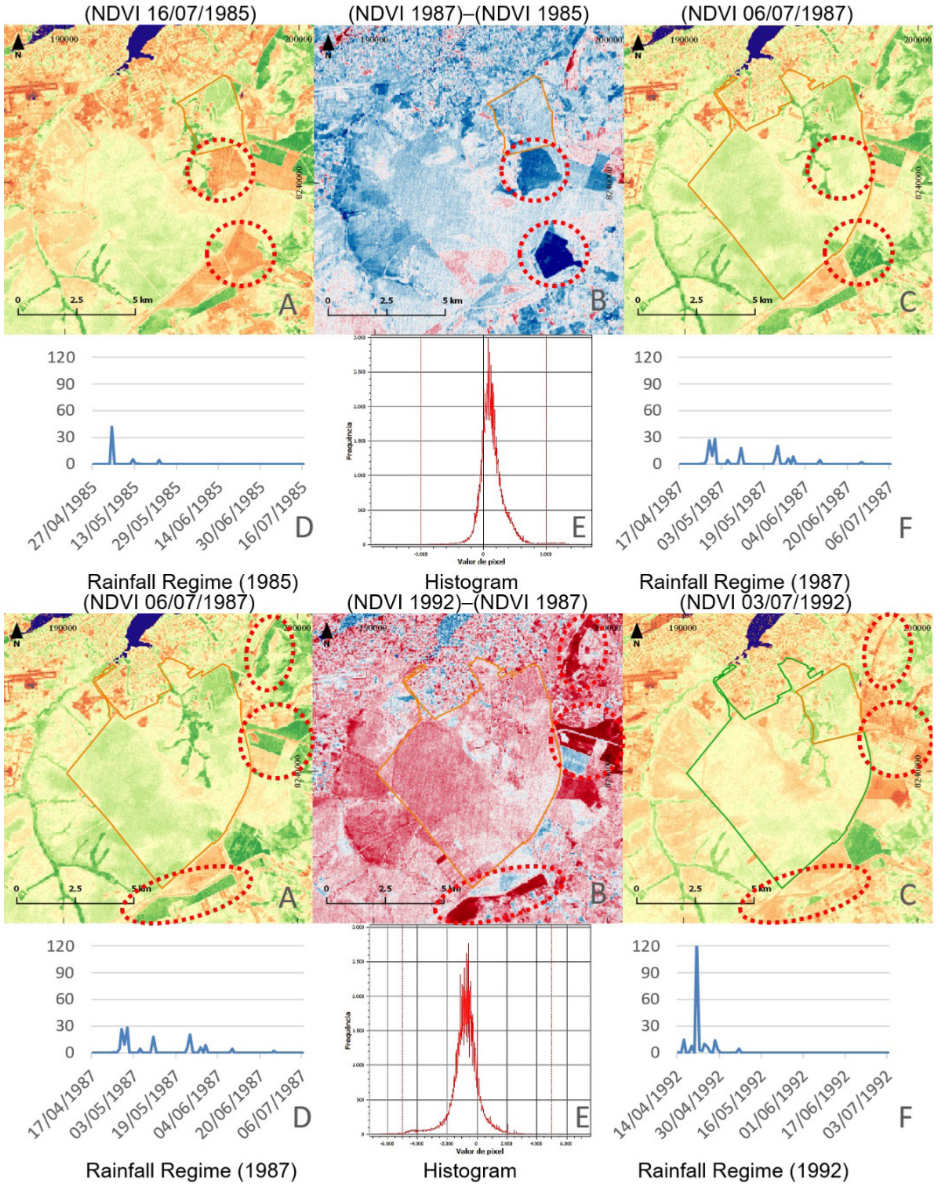
Figure 3: NDVI variation in the period from 1984 to 1985 (B) and NDVI from the respective years (A and C). Rainfall patterns were previous to the scene date (D and F) and histogram of the visible excerpt in the image (E).



Source: SUTEC (2018); adapted from ESPA, 2018; INMET, 2018.

In the period from 1985 to 1987 (Fig. 4) the histogram was invested and presented a positive dislocation. The region affected by the fire in 1985 was recovered and presented a spectral response similar to BBG's west and South sectors. Southeast of BBG is the place identified as "Zone A - Restricted" (Distrito Federal, 2018). It presented a positive answer in NDVI values that along with the recovered area resulted in the positive asymmetry of the histogram curve. Generally, the areas covered by low-height vegetation presented an increase. On the other hand, the areas of dense vegetation presented a decrease.

Figure 4: NDVI variation in the period from 1985 to 1992 (B) and NDVI from the respective years (A and C). Rainfall patterns were previous to the scene date (D and F) and histogram of the visible excerpt in the image (E).

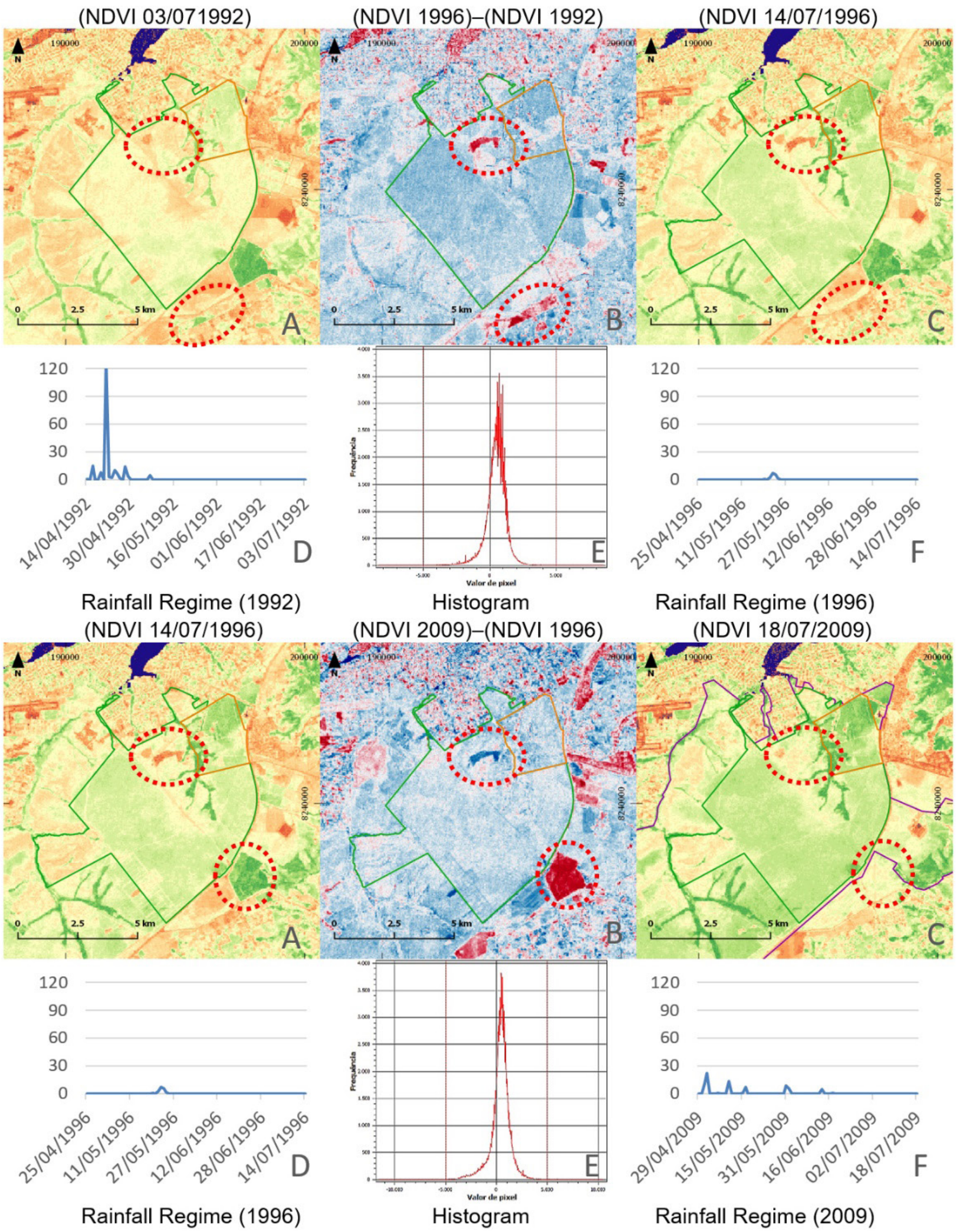


Source: SUTEC (2018); adapted from ESPA, 2018; INMET, 2018.

In the period from 1987 to 1992 (Fig. 4) the histogram curve presented again a negative dislocation. It was perceptible a marked decrease in the overall scene, particularly in the east portion, even when considered the Rural Area by the Territorial Planning (PDOT) of 1992 - Plano de Ordenamento Territorial (Distrito Federal, 2009b). It was possible to identify a process of vegetation suppression in Tororó Ecological Park (EP), identified in the South and in the region where posteriorly would be installed the Botanical Garden Housing Sector (HS) and Mangueiral HS, identified in the Northeast.

In the period from 1992 to 1996 (Fig. 5) it was verified an increase in the spectral response of NDVI, particularly focused on BBG and BBGES areas. The histogram curve was presented slightly positive. It was verified an intensification of vegetation suppression in Tororó EP (South) and a fire-scar in the higher portion of BBGES.

Figure 5: NDVI variation in the period from 1992 to 2009 (B) and NDVI from the respective years (A and C). Rainfall patterns were previous to the scene date (D and F) and histogram of the visible excerpt in the image (E).

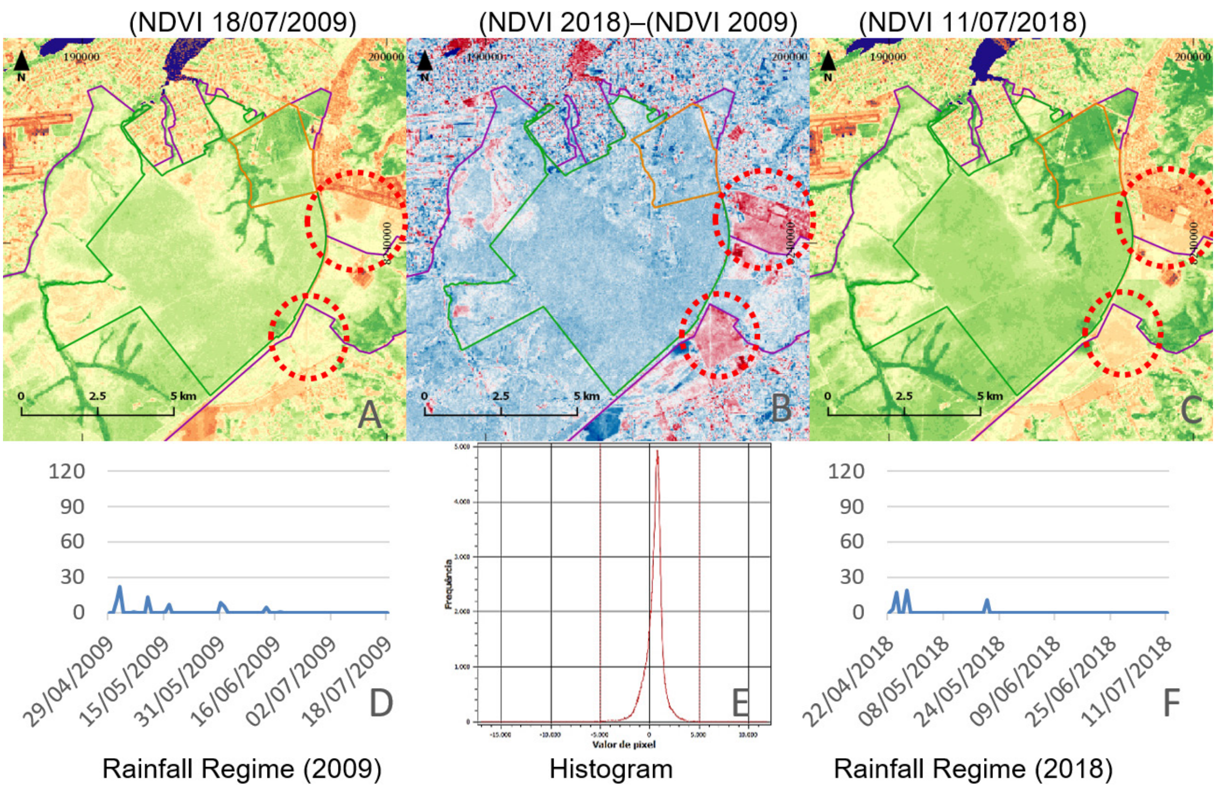


Source: SUTEC (2018); adapted from ESPA, 2018; INMET, 2018.

In the period from 1996 to 2009 (Fig. 5) there was a concentration of values close to zero, which resulted in a condensed curve in the histogram, slightly positive. It was verified the recovery of the fire-scar in the higher portion of BBGES and it was verified a contrary movement in the region of "Zone A - Restricted".

In the period from 2009 to 2018 (Fig. 6), the condition of the previous period was repeated. There was a concentration of values close to zero and a condensed curve in the histogram, slightly positive. The highlights identified the urbanization processes of Mangueiral HS in the Northeast, and an intensification related to the decrease of NDVI value in the region "Zone A - Restricted".

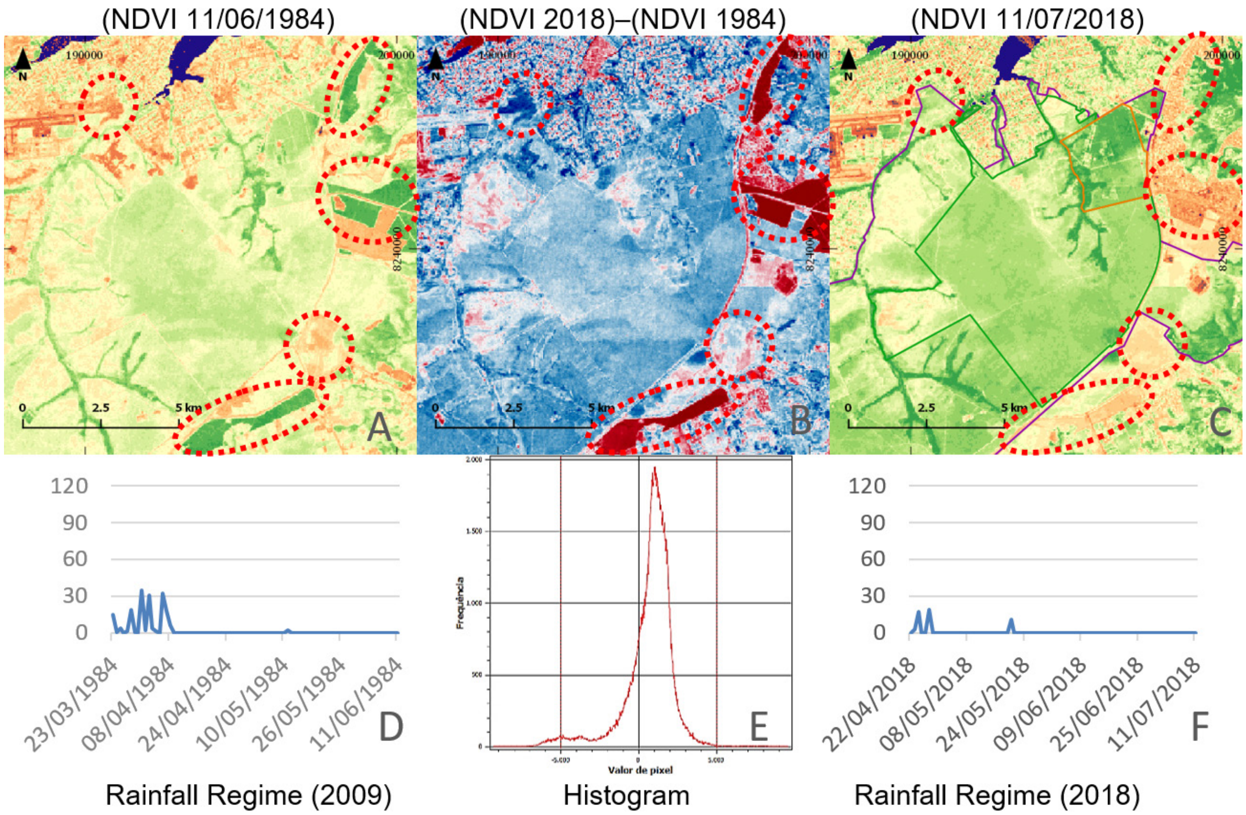
Figure 6: NDVI variation in the period from 2009 to 2018 (B) and NDVI from the respective years (A and C). Rainfall patterns were previous to the scene date (D and F) and histogram of the visible excerpt in the image (E).



Source: SUTEC (2018); adapted from ESPA, 2018; INMET, 2018.

The overall variations from 1984 to 2018 (Fig. 7) generated a histogram ~~as~~ product. It contains a gaussian curve which brings the summation of all the analyzed processes. The mode close to zero was identified, which displaced the apex of the curve to the left. Even considering this scenario, the negative values cannot be discarded because, although the values close to zero are not significant, the values more distant presented relevance, marked by deforestations.

Figure 7: NDVI variation in the period from 1984 to 2018 (B) and NDVI from the respective years (A and C). Rainfall patterns were previous to the scene date (D and F) and histogram of the visible excerpt in the image (E).



Source: SUTEC (2018); adapted from ESPA, 2018; INMET, 2018.

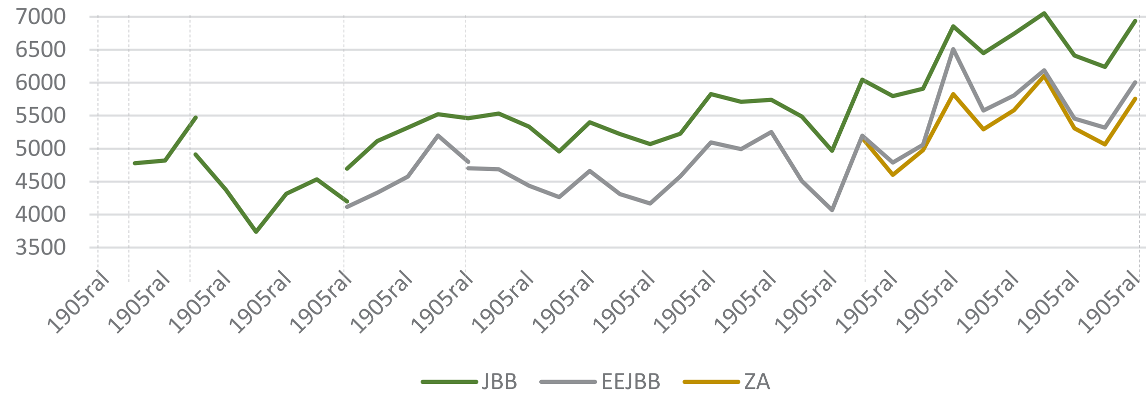
In the Northwest quadrant it was a significant increase in NDVI values related to the neighboring area of International Airport Juscelino Kubitschek. It has not been described before due to presenting a gradual improvement. At Northeast of Botanical Garden HS and Mangueiral HS it the highest vegetation suppressions related to consolidated urbanization processes was represented. At South, there was a suppression of Tororó EP's area.

The variation of "Zone A - Restricted" does not appear due to its return to the initial condition. It is highlighted that the visualization of its variation was possible only when an analysis year-by-year is conducted. Generally, it is possible to visualize growth, mainly in the portion in which the BZ of BBGES is included.

It is important to emphasize that the urbanized region near BBG and BBGES accords to the Guidelines for Land Use of the South/Southeast Region. This document allows a transition area with a green belt of at least 300m, and the DIUR 03/2014 describes a buffer zone around the Botanical Garden.

In conclusion, the analysis allows to verify a considerable growth in NDVI average values in the overall scene. From the cutting of scenes, based on perimeters (Fig. 2), an individualized average value to analyze the specific growth during the periods was obtained (Chart 2).

Chart 2: Variation of NDVI average values of BBG, BBGES, and BBGES' BZ, according to the analyzed periods



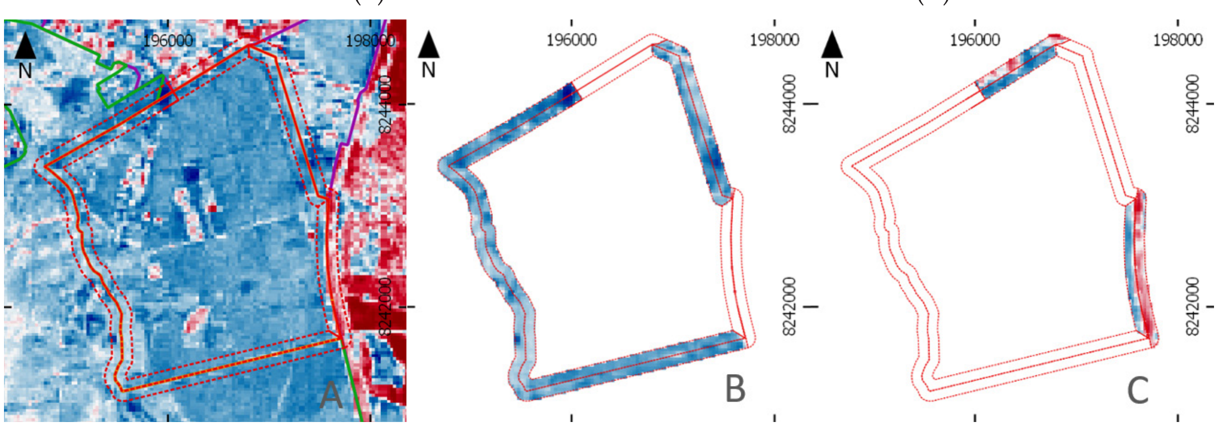
Source: INMET (2018).

The observed growth evolution in the multitemporal composition from 1984 to 2018 can be observed by the positive variation in all areas. BBG and BBGES presented significant increase of NDVI values subsequently to BZ creation. Identified in the BBG Master Plan (2010) as 'Mata de Galeria' (riparian forest), this phytophysiognomy presents a high percentage of the total BBG area. At BBGES this percentage is lower. This justifies the positive difference of average values obtained for BBG at the expense of BBGES averages.

Diagnosis of vulnerability in BBG perimeter

After studying NDVI evolution in the scene cutting, the aim was to identify the potentially conflicting areas of BBG with a higher variation. Some oscillations inside BBG, generated by internal spatial changes were observed as expected in botanical gardens. Therefore, the evaluation focused on perimeter regions that also presented variations without changes in the use. For this purpose, two buffers were defined both internally and externally 100 m distant from neighboring areas to other reserves, and ~~areas~~ in contact with the urbanized area (Fig. 8).

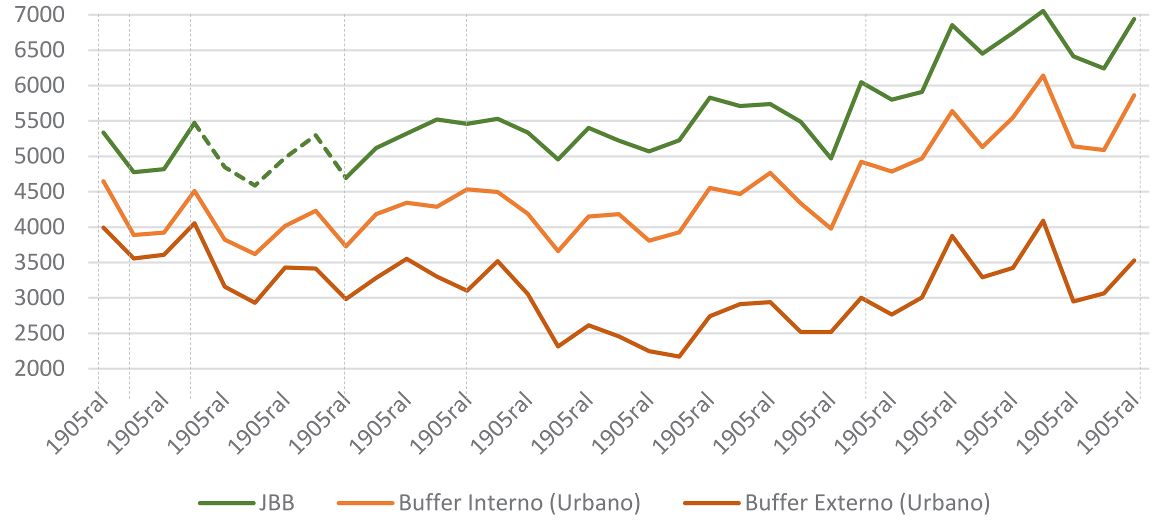
Figure 8: NDVI variation in the period from 1984 to 2018 (A) and cutting of the buffer neighboring to the reserve (B) and the one of contact with urbanized areas (C).



Source: Adapted from SUTEC (2018); ESPA (2018).

For BBG data generation in the period from 1987 to 1992, the option of maintaining the original perimeter was taken to allow the homogeneity of the sample's data, which allowed to observe that the neighbor areas to the reserves – protected by BZ or by BBGES – did not present significant variation in NDVI (Chart 3).

Chart 3: NDVI variation in the period from 1984 to 2018 at BBG, and internal and external cutting of buffer neighboring to the reserve; B: NDVI variation in the period from 1984 to 2018 at BBG, and internal and external buffer cutting in contact with urbanized areas.



Source: Adapted from ESPA (2018).

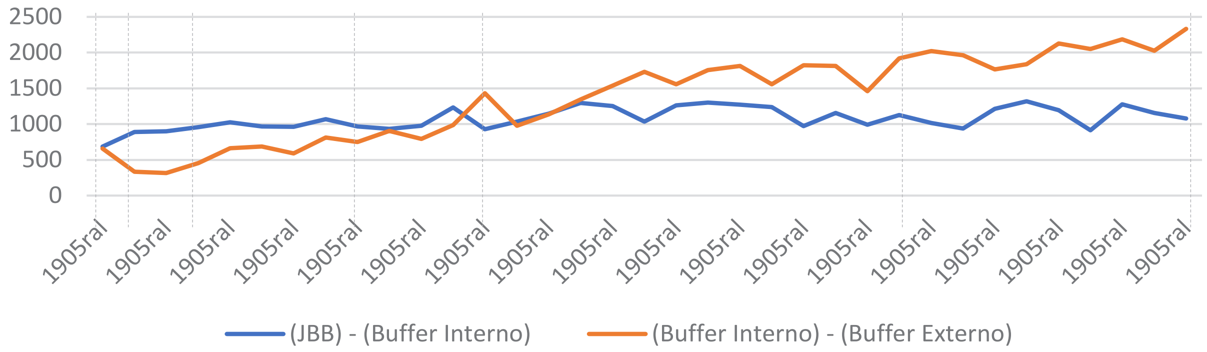
On the other hand, in the areas with direct contact with urbanization a discrepancy in NDVIs' average values was verified (Chart 3). Observing the buffer chart's pattern, it is explicit the difference between the reserve area's average when compared with the urbanized area.

As expected, the NDVI value in the urbanized area nearest BBG shows a lower presence of phytomass. The internal area around this limit also followed this behavior. From the data presented in Chart 3B, it was questioned the behavior of the internal edge excerpt was analyzed, at the expenses of BBG's total area. The aim was to evaluate if the evolution of average values followed the overall development of the garden, such as occurred in the internal edges neighboring ~~to~~ the reserves. It is highlighted that the possibility of variation in values occasioned by phytophysiognomies differences is not discarded. The subtraction of the average of BBG's NDVI values with the internal buffer was performed, allowing to identify sector variations based on the total area.

At the same time, it was questioned whether the influence of urbanization processes on the surroundings would interfere with BBG's internal dynamics. The internal average was then subtracted from the external, aiming to identify if the behavior of the urbanization evolution at the external edge influenced directly the internal one.

Comparing the subtractions (Chart 4) it was possible to identify an inversion in the variation pattern since 1996. Even though there was urban pressure, this inversion shows that the internal edge has been evolving along with the park. The internal edge presented a very subtle expansion in its interval when compared to BBG (blue line). It was not possible to compare the previous period as urban occupations began in the mid-1970s. However, this can be an indicator of the NDVI difference stabilization curve. It is emphasized that the most relevant data in this chart is that despite external urban pressure, BBG's internal edge followed the overall development of the area.

Chart 4. NDVI variation in the period from 1984 to 2018, related to the difference between BBG and internal buffer (urban), and between internal buffer (urban) and external buffer (urban).



Source: Adapted from ESPA (2018).

CONCLUSION

This study presented a quantitative analysis of phytomass, and it did not consider plant species. To determine the accuracy of obtained data it would be necessary to conduct field analyses, impossible to perform due to the actual Covid 19 restrictions. The areas that presented intense vegetation suppression at the analyzed period are closely related to the urbanization process. It is reaffirmed that the period of higher phytomass decrease in the Botanical Garden HS and Jardim Mangueiral HS was before 1992 when the region belonged to the rural domain.

The analysis year by year allowed more precise identification of the vegetation suppression and enabled to determine the effectiveness of BBG and BBGES' preservation. Discrepancies between the legislation and territorial planning reveal the urgent need to create mechanisms by which dialogue about urban areas demands and green areas protection can be done. BBGES' BZ could include the transition area with green belt and the Botanical Garden's buffer strip, therefore, considering expanding the legal protection, to maintain the area integrity and allow certain autonomy for urban guidelines.

It is highlighted the fact that Brazilian botanical gardens are, generally, inserted in a dense urban grid, which arises concerns. To be effective, preservation should consider the botanical gardens' peculiarities and then question the forms and levels of protection, less effective if compared with the protection of the conservation units. The importance of contemporary botanical gardens as representative of the flora makes them a potential CU. Its role goes besides the protection itself, as botanical gardens contribute also to the cultural heritage of a country. The lack of appropriate levels of protection puts this value at severe risk. Protection *versus* use dynamics is the major dilemma of those spaces, and for instance, the biggest obstacle to their inclusion in Brazilian law as a CU. The fact that they are multi-shaped, multifunctional, and their cultural ecosystem services are closely related to the urban context, leads to an urgent reflection around the very proper creation of specific forms of management. This study also emphasizes the importance of the creation of buffer zones, as happens with CUs categorized as 'strict protection'. Combined with a management plan, these measures can assure their protection, even in face of great urban influence. mainly when inserted in the urban grid.

The in-situ preservation as one of the botanical gardens' characteristics, ratified in the Brazilian Federal Resolution 339/03, represents an addition of meaning for those places. In 2005, the rupture of a dichotomized view by UNESCO symbolized a new perspective regarding natural and cultural heritage (Ribeiro, 2007). However, the environmental legislation in Brazil does not incorporate this conceptual update. The discussion around cultural factors remains neglected when the issue is the natural heritage. Brazilian environmental legislation needs to update the way of acknowledging cultural heritage, to maintain one of its most important functions of representing the collective imagery of the relation between man and nature.

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