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Space-Time Dynamics of Vegetable Coverage in the Intermediary Geographical Region of Ilhéus-Itabuna

Andrêssa Pereira de Jesus[1]
Roberto Ferreira Machado Michel[1]

[1]Universidade Estadual de Santa Cruz (UESC), Programa de Pós-graduação em Desenvolvimento Regional e Meio Ambiente, Ilhéus, BA, Brasil.

Abstract

The objective of this study is to evaluate changes in vegetation cover in the Ilhéus-Itabuna geographic intermediate region from 1984 to 2019 using the Normalized Difference Vegetation Index (NDVI), Enhanced Vegetation Index (EVI), and Soil-Adjusted Vegetation Index (SAVI). Data was processed through the Google Earth Engine programming interface, using image collections from the TM/Landsat 5 and OLI/Landsat 8 sensors. After creating the indices, areas with different uses were selected, and the NDVI time series graphs were created. It was found that the vegetation density in the region decreased from 1984 to 1999 and increased from that year. The NDVI and EVI showed similar behavior, unlike the SAVI, which lower averages. Average NDVI values were higher in (June-August), due to the association of these conditions with higher soil moisture. In the pasture area, peaks of heat (January-March) drove vegetative activity due to the favorable climate and availability of water and sunlight.

Keywords: Temporal analysis, Remote sensing, NDVI, Google earth engine, Urban planning.

1. INTRODUCTION

Human-induced environmental changes are intense and have multiple impacts on soil, water, atmosphere, and biodiversity, and thus on regional development (Custodio, 2020). With the development of society in recent decades, the opportunities to change the earth's surface have increased significantly, and the scale and intensity of land use have changed dramatically (Hu et al., 2018and change detection techniques are the most important component of land-updating methods. Previous research has confirmed that simple change detection based on Landsat images from two different years with two different phenophases yields unsatisfactory results and may induce many misclassifications and pseudo-change identifications because of the phenological differences between remote sensing images. With the support of the Google Earth Engine (GEE). With the aggravation of environmental problems, the need arose to develop methods and techniques to monitor the changes caused by human intervention. In recent decades, orbital remote sensing has made it possible to detect and map the spatial and temporal evolution of changes in the Earth's surface using multispectral sensors (Custodio, 2020). Monitoring and understanding the dynamics of land cover is important to detect its influence on ecosystem structure and function (Huang et al., 2017). Land use change detection can identify potential environmental events associated with rapid urbanization, native vegetation conversion, and agricultural expansion. Assessing and monitoring these changes is essential for developing integrated land and water resource management strategies (Zurqani et al., 2018).

Cloud-based geospatial analytics platforms like Google Earth Engine (GEE) have enabled longer-term time series monitoring, granting users efficient access to vast remote sensing data. This facilitates the observation of Earth's surface changes over time, providing valuable insights into environmental and climate processes on broader temporal scales. This expanded the possibilities for studying and understanding these phenomena, allowing for more comprehensive and detailed analyses.

Therefore, changes in their dynamics are a useful indicator of variations in these conditions. In the southern and extreme southern regions of Bahia, soil structure, land use, and land cover have changed significantly in a short period of time. The south is mainly characterized by cacao cultivation and the extreme south by eucalyptus cultivation and cattle ranching, amidst existing social conflicts (indigenous lands and settlements) (Magalhães & Favareto, 2020). In this way, it is assumed that land use directly influences vegetation cover and that this change is sensitive to climatic conditions, especially temperature.

These changes significantly affect soil, water, atmosphere and biodiversity, impacting regional development and the quality of life of local residents. Given the region's prolonged interference and its status as part of the Atlantic Forest, studies are needed to assess the impact on vegetation caused by such activities. The present study aims to evaluate the changes in vegetation cover in the central geographical region of Ilhéus-Itabuna from 1984 to 2019 using the Normalized Difference Vegetation Index (NDVI), Enhanced Vegetation Index (EVI) and Soil Adjusted Vegetation (SAVI) with different types of uses (pasture, forest, cacao cabruca, agriculture, and eucalyptus cultivation), selecting areas characteristic of each use, in the municipalities of Uruçuca, Ilhéus, Firmino Alves, Santa Cruz Cabrália, Eunápolis and Porto Seguro, and how these uses respond to temperature variations in the region.

2. MATERIAL AND METHODS

2.1. Study area

The intermediate geographic region of Ilhéus-Itabuna (formerly Mesoregion of Southern Bahia) (Figure 1), named after the new IBGE regionalization of 2017, is covered by 51 municipalities. It is composed of four intermediate geographic regions: Ilhéus-Itabuna (22 municipalities); Teixeira de Freitas (22 municipalities); Eunápolis-Porto Seguro (8 municipalities); and Camacan (8 municipalities) (Bahia de Aguiar, 2018).

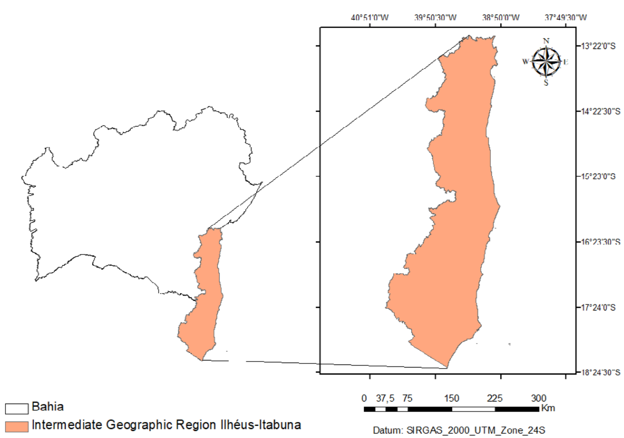

Figure 1. Location of the Intermediate Geographic Region of Ilhéus-Itabuna.

Source: Elaborated by the authors.

The region has a humid tropical climate with no dry season, with average annual temperatures that vary between highs of over 24 °C and lows of 21 °C, with monthly averages over 18 °C, the warmest months being from December to March and July and August with lower temperatures. Precipitation usually falls throughout the year, so there is no pronounced dry season, only less precipitation in August and March, with a decreasing trend, annual rainfall exceeds 2000 mm. The region is characteristic of the Atlantic Forest, with varied soils in which deep low natural fertility latosols and argisols predominate (Rocha, 2008).

The figure below (Figure 2) shows the location of the points selected for the analysis of the NDVI time series.

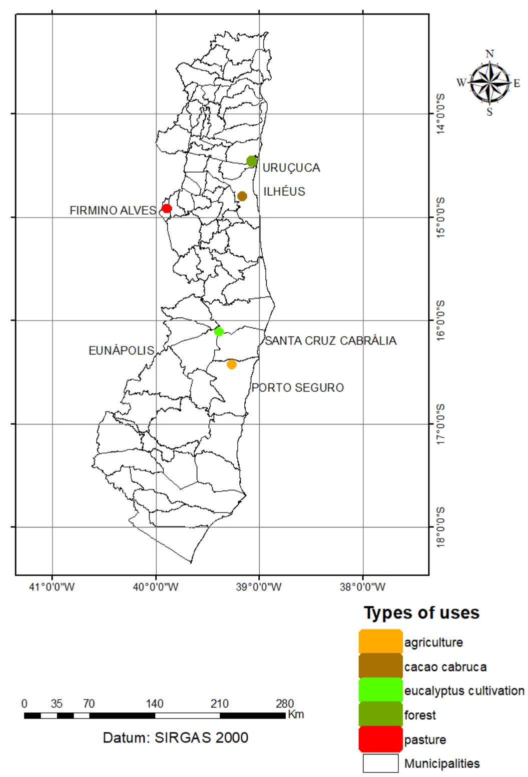

Figure 2. Location of areas selected for temporal analysis of NDVI.

Source: Elaborated by the authors.

The agricultural polygon is located at Fazenda Bom Futuro, district of Vale Verde, belonging to the municipality of Porto Seguro (BA). The cocoa area is located in a cocoa cultivation space using the cabruca system, located in the district of Salobrinho, municipality of Ilhéus (BA). In the cabruca system, small trees, shrubs and herbaceous plants are removed, leaving only the larger trees standing to shade the cocoa tree (Lobão et al., 2023).

The third region studied corresponds to eucalyptus cultivation for the manufacture of cellulose, located on the border of the municipalities of Eunápolis (BA) and Santa Cruz Cabrália (BA). The forest polygon is located in the Serra do Conduru State Park, close to the town of Serra Grande, in the municipality of Uruçuca (BA). For pasture analysis, the area of a cattle farm was observed, located in the district of Itaiá, belonging to the municipality of Firmino Alves (BA).

The regions were selected because the activities carried out in each were already known, and these were the activities of interest for each use.

2.2. Historical context

Chiapetti (2009) notes that Portuguese colonizers initially settled the intermediate geographic regions of Ilhéus-Itabuna and Camacan in southern Bahia due to European economic interests. Over time, cocoa monoculture expanded, alongside sugarcane and other crops. In 1822, cacao gained importance in the region. Cerqueira Neto (2013) highlights that after declining in the latter half of the 20th century, cocoa cultivation began sharing space with cattle ranching in the Southern Region. This shift intensified cattle ranching, leading to a divide from the center where cocoa predominates, resulting in a distinct region known as the extreme south.

In the far south, including Teixeira de Freitas and Eunápolis-Porto Seguro regions, settlement initially relied on Atlantic Forest timber extraction. However, from the 1970s, socioeconomic shifts occurred with the government's promotion of reforestation and eucalyptus cultivation, leading to environmental impacts and hindering local farming (Almeida et al., 2008; Oliveira, 2021).

Currently, eucalyptus cultivation is responsible for significant socio-productive changes in the region, including soil structure, although traditional activities such as livestock, subsistence agriculture, and fishing are still very important to the regional economy (Almeida et al., 2008). In these regions, to this day, there are often numerous land conflicts involving rural settlements, peoples and traditional communities.

2.3. Processing

Landsat data processing was done using the Google Earth Engine platform in JavaScript, following Santos et al. (2018) methodology, utilizing TM/Landsat 5 and OLI/Landsat 8 sensor image collections at 30 x 30 m spatial resolution. Images from the ETM+/Landsat 7 sensor were not included in the study because the scan line corrector (SLC) sensor on this satellite began to fail in 2003, compromising the quality of the data. A GEE code editor script[1] was used to extract the NDVI, EVI, and SAVI data. Two features of each index were used for Landsat 5 and 8, extracted every five years from 1984 to 2019 (1984, 1989, 1994, 1999, 2004, 2009, 2014, and 2019) since Landsat 5 uses band three for the red light spectrum (0.63 – 0.69 μm) and band four for the near infrared spectrum (0.76 – 0.90 μm), while Landsat 8 uses band four for the red light spectrum (0.64 – 0.67 μm) and band five for the near infrared spectrum (0.85 – 0.88 μm). The NDVI is calculated according to Rouse et al.(1973) using the following equation (1), resulting in pixels with values between -1 and 1:

$$NDVI=(NIR-RED)/(NIR+RED) \quad (1)$$

NIR: near-infrared waves; RED: red waves.

The EVI, according to Huete et al. (2002), is calculated using the spectral bands of near infrared, red and blue light (band one on Landsat 5 [0.45 – 0.52 μm] and band two on Landsat 8 [0.45 – 0.51 μm]) to indicate the vegetation intensity of the region using the following equation (2):

$$EVI=G(NIR-RED)/(L+NIR+C1* RED -C2* BLUE) \quad (2)$$

Where: NIR: near-infrared waves; RED: red waves; BLUE: blue waves; G: gain factor (G = 2.5); L: ground interference adjustment factor (L = 0.5, given for unknown locations); C1: atmospheric effects adjustment coefficient for red (C1 = 6); C2: atmospheric effects adjustment coefficient for blue (C2 = 7.5).

SAVI, proposed by Huete (1988), is an improved NDVI, used to minimize the influence of soil reflectance on NDVI by the constant L, as shown in the following equation (3):

$$SAVI=((1+L)*(NIR-RED))/(L+NIR+RED) \quad (3)$$

Where NIR: near-infrared waves; RED: red waves; L: adjustment factor for ground clutter (L = 0.5, given for unknown sites).

The indices were divided into five classes, namely: class I (-1/ 0), areas with water, clouds and exposed soil; class II (0/0.25) for very low cover index; class III (0.25/ 0.5) class 3 for low; class IV (0.5/ 0.75), moderately low and class V (0.75/ 1), high for denser vegetation areas.

Then, the median of the collections was calculated using the median filter, where the best pixel for that region is selected from all images in the selection. For the time series plots[2], January to March was analyzed as the warmest season and June to August as the coldest season, although there is no defined dry season. Five regions with different land uses were

[1] Script Landsat 5: https://code.earthengine.google.com/c4584660be9534098b0cd1d191f915ee
Script Landsat 8: https://code.earthengine.google.com/8429198bfc5ef8fb32da0991521eeffe

[2] Script: https://code.earthengine.google.com/5521d5b3ae2ac3b04bd413cf35f1442a (adapted from CUNHA (2021))

selected, namely pasture, forest, cacao cabruca, agriculture, and eucalyptus cultivation. From these, the NDVI mean values were extracted for the mentioned stations between the years 1984 and 2019.

2.4. Statistics

The relative standard deviation (%RSD), or coefficient of variation (CV), was used to quantify the dispersion of the data in relation to the mean. A lower %RSD indicates greater data homogeneity. It is calculated using the ratio between the standard deviation (SD) and the mean of the data multiplied by 100 to express the value as a percentage (Afonso & Nunes, 2019). The results of the statistical analysis of the relative standard deviation (%RSD) for each region studied are shown in the table below (Table 1).

To determine if NDVI differences between land uses and time intervals were statistically significant, a two-way ANOVA and Tukey HSD post-hoc test (5% significance level) were performed using Excel tools.

Table 1. Standard Deviation (SD) and Relative Standard Deviation (%RSD) values of the polygons.

Regions	SD	%RSD	N° of observations
Agriculture (Jan-Mar)	0.129	24.749	60
Agriculture (Jun-Aug)	0.107	18.113	84
Cacao cabruca (Jan-Mar)	0.148	19.903	103
Cacao cabruca (Jun-Aug)	0.110	13.953	160
Eucalyptus (Jan-Mar)	0.177	26.715	98
Eucalyptus (Jun-Aug)	0.167	25.043	115
Forest (Jan-Mar)	0.235	33.741	117
Forest (Jun-Aug)	0.142	19.150	161
Pasture (Jan-Mar)	0.138	23.341	58
Pasture (Jun-Aug)	0.135	23.730	73

Source: Elaborated by the authors.

3. RESULTS

The NDVI, EVI and SAVI indexes of the region show large variations in the analyzed 35 years.

The average NDVI values determined for each studied year ranged from 0.354 in 1999 as the lowest average value to 0.568 in 2019 as the highest value (Figure 3). The percentage of NDVI for each indicated class is shown in Table 2.

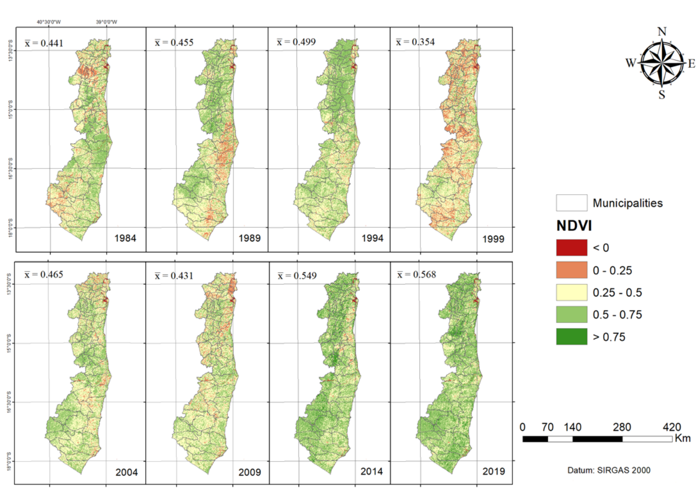

Figure 3. Time evolution of the NDVI for the years 1984 to 2019.

Source: Elaborated by the authors.

Table 2. Percentage of NDVI vegetation cover for each analyzed class.

Year	Percentage (%)				
	Class I	Class II	Class III	Class IV	Class V
1984	0.63	12.23	49.65	37.06	0.43
1989	0.66	10.92	46.15	41.41	0.85
1994	0.68	4.41	42.88	51.45	0.58
1999	0.52	25.89	55.17	18.39	0.03
2004	0.71	6.47	51.24	41.36	0.23
2009	0.54	10.42	56.16	32.76	0.12
2014	0.67	2.88	30.30	58.12	8.03
2019	0.70	1.37	26.94	62.31	8.69

Source: Elaborated by the authors.

The average annual EVI values obtained ranged from 0.399 in 1999, the lowest average, to 0.601 in 2019, the highest average. SAVI maps were also created, with annual average values of 0.230 in 1999 as the lowest average and the highest of 0.367 in 2019. The percentage of each class indicated is shown in (Figure 4 and 5, Tables 3 and 4).

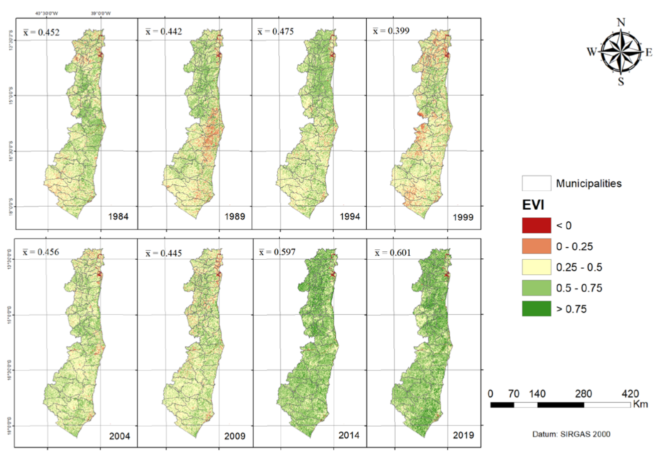

Figure 4. Time evolution of the EVI for the years 1984 to 2019.

Source: Elaborated by the authors.

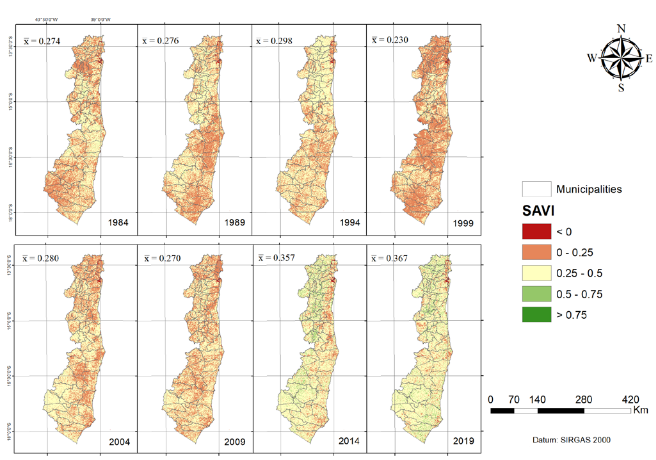

Figure 5. Time evolution of the SAVI for the years 1984 to 2019.

Source: Elaborated by the authors.

Table 3. Percentage of vegetation cover of EVI for each analyzed class.

Year	Percentage (%)				
	Class I	Class II	Class III	Class IV	Class V
1984	0.61	6.73	56.44	33.64	2.57
1989	0.66	10.03	53.91	32.89	2.52
1994	0.67	3.83	53.17	40.02	2.31
1999	0.56	13.41	62.38	22.35	1.30
2004	0.70	4.05	60.03	34.14	1.08
2009	0.53	6.54	59.37	32.05	1.52
2014	0.65	0.66	22.87	61.04	14.78
2019	0.69	0.68	23.06	58.17	17.40

Source: Elaborated by the authors.

Table 4. SAVI vegetation cover percentage for each analyzed class.

Year	Percentage (%)				
	Class I	Class II	Class III	Class IV	Class V
1984	0.61	42.37	55.97	1.05	0.00
1989	0.66	40.45	57.76	1.13	0.00
1994	0.67	29.63	68.77	0.94	0.00
1999	0.56	60.39	38.71	0.34	0.00
2004	0.70	36.66	62.28	0.35	0.00
2009	0.53	40.90	58.04	0.53	0.00
2014	0.65	15.45	74.78	9.11	0.00
2019	0.69	10.34	79.71	9.26	0.00

Source: Elaborated by the authors.

For each polygon analyzed, two NDVI time series plots were created (Figure 6), corresponding to the warmest season (January, February, and March) and the coldest (June, July, and August). The agricultural polygon had an average NDVI of 0.520 for the warmest period and 0.592 for the coldest period. In the cocoa area, cocoa cultivation is carried out according to the Cabruca, with NDVI averages of 0.745 and 0.786 for the warmest and coldest periods, respectively.

The third studied region corresponds to a eucalyptus plantation for pulp production. Here, NDVI mean values of 0.664 and 0.668 were obtained for the warmest and coldest periods. The forest polygon is located in the Serra do Conduru State Park. For this region, average values of 0.697 were obtained for the warmest period, with some negative values in 1987, 1990, 2008 and 2011, and 0.742 for the coldest period. These negative values may be associated with the presence of clouds, smoke, dust, fog or calibration errors in the sensors, which may interfere with the capture of satellite images.

The grazing analysis focused on a cattle farm, and the NDVI averages were 0.589 in hot periods and 0.569 in cold periods.

The relative standard deviation analysis revealed that cocoa cultivation during the coldest period exhibited the lowest data dispersion (13.953%), indicating homogeneity. Conversely, forest areas during the hottest period showed the highest dispersion (33.741%), attributed to isolated negative NDVI values, leading to greater heterogeneity. Other regions displayed average dispersion, with eucalyptus and pasture areas exhibiting greater dispersion across both periods. For the ANOVA, p-value of 0.0048, below 0.05, indicates statistically significant differences in NDVI between land use groups. The Tukey HSD test showed, through pairwise comparisons between different land uses, that the significant differences are: Cacao cabruca vs. Pasture (0.015), Agriculture vs Cacao cabruca (0.029) and Forest vs. Pasture (0.029).

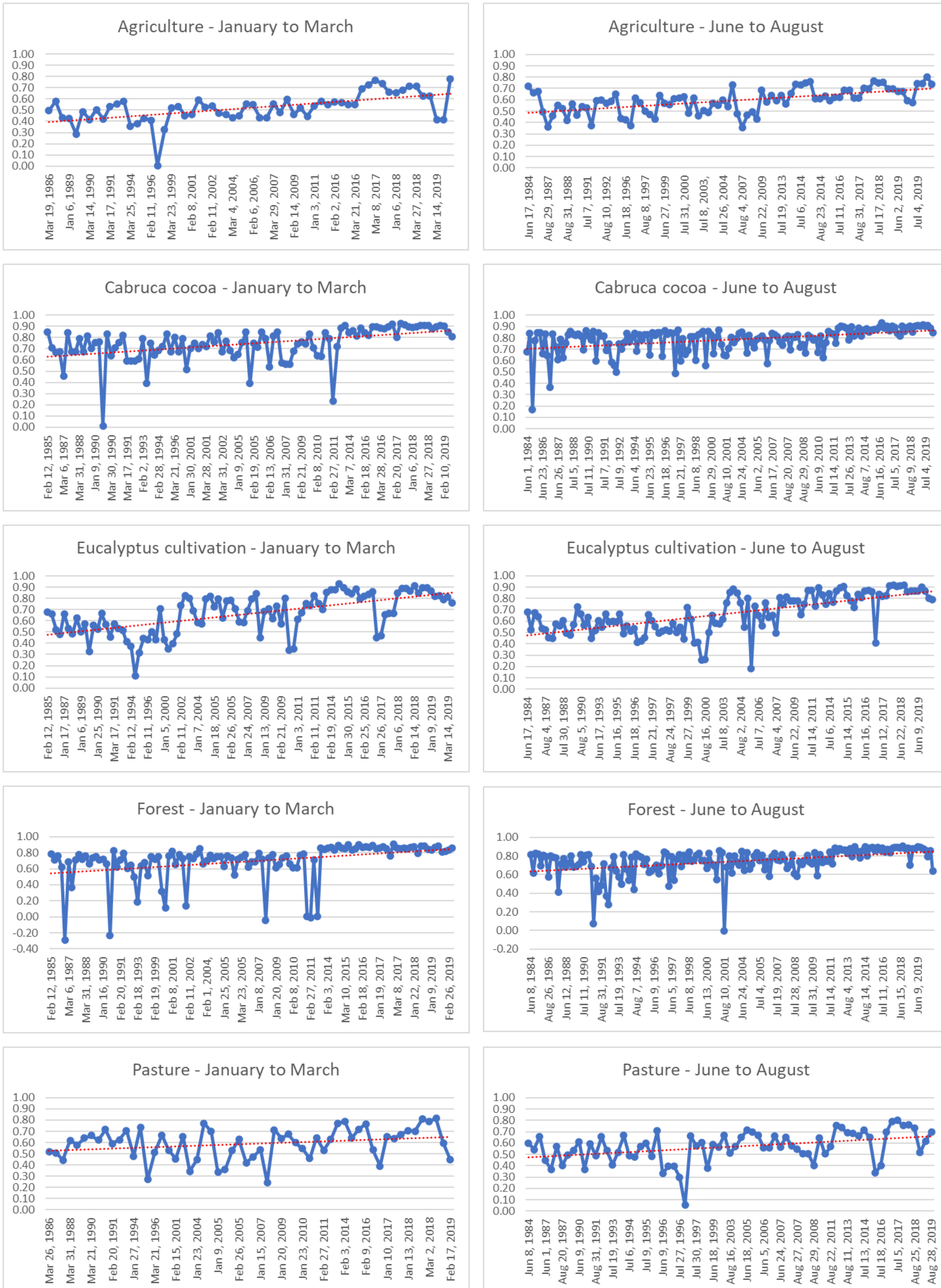

Figure 6. NDVI time series plots for each polygon analyzed.

Source: Elaborated by the authors.

4. DISCUSSION

Changes in NDVI over time could be identified. In 1984, most of the vegetation cover in the region fell into class III (low NDVI index), followed by class IV (moderately low index). In 1989, there was a small reduction in vegetation density. For 1994, there was an increase in vegetation density, according to Almeida & Teixeira (2010), the area of forests and planted forests in southern Bahia grew significantly in these years, indicating an increase in reforestation activity in the region. A sharp decrease in vegetation was observed from 1999 onwards, with very low and low coverage rates. A significant decrease in dense vegetation was observed. Also according to Almeida and Teixeira (2010), despite the increase in planted forests, there was a reduction in the area of forests and natural forests in the region, reflecting the deforestation of the Atlantic Forest, initially caused by the exploitation of loggers and farmers.

In 1984, the vegetative index of the region was higher than in 1999. This lower vegetative vitality is more pronounced in the communities of the south coast dedicated to cacao cultivation and in the areas of the extreme south dedicated to forestry, which is consistent with the statements of Blinder (2005), who analyzed the fragmentation of the Atlantic Forest in 1975 and 1995. The author notes that cocoa cultivation in the southern region decreases anthropization compared to the extreme south, where activities like cattle ranching, logging, and eucalyptus forestry transform vegetation extensively. According to Blinder (2005), this region still retains significant remnant areas of Atlantic Forest, and it is also the region where forest reserves are being rapidly converted to other uses. Almeida & Teixeira (2010), highlights the significant reduction in natural vegetation, especially in woodlands and natural forests, during the 1990s in the extreme south of Bahia.

Cavalheiro et al. (2022) state that the impact of eucalyptus plantations varies based on pre-existing conditions. Converting pastures to eucalyptus can benefit fauna, but clearing native forests for eucalyptus cultivation can have adverse effects.

In 2004, an increase in vegetation was observed compared to 1999, and a slight decrease in 2009. In 2014, there was a transition from low vegetation to denser vegetation, culminating in 2019 with a significant increase in vegetative vigor compared to 2014.

According to Barbosa & Buriti (2021), vegetation is an indicator of environmental conditions, as well as properties that influence climate, hydrology, the biogeochemical cycle and the energy balance of many ecosystems. The annual average NDVI series showed a vegetation density of 0.354 in 1999 and a peak of 0.568 in 2014, showing an upward trend. This increase may be linked to the creation of protected areas throughout the region, such as the RPPN das Nascentes and Lagoa Encantada in the south and the RPPN Bozi in the extreme south. Santos & Nunes (2015), in their study of land use and land cover in environmental protected areas (APAs) in the state of Goiás, found that even UCs without management plans or unit management played an important role in the conservation of native vegetation.

Higher vegetation rates were found in reforestation and conservation areas, while lower rates were linked to deforestation and conversion to eucalyptus plantations. Overall, vegetation density fluctuated significantly, with a recent increasing trend due to conservation initiatives.

Similar behavior to the NDVI was observed for the EVI, with vegetation cover mostly between the III and IV classes of mean vegetation cover. The annual EVI averages were similar to those found in the NDVI. Dias (2017) notes that EVI is more sensitive to variations in canopy structure in regions with higher biomass production. EVI responds more sensitively to changes in land cover. Variations in indices are influenced by several factors, which depend on the characteristics of the vegetative environment during the growth period. The introduction of eucalyptus and cocoa cultivation in some regions may be responsible for the increasing trend in EVI (Silva Junior et al., 2021).

The SAVI index had lower values compared to the other indices, not exceeding 0.75, and its coverage varied between the II and III classes. Gomes et al. (2013), in their study, state that low SAVI values indicate sites with high values of basal area, biomass and volume, due to a greater or lesser amount of shade due to canopy structure. Furthermore, the introduction of eucalyptus cultivation, the processes of removal of native forest, introduction of eucalyptus cultivation and reforestation with the introduction of cocoa in certain areas may have contributed to the lower values, in addition to their correction for the soil effect, which can reduce index values.

NDVI showed a growth trend over the years in the warmer period for the agricultural region from 1984 to 2019, and the same behavior was observed in the colder period. In the municipality of Porto Seguro, characterized by a humid and humid to sub-humid climate, the average values obtained for both cases (0.520 and 0.592) indicated the presence of low to moderately low vegetation.

Despite the upward trend in both cases, there was a subtle difference in the trend line, with a slightly higher onset for the colder period compared to the warmer period. The Cacao cabruca area also showed a growth trend over the years for the two periods analyzed, although this showed less variation and a more constant trend compared to the agricultural environment. This is due to the planting, growing, and harvesting periods in the agricultural plantations. Silva et al. (2019) states that it is possible to understand that the planting period, harvest time, plant development, as well as when they suffer from a period of drought, influence NDVI values. The average values for warm and cold periods (0.745 and 0.786, respectively) indicate denser vegetation at this site, expressing the lower impact of intercropping cocoa and native forest compared to conventional plantations. Anyimah et al. (2021) indicate that the temporal pattern of cocoa NDVI is influenced by occurrence patterns and soil moisture, impacting vegetation.

The polygon corresponding to eucalyptus cultivation showed a growth trend, with a greater variation of this growth. Unlike the other studied areas, which showed at least a small difference, this region showed a very similar growth trend in the two studied periods (warm and cold). This influence could be related to the production cycle of eucalyptus, which requires a period of 5 to 7 years to be suitable for pruning, and to the fact that it adapts easily to soil and climate modes (Feitoza et al., 2017). The average values of 0.664 and 0.668 (moderately low vegetation) for the warm and cold periods, respectively, reinforce the understanding that climate problems in the region do not affect the growth cycle of eucalyptus. Oliveira et al. (2021), in their study on changes in land use and occupation in the municipality of Eunápolis, detected that the eucalyptus areas were those that obtained the most significant gains in land use, expanding, especially, in the old pasture areas.

The forest region showed an increasing NDVI trend, with greater data uniformity during the colder period than the warmer period. Average NDVI values were 0.697 (hot period) and 0.742 (cold period), indicating lower vegetative vitality during higher temperatures. Despite this, both averages suggest good forest maintenance, likely due to the state park's implementation. Rosemback et al. (2010), in a study of vegetation cover in Southern Brazil, found that the NDVI values of the Dense Ombrophilous Forest remained stable throughout almost the entire year and the highest values occurred at the beginning of the year, in summer and autumn. Berveglieri et al. (2021) states that changes in successional stages are characterized by variations in the structure of the canopy, thus, the larger canopy of trees in the Dense Ombrophilous Forest provides higher and more stable NDVI values throughout the year.

In the pasture area, a growth trend was observed in the time series in both situations, although this occurred at lower NDVI indices, similar to the agricultural polygon. According to Pavão et al. (2017), lower NDVI values are found in pastoral and urban areas, which is due to the lower density of vegetation distribution in these areas. With average values of 0.589 (hot period) and 0.569 (cold period), characteristic of low to moderately low vegetation, this region was responsible for the lowest averages, possibly since it is degraded pasture most of the time. According to Serrano et al. (2021) in degraded pastures it is common to observe lower NDVI values compared to healthy pastures. Being an indication of the reduction in the quality and health of pastures, reflecting the loss of vegetation cover, species diversity and vegetative vigor in these areas.

The agricultural polygon showed some annual variation in its average, which, according to Vicente et al. (2012), in plantation areas are related to the phenological cycles of the target plants associated with the growing and harvesting phases. In contrast, forest and pasture areas showed less variation, with pasture areas showing smaller amplitudes of variation.

A statistical analysis shows that there are significant differences in NDVI between some land uses. These differences suggest that land use has a real impact on the area's vegetation index, observed mainly between forest and cacao areas, compared to agriculture and pasture.

5. CONCLUSIONS

There has been a significant increase in the region's vegetation cover over time. It was possible to observe that there was a reduction in vegetation cover in the region until 1999, this being the year with the lowest coverage rate. However, after this reduction, there was an increase in vegetation in subsequent years.

The NDVI and EVI indices showed similar behavior in determining the vegetation cover of the region, in contrast to the SAVI index, which showed the greatest difference with lower annual averages compared to the other indices.

The dynamics of vegetation cover of cacao cultivation in a Cabruca system is similar to that in forest areas, with higher NDVI average values. The areas identified as forest and cabruca had the highest average values of their indices, compared to the other areas that had other land uses, such as pasture and eucalyptus.

In most cases analyzed, average NDVI values are higher during colder temperatures due to increased soil moisture, favoring plant growth. However, pastures exhibit higher average values in the hot season, indicating peak vegetative activity facilitated by favorable climate conditions and abundant water and sunlight, attributed to pasture management practices.

This study may be useful in understanding changes in vegetation cover over the years, the impacts on regional development and quality of life, and assist in the development of sustainable land use strategies, such as reforestation and conservation.

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CORRESPONDENCE TO

Andrêssa Pereira de Jesus

Universidade Estadual de Santa Cruz, Programa de Pós-graduação em Desenvolvimento Regional e Meio Ambiente, Rod. Jorge Amado, Km 16, CEP 45662-900, Ilhéus, BA, Brasil.

e-mail: andressap0803@gmail.com

AUTHORS' CONTRIBUTIONS

Andrêssa Pereira de Jesus: Data curation (Equal), Investigation (Equal), Methodology (Equal), Software (Equal), Writing – original draf (Equal).

Roberto Ferreira Machado Michel: Conceptualization (Equal), Methodology (Equal), Supervision (Equal), Writing – review & editing (Equal).

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