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Papers

# Drivers of vulnerability to climate change in the southernmost region of Bahia (Brazil)

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**Abstract**
The region that comprises the Atlantic Forest is one of the most degraded areas of the planet, being especially vulnerable in climate change scenarios, which project a mean temperature increase between 2ºC and 3ºC by 2070 for the Brazilian Northeast region. This article aims to analyze the main drivers of socio-environmental vulnerability in the Atlantic Forest region that comprises the southernmost identity territory of Bahia (Brazil) and their potential consequences for coping with climate change. To this end, historical data on land use and occupation was spatialized and evaluated, along with socioeconomic indicators and legal environmental adequacy in the municipalities that make up this territory. The results indicate four structural drivers that generate regional vulnerabilities: the persistence of deforestation; the continuous expansion of monoculture areas; the maintenance of low levels of well-being of the population; as well as a picture of legal environmental liabilities. Based on the analysis of these data, strategies are proposed to increase the adaptive capacity to climate change in this region, especially considering the role of municipalities as a central actor in the implementation of adaptation actions by incorporating into their existing planning instruments indicators and strategies that address the multiple current challenges, especially when the federal government seems to be neglecting climate change.



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## INTRODUCTION

In the context of climate change, the adaptive capacity of the Atlantic Forest is compromised, as well as that of the associated social systems (BELLARD *et al.*, 2014; LAPOLA *et al.*, 2014; SCARANO; CEOTTO, 2015; SCARANO, 2017). The loss and fragmentation of habitats, for example, hinder eventual adjustments of organisms and ecosystems to the new climatic conditions (IPCC, 2014; BUSTAMANTE *et al.*, 2019), and may also reduce the supply of ecosystem services to human populations (FISHER *et al.*, 2014; REZENDE *et al.*, 2018b; PIRES *et al.*, 2018).

Climate change introduces new challenges to the territories, in addition to the intensification of existing vulnerabilities, especially in developing countries, where there are poor infrastructure and state regulatory frameworks, as well as economic dependence on the exploitation of natural resources (ADGER *et al.*, 2006; MAGRIN *et al.*, 2014). For the ends of this work, vulnerability is considered to refer to the degree to which a system is likely or unable to cope with the adverse effects of climate change due to climate variability and the occurrence of extreme events and their consequences (IPCC, 2014).

Many studies have shown the relationship between changes in land use and the various dimensions of vulnerability, especially with regard to water and vegetation (PERUCHI TREVISAN et al., 2020), ecosystem services (METZGER et al., 2006), fauna in contexts of climate change (REECE et al., 2013; ZHAO et al., 2019), and human populations (HALLEGATE *et al.*, 2016; ALVES, 2021).

Forests are important elements for adaptation and resilience strategies, since their ecosystem services guarantee water supply and climate regulation, among others (IPBES, 2019; SCARANO, 2017; REZENDE *et al.*, 2018b). The conversion of forests into conventional productive systems can lead, in the short and medium-term, to an improvement in traditional indexes of measurement of development, such as an increase in Gross Domestic Product (GDP) and an improvement in the Human Development Index (HDI). However, such practices are established based on a pattern of territory occupation that is highly degrading of nature and that has shown to be unsustainable in the long run, in addition to generating greater social and climatic disturbances (ABRAMOVAY, 2010; SILVA *et al.*, 2017).

Projections indicate that Brazil will be affected by climate change, with a mean temperature increase of 2°C to 3°C by 2070, reaching mainly the Midwest, North and Northeast regions (SALAZAR *et al.*, 2007; PBMC, 2014). In the last decade, the country has experienced some water restriction events in urban areas located in the Atlantic Forest, such as the states of São Paulo and Bahia (ESCOBAR, 2015; MARENGO *et al.*, 2018), which could be amplified in climate change scenarios.

Deforestation in the Atlantic Forest persists, having grown almost 28% between 2018 and 2019, and in the state of Bahia the rate of growth in deforestation compared to the previous period was 78% (SOS MATA ATLÂNTICA, 2020). The southernmost territory of the state of Bahia still holds the largest Atlantic Forest remnants in the state, having experienced pronounced population and economic growth in recent decades while changing land use and occupation (AMORIM; OLIVEIRA, 2007). Thus, understanding these indicators from a historical perspective will enable the evaluation of the vulnerabilities and adaptation potentials of this territory in the context of climate change, contributing to the debate on public policies aimed at sustainability.

This article aims to analyze the main drivers of socio-environmental vulnerability in the territory of the Atlantic Forest in southernmost Bahia (Brazil) and their potential consequences for facing climate change. For this, historical data on land use and occupation, socioeconomic indicators and legal environmental debt were assessed in the municipalities that make up this territory.

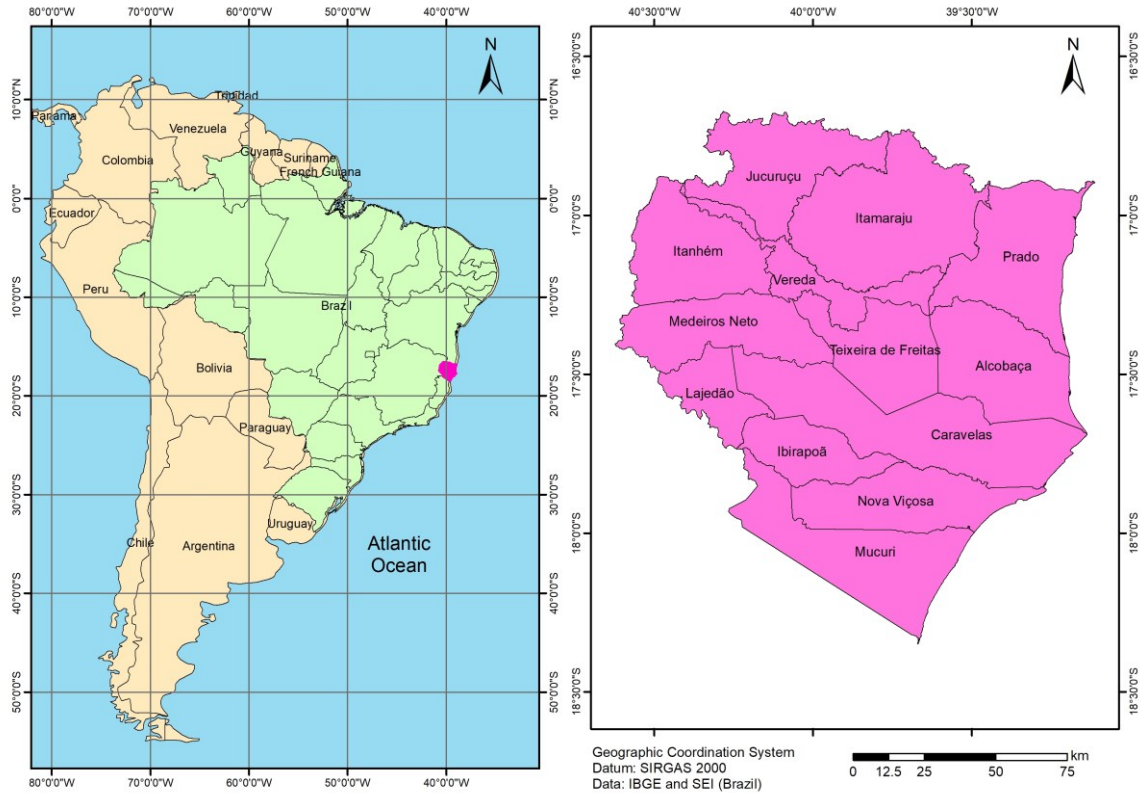
## MATERIALS AND METHODS

### *Study area*

The southernmost identity territory of the state of Bahia is inserted in the Atlantic Forest biome of northeastern Brazil and has a total area of 18,535.98 km² (Figure 1). It is composed of 13 municipalities, limiting to the East with the Atlantic Ocean, and houses an estimated population of 416,859 inhabitants (319,483 urban and 97,376 rural), which contribute nearly 3% to Bahia's GDP (SEI, 2015). The main sectors of the regional economy are trade and services (56%), agriculture and livestock (25%) and industry (19%). The municipalities of Teixeira de Freitas and Mucuri concentrate

48.9% of the regional GDP, due to the trade and services sector in the first and to the cellulose and paper industry in the second (SEI, 2015).

Figure 1 - Municipalities of the southernmost identity territory of Bahia (Brazil).




Source: The authors (2021).

### *Land use and occupation*

Land use and occupation data were obtained from the Bahia Forest Forum, which made a database available for the years 1990 to 2018, on a 1:25,000 scale in *shapefile* format. These data were spatialized and analyzed using the software ArcGIS 10.4. The classes were grouped and classified as follows: natural forest, forestry (mainly *Eucalyptus sp.*), pastures, agriculture, and other uses (which includes rock outcrops, roads, water bodies, urban areas, and other infrastructures). The natural forest class includes areas with fragments larger than 18 hectares, encompassing primary and secondary forests, mangroves, *restingas* and *muçunungas*. The agriculture class includes annual and perennial crops. The pasture class includes managed and extensive pastures.

The main changes in land use and occupation were evaluated based on the percentage of variation and distribution of classes in the territory. The forest deficit was calculated based on the percentage of existing natural forest in each municipality in 2018, considering that this entire region was originally covered by the Atlantic Forest biome (2.5% of the municipal area for infrastructure, rock outcrops and water bodies).

### *Socio-economic indicators*

The socio-economic indicators of the municipalities were collected from public databases, namely: municipal GDP (2010 and 2017), per capita GDP (2017), mean salary (2017) (IBGE, 2020b) and Firjan Index of Municipal Development (FIMD) (FIRJAN, 2018) as a well-being indicator at the local level for the years 2005 and 2016.

The FIMD was generated annually for all Brazilian municipalities from 2005 to 2016 (the last year it was published), using official standard indicators produced by the Brazilian government, and sought to represent socioeconomic well-being through three essential components of human well-being: employment and income, education, and health. The complete methodology is described by FIRJAN (2018).

To understand the level of relationship between the socioeconomic variables (FIMD and

the workers' mean wages in each municipality) and land use and occupation (percentage of coverage of natural forest, forestry, pasture and agriculture), data normality analysis was performed, as well as a subsequent correlation analysis. For the variables with normal distribution, Pearson's simple correlation analysis (r) ($P < 0.05$) was performed, while for the variables that did not follow normal distribution, Spearman's simple correlation analysis was performed (p) ($P < 0.05$). Finally, a cluster analysis was performed by behavioral and spatial similarity to find spatial patterns, using spatial contrast by closest neighbors, calculated by Euclidean distance, which grouped the municipalities in high, medium and low values for each variable.

### *Legal environmental debt*

For the analysis of the legal environmental debt, the data referring to the situation of the *Área de Preservação Permanente – APP* (Permanent Preservation Area and *Reserva Legal – RL* (legal reserve), both instruments of the Federal Law No. 12,651/2012 (BRASIL, 2012), were extracted from the State System of Environmental Information of the government of the state of Bahia, through the analysis of the *Cadastro Ambiental Rural* - CAR (Rural Environmental Registry) until June 2020. These data are related to rural properties whose owners have signed *Termos de Ajustamento de Conduta – TAC* (Conduct Adjustment Terms) with the Regional Environmental Public Prosecutor's Office of Teixeira de Freitas. They refer to environmental irregularities in the eucalyptus forestry activity in the study area. These data were analyzed by municipality to assist in understanding the regional legal environmental debt.

## RESULTS

### *Land use and occupation*

The southernmost region of Bahia has 28% of its area covered by natural vegetation, mainly comprising forests in initial, medium, and advanced stages, as well as mangroves, *muçununga*s, trees, shrubs and herbaceous *restinga*, rupestrian fields, wetlands and floodplains (Figure 2). Two-thirds of the region, approximately 71.5%, are covered by non-natural categories, with cattle pastures occupying 47%, eucalyptus monocultures covering 18%, and agriculture 4% of the region, considering perennial crops, sugar cane, coffee and citrus. The remaining 2.5% is occupied by urban and highway infrastructure, rock outcrops and water bodies.

The native vegetation is concentrated in the northeasternmost and easternmost areas of the region, which correspond to the most coastal areas (Figures 2 and 3). The *Unidades de Conservação – UC* (Protected Areas) and indigenous lands of the region are in this area. Among them, there are the National Parks *Parque Nacional do Descobrimento* and *Parque Nacional Marinho dos Abrolhos*, in addition to the *UC*s for sustainable use of natural resources *Reserva Extrativista (RESEX) de Cassurubá*, *RESEX Marinha do Corumbau* and the *Área de Proteção Ambiental Ponta da Baleia/Abrolhos* (MAPES, 2021).

Forestry and pastures have increased their areas in the last thirty years by 131% and 10%, respectively (Figure 2, Table 1). Conversely, native vegetation and agriculture reduced their occupation areas by 34% and 11% in the same period.

The same historical pattern that occurred for the entire region is reproduced internally in each municipality in relation to the increase in forestry areas and the reduction of natural vegetation areas. For some municipalities, the forestry areas have increased by more than a thousand percent in the last thirty years (Ibirapuã and Lajedão). Currently, Alcobaça, Caravelas, Mucuri and Nova Viçosa present forestry in more than 30% of their territories, reaching 50% of the Nova Viçosa area. Municipalities in the westernmost portion of the region (Medeiros Neto, Jucuruçu and Itanhém) did not have any eucalyptus area in 1990; however, all of these municipalities present them today, covering 4% of the Medeiros Neto territory.

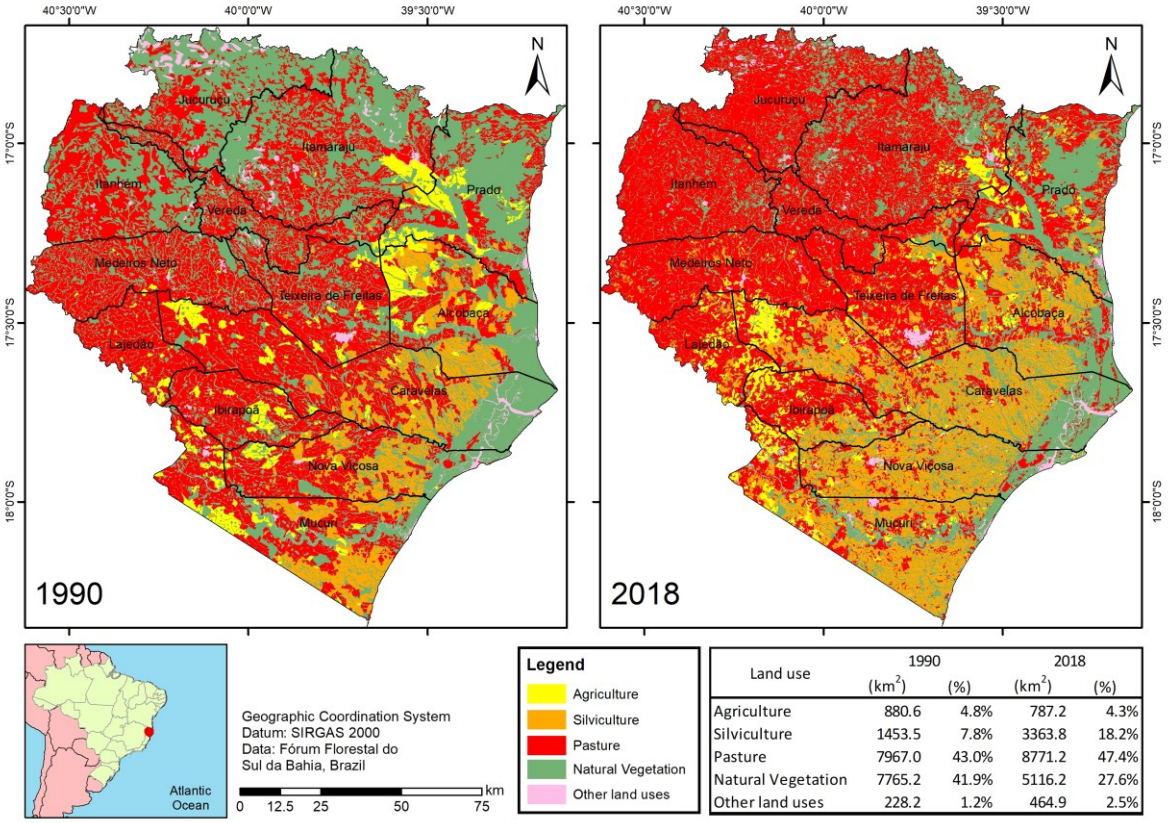
The pattern of reduction of the natural vegetation in all municipalities is more evident in Itanhém, Jucuruçu, Medeiros Neto and Teixeira de Freitas, which have lost more than 50% of their natural vegetation areas in the last 30 years. The most illustrative case of this process of degrading natural ecosystems occurred in Jucuruçu, where native forests covered 65% of the territory in 1990, having reached only 23% of forest areas in 2018.

**Table 1 -** Land use and occupation in the municipalities of southernmost Bahia from 1990 to 2018 (km²).

| Municipalities | Agriculture | | | Silviculture | | | Pasture | | | Natural vegetation | | | Other land uses | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 2018 | Var[a] | 1990 | 2018 | Var[a] | 1990 | 2018 | Var[a] | 1990 | 2018 | Var[a] | 1990 | 2018 | Var[a] |
| Alcobaça | 10.95 | 3.88 | -64.60 | 25.30 | 35.07 | 38.62 | 23.63 | 23.67 | 0.18 | 39.12 | 35.32 | -9.74 | 0.82 | 1.90 | 132.29 |
| Caravelas | 5.07 | 5.35 | 5.49 | 14.78 | 36.46 | 146.68 | 42.50 | 21.01 | -50.57 | 35.74 | 33.94 | -5.05 | 2.01 | 3.29 | 64.20 |
| Ibirapuã | 8.94 | 12.23 | 36.80 | 1.48 | 18.74 | 1166.08 | 63.26 | 49.24 | -22.16 | 25.32 | 18.16 | -28.28 | 0.28 | 1.57 | 461.68 |
| Itamaraju | 3.34 | 3.26 | -2.63 | 0.15 | 0.70 | 368.63 | 37.03 | 59.72 | 61.26 | 56.01 | 34.50 | -38.40 | 0.73 | 1.77 | 144.13 |
| Itanhém | 0.00 | 0.09 | - | 0.00 | 0.12 | - | 54.83 | 80.20 | 46.28 | 44.15 | 18.62 | -57.83 | 0.29 | 0.98 | 235.16 |
| Jucuruçu | 0.00 | 0.03 | - | 0.00 | 0.33 | - | 28.42 | 72.80 | 156.17 | 64.89 | 23.23 | -64.20 | 0.18 | 3.60 | 1852.71 |
| Lajedão | 4.95 | 14.89 | 200.65 | 0.04 | 8.75 | 20000.44 | 76.42 | 65.45 | -14.36 | 17.44 | 9.44 | -45.88 | 0.36 | 1.28 | 259.53 |
| Medeiros Neto | 0.81 | 1.86 | 130.27 | 0.00 | 4.32 | - | 65.21 | 81.36 | 24.76 | 31.26 | 10.53 | -66.32 | 1.95 | 1.93 | -0.77 |
| Mucuri | 8.65 | 7.93 | -8.26 | 22.01 | 39.72 | 80.43 | 38.20 | 22.05 | -42.27 | 28.52 | 26.75 | -6.21 | 1.83 | 3.16 | 72.42 |
| Nova Viçosa | 3.74 | 2.13 | -43.02 | 21.28 | 50.10 | 135.49 | 39.00 | 13.14 | -66.31 | 33.52 | 30.83 | -8.03 | 2.35 | 3.70 | 57.31 |
| Prado | 9.28 | 5.31 | -42.82 | 0.89 | 6.57 | 637.05 | 25.81 | 36.80 | 42.55 | 62.66 | 49.14 | -21.58 | 1.12 | 2.05 | 82.72 |
| Teixeira de Freitas | 3.57 | 4.11 | 15.17 | 1.47 | 15.55 | 954.59 | 56.75 | 62.04 | 9.31 | 35.47 | 13.49 | -61.97 | 1.96 | 4.76 | 142.93 |
| Vereda | 0.82 | 0.65 | -20.39 | 0.75 | 4.64 | 518.08 | 56.22 | 72.24 | 28.49 | 40.34 | 21.17 | -47.53 | 1.16 | 1.26 | 8.29 |
| TOTAL | 4.76 | 4.25 | -10.60 | 7.85 | 18.16 | 131.43 | 43.02 | 47.36 | 10.09 | 41.93 | 27.63 | -34.11 | 1.23 | 2.51 | 103.75 |

[a]Percentage variation among the periods analyzed.
Source: The authors (2021).

Figure 2 - Historical change for the main classes of land use and occupation in southernmost Bahia for 1990 and 2018.




| Land use | 1990 | | 2018 | |
|---|---|---|---|---|
| | (km²) | (%) | (km²) | (%) |
| Agriculture | 880.6 | 4.8% | 787.2 | 4.3% |
| Silviculture | 1453.5 | 7.8% | 3363.8 | 18.2% |
| Pasture | 7967.0 | 43.0% | 8771.2 | 47.4% |
| Natural Vegetation | 7765.2 | 41.9% | 5116.2 | 27.6% |
| Other land uses | 228.2 | 1.2% | 464.9 | 2.5% |

Source: The authors (2021).

The largest increases in pasture areas occurred in municipalities that already had large areas in 1990, such as Jucuruçu, Itamaraju and Itanhém (Table 1, Figure 2). In 2018, pastures occupied more than half of the areas of these municipalities, as well as in Lajedão, Teixeira de Freitas and Vereda, reaching 81% of the Medeiros Neto area. There was a reduction in pasture areas in the municipalities of Nova Viçosa, Caravelas, Mucuri, Ibirapoã and Lajedão.

The areas used for agriculture were reduced by 11% in the same period across the region. Lajedão, for example, increased its agricultural area by two hundred percent, while Alcobaça had a 65% reduction.

The class "other land use" has increased by one hundred and three percent in the last thirty years, currently corresponding to 2.5% of the territory, due to the increase in urban areas and associated road infrastructures.

In 2018, pastures continue to occupy most of the territory, having increased their overall participation by 10% in the last 30 years. There was a migration of this activity to the northwesternmost portion of the region, to the municipalities of Itanhém, Jucuruçu and Itamaraju, having reduced its participation in more southern municipalities, such as Caravelas, Nova Viçosa and Mucuri, which were occupied by forestry. This general panorama shows that pastures occupied areas that thirty years ago comprised remnants of natural vegetation. At the same time, in more southern areas, forestry has expanded, strongly increasing its presence in these municipalities.

Regarding the deficit of natural forests, the municipalities of Ibirapuã, Itanhém, Lajedão, Medeiros Neto and Teixeira de Freitas have natural vegetation coverage values close to or below 20% of the municipal areas (Table 1).

### *Socio-economic indicators*

The municipalities have a mean population density of 25 inhabitants/km², with Teixeira de Freitas being the most densely populated with 138 inhabitants/km² and Jucuruçu the least densely populated municipality with 6 inhabitants/km² (IBGE, 2020b). In the 2010-2019 period, the population of the region grew in almost all municipalities, with a regional mean of 8%, which indicates a trend of recent population increase (Table 2).

The local economic activities that contribute the most to the GDP are agriculture and services, with the industry being a sector of punctual expression, with prominence only in two municipalities, which develop cellulose exports (Mucuri), dairy production and an ethanol plant (both in Ibirapuã). Between 2010 and 2017, regional GDP increased by 68%, considering the sum of the municipal GDPs in the southernmost region.

In general, the municipalities showed growth in their per capita GDPs in the 2014-2017 period (except for Jucuruçu and Lajedão) and, in all cases, the per capita GDP in the municipalities is higher (regional mean of nearly R$ 16,000 or US$ 4,848) than the population's mean salary (mean of 1.8 minimum wages), with higher values in Mucuri and Ibirapuã. In 2017, the national minimum wage corresponded to R$ 937 or US$ 284.00 The increase in the per capita GDP does not reflect the mean monthly salary of formal workers in the 2014-2017 period, with an inverse movement (increase in per capita GDP and reduction in the mean salary) in Ibirapuã, Nova Viçosa, Prado and Teixeira de Freitas, and mean wage stagnation with a drop in the per capita GDP in Jucuruçu and Lajedão (Table 2). Also, there was a reduction of nearly 2% in the rate of the employed population considering the entire region in the same period (2014-2017).

The well-being index FIMD increased in all the municipalities between 2005 and 2016 (Table 2), indicating a general improvement in the population's well-being. In 2005, the mean FIMD in the region was 0.46, having increased to 0.58 in 2016, which kept the region in the range of regular development.

**Table 2** - Main socio-economic indicators of the thirteen municipalities that make up southernmost Bahia.

| Municipalities | Population 2019 | Population density 2019 (hab/km²) | Municipal GDP 2010 (R$ milhões) | Municipal GDP 2017 (R$ milhões) | Mean salary[a] 2017 | Per capita GDP 2017 (R$) | Employed population 2014 (%) | Employed population 2017 (%) | FIMD (2005) | FIMD (2016) |
|---|---|---|---|---|---|---|---|---|---|---|
| Alcobaça | 22,470 | 15.16 | 179.46 | 264.12 | 1.80 | 11,298.81 | 6.8 | 6.7 | 0.393 | 0.546 |
| Caravelas | 22,016 | 9.26 | 262.80 | 322.13 | 1.80 | 14,165.63 | 8.4 | 10.4 | 0.475 | 0.560 |
| Ibirapuã | 8,637 | 11.20 | 85.17 | 248.67 | 1.70 | 28,091.82 | 17.3 | 18.5 | 0.487 | 0.639 |
| Itamaraju | 64,486 | 27.32 | 491.52 | 873.03 | 1.60 | 12,961.47 | 12.4 | 12.3 | 0.395 | 0.580 |
| Itanhém | 19,405 | 13.92 | 126.61 | 222.44 | 1.60 | 10,850.26 | 6.7 | 6.9 | 0.422 | 0.619 |
| Jucuruçu | 9,126 | 6.26 | 83.50 | 95.04 | 1.40 | 9,576.40 | 5.7 | 7.0 | 0.407 | 0.468 |
| Lajedão | 3,955 | 6.33 | 33.22 | 54.63 | 1.50 | 13,429.57 | 35.2 | 9.3 | 0.509 | 0.607 |
| Medeiros Neto | 22,680 | 17.29 | 160.95 | 327.33 | 1.50 | 13,878.32 | 10.8 | 11.4 | 0.531 | 0.570 |
| Mucuri | 41,748 | 23.35 | 1,264.67 | 1,976.30 | 3.40 | 46,974.21 | 18.3 | 19.0 | 0.489 | 0.627 |
| Nova Viçosa | 43,376 | 32.95 | 273.96 | 480.31 | 2.00 | 10,903.17 | 15.7 | 14.4 | 0.475 | 0.535 |
| Prado | 28,174 | 16.69 | 255.39 | 435.60 | 1.60 | 14,853.81 | 9.5 | 10.4 | 0.424 | 0.531 |
| Teixeira de Freitas | 160,487 | 137.68 | 1,302.93 | 2,311.89 | 1.90 | 14,298.26 | 18.1 | 16.7 | 0.599 | 0.663 |
| Vereda | 6,205 | 7.93 | 59.41 | 71.69 | 1.60 | 10,829.05 | 6.1 | 8.1 | 0.396 | 0.547 |
| Total/ Mean | 452,765 | 25.03 | 4,579.58 | 7,683.17 | 1.80 | 16,316.21 | 13.2 | 11.6 | 0.462 | 0.576 |

[a]Minimum wage in 2017: US$ 284.00.

Sources: IBGE (2020a; 2020b); Firjan Index of Municipal Development (FIRJAM, 2018).

### *Legal environmental debt*

1,573 rural properties, whose areas total 4,261 km², are committed to remedying their environmental debts under the supervision of the Public Prosecutor's Office in the southernmost region of Bahia (Table 4). These properties are in all municipalities of the study area, with 975 (62%) of small size, 441 (28%) medium and 157 (10%) large, according to Law No. 8,629/93 (BRASIL 1993). The municipalities with the largest areas of degraded APPs and RLs are Mucuri, Teixeira de Freitas, Caravelas and Nova Viçosa. These values affect more than 4% of the areas of the municipalities of Mucuri and Teixeira de Freitas.

**Table 4** - Legal environmental debt of Permanent Preservation Areas and legal reserve in the municipalities of southernmost Bahia.

| Municipalities | Number of rural properties | Total area of rural properties (km²) | Degraded areas (APP and RL) (km²) | Municipal area (km²) | Degraded areas (APP and RL) as a percentage of the municipality's area |
|---|---|---|---|---|---|
| Alcobaça | 184 | 727,20 | 15,32 | 1,482,29 | 1,03 |
| Caravelas | 362 | 1,091,80 | 45,48 | 2,377,87 | 1,91 |
| Ibirapuã | 69 | 193,40 | 5,83 | 771,10 | 0,76 |
| Itamaraju | 15 | 27,13 | 5,05 | 2,360,29 | 0,21 |
| Itanhém | 9 | 6,22 | 0,08 | 1,394,17 | 0,01 |
| Jucuruçu | 6 | 10,35 | 0,09 | 1,457,86 | 0,01 |
| Lajedão | 8 | 14,90 | 1,51 | 624,35 | 0,24 |
| Medeiros Neto | 34 | 62,28 | 2,50 | 1,311,74 | 0,19 |
| Mucuri | 376 | 1,004,06 | 81,18 | 1,787,63 | 4,54 |
| Nova Viçosa | 336 | 647,25 | 38,30 | 1,316,38 | 2,91 |
| Prado | 62 | 134,03 | 5,39 | 1,687,83 | 0,32 |
| Teixeira de Freitas | 105 | 254,99 | 49,35 | 1,165,62 | 4,23 |
| Vereda | 7 | 88,00 | 9,00 | 782,14 | 1,15 |
| Total | 1,573 | 4,261,63 | 259,09 | 18,519,27 | 1,40 |

Source: The authors (2021).

There is the potential to restore 259 km² of degraded forest areas in southernmost Bahia. Approximately half (49%) of all the partially or totally degraded APP and RL areas are in large rural properties, which correspond to only 10% of the total properties analyzed.

### *Correlation analysis*

The municipalities with the largest forestry areas have smaller pasture areas ($p = -0.87$, $P < 0.001$), larger agriculture areas ($p = 0.60$, $P < 0.05$) and higher mean salaries of the workers ($p = 0.82$, $P < 0.001$) (Table 3). The municipalities with the largest pasture areas, on the other hand, have the lowest mean salaries ($p = -0.78$, $P < 0.01$) and the lowest natural forest coverage ($r = -0.64$, $P < 0.05$). A moderate negative correlation was also found among the municipalities with the largest areas of natural forest cover and the FIMD ($r = -0.57$, $P < 0.05$).

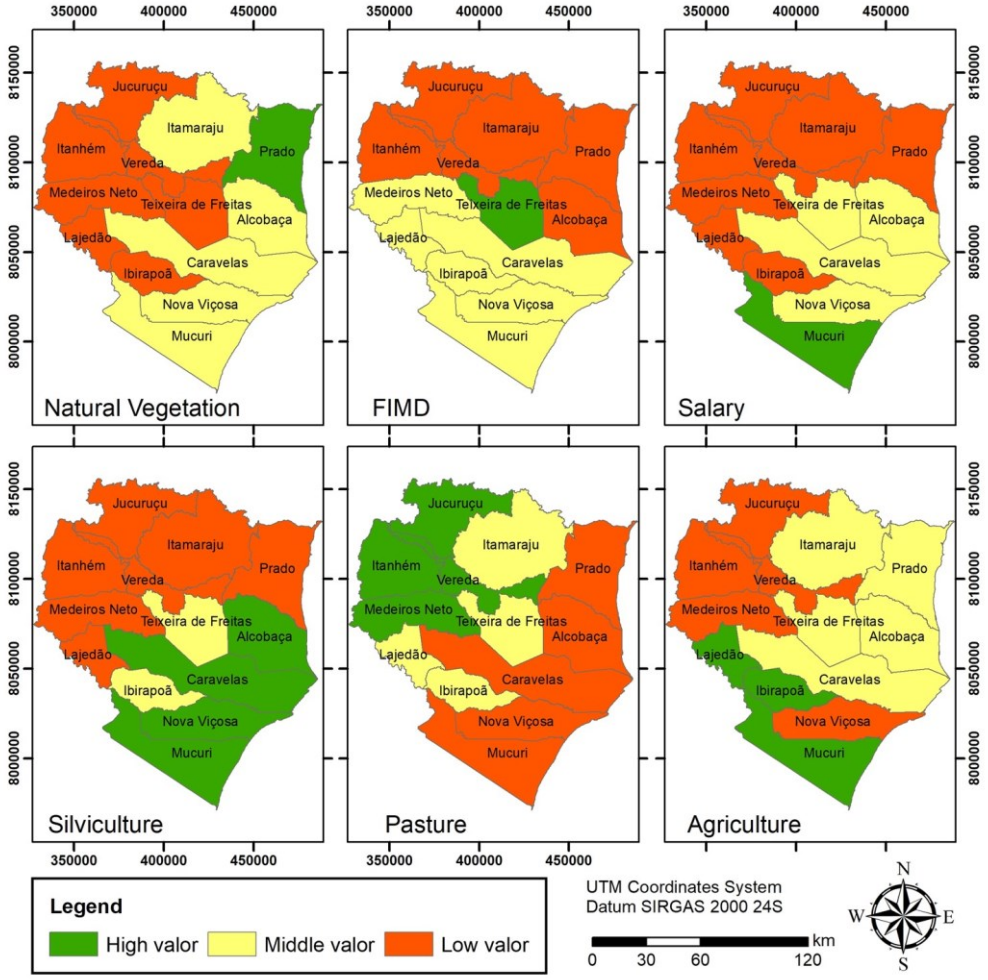
**Table 3** - Pearson (r) and Spearman (p) simple correlations for the land use and occupation and socioeconomic variables.

| | Pearson (r) | | | | Sperman (p) | |
|---|---|---|---|---|---|---|
| | Natural vegetation | Pasture | Agriculture | FIMD[a] | Silviculture | Mean salary |
| Natural vegetation | 1.00 | | | | | |
| Pasture | -0.64[b] | 1.00 | | | | |
| Agriculture | -0.19 | -0.22 | 1.00 | | | |
| FIMD[a] | -0.57[b] | 0.04 | 0.38 | 1.00 | | |
| Silviculture | 0.23 | -0.87[d] | 0.60[b] | 0.30 | 1.00 | |
| Mean salary | 0.31 | -0.78[c] | 0.36 | 0.16 | 0.82[d] | 1.00 |

[a]Firjan Index of Municipal Development; [b]Significant correlation at $p < 0.05$; [c]Significant correlation at $p < 0.01$; [d]Significant correlation at $p < 0.001$. Source: The authors (2021).

Cluster analysis (Figure 3) indicates that the municipalities located in the central-western portion of the region have the smallest areas of natural forest, coinciding with the largest areas of pasture. The highest values of the well-being indicator FIMD are found in the municipalities located in the central-south portion of the region, with the highest value in Teixeira de Freitas. The highest salaries and areas of forestry are found in the municipalities located in the southeast of the region, with the municipality of Mucuri presenting the highest salaries in the region. While the largest areas of agriculture are concentrated in the municipalities in the southernmost portion of the region.

Figure 3 - Cluster analysis for the main land use and socioeconomic variables in the municipalities of southernmost of Bahia.




Source: The authors (2021).

## DISCUSSION

### *Vulnerabilities and potentials of adaptation in southernmost Bahia*

The main drivers of changes in land use and occupation in southernmost Bahia are pastures for cattle, which occupy almost half of the regional area, and eucalyptus forestry, which occupies nearly 18%. These economic sectors are intensive in the use of land, as they transform complex natural systems in terms of biological diversity and ecosystem services into simplified monoculture systems (SOUZA *et al.*, 2020). Taken as a whole, the regional economic activities have disregarded the benefits of the existence of the Atlantic Forest, which contributes to the situation of vulnerability, especially with regard to water and vegetation (PERUCHI TREVISAN et al., 2020), ecosystem services (METZGER et al., 2006), and human populations (HALLEGATE *et al.*, 2016). In recent years, the region has faced water restriction phenomena, which have caused

harms to the economic activities related to agriculture and public supply (VIEIRA, 2016).

The eucalyptus forestry activities in the region increased the participation of Bahia in the country's total exports and boosted the state's economy. As a result, the rural landscape has undergone important changes, expressed in the reduction of the number of agricultural activities and the concentration of land. The reorganization of the local land structure led to a reduction in the number of jobs generated in the countryside and in the participation of family farming, resulting in an increase in the urban population (ALMEIDA *et al.*, 2008). The urban structures of many municipalities have undergone changes in a short time, as manifested in the increase of "other land uses" (Table 1), without the cities having been prepared for it, resulting in swelling of the peripheries and increased occupations in the form of an invasion (CERQUEIRA NETO, 2013).

The positive correlation of the municipalities with larger forestry areas and the workers' mean salary indicates that the eucalyptus forestry industry and the entire associated production chain have contributed to the increase in the total and per capita GDPs of the municipalities (ALMEIDA *et al.*, 2008). This productive chain demands more qualified labor and, therefore, higher wages, unlike the extensive livestock farming practiced in the region, which is in the municipalities with the lowest wages. Recent studies in the Amazon show that livestock dominance is negatively associated with human well-being at the local level due to the use of large areas, low productivity, and demand for labor, in addition to the generation of conflicts in the field (SILVA *et al.*, 2017).

As forestry started to occupy larger areas in the southeasternmost portion of the region, which was previously occupied mainly by pastures (Fig. 3), livestock economic activity in these municipalities seems to have migrated to the municipalities in the northwesternmost portion of the region, which caused an increase in pasture areas and deforestation in the municipalities of Itanhém, Jucuruçu, Vereda and Itamaraju. This phenomenon is similar to "spillover", when an initiative or policy implemented in one region indirectly changes the dynamics of land use and occupation in another adjacent or distant region (MEYFROIDT *et al.*, 2020). In addition to changing the dynamics of the economic activities, this process has caused the reduction of natural carbon stocks through deforestation in the destination area. The expansion of the eucalyptus forestry has occurred especially over the pasture areas in the municipalities of southernmost Bahia. Figures 2 and 3 show that the municipalities of Mucuri, Nova Viçosa, Ibirapuã, Caravelas and Alcobaça have undergone a process of replacing pasture areas with forestry areas in the last 30 years. The agriculture areas do not seem to compete with the eucalyptus areas, as they are more punctual and use less space, maintaining their importance in municipalities such as Mucuri, Ibirapuã and Caravelas, mainly in the westernmost portion of these municipalities, which are the most distant regions from the areas related to the eucalyptus processing chain.

Also, the increase in the regional FIMD from 2005 to 2006 was accompanied by a reduction in the differences among municipalities, which are manifested in the lower variation coefficient in 2016 (0.09) compared to 2005 (0.13), suggesting a convergence of human development indicators in the region. Even so, these values are below the national mean, which in 2016 reached 0.67 (FIRJAN, 2018). This improvement in the human well-being indicators occurred across the country in this period, even if in an irregular and discontinuous manner in many regions, driven by a cycle of national economic growth associated with the international economic dynamics (SILVA et al. 2017). Barberia and Biderman (2010) argue that, due to the size and regional discrepancies of Brazil, it seems that there is not a national convergence process, but several points of balance or multiple development trajectories associated with regional dynamics and characteristics, which demand different adaptation strategies to address the challenges posed by climate change (KASECKER et al. 2017).

Considering the legal environmental debt, there is the potential to restore 259 km² of degraded forest areas in southernmost Bahia. 49% of all the partially or totally degraded APP and RL areas are in large rural properties, which correspond to only 10% of the total properties analyzed. To meet the challenge of forest restoration and inspection, the environmental agencies can direct efforts towards these properties, in order to have more effective results in the short and medium terms. In addition, the restoration of these already mapped and known areas can contribute to the national efforts to mitigate and adapt to climate change, expressed in the UNFCCC, especially in the Paris Agreement (REZENDE et al., 2018b; IPCC, 2019). It is estimated that there is an environmental debt in Brazilian rural properties in the order of 200,000 km² (SOARES-FILHO et al., 2014).

It is worth noting that when registering rural properties in the CAR, the owners declare their state of conservation and those that are partially and totally degraded will require forest restoration actions, although there is the possibility that many areas have been wrongly declared as preserved, also requiring restoration. Data in this study correspond to nearly 10% of all properties registered in the CAR, these being the properties monitored by the Public Prosecutor's Office. That is, the legal environmental debt of the rural properties must be much greater than that presented in this study. According to Rezende et al. (2018b), legal environmental adequacy can be an important factor to assess the adaptability of the territories in contexts of climate change.

Interestingly, the municipalities with the largest natural forest areas have the lowest FIMD values. These municipalities have in their territories the main protected areas of the region (*Parque Nacional do Descobrimento*, *Parque Nacional Marinho dos Abrolhos*, *RESEX Cassurubá* and RESEX *Corumbau*), in addition to other coastal protected areas (MAPES, 2021). This relation needs to be better understood in future studies.

Given all this context, the main structural factors that generate regional vulnerabilities in southernmost Bahia are related to the persistence of deforestation in the Atlantic Forest, which currently occupies less than a third of its original area; to the continuous expansion of monoculture areas (pastures and forestry); and to the maintenance of well-being rates below the national mean values, which is manifested in the discrepancy among the municipalities' per capita GDP, the workers' mean salary and the FIMD well-being indicator. In addition, the legal environmental debt identified suggests that there are failures to comply with the legislation related to forests in the region.

The entire study area presents elements of vulnerability that must be addressed to build adaptive capacity. For planning and prioritizing the use of resources, the municipalities of Itanhém, Vereda and Jucuruçu, located further Northwest of the region, are those that are most vulnerable to climate change due to the overlap of different drivers (Table 1 and Figure 3): smaller natural forest areas, larger pasture areas, lower indicators of well-being (FIMD) an

d salary, and smaller agriculture areas. A second group of municipalities includes Medeiros Neto, Lajedão and Ibirapuã, which also have the smallest natural forest areas, the lowest mean wages and mean FIMD. In addition, according to Rezende *et al.* (2018b), the municipalities of the two aforementioned groups have a deficit of riparian vegetation above 60%, reaching more than 80% in Vereda, Itanhém, Medeiros Neto and Lajedão.

The challenges posed by the current territorial context and those resulting from climate change must be addressed from the perspective of "multi solving strategies", that is, strategies that seek to deal with several and complex problems at the same time. The consolidation and expansion of the protected areas and their interconnection through ecological corridors in the region represent an important step towards the reduction of regional environmental vulnerabilities, especially riparian vegetation, on hilltops and slopes and in headwaters. Rezende *et al.* (2018b) verified that there is a deficit of riparian vegetation in all municipalities of southernmost Bahia above 40%, reaching between 80% and 100% of riparian vegetation deficit in the most Midwestern municipalities (Teixeira de Freitas, Vereda, Itanhém, Medeiros Neto and Lajedão), which are mainly occupied by pastures. Except for Teixeira de Freitas, these municipalities present average and low values for the well-being indicator FIMD considering the context of the region, in addition to the lowest salaries (Figure 3).

Moreover, payment for ecosystem services (PES) strategies, which are already supported by state and national legislation (Bahia State Law No. 12,223/2015, and Federal Law No. 14,119/2021), can leverage conservation initiatives in the region, especially regarding the riparian forest, hilltops, river headwaters and degraded areas, reinforcing the command-and-control actions expressed in the existing legislation (REZENDE *et al.*, 2018a). As the deficit of riparian forest in the region is above 40% in all municipalities, PES schemes could be designed under the scope and action of the region's watershed committees (e.g. Committee for the Peruípe, Itanhém and Jucuruçu Rivers), which have been in operation for at least a decade and counts on broad representation from the regional society. Schemes like this have already been developed in Brazil, as in the municipality of Extrema, state of Minas Gerais (JARDIM; BURSZTYN, 2015), and could combine the forest restoration approach with the provision of ecosystem services related to water, biodiversity, and carbon sequestration and storage.

Kasecker *et al.* (2017) mapped priority municipalities in Brazil for the implementation of ecosystem-based adaptation (EbA) policies considering indicators of poverty, natural vegetation cover, and exposure to climate

change. Most of the hotspots are in the Caatinga, Cerrado, and Amazon biomes, with a few municipalities in the Atlantic Forest, none of them in the study area of this work. They proposed four immediate actions to reverse the situation of vulnerability: i. expansion of the *Bolsa Verde* (Green Bag), that is a Federal program devoted to families in situation of extreme poverty, which develop environmental conservation activities; ii. implementation of the existing protected areas to improve local livelihoods and economic opportunities; iii. increasing synergies between mitigation and adaptation policies to finance adaptation actions; and iv. integration of these proposals into municipal plans. Some of these actions are already being implemented in the study area, especially the establishment of protected areas, but they still deserve investment to be effectively functional. Actions related to public policies and synergies are still to be developed, and the results of this work can foster these vectors.

A pioneering initiative to address climate change through ecosystem-based adaptation in municipal plans was carried out in the municipality of Porto Seguro (BA), with the establishment of the Municipal Plan for the Recovery of the Atlantic Forest (PMPS, 2014). The analysis of local vulnerability to climate change and its incorporation in a municipal planning instrument represents an advance in the treatment of this theme at the municipal level, besides addressing the interrelations between biodiversity, climate change and well-being of local populations. In order to strengthen initiatives like this, strategies to reduce vulnerabilities and increase adaptive capacity to climate change must begin to be designed at the municipal and state levels, in line with the National Adaptation Plan, launched in 2016 (BRASIL, 2016), and should consider: 1. reducing poverty; 2. participatory reforestation, income generation, municipal and state policies and plans that promote sustainable practices (e.g., PES and promotion of agroecology); 3. incorporate climate information in decision-making (hydrological monitoring of the region's basins, soil cover, sea level rise); and 4. addressing impacts directly (e.g., managing coral reef response to bleaching, managing water scarcity).

The legal environmental liability in the region can generate opportunities for forest restoration on private properties in the region, combining legal adequacy with the generation of jobs and income and the recovery of the Atlantic Forest. These synergistic actions can be strengthened through AbE strategies (SCARANO, 2017), especially in this area of the Atlantic Forest that still has great biological and cultural diversity, thus composing an important regional, national and even global asset for reversing the current trajectory of climate change and biodiversity loss.

## FINAL CONSIDERATIONS

The vulnerability drivers identified in this study impose many current and urgent challenges for regional environmental governance. The reversal of this scenario lies in the design and adoption of strategies based on the potential of regional biodiversity and poverty reduction, combining public policies of command and control and financial incentives that value the ecosystems and their services. The municipalities can assume a leading role in this context by incorporating into their existing planning instruments indicators and strategies that address the multiple current challenges, especially when the federal government seems to be neglecting climate change. Restoring and conserving ecosystems and their services is the best way to reduce existing socio-environmental vulnerabilities, whle also contributing to climate change adaptation and mitigation, generating income, and reorienting the regional development process, which currently still occurs to the detriment of the local ecosystems.

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## AUTHORS' CONTRIBUTION

Frederico Monteiro Neves conceived the study, collected and analyzed the data and wrote the text. Guineverre Alvarez and Fábio Fernandes Corrêa designed the study, collected data, and reviewed the text. João Batista Lopes da Silva collected and analyzed the data and revised the text.