Natural Cover suppression patterns used in PRODES Caatinga mapping

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Abstract

Since 2022, we have mapped native vegetation removal for all Brazilian biomes within the scope of the PRODES Project. In this study, our main objective was to present interpretation criteria for feature detection used to identify natural vegetation removal throughout the Caatinga. To this end, we created a catalog of typical patterns that can be used for supervised and unsupervised deforestation mapping. We used PRODES data from 2023 year's PRODES Caatinga based on the composition of top of atmosphere (TOA) reflectance images from MSI/Sentinel-2 satellite. The original reflectance data was used to generate false color images in the following combination: band 8 (Red), band 11 (Green) and band 4 (Blue). This image was then visually classified into different natural vegetation removal classes. These are good examples of what PRODES interpreters have encountered throughout this diverse region and can help any future mapping efforts of the Caatinga.

1. Introduction

The Caatinga is a biome (sensu IBGE) unique to Brazil, covering 10% of the country and 70% of the Northeast Region. It is characterized by a semi-arid climate with long droughts and rains concentrated in a few months. The local flora is adapted to water scarcity, and it includes a variety of species and life forms including thorny bushes and trees like the Espinheiro (Senegalia polyphylla), water storing trees like the Barriguda (Ceiba glaviozii), cacti such as Mandacaru (Cereus jamacaru) and Xique-xique (Pilosocereus polygonus), as well as diverse bromeliads and vines. The fauna of the Caatinga is rich and unique, home to endemic species such as jaguars, armadillos, sloths, maned wolves and various birds. This biome is vital for regional climate regulation and provides habitat for many species, but it faces threats such as deforestation and desertification (Silva et al., 2019).

Since 1988, INPE received from Brazilian Government the mission of developing and operating a system of monitoring to calculate annually the deforestation rate for the entire Brazilian Legal Amazon (BLA) through satellite images: the PRODES Project[1]. From 2003 onwards, BLA mapping became digital, but some criteria were maintained to continue historical comparability: visual interpretation to prioritize accuracy, minimum mapping area at 6.5 hectares and incremental deforestation mapping (Almeida et al., 2021). Since PRODES digital, it became possible to map land cover change using different sensors and satellites, such as the CBERS, IRS, DMC2 series.

In 2003, at COP-9[2] in Milan, the concept that developing countries can receive payments for reducing emissions and increasing forest carbon stocks was instituted in the REDD[3] framework (Reduction of Emissions by Deforestation or forest Degradation). In 2013, the Warsaw Framework (COP-19) implemented the REDD+ (adding sustainable forest management and the increase in forest carbon stocks) within the scope of the UNFCCC[3], which establishes the requirements for the recognition of forest loss mitigation results in developing countries, as well as the ways to obtain payments for these results (MMA, 2023).

The UNFCCC mandates that to be eligible for payments, developing countries must submit (I) a national strategy or plan, (II) a national forest emissions reference level (FREL), (III) a robust and transparent national system for monitoring and reporting on REDD+ activities (MRV – Measurement, Reporting and Verification) and (iv) an information system on the implementation of REDD+ safeguards (MMA, 2023). PRODES meets all these requirements for the BLA. In 2016, the mapping also included the Cerrado biome, whose FREL was approved in 2017 (MMA, 2023).

In order to continue meeting the goals of the National Climate Change Policy (PNMC) and to meet the national REDD+, the Project Environmental Monitoring of Brazilian Biomes by Satellites (PMABB) expanded the original goals of PRODES. Atlantic Forest, Caatinga, Pampa and Pantanal were included within the scope of the PRODES framework to be carried out by 2020 (Ordinance MMA 365/2015).

For the Caatinga biome, deforestation mapping by PMABB/Funcate (up to 2022 year) followed some specificities, regarding Amazon and Cerrado mapping, such as: 1 hectare of minimum mapping area; only Landsat series for mapping; calendar for getting satellite images located, preferably, in the quarters of August, September and October, with the possibility of uses auxiliary images in case of clouds in the primary image; false color composition of bands for visual interpretation (color/band): RED/NIR, GREEN/SWIR and BLUE/RED. The classes used from 2017 onwards were: reservoir, cloud and relief shadow, deforestation residual and deforestation (Almeida et al., 2021).

The unique characteristics of the Caatinga make it a biome of great ecological, cultural and social relevance. Its abundant biodiversity, the high number of endemic species and the specific adaptations to drought demonstrate the capacity of life to survive in adverse conditions (Lima et al. 2020). During the dry season, the vegetation loses its leaves, giving the landscape an arid and desolate appearance. During the rainy season, the biome transforms, revealing a lush green environment (Silva et al. 2004), which can make mapping vegetation cover removal different from other biomes.

The mapping for the year 2023 was carried out exclusively by INPE, with some interpreters located in UFCG and Univasf universities, inside Caatinga biome. Some methodological adjustments were made in Caatinga mapping, such as: updating the image acquisition calendar, considering that the biome has a wide variation in cloud cover within this period. Therefore, the

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total area was separated in 3 priority zones, West (Jul 1 to Aug 15), Central (Aug 16 to Oct 15) and Eastern (Oct 16 to Dec 15); exclusive use of 20-meter Sentinel-2 satellite images; cloud detection by digital classification or vector edition assisted by Plugin "Geo SAM/QGIS"; expansion of bookmarks, such as, degraded areas, exposed soil from intermittent rivers and exposed soil from flagstones, and; expansion of auxiliary data for cases of doubt, such as, Planet Satellite images, radar images (Sentinel 1), Global Land Analysis & Discovery map products (https://glad.umd.edu/), hydrography and vegetation maps from IBGE (scale 1:250,000), digital terrain model from SRTM and Ecoregions maps (Velloso et al., 2002).

Currently, the mapping of the natural vegetation removal in the Caatinga by PRODES is in full progress. It is a biome with highly seasonal vegetation, with certain phytophysiognomies with low natural tree cover and the presence of gradual vegetation degradation for decades. Such characteristics are a challenge for the identification of natural vegetation removal by PRODES in this biome. Given this fact, it is important to catalog patterns in satellite images that can generate uncertainties in the interpretation of natural vegetation removal, whether for digitization or automatic classification. Therefore, this work aims to present interpretation criteria for feature detection used to identify natural vegetation removal in the Caatinga biome, from Sentinel-2 images.

2. Objective

Considering the characteristics of the Caatinga biome that influence the mapping dynamics, we will address the visual detection of changes in natural cover in a process that involves comparing multispectral images.

The purpose is to identify visual interpretation criteria for accurate detection that minimizes inconsistencies related to false-positive polygons. With this objective, this study is intended to be specifically focused on detecting suppression of native vegetation, using Sentinel-2 images with false-color band composition and based on experience gained while mapping the region.

Our study has the following specific objectives:

● Define typologies of suppression of native vegetation of mapped and unmapped features as suppression of native vegetation by PRODES Caatinga 2023.
● Describe photointerpretation elements in each of the mapped and unmapped typologies as vegetation suppression by PRODES Caatinga 2023.

To this end, we create a catalog of typical patterns that can be used for supervised and unsupervised deforestation mapping.

3. Method of analysis

For this study, we used natural vegetation removal Caatinga data from 2023 year's PRODES Caatinga (TerraBrasilis, 2023) carried out by the National Institute of Space Research (INPE), with interpreters with extensive experience in mapping the Biome.

3.1 Image acquisition and composition

The 2023 year's mapping was interpreted based on the composition of top of the atmosphere reflectance images from MSI/Sentinel-2 satellite with 20 meters of spatial resolution.

The composition of false-color bands 8 (Red), 11 (Green) and 4 (Blue) was performed, in this respective stacking order, with band 8 (Red) corresponding to the near infrared, band 11 (Green) to SWIR 1 and band 4 (Blue) referring to the red band.

Considering that the biome presents a large variation in cloud cover, images from the MSI/Sentinel-2 satellite were used from August 15, 2023 to December 15, 2023.

For this stage of image acquisition and composition, the Google Earth Engine and QGIS software were used.

3.2 Mapping Criteria

The mapping process involves visual analysis of MSI/Sentinel-2 images, a minimum mapped area of 1 hectare (i.e., smallest features to be included in the map) and the operational scale used was of 1:75,000.

For this mapping stage, the TerraAmazon and QGIS software were used.

3.3 Detection and Visual Classification of Alterations of Native Land Cover

In the visual analysis of the multispectral images, a comparison was made based on temporal identification between the years 2022 and 2023 to detect features with suppression of native vegetation and areas not mapped as suppression of native vegetation by PRODES.

Visual interpretation of images consists of identifying features based on the different characteristics they present in the image (Novo, 2010). This interpretation depends on specific patterns and types found in them, which vary according to the diversity and peculiarities of the subregions of the Caatinga biome, in addition to the dynamics of land use and the influence of elements such as fire and humidity. In the visual analysis of multispectral images, fundamental elements known as photointerpretation elements are used, which guide the process of recognizing and identifying targets on the Earth's surface. These elements include: color (hue present in the image, such as cyan, red and green), tone (intensity or brightness ranging from white to black), texture (arrangement or repetition of textural elements, classified as fine, medium or coarse, and may also be smooth or rough), shape (spatial arrangement of elements, which may be regular or irregular), pattern or structure (organized repetition of shapes, which may be regular or irregular) and size (a characteristic dependent on the working scale, useful for describing and identifying targets at that specific scale).

The definition of the types of features with suppression of native vegetation mapped by PRODES and of features not mapped as suppression of native vegetation by PRODES was supported by the methods of visual/temporal comparison of MSI/Sentinel-2 images and identification of elements of the photointerpretation of MSI/Sentinel-2 images.

4. Results

The Caatinga is a biome with unique and heterogeneous characteristics and features phytophysiognomies with low natural tree cover, highly seasonal vegetation and gradual degradation, which can generate uncertainty in detecting the removal of native vegetation suppression. Considering these challenges, a catalog of typical patterns was developed for when there is detection of removal of native vegetation suppression and when there is no detection of native vegetation suppression, according to PRODES.

The catalog is presented in Table 1 and Table 2 of the Appendix of this study.

The suppression of native vegetation is detected when, in the visual and temporal comparison of the MSI/Sentinel-2 images, changes in the earth's surface are noticeable, with analysis of the conversion of natural vegetation to exposed soil, agriculture, artificial reservoirs and intentional burning (Table 1).

The suppression of native vegetation is detected when identifying the elements of the photointerpretation of the MSI/Sentinel-2 images. The color can vary from white to blue, the texture from smooth to rough and the shape regular or irregular. When dealing with the heterogeneity of elements, it is essential for this detection to evaluate the context of the area and the changes in the vegetation cover (Table 1).

When using the visual and temporal comparison of MSI/Sentinel-2 images, some changes in natural cover were not considered as native vegetation suppression. These typologies were defined as burns in natural areas, rocky outcrops and exposed soil of intermittent rivers (Table 2).

The elements of the photointerpretation of MSI/Sentinel-2 images of the features not mapped as native vegetation suppression can also vary in colour from white to blue, the texture from smooth to rough and the shape regular or irregular. In the case of this similarity with the features detected as native vegetation suppression, it was essential to evaluate the context that the area remained with natural cover over time (Table 2).
When comparing Table 1 and Table 2, we identified that there is little difference in the variation of colour, shape and texture. This fact makes it difficult to standardize the elements of interpretation of the features that did and did not occur native vegetation suppression.

Uncertainties in detecting the removal of native vegetation suppression increase the chances of false-positive polygons

The following can contribute to the chances of reducing the detection of false-positive polygons: selecting images with little or no cloud cover, increasing the target detection period, visual mapping experiences in the region, and evaluating the context of the area.

5. Discussion

There is variation in the structure of vegetation, from forests to xerophilic shrubs and also in its geography (Fernandes & Queiroz, 2018). This structural gradient adds complexity to the visual interpretation and requires careful analysis.

Our results show that the observed patterns can characterize suppression of natural vegetation if they are interpreted taking into account aspects that differentiate it from a natural landscape structure unchanged by human action. Carrying out an analysis of natural vegetation removal patterns make it possible to have a broader and more accurate understanding of vegetation dynamics and its causes (Hansen, et al., 2013).

The shape and the context of the observed fragment must be carefully considered when observing satellite images to detect deforestation. A circular or concentric pattern, where the opening of circular or concentric areas in the vegetation indicates a possible expansion of agriculture (Table 1); the linear clearcut pattern in a rectilinear form, are usually associated with the suppression of large expanses of the vegetation in straight lines or flat geometric shapes; The deforestation border pattern also allows visualization between the removed vegetation and the remaining area, as it presents an abrupt transition that can be seen in the image, generally changing the colour and texture of the location (Table 1).

Vegetation mapping presents several challenges and one that stands out is the finding of false positives of different types and sizes (Table 2). This problem is significantly complex and can lead to incorrect estimates and thus distortions in the observation of environmental impact (Câmara, et al., 2005). This interpretation key for the Caatinga can help to mitigate possible inconsistencies related to the issue. Our work, based on 2656 hours of experience mapping the region, addresses descriptive and consistent examples that, if carefully considered, can improve the accuracy of mapping.

Considering the landscape of the Caatinga, bare soil related to desertification, fires and intermittent rivers have a high risk of being confused with areas of anthropogenic vegetation suppression (Table 2) while actually consisting of natural features, seasonal aspect changes or conversion of the vegetation that was not caused by human activities aiming to use the area.

6. Conclusion

This study, which is based on extensive observation of the whole Caatinga area, presents a catalogue of the main observable features that can support the decision criteria for deforestation mapping. These are good examples of what PRODES interpreters have encountered throughout this diverse region and can help any future mapping efforts of the Caatinga.

The study highlights the importance of region-specific knowledge, robust tools and methodologies to monitor and understand changes in the biome's vegetation cover, providing important insights into the patterns and dynamics of vegetation suppression mapping in the Caatinga.

We suggest that this work can help in identifying features in Sentinel-2 satellite images and it also provides support for further studies in the Caatinga ecoregion.

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Appendix

PRODES	Definition typologies	Description of the photo interpretation elements	Sentinel Image (8R/11G/4B)
NATURAL VEGETATION REMOVAL	Native vegetation removal with bare soil on the date of detection	Colour: light green, white, gray, lilac. Texture: smooth or slightly rough Shape: regular or irregular Context: poorly defined edges with native vegetation. Usuallly, bare soil precedes the conversion to pasture, agriculture, or other land uses.	
	Native vegetation removal with conversion to agriculture	Colour: green, red and blue. Texture: smooth or rough. Shape: regular, rectangular or circular. Context: may have well-defined limits. Circular shapes characterize central pivots but conversion to agriculture on intermittent rivers is also common (linear pattern in this case). Plots with orderly shapes and colour varieties depends on the vigor, development and type of culture in the cultivation area.	
	Native vegetation removal with conversion into artificial reservoirs	Colour: blue, black or varied depending on the load and depth of sediments in the water body. Texture: smooth. Shape: irregular. Context: dam or reservoir with water retention. In most features the shape can be marked by a straight line of the natural watercourse barrier.	
	Native vegetation removal with conversion into anthropogenic burned areas	Colour: black, blue. Texture: smooth. Shape: regular. Context: well-defined geometric features connected to agricultural and pasture areas.	

Table 1 – Catalog Natural vegetation removal examples.

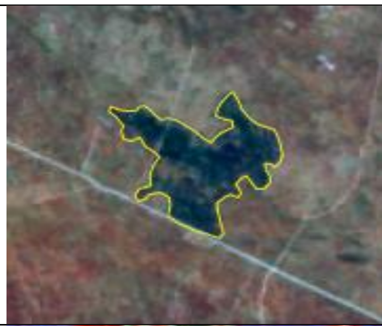
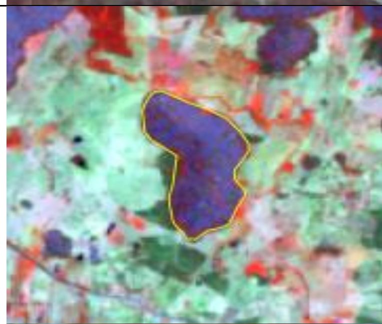
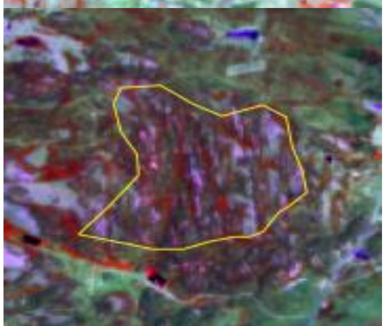
PRODES	**Definition typologies**	**Description of the photo interpretation elements**	**Sentinel Image (8R/11G/4B)**
NOT MAPPED NATURAL AREAS	Burning in natural areas	<u>Colour</u>: black, blue. <u>Texture</u>: smooth or rough. <u>Shape</u>: irregular. <u>Context</u>: they occur in areas without evidence of human intervention, in isolation close to areas with natural vegetation or close to areas in a natural context.	
	Rocky outcrop	<u>Colour</u>: brown, purple, red. <u>Texture</u>: rough. <u>Shape</u>: irregular and varies according to the geological characteristics of the area. <u>Context</u>: usually occurs in areas with steep elevation or areas of *Lajedo* vegetation.	 
	Bare soil on intermittent rivers	<u>Colour</u>: white, green. <u>Texture</u>: smooth or rough. <u>Shape</u>: irregular and linear <u>Context</u>: riverbed swith seasonal water flow that presents bare soil in the dry season.	

Table 2 – Catalog Not mapped natural areas examples.