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SPATIOTEMPORAL DYNAMICS OF AGRICULTURAL PRODUCTION DIVERSITY IN SERGIPE AND ALAGOAS BETWEEN 1999-2018

ABSTRACT

This work analyzes the spatiotemporal dynamics of agricultural diversity in Sergipe and Alagoas from indices based on Shannon entropy defined from the IBGE annual estimates for planted area, herd, and dairy animals population and values of animal production and temporary permanent crops between 1999 and 2018. We transformed municipal indices into surfaces of agricultural diversity through ordinary kriging. The results show trends of decreasing or increasing diversity in specific regions of the studied area.

***Key words** – Ordinary kriging, Low São Francisco watershed, public policy, sustainability.*

1. INTRODUCTION

Authors [1–3] have related the diversity of agricultural production at the regional scale to the social, economic, and environmental sustainability level.

Teixeira & Ribeiro [1] showed a positive correlation between the diversity of municipal agricultural production in Minas Gerais and the conservation of native vegetation (forest fragments). Tisdell et al. [2] obtained this same relation in Bangladesh.

Silva [3] carried out a study on Brazilian agricultural diversity, extending the survey carried out by [1] to all municipalities, all agricultural activities (agriculture, livestock, plant extractivism, animal production, aquaculture, forestry) and considering annual values from IBGE estimates between 1999 and 2018. The authors showed that there is evidence that municipalities with a decreasing trend in diversity experience higher rates of loss of native vegetation.

Teixeira & Ribeiro [1] observed these diversity variations at the regional scale and intra-regional level, as demonstrated. Silva et al. [3] observed large regional patterns, with emphasis on the Cerrado region in the Midwest and intra-regional differences such as in Minas Gerais, confirmed by [1].

In general, it affects the elaboration of territorial public policies focusing on sustainability, which must consider these differences at the time of their development.

This work aims to investigate this agricultural diversity in the states of Alagoas and Sergipe, Brazil, by generating agricultural diversity surfaces for these indices proposed by [3]. A more precise description of this region's spatiotemporal diversity dynamics should support a more effective public policy design.

2. MATERIAL AND METHODS

2.1. Studied area

The studied area comprised the 177 municipalities in the states of Sergipe and Alagoas, emphasizing the municipalities of the Baixo São Francisco watershed (Fig.1). For the spatial interpolation, we considered a buffer zone referring to the second neighboring (Queen criteria) municipalities of the states of Sergipe and Alagoas.

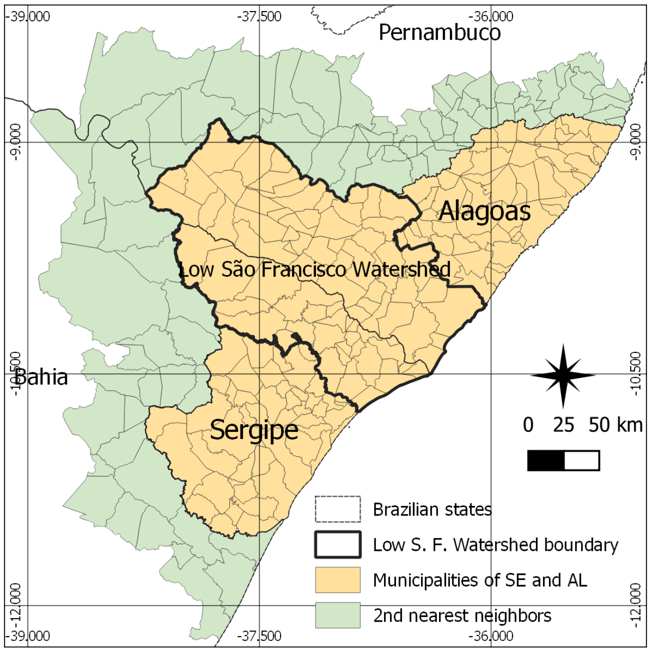


Figure 1: The studied area comprises the states of Sergipe and Alagoas, Brazil. We defined a buffer zone based the second neighbors for spatial interpolation. A second region of interest is the Low São Francisco Watershed. Source: elaborated by the authors.

2.2. Spatial panel agricultural diversity data

The dataset comprises five agricultural diversity indices covering herd and dairy animals population (DIV.HERD), planted area with temporary crop (DIV.PLANT.T), production's value for animal production (DIV.VL.PRODANI), permanent crop (DIV.VL.P), and temporary crop (DIV.VL.T) considering only the states of Sergipe and Alagoas and covering the period between 1999 and 2018. Silva et al. [3] calculated these indices for all Brazilian municipalities from the IBGE's annual estimates of raw variables using Shannon's entropy equation (Eq. 1).

$$DIV_l = -\sum_{i=1}^{m}\left[\frac{y_i}{\sum_{j=1}^{m} y_j} log_m\left(\frac{y_i}{\sum_{j=1}^{m} y_j}\right)\right] \quad (1)$$

where m is the number of raw variables for the category l and y_i is the value of the ith raw variable for each year, category, and municipality. The diversity index DIV values vary from zero (without diversity) to one (highest diversity). All unavailable raw data have been replaced with zeros, which means no agricultural diversity is present.

Fig. 2 shows the clustering obtained by [3] for the studied municipalities. We observe that the Low São Francisco Watershed is dominated by cluster B, **nationally** associated with a a high diversity of herd and dairy population and production value for temporary and permanent crops, but also associated with a low diversity of animal production value. Urbanized municipalities such as Aracaju and Maceió are associated with cluster F, representing municipalities with a steadily low diversity throughout the studied period.

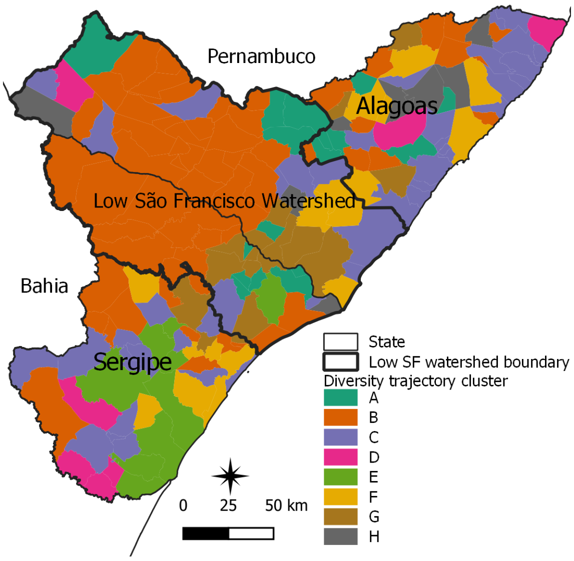


Figure 2: Trajectory clusters for the states of Sergipe and Alagoas, Brazil. Source: [3].

Table 1 shows a statistical summary of the five indices considering only the states of Sergipe and Alagoas. When compared with the basic statistics for the whole of Brazil [3], we observe that only the herd population plus dairy animals diversity index showed median and mean greater than national values.

Table 1: Statistical summary of the five diversity indexes considering only Sergipe and Alagoas. Source: elaborated by the authors.

Category	Diversity index	Median / Max	Mean $\pm sd$
Herd population + dairy animals	DIV.HERD	0.54 / 0.80	0.52 $\pm$0.14
Animal production value	DIV.VL. PRODANI	0.13 / 0.70	0.17 $\pm$0.13
Temporary crop production value	DIV.VL.T	0.19 / 0.54	0.19 $\pm$0.13
Permanent crop production value	DIV.VL.P	0.12 / 0.57	0.13 $\pm$0.13
Temporary crop planted area	DIV.PLANT.T	0.29 / 0.49	0.27 $\pm$0.09

2.3. Ordinary kriging

To generate smooth surfaces from the municipal agricultural diversity indices, we adopted the ordinary kriging method directly on the indices for the case of asymmetry less than or equal to zero, otherwise on the square root of the index for each year. We assumed the isotropy hypothesis for the spatial distribution of the indices.

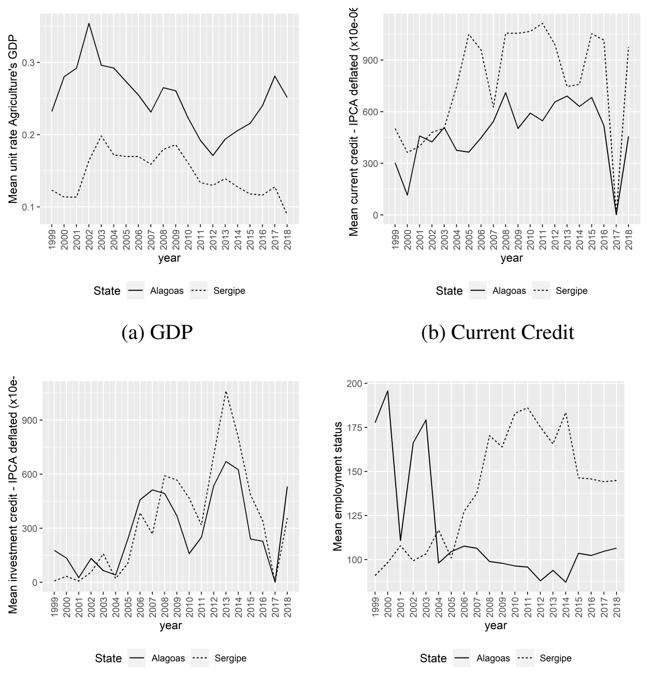
We carry out ordinary kriging for each variable-year by automatically defining the variogram parameters and fitting it to a model [4]. We evaluated the spherical, exponential, Gaussian, and Matern with Stein's parameterization [5] models for each kriging process.

We generated one hundred thematic maps (five variables $\times$ 20 years), and we created the classes for equal intervals (0.1) of the interpolated values, thus generating ten classes.

2.4. Covariates

To help the interpretation of the temporal evolution of diversity surfaces in Sergipe and Alagoas, we selected some covariates (state average): unit rate of the agricultural Gross Domestic Product (GDP), cost credit, and investment in Reais, deflated by the IPCA index, and total jobs registered by RAIS (Fig. 3).

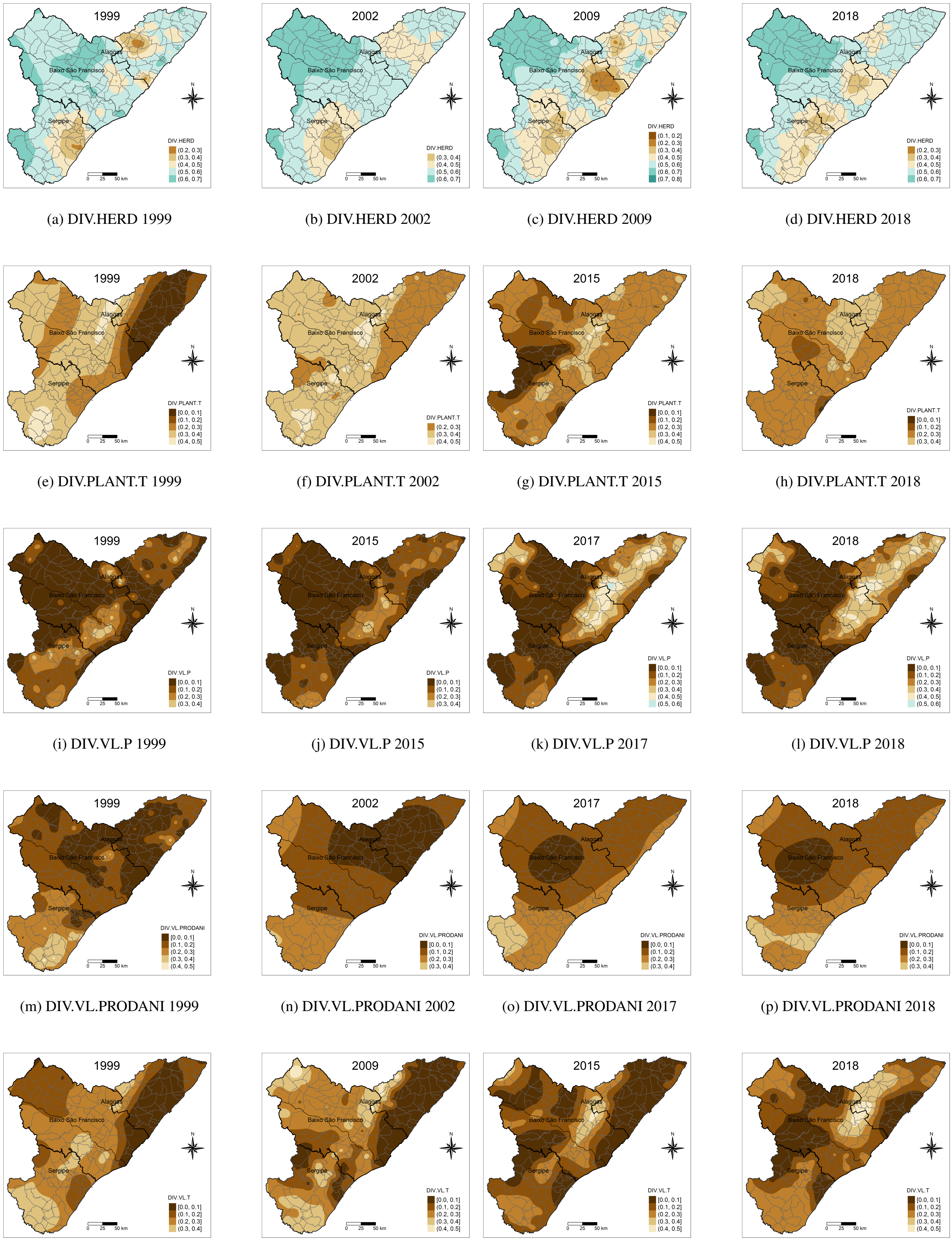
For the GDP covariate, we observe that except between 2013 and 2018, Alagoas and Sergipe follow almost the same trend. The current credit trend varies mainly between 2003 and 2015. The investment credit curves are almost the same for these two states, except for the years between 2006 and 2008. The employment status presents opposite trends since 2005, Sergipe showing steady growth and Alagoas a moderate decay.



(a) GDP (b) Current Credit

(c) Investiment credit (d) Employment status

Figure 3: Covariates: (a) mean of unit rate of the agricultural Gross Domestic Product (GDP), (b) mean current credit and (c)investment in Reais, deflated by the IPCA index, and (d) mean of total jobs registered by RAIS. Source: elaborated by the authors.



(a) DIV.HERD 1999 (b) DIV.HERD 2002 (c) DIV.HERD 2009 (d) DIV.HERD 2018

(e) DIV.PLANT.T 1999 (f) DIV.PLANT.T 2002 (g) DIV.PLANT.T 2015 (h) DIV.PLANT.T 2018

(i) DIV.VL.P 1999 (j) DIV.VL.P 2015 (k) DIV.VL.P 2017 (l) DIV.VL.P 2018

(m) DIV.VL.PRODANI 1999 (n) DIV.VL.PRODANI 2002 (o) DIV.VL.PRODANI 2017 (p) DIV.VL.PRODANI 2018

(q) DIV.VL.T 1999 (r) DIV.VL.T 2009 (s) DIV.VL.T 2015 (t) DIV.VL.T 2018

Figure 4: Thematic maps for agricultural diversity (herd, planted are with temporary crops, and value of production for animal, temporary and permanent crops) surface for Sergipe and Alagoas, Brazil. Source: elaborated by the authors.

3. RESULTS

Fig. 4 shows some agricultural diversity thematic maps for the states of Sergipe and Alagoas, highlighting the first (1999) and last (2018) years and two more maps where we can observe a change in the general diversity spatial distribution pattern.

The herd population plus dairy animals diversity thematic maps show small changes in its spatial distribution, increasing a little diversity in the semi-arid region of both states between 1999 and 2018, maintaining a low diversity in the region East-South of Sergipe during all period, and a huge low diversity in the Low São Francisco watershed near the river mouth for the year 2009 (Figs. 4a-d).

The temporary crop planted diversity maps show a more significant spatial distribution change. In 1999 the Alagoas's litoral North showed the lowest diversity region, alleviated by the years 2001/2002 until 2015 when we observed a huge decrease of diversity in the Sergipe's West region. In 2018 we observed a more homogeneous low diversity in both states (Figs. 4e-h).

The permanent crop production value diversity maps show a shallow diversity for the entire region (Figs. 4i-j). Nevertheless, this spatial pattern has changed significantly since 2017 in the Low São Francisco watershed river mouth and the North of the Alagoas. This region increases its permanent crop production value diversity (Figs. 4k-l).

The animal production value thematic maps show that the Alagoas state concentrated in 1999 the lowest diversity (Fig. 4m), since 2002, this lowest diversity region focuses on one specific area of Alagoas (Fig. 4n), migrating to the Low São Francisco watershed region (Fig. 4o) and concentrating since 2018 in in the high sertão of Sergipe (Figs 4p).

The temporary crop production value thematic maps show, between 1999 and 2015, a significant decrease of diversity in the west and near the capital of Sergipe and in different areas of the Low São Francisco watershed (Figs. 4q-s). Since 2015 we observed an increase in diversity in the Agreste region of Alagoas, which increased in 2018 (Figs. 4s-t).

4. DISCUSSION

The region of the lower São Francisco basin is where the studied region's most frequent group predominates, the trajectory group F. This follows the national pattern identified by [3] for the variables DIV.HERD and DIV.PRODANI , but not for the variables DIV.VL.P and DIV.VL.T. As seen in Fig. 4i-l, this region has the lowest levels of diversity, below the national average (Table 1), and it tends to decrease levels of agricultural diversity in terms of production value for temporary crops (Fig. 4q-t), due to the expansion of the maize crop in this region.

Globally, there is a maintenance or decrease in agricultural diversity in Sergipe while Alagoas continues diversifying its agricultural activities. Mainly for the diversity indices related to the value of production of permanent and temporary crops, especially in the region that goes from the wild to the coastal lowlands of Alagoas, where we observe a strong trend of diversification of these indices from 2015 onwards. This period coincides with a substantial increase of credit since 2010 followed by an abrupt drop in the current (since 2016) and investment (since 2013) credit (Fig. 3b-c) for both states. Its interesting to observe that the increase agricultural diversity in Alagoas have been followed by a small increase in the employment rate since 2014, and the reserve to the Sergipe state (Fig. 3d).

5. CONCLUSIONS

There are changes in the spatial distribution of agricultural diversity for the region studied for all variables, although this occurs at different intensities. The semi-arid part of the lower São Francisco basin shows a tendency to maintain or increase the diversity of the herd and dairy animals population but maintain low diversity for permanent crops and animal production and showed a tendency to decrease the diversity of temporary crops.

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