MAPPING SECONDARY VEGETATION IN THE BRAZILIAN CERRADO - METHODOLOGICAL INNOVATIONS OF THE TERRACLASS PROJECT

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Abstract

The TerraClass Cerrado Project is an essential initiative for tracking land-use changes in the Brazilian Cerrado, an ecologically important threatened Brazilian biome. Launched in 2013, the project uses satellite imagery and advanced remote sensing techniques to map land cover types, focusing on secondary vegetation (SV), which is central for carbon storage, biodiversity, and water regulation. From 2018 to 2022, the SV area decreased significantly, with an 11% loss between 2020 and 2022, mainly due to the conversion into pasture. Despite these losses, 65% of the SV area in 2020 persisted until 2022, indicating resilience potential. Improved mapping accuracy (90.9% in 2022) highlights TerraClass's growing precision, which is essential for informing sustainable land-use policies. However, challenges in accurately detecting SV persist due to the fragmented nature of regenerating lands. TerraClass's data is instrumental in shaping conservation strategies to balance agricultural demands with ecological preservation in the Cerrado.

Key words **—** land-use, land-cover, natural area, classification, savannah.

1. INTRODUCTION

The TerraClass Cerrado Project is a fundamental initiative for understanding land use and land cover dynamics in Cerrado - Brazil's second-largest biome. The Cerrado holds unparalleled ecological significance, housing around 5% of global biodiversity and playing a central role in the hydrological cycle of South America. However, this biome has been severely impacted by agricultural expansion and the conversion of its natural areas into pastures and crops, especially soybeans and cattle ranching, making it one of the most threatened areas in Brazil [1].

The TerraClass Cerrado was launched in 2013 as an extension of the TerraClass project, initially focused on the Amazon, with the aim of mapping and monitoring deforested areas converted for agricultural use [2]. The project employs satellite imagery combined with advanced remote sensing techniques, enabling precise identification of land use and cover across the biome. Furthermore, TerraClass provides a broader understanding of human settlement processes, the advance of agricultural frontiers, and anthropogenic pressures on the Cerrado.

The importance of TerraClass Cerrado is directly tied to its ability to provide detailed and up-to-date data on the biome. TerraClass data are the basic information for developing public conservation policies, sustainable land management, and international commitments to mitigate climate change [3]. The data generated by the project is used by various sectors, from research institutions to government agencies, to implement strategies that reconcile agricultural production with environmental preservation.

Here we present the methods applied to the TerraClass Cerrado Project for Secondary Vegetation (SV) mapping, an important stage of this land cover mapping. The main results and system accuracy are also discussed.

2. MATERIAL AND METHODS

The mapping of the Cerrado biome is carried out by ecoregions, which were initially defined by Sano et al [4] and updated by Valeriano, in 2021. For each of the 20 ecoregions, we construct a mask with the last year's deforestation, water, and agriculture classes. Then we define the processing priority of ecoregions based on the dry season, generally from southwest to northeast. After that, we create a data cube, with an image time series of three months from Brazil Data Cube (BDC), using Sentinel-2/MSI satellite data, bands: B04 (red), B8A (NIR narrow), B8A (mean texture in 5x5 pixel window), B11 (SWIR); and the spectral indices: NDVI [5], NBR [6], NDWI [7] and AWEINSH [8] (Figure 1).

Only pixels located outside the mask are considered for the mapping. Once the data cubes have been created, three main steps follow to identify the SV areas: clustering, labeling, and editing.

Clustering is conducted using Self-Organizing Maps (SOM) [9] for dimensionality reduction. The data is categorized into 400 clusters, each of which is represented by a codebook vector, which groups a distinct set of time

series. Then, Hierarchical Clustering (HC) is applied to codebook vectors, producing a set of 150 final clusters [10].

In the labeling step, a team of Cerrado remote sensing experts reviews all the clusters and uses Sentinel-2/MSI images (bands B8, B4, B3, in an RGB filter) to identify the clusters corresponding to the Secondary Vegetation class.

For the editing step, these clusters are first converted into vectors and divided by cells of 10x10km. Then, an interpreter visits every cell to reshape, erase, or modify polygons of secondary vegetation by comparing Sentinel-2/MSI images (Bands B8, B4, B3) with the same temporal image series of the data cube (3 months). A senior specialist, or auditor, reviews the limits, checking and, when necessary, correcting the edits.

The polygons resulting from theSV mapping of the Cerrado Biome will be integrated with other classes, produced by other teams and methodologies, to create the annual land use and land cover map - TerraClass Cerrado.

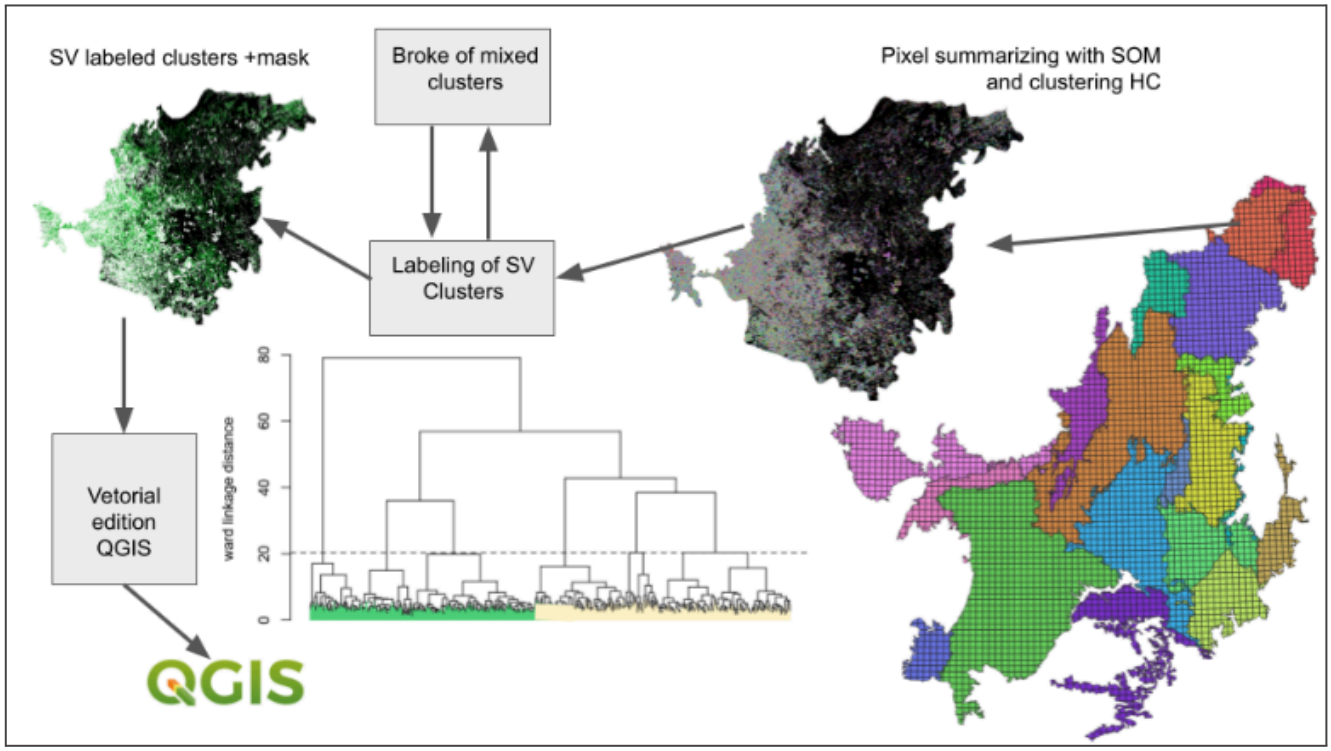


Figure 1. Methodological workflow for mapping secondary vegetation (SV) in the Cerrado.

3. RESULTS AND DISCUSSION

Mapping secondary vegetation in the Cerrado presents unique challenges due to its fragmented, transitional nature, which complicates accurate detection through remote sensing. SV often includes various successional stages, where tree cover, shrub density, and vegetation types differ significantly, making spectral differentiation difficult [2]. Additionally, human-induced activities such as frequent fires, livestock grazing, and small-scale farming constantly modify these areas, further hindering precise classification [11].

We present an effort to develop a concise and clear method using national technology, open-source tools, and leading innovations in remote sensing, which collectively enhance the reliability of our work.

In 2018, approximately 93,000 km² of SV were mapped, in 2020 it was 86,000 km², and in 2020 it was 76,000 km². There was an 11% reduction in the SV area between 2020 and 2022. Analyzing the transition of TerraClass classes, most of the SV area that was suppressed between 2020 and 2022 was converted to pasture: 32 thousand km², which corresponds to 35% of the total SV loss. Regarding permanence, 56 thousand km² in 2020 remained as SV in 2022, corresponding to 65% of the SV area.

The TerraClass 2022 map has an overall accuracy of 90,9% with ±1,6% confidence interval. It is 2,6% better than the 2020 map which has 88,3% global accuracy with ±1.6% confidence interval. The user accuracy of SV is 88,3% with a 3.7% confidence interval and the productor accuracy is 49.4% with an 8.6% confidence interval [13] .

The findings from the TerraClass Cerrado data illustrate significant and concerning trends in land-use changes in the Brazilian Cerrado, especially regarding secondary vegetation (SV). The 11% decrease in SV from 2020 to 2022, with 35% of this loss transitioning into pastures, suggests continued expansion pressures from agriculture. This dynamic aligns with studies indicating Cerrado's

vulnerability to agribusiness expansion, especially for soybean production and cattle ranching [1; 12].

Such losses have broader ecological implications, previously discussed, acting as an essential buffer that can gradually return ecological functions to degraded areas [1]. However, as TerraClass data indicate, 65% of the SV area persisted, showing that under certain conditions, SV can contribute to resilience in the Cerrado landscape. This persistence is essential for forming ecological corridors and aiding in the recovery of ecosystem services. Nevertheless, the lower producer accuracy (49.4%) of SV in 2022 reflects a continued challenge in mapping these areas accurately, potentially due to the fragmented and transitional nature of regenerating lands, which can complicate classification [2].

The high accuracy levels in 2022 (90.9%) also underscore TerraClass's valuable role in tracking these trends with increasing precision, which is essential for creating and implementing policies that protect regenerating lands. For instance, incentives for sustainable land use and agroforestry initiatives could aid in balancing agricultural needs with conservation goals [11]. The need for robust policies is more critical than ever, as indicated by these data, to maintain the resilience and productivity of the Cerrado under mounting land-use pressures.

4. CONCLUSIONS

The TerraClass Cerrado Project's secondary vegetation (SV) mapping provides critical information about the land use change dynamics within one of Brazil's most biodiverse and environmentally valuable biomes. The observed decline of SV between 2020 and 2022, with a significant portion converted to pasture, highlights the ongoing pressures from agricultural expansion in the region. This trend poses risks not only to biodiversity but also to the Cerrado's role in carbon sequestration, water regulation, and ecological resilience. However, the persistence of 65% of SV from 2020 to 2022 suggests that, under supportive conditions, secondary vegetation can play a role in ecological recovery and landscape connectivity, offering potential pathways toward sustainable land management.

The advancements in TerraClass Cerrado's accuracy rates demonstrate the project's value as a tool for monitoring these trends with precision, thus informing policy and conservation efforts. However, the challenges in accurately mapping SV underscore the need for continued methodological improvements and better integration of national and local land-use policies. Effective policy measures, such as incentives for agroforestry and sustainable agriculture, are essential for balancing development needs with the conservation of secondary vegetation, which remains a cornerstone of Cerrado's resilience. As this biome faces increasing land-use pressures, TerraClass Cerrado's findings provide a foundation for both conservation strategies and sustainable agricultural planning, aiming to ensure a balance between economic activity and ecological preservation.

5. ACKNOWLEDGMENT

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