WOODY ENCROACHMENT IN THE TRANSITIONAL ZONE BETWEEN AMAZÔNIA-CERRADO-PANTANAL

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ABSTRACT

Recent studies suggest that vegetation encroachment is occurring in the Brazilian Savannah (Cerrado) and in its transitional ecotones. This study aimed to quantify woody encroachment in the 'Serra das Araras' protected area, located at the transition among Amazônia – Cerrado – Pantanal biomes, over a 32-year time period. We used a remote sensing approach based on the time-series analysis of the maximum Enhanced Vegetation Index (EVI) as an index of woody encroachment, from the Landsat collection. We found that three-quarter of the Serra das Araras presented clear evidence of woody encroachment. The savannah class was the most affected, with 89% of its area presenting evidence of a woody encroachment process. The historical fire suppression seems to have favored the vegetation encroachment in Serra das Araras protected area.

Key words — *Savannah, woody encroachment, remote sensing, Landsat.*

1. INTRODUCTION

Savannahs cover around 20% of the Earth's surface and are the second largest major plant formation in the Neotropical region, with an original coverage of about three million square kilometers[1]. Savannahs encompass a mosaic of different vegetation types, formed by sparse grasslands to dense woody landscapes in which woody cover can vary spatially and temporally[2]. This ecosystem provides unique habitats and contributes to global biodiversity and ecosystem services[3]. It is also considered critical in the global carbon cycle as they account for 30% of terrestrial net primary production (NPP)[4]. Furthermore, it is undergoing several changes due to climate change and anthropogenic intervention.

It is well stablished that savannahs are presenting woody encroachment phenomenon worldwide[5,6]. Woody encroachment can be defined as a rapid increase in biomass, stem densities or cover of forest-like formations, resulting in a biome switching from open to a closed canopy system[5, 7, 8]. This phenomenon has several impacts, such as loss of biodiversity, changes in global carbon cycles, water resources and land-atmosphere interactions[9].

The causes behind woody encroachment varies among regions and ecosystems. Nonetheless, it is being associated by literature to global factors, such as the increase in the availability of resources due to the increase of CO_2 in the atmosphere[6, 10–12], and regional factors, such as changes in the frequency of fires, herbivory, increase of rainfall and land use abandonment[13, 14].

Brazil has the largest savannah area in the Neotropical region, the Cerrado biome. Cerrado is the most threatened of the Brazilian biomes since the rates of deforestation is five times higher than Amazônia and it has less effective environmental rules[15]. Recent studies show that the Cerrado is also undergoing the woody encroachment process, mainly in a transitional area with other Brazilian biomes, such as Amazônia[16] and Atlantic Forest[17]. Also, these studies have shown that the main local cause behind the woody encroachment in the Cerrado is the fire suppression[18].

However, in the Cerrado, most of the analysis of woody encroachment is made at the plot-level. Nonetheless, with the historical time-series of Landsat images, it is possible to expand the analysis to the landscape and regional scales. Thus, the aim of this work is to analyze the trend of the maximum enhanced vegetation index (EVI) in a transitional zone among Amazônia – Cerrado – Pantanal biomes from 1985 to 2017 to find evidence of woody encroachment.

2. MATERIAL AND METHODS

2.1. Study area

The study area comprises a conservation unit located at the Cerrado-Amazônia-Pantanal transition zone in the south-west of Mato Grosso state (Figure 1). The Serra das Araras conservation unit was created in 1982 and has an area of 271 km². We used the land cover classification of MapBiomas that divided the vegetation types into three main classes: wooded grasslands (*Campos*), savannah (*Cerrado sentido restrito and Parque Cerrado*) and forest formations (*Cerradão, Mata semidecídua, Mata ciliar*).

The area was being protected from fire since its creation, although there have been a few accidental fires coming from the nearby pastures. Currently, there is a project (CERFogo) occurring in this conservation unit to restore the composition of savannah vegetation using fire management. This project will assess the influence of fire suppression on the savannah composition. Thus, it is desirable to have historical data and trends as a subsidy for future analyses and policy conservation.

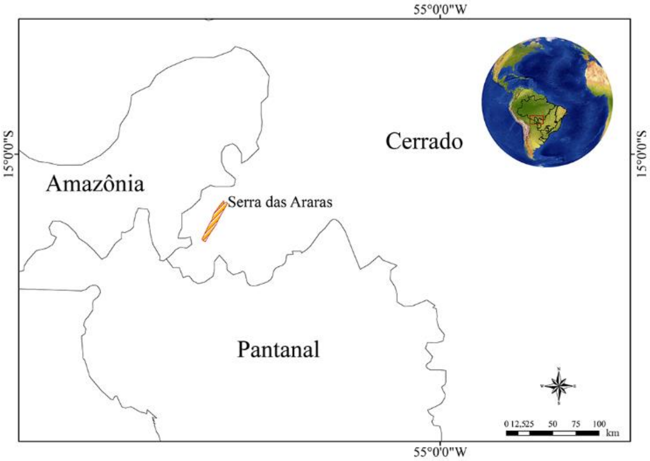

Figure 1. Study area in orange located in a transitional zone between Amazônia, Cerrado and Pantanal wetlands.

2.2. Material and methods

The Google Earth Engine platform was used to generate the time-series of Landsat Enhanced Vegetation Index (EVI) from 1985 to 2017. We used the Tier 1 collection of Landsat 5, 7 and 8. This product was already geometrically and atmospherically corrected to surface reflectance. We also applied a cloud mask through our time-series to avoid using pixels with cloud coverage.

To estimate the tendency of woody encroachment process in Serra das Araras, we calculated the yearly maximum EVI from 1985 to 2017 using an ImageCollection reduction tool from Google Earth Engine platform. The EVI index was used because it demonstrated a strong correlation with the tree basal area in the Cerrado[19].

To find the pixels with woody encroachment evidence we performed a pixel-by-pixel linear regression using the Raster R package[20]. Changes were considered significant for pixels that presented a best-fit line using an F-test with a 10% of significance level (p-value < 0.1).

In order to analyze the fire dynamics as a local driver of the woody encroachment phenomenon in the Serra das Araras region, we used auxiliary data of the burned area. Burned area dataset from 2001 to 2017 was obtained from the monthly MODIS Burned Area product (MCD64A1 Collection 6). We transformed the monthly dataset to the total annual burned area. Land use and land cover data were obtained from MapBiomas (Project of Annual Mapping of Land Cover and Land Use in Brazil, Collection 3).

3. RESULTS AND DISCUSSION

3.1. Trends of woody encroachment in Serra das Araras

We found that approximately 75% (200 km²) of the total area of Serra das Araras presented an increase in the annual EVI_{max} ($p<0.1$). The positive trend of EVI_{max} is spatially spread throughout the entire area of the conservation unit (Figure 1). The average slope for the total area was 0.003, this indicates an average increase of 0.096 in the EVI_{max} units over 32 years. However, the pixels with higher slopes indicated an increase up to 0.32 in the EVI_{max} units over time. Less than 0.1% (0.1 km²) presented a decrease in the EVI_{max} during this 32-years analysis ($p<0.1$). We also identified that all the pixels inside the plots from CERFogo project presented a significant increase in the EVI_{max} ($p<0.1$).

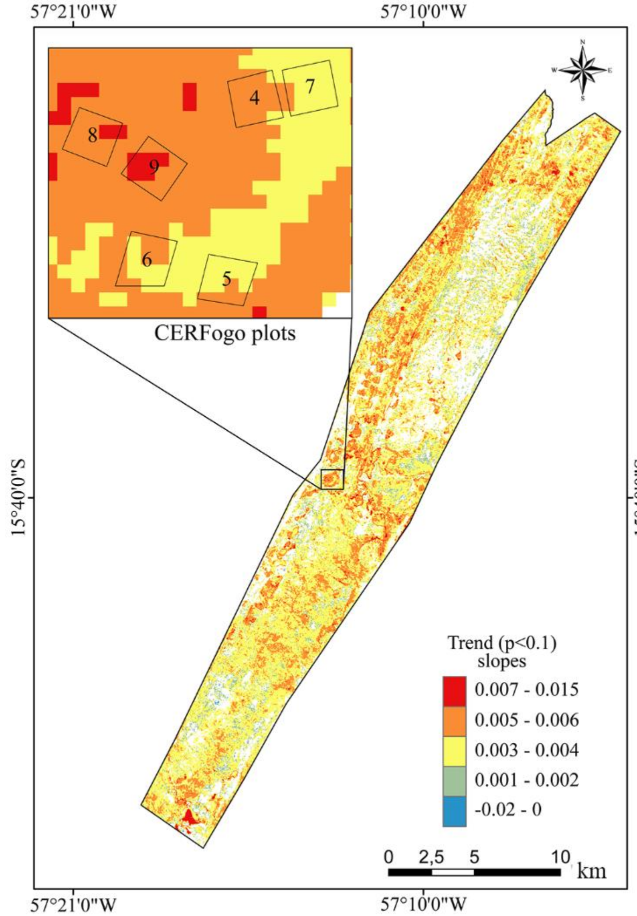

Figure 2. Pixel-by-pixel trend of the yearly maximum EVI time-series (1985 to 2017) for the role Serra das Araras conservation units and CERFogo plots. The non-significant pixels were masked out.

Evaluating the area of positive slopes for each land cover class, we estimated that 89% of the savannah class inside Serra das Araras presented evidence of woody encroachment. This was followed by forest formations (68%) and wooded grasslands (64%) (Table 1).

Table 1. Total area (km²) with a positive trend of EVI_{max} by total vegetation area inside the reserve

Land cover	Area (km²)	%
Forest formations	103	68
Savannah	84	89
Wooded grasslands	16	64

On average, the land cover that presented the highest increase in the EVI_{max} was savannah ($r^2=0.51$; $p<0.05$), with an average increase of 0.12 in the EVI_{max} units. This was followed by forest formations and wooded grasslands ($r^2=0.35$; $p<0.05$), with an average increase of 0.07 and 0.09 in the EVI_{max} units, respectively (Figure 3). This result indicated that in all three classes the vegetation encroachment occurred and is continuing.

Also, by calculating an EVI average threshold of open savannah, dense savannah and forest-like formations, it was possible to observe the average trend for each class (Figure 3). We found that the savannah class was classified as open savannah in 1985 and by 2005 had shifted to dense savannah threshold and continued to increase in the following years. Currently, it is close to achieving the forest threshold. The Cerrado forest formations *(Cerradão, Mata Semidecidua, and Mata Ciliar)* also shifted from dense savannah in 1985 to forest-like formation in 2017. Besides the increasing trend of the EVI_{max} in the wooded grasslands, they still remain as open savannahs, though they are close to reaching the dense savannah threshold.

We also calculated the average trends of EVI_{max} for the plots of CERFogo project (Figure 4). All six plots were classified as open savannah in 1985 and currently present a pattern of dense savannah. This corroborates with observations by the conservation unit personnel.

Studies have reported, at the plot-level, increases in biomass and changes in the Cerrado vegetation composition due to the woody encroachment phenomenon [8,16,19,21,22]. Our findings suggest that in the Serra das Araras the woody encroachment is spatially widespread. This phenomenon can bring serious consequences to the biodiversity of this conservation unit, such as a loss of adapted fauna and flora as stated in other areas of Cerrado[18,19].

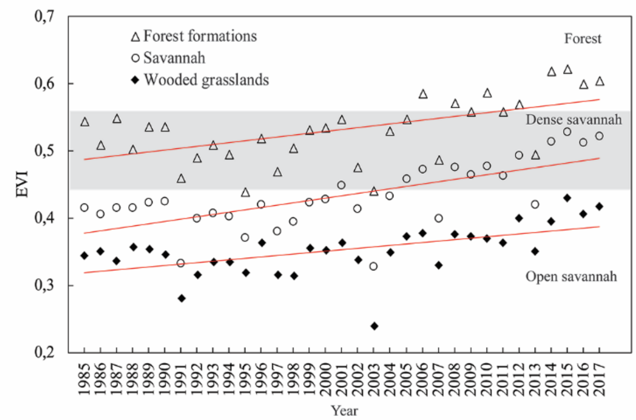

Figure 3. Mean yearly maximum EVI by land cover class of MapBiomas in 2017 of Serra das Araras. The grey area is the EVI average threshold of transition between open savannah-dense savannah and dense savannah-forest-like formation. All trend lines were significant (p<0.05).

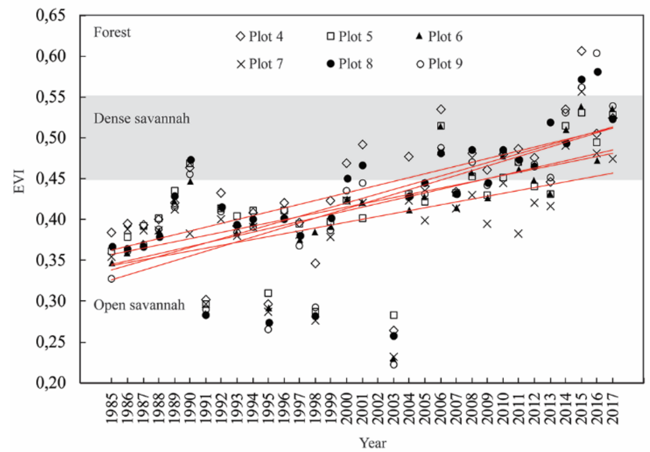

Figure 4. Yearly maximum EVI inside the plots of savannah vegetation in Serra das Araras where is occurring the current CERFogo project. The grey area is the EVI average threshold of transition between open savannah-dense savannah and dense savannah-forest-like formation. All trend lines were significant (p<0.05).

3.2. Fire dynamic in Serra das Araras

In the last 17 years, the conservation unit presented seven fire events (Figure 5a) with 2017 showing the largest burned area (34 km²). Spatially fire events were located at the northeast and southeast side of the reserve (Figure 5b), where the EVI_{max} trend was lower. This is the highland side of the reserve and is composed mostly by wooded grasslands. We estimated that about 21% of the total area presented at least one fire occurrence since 2001. Most of the area burned only once in this period, and we identified small patches that burned two and three times (Figure 5b). These fires come from neighborhood farms. Conversely, within 79% of the conservation unit no fires had occurred within the last 17 years. This indicates that fire suppression can be the cause of the EVI_{max} increase throughout the conservation unit.

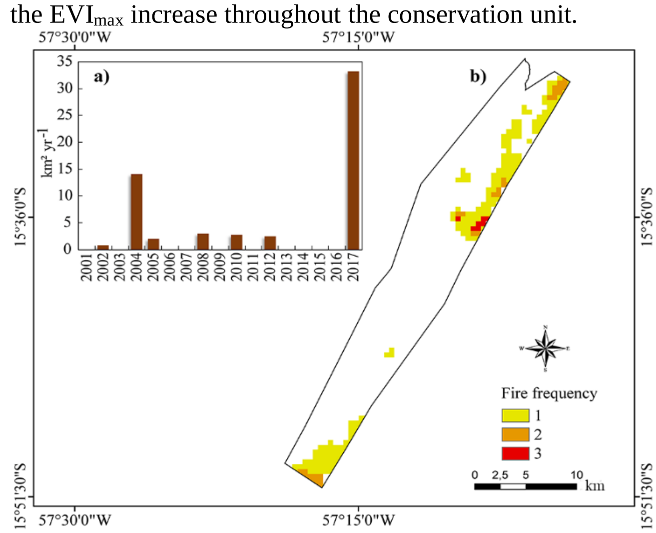

Figure 5. a) Annual burned area (km²) and b) Spatial burned area and frequency.

Fire suppression is appointed as the main factor of woody encroachment in Brazilian savannahs, mainly in protected areas where the fire is seen as an ‘enemy’[18]. Nonetheless, fire suppression causes the advance of forest like species over savannah species adapted to fire events[17, 18]. This process leads to an unprecedented loss of biodiversity and biome shift. Since most of the Serra das Araras area presented fire suppression and strong evidence of woody encroachment, it is important to develop a policy of fire management in order to maintain the savannah biodiversity and the conservation of Cerrado.

4. CONCLUSION

In summary, our study shows strong evidence that woody encroachment has been occurring in Serra das Araras over the last 32 years. All the land cover classes of Serra das Araras are presenting a significant increase in the EVI_{max}. However, the savannah class seems to be the most critical, since the woody encroachment is occurring in almost 89% of its area. This may put at risk the future of the savannah species biodiversity due the advance of forest formations. The historic fire suppression inside the protected area appears be the local driver behind of these changes in the vegetation.

The use of remote sensing time-series is important to give a panorama of the vegetation changes. Therefore, in order to improve understanding of the vegetation dynamics and develop conservation policy for the Cerrado and transitional areas, remote sensing products should be associated with field validation in the future.

5. ACKNOWLEDGMENTS

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