PASTURE LAND COVER CHANGE IN SÃO PAULO STATE, BRAZIL

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ABSTRACT:

Pastures are complex land covers with a variety of land use systems. This land cover occupies large areas in the globe and is mainly used for livestock production. Brazil is one of the largest livestock producers and has extensive pasture areas. We analyzed the pasture land cover change of the São Paulo State between the years 2000 to 2015. São Paulo was chosen as study case due to its large industrial and agricultural importance and its expressive land cover changes over past decades. It was analyzed land covers databases generated by the Brazilian Annual Land Use and Land Cover Mapping Project (MapBiomas Project) – Collection 4. Transition matrix was generated to analyze the land cover change during the period. Gain, loss, total change, net change and swap were calculated in terms of area. Total pasture area decreased but continues the largest land cover of the São Paulo State; with 79.5% of persistence in the area. Main changes were from losses of pastures and gains in agriculture. Most of the changes to pasture came from other non vegetated areas and grassland categories. These results demonstrated the relevance of pastures areas in land cover change dynamics to address land use policy and plan future land use scenarios.

1. INTRODUCTION

Land use and land cover change (LUCC) is an important issue in the context of environmental change and sustainability at global, regional and local scales (Feddema, 2005; Hu et al., 2019; Zomer et al., 2016). LUCC significantly impacts keys aspects of Earth’s functions, such as climate warming (Gogoi et al., 2019), climate change (Lambin et al., 2001), biodiversity (Lambin et al., 2003), soil degradation (Yang et al., 2003) and ecosystems services (Swetnam et al., 2011). Consequently, these changes impact the resilience of places and humans to social-political, economic and environmental events.

Quantitative analysis of LUCC is an important way to understand land cover and land use trends and help policymakers to better address uses and sustainable actions for actual and future scenarios (Garrett et al., 2018). However, it demands appropriate and concise land cover and land use databases over different spatio-temporal scales. Despite land cover datasets have been improved due to earth observing products, land uses still need elucidation (IPCC, 2000; Lambin et al., 2001), mainly due to the difficult to enumerate the wide range of possible uses precisely at high spatial and temporal resolutions. In absent of these data, land cover change analysis could help to address direction and patterns of land use information.

Pasture is an example of a complex land cover type with a variety of land use systems. Pasture land extensively used for livestock production covers around 3 billion hectares (FAO, 2019; Ramankutty et al., 2008), which have been recognized for their potential for intensification — for example with the conversion to mixed crop-pasture systems — and associated possibilities for land sparing and land use diversification, greenhouse gas emission mitigation (Cardoso et al., 2016; de Oliveira Silva et al., 2018), bioenergy expansion (Jaiswal et al., 2019, 2017), and more sustainable agricultural production (de Oliveira Silva et al., 2016).

In the year 2016, Brazil's livestock production was ~43 million tonnes, equating to 5% of total global production (FAO, 2018). This makes Brazil the world’s fourth-largest livestock producer, and an important country in scenarios considering current and future global feed supply. Since most Brazilian livestock production is spread over pasture land areas, pasture land cover change analysis is critical and globally important to address intensification potential and land use policy scenarios. Despite its importance, spatio-temporal trends remain poorly understood.

Based on this, we analyzed the pasture land cover change for the period from 2000 to 2015. We chose the São Paulo State of Brazil as a study case – the most populous, richest and important industrial and agricultural producer – which experienced expressive changes in the territory and conflict of use over past decades. Then, we aimed to identify the land cover change process and to evaluate the pasture land change patterns.

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2. MATERIAL AND METHODS

2.1 Study Area

The study case was the São Paulo State of Brazil (Figure 1). São Paulo is located in the Southwest Region of Brazil, with 248,219.481 km² (IBGE, 2011) and comprehends parts of the Atlantic Forest and Cerrado biomes.

Figure 1. Location of São Paulo State of Brazil in the context of South America

The altitude tropical climate is predominant in the Central Region of the State, characterized by rainy summers and dry winters with average temperatures above 22ºC in the hottest month. In the Northwest, the climate is tropical rainy, characterized by significantly warmer temperatures and very dry winter. In the Southern, there are ranges of tropical climate, with high temperatures in the summer and no dry winter season. The coast has a tropical rainy climate without a dry season and average rainfall of the driest month exceeding 60 mm (http://www.bibliotecavirtual.sp.gov.br/temas/sao-paulo/sao-paulo-clima.php).

São Paulo has the most developed economy in Brazil, spread over diversified sectors. The total population is estimated to 45.919.049 people (IBGE, 2019), being the most populous state of Brazil. São Paulo is one of the biggest beef exporter of Brazil and, consequently, an important region to analyze pasture land cover trends.

2.2 Land cover data

The land covers databases were obtained from the Brazilian Annual Land Use and Land Cover Mapping Project (MapBiomas Project) – Collection 4. MapBiomas project is a collaborative network that involves several experts for automated classification of Brazil's annual land use and land cover time series. All these annual land cover/use maps are produced by pixel-per-pixel classification of Landsat satellite images, with a spatial resolution of 30 m.

We analyzed the land cover databases of years 2000 and 2015 (15-years interval). Land cover maps for these years are shown in Figure 2.

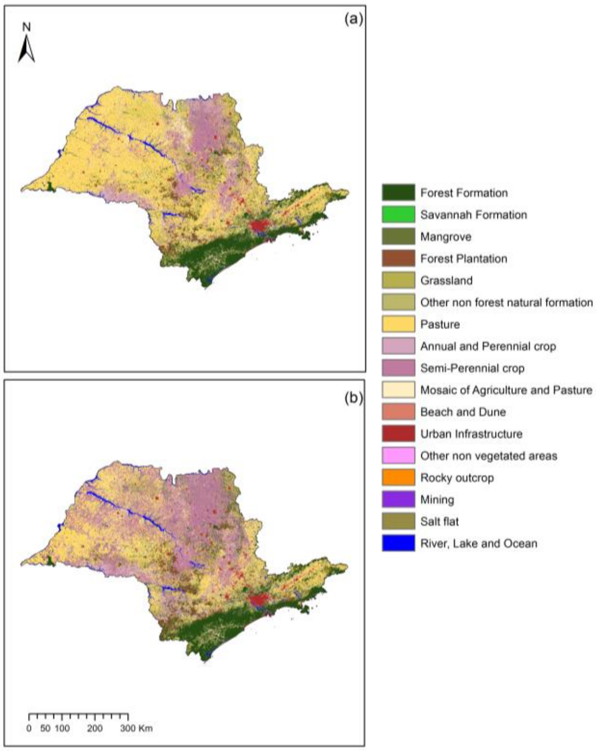

Figure 2. Land cover of the São Paulo State in years 2000 (a) and 2015 (b) according to the classification scheme of MapBiomas Project - Collection 4

Description of the land cover categories that occurred in São Paulo State in these years, their respective ID's and legend colors are described in Table 1. Detailed information about classification methodology and datasets can be found in https://mapbiomas.org/en.

ID	Category
	Forest
3	Forest Formation
4	Savannah Formation
5	Mangrove
9	Forest Plantation
	Non Forest Natural Formation
12	Grassland
13	Other non forest natural formation
32	Salt flat
29	Rocky outcrop
	Farming
15	Pasture
19	Annual and Perennial Crop
20	Semi-perennial Crop
21	Mosaic of Agriculture and Pasture
	Non vegetated area
23	Beach and Dune
24	Urban Infrastructure
25	Other non vegetated area
30	Mining
	Water
33	River, Lake and Ocean

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Table 1. Land cover classification system of MapBiomas Project – Collection 4 for the São Paulo State

2.3 Land cover change analysis

The proportion of each category of land cover and year was computed. Transition matrix was generated to analyze the proportion of land cover change from the year 2000 to 2015. This matrix indicates the proportion of land cover categories that change or remain persistent during the period of analysis. The proportion of each category was calculated according to the values of the year 2000. Despite the focus of this study was the pasture land cover change, we analyzed the transition of all categories aiming to identify the possible source of change and trends in the period of analysis. The transition matrix was computed using the ‘lulcc’ package (Simon Moulds, 2019) of R-3.6.1 software (R core team, 2016).

Based on the proportion of land cover change, it was calculated the gain, loss, total change, net change and swap in terms of area for each category. The gain is related to the increase in the land cover category between the study period, while the loss is the decrease in the same period. Total change is the sum of gain and loss. The net change is the difference of the total proportion in each category between years t2 (2015) and t1 (2000) and swap is the difference between total change and absolute value of net change. Swap highlights the location of possible changes, when changes occur in the location of the category between time t1 and t2, while the quantity of change remains the same (Pontius et al., 2004).

Additionally, it was generated maps of pasture and agriculture changes between the years 2000 and 2015 for analyzing spatial patterns of persistence, gain and loss for these categories. In this case, the category considered as ‘Agriculture’ encloses the categories ‘Annual and Perennial Crop’ and ‘Semi-perennial Crop’ of the original categories (ID’s 19 and 20 of Table 1).

3. RESULTS

Visual observation of land cover in Figure 2 highlighted the relevant presence of pasture in São Paulo State in the years 2000 and 2015. Crops categories are also important land covers and represented, together with pasture cover, 72% and 69% of total land cover area in years 2000 and 2015, respectively. Also, it was possible to note some spatial changes in these classes over the years.

The transition matrix of the land cover change is presented in Table 2. This matrix represents the changes in all 17 categories that occurred in São Paulo State between the years 2000 and 2015. About 79.5% of pasture cover area persisted. Most proportion of loss was for ‘Mosaic of Agriculture and Pasture’, ‘Annual and Perennial Crop’ and ‘Semi-perennial Crop’ categories. In contrast, most gains to this category - proportionally to the original areas of these categories in year 2000 - came from ‘Other non vegetated area’ and ‘Grassland’ categories. Despite these changes, it is also important to note the changes from ‘Savannah Formation’ to ‘Pasture’, ‘Grassland’ to ‘Annual and Perennial Crop’ and ‘Annual and Perennial Crop’ to ‘Semi-perennial Crop’.

	3	4	5	9	12	13	15	19	20	21	23	24	25	29	30	32	33
3	93.88	0.44	0.06	0.83	0.33	0.03	1.56	0.82	0.16	1.73	0.00	0.03	0.04	0.01	0.00	0.00	0.08
4	33.13	36.83	0.00	1.30	8.89	0.05	10.38	6.95	1.85	0.04	0.00	0.03	0.36	0.00	0.00	0.00	0.18
5	6.66	0.00	93.03	0.06	0.00	0.00	0.00	0.00	0.00	0.17	0.00	0.07	0.00	0.00	0.00	0.00	0.01
9	3.54	0.02	0.00	94.99	0.11	0.00	0.49	0.18	0.04	0.54	0.00	0.02	0.05	0.00	0.00	0.00	0.01
12	12.65	6.47	0.00	0.93	42.81	0.00	21.41	10.40	3.15	0.03	0.00	0.13	0.95	0.00	0.00	0.00	1.06
13	3.68	0.06	0.00	0.01	0.00	77.00	2.83	0.05	0.13	10.37	0.00	0.00	0.00	0.00	0.00	0.00	5.86
15	1.32	0.27	0.00	0.50	0.64	0.03	79.49	4.72	4.18	8.43	0.00	0.20	0.17	0.01	0.00	0.00	0.04
19	4.70	1.28	0.00	0.26	2.55	0.01	11.84	57.56	17.95	2.62	0.00	0.37	0.57	0.00	0.00	0.00	0.29
20	0.22	0.01	0.00	0.11	0.21	0.01	3.26	4.45	88.32	3.17	0.00	0.09	0.13	0.00	0.00	0.00	0.01
21	3.78	0.01	0.00	0.37	0.00	0.44	15.22	3.57	8.20	67.26	0.00	0.78	0.10	0.03	0.01	0.00	0.22
23	0.05	0.00	0.00	0.00	0.00	0.00	0.06	0.13	0.00	0.13	70.41	14.85	12.11	0.00	0.00	0.00	1.28
24	0.05	0.00	0.00	0.01	0.03	0.00	1.22	0.30	0.16	2.02	0.01	95.74	0.35	0.00	0.03	0.00	0.07
25	2.72	0.35	0.00	1.52	4.82	0.01	28.65	13.14	10.13	3.41	0.05	5.44	25.93	0.02	0.18	0.00	3.60
29	3.01	0.00	0.00	0.08	0.00	0.00	3.59	0.02	0.00	2.56	0.00	0.06	0.03	90.60	0.00	0.00	0.04
30	0.66	0.00	0.00	0.17	0.12	0.00	8.54	0.61	1.75	11.34	0.00	20.38	10.70	0.00	39.94	0.01	5.76
32	4.89	0.00	4.04	0.00	0.00	0.00	0.00	0.00	0.00	9.80	0.00	6.54	1.48	0.00	0.05	66.78	6.42
33	0.45	0.01	0.00	0.02	0.29	0.17	0.14	0.27	0.02	0.54	0.01	0.15	0.07	0.00	0.01	0.01	97.83

Table 2. Transition matrix of LUCC in São Paulo State between the years 2000 and 2015 (unit: % of area). Proportions were calculated according to the year 2000 (rows). Cells filled with gray colors represent the percentage of persistence area in the class between these years. Names of categories related with these ID’s are shown in Table 1

Table 3 shows the area of land cover change in terms of the gain, loss, total change, net change and swap. The highest cover changes occurred in the categories of Farming (ID’s 15, 19, 20 and 21, respectively, ‘Pasture’, ‘Annual and Perennial Crop’, ‘Semi-perennial Crop’ and ‘Mosaic of Agriculture and Pasture’), summing more than 80% of all changes during the period between 2000 and 2015. Pasture cover (ID 15) presented the highest loss, total and net change areas, and the second higher swap value. These changes corresponded to about 51%, 34%, 49% and 26% of the total amount of these changes, respectively. ‘Mosaic of Agriculture and Pasture’ (ID 21) showed the highest gain, followed by ‘Semi-perennial Crop’ category (ID 20). In contrast, this ID 21 presented the second higher loss and total change, and the highest swap. Outside these categories of Farming, ‘Forest Formation’ presented the most expressive changes, with gain higher than loss and swap of about 9% of the total area of swap’s occurrence.

ID	Gain	Loss	Total Change	Absolute value of Net Change	Swap
3	4464.7	3068.7	7533.4	1395.9	6137.5
4	958.3	656.4	1614.7	301.8	1312.9
5	30.6	12.7	43.3	17.8	25.4
9	1265.1	327.9	1593.1	937.2	655.9
12	1569.8	1667.5	3237.4	97.7	3139.7
13	180.0	163.0	343.0	16.9	326.0
15	**8572.4**	**25839.5**	**34411.9**	**17267.1**	**17144.8**
19	9059.2	6373.4	15432.6	2685.8	12746.8
20	10402.1	3230.5	13632.6	7171.6	6461.0
21	13060.0	8573.9	21633.8	4486.1	17147.7
23	1.2	3.8	5.0	2.7	2.3
24	624.2	251.4	875.6	372.8	502.8
25	438.4	647.6	1085.9	209.2	876.7
29	26.3	14.3	40.7	12.0	28.6
30	10.3	12.6	22.9	2.3	20.7
32	0.8	1.2	2.0	0.4	1.6
33	312.0	130.6	442.7	181.4	261.3
Total	50975.2	50975.2	101950.5	35158.7	66791.8

Table 3. Land cover changes in terms of area (km^2) for each category. Bold numbers highlight the pasture land changes. Names of categories of these ID’s are shown in Table 1

The spatial distribution of the persistence, gain and loss for the categories ‘Pasture’ (ID 15) and Agriculture (ID’s 19, 20 and 21) is shown in Figure 3. Pasture cover showed an expressive persistence area (as shown in Table 2) spread over São Paulo

State. Some areas with small pasture occurrences were in North-Central axis (region of persistence of Agriculture) and South regions. Large regions with loss of pasture areas occurred over the borders around the persistence of pasture areas, mainly in Western region of the State. These areas with loss in pasture cover seemed to be the main region of gain in Agriculture cover. This category presented lower persistence area than Pasture cover and small loss during the period. Pasture cover did not show spatial pattern for gain area.

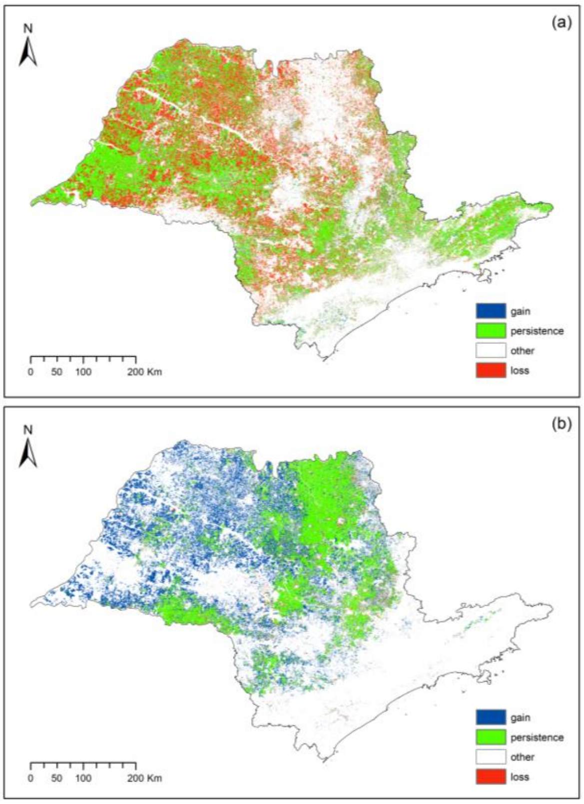

Figure 3. Change in the Pasture (a) and Agriculture (b) categories between the years 2000 and 2015. In this figure, Agriculture encloses the categories 'Annual and Perennial Crop' and 'Semi-perennial Crop' of the original categories (respectively, ID's 19 and 20 of Table 1)

4. DISCUSSION

The State of Sao Paulo has the largest agricultural Gross Domestic Product (GDP) in Brazil (Camargo Filho, 2008) and a diversified coverage changes over time (Colistete, 2015). The results showed in this study corroborated these changes in areas with agriculture and pasture, where massive land cover change - more than 80% of all changes - occurred inside the Farming categories ('Pasture', 'Annual and Perennial Crop', 'Semi-perennial Crop' and 'Mosaic of Agriculture and Pasture') (Table 2 and 3). We also noted changes in the location of these land covers, which were expressed by the highest swap values (Table 3). Normally, these changes are linked with costs and price of production, infrastructure, market's strategies, climate conditions and resource availability.

Most changes in Farming categories came from loss of pasture to gain in agriculture. The results showed the highest gain of 'Pasture' to 'Mosaic of Agriculture and Pasture' categories. However, it must to have caution in considering this category in the land cover change analysis, since it considers areas used for farming that were not possible to define land cover as pasture or crop. Then, this category could represent either persistence of pasture or change to crop (and vice-versa), some type of crop-livestock mixed systems or limitation of the land cover map due to the classification process. Because of this, we could not explore deeply and analyze change patterns associated with this category.

Proportions of gains in the other Farming categories ('Annual and Perennial Crop' and 'Semi-perennial Crop' from 'Pasture') were similar. Expressive gain in 'Semi-perennial Crop' category was mainly pushed by sugarcane expansion over the years and driven for ethanol production (Camargo et al., 2008; Sparovek et al., 2007) - the highest destination of sugarcane in Brazil (about 51%) (UNICA, 2015). São Paulo State is the highest producer of sugarcane in Brazil (about 56% of the total) (IBGE, 2015) and its expansion over last decades was mainly pushed by the increase of prices and area; illustrating a land use conflict (Camara and Caldarelli, 2016; Camargo et al., 2008). In contrast, the loss of pasture area was associated with decreasing in animal units of about 25% (considering the period between 2003 and 2013) (Camara and Caldarelli, 2016; IBGE, 2015).

Main changes from 'Pasture' to 'Annual and Perennial Crop' could be mainly explained by transitions for soybean (Camargo et al., 2008). Differently of the transition to 'Semi-perennial Crop', this type of changes could also be related with pasture intensification due to consortium of crop-livestock systems (e.g., reforming the pasture areas with an initial cultivation of legumes, as soybean or bean) or providing feed supply to animal in the inter-cycles of pastures (e.g. maize); and, consequently, getting additional farming products.

Pasture intensification in Brazil is normally correlated with decreasing of pasture area (Barretto et al., 2013). In agriculturally consolidated areas of southern and southeastern Brazil (the region of the São Paulo State), land intensification – both cropland and pastures – coincided with either reduction of both areas, or cropland expansion at the expense of pastures (Latawiec et al., 2014); similarly with our results. Brazil's agriculture intensification had risen, mainly pushed by public policies (e.g., the Low-Carbon Agricultural Plan - "ABC Plan; (Brasil, 2012) and private initiatives. It could represent an increase in production and soil quality (Andrade et al., 2006; Eaton et al., 2011) or, if not well planned, a decreasing of quality dues to high use intensity of the land (Abdalla et al., 2018; Conant and Paustian, 2002).

In contrast, most gains for pasture areas came from 'Other non vegetated area' and 'Grassland' categories. The first category consisted of a mixed class including, for example, tillage and exposed soil. It could mean that these areas were initially in preparation for farming cultivation, in an inter-cycle period or degraded (considered here as predominance of exposed soil); and, then, they were converted to cultivated pasture. Instead, the conversion from 'Grassland' may have been favored by inputs and resource increasing for livestock production associated with higher technology offer to support large animal unit per area.

However, the presence of some gain from 'Savannah Formation' to 'Pasture' could denote conversion of Cerrado biome (the Brazilian's Savannah), an import and threatened biome due to farming conflicts (Durigan et al., 2007).

Despite the quantities of changes, it is also important to analyze their spatial behavior, as presented in Figure 3. Western region of São Paulo State – a traditional livestock producer - showed significant losses of pasture to agriculture. Also, a spatial pattern of pasture gain was not explicitly visualized. Instead, many gains of agriculture were distributed around the border of pasture areas; which demonstrate an advance of agricultural frontier over this pasture cover.

Although the greater loss of pasture areas, it is still the largest proportion of land cover in São Paulo State. Our results demonstrated the importance of this land cover, where changes could impact the livestock sector and regional economy, as well as produce social and ecological effects; such as market and land prices, degradation and water availability. Consequently, it could address land use policies and help planning future scenarios for bioenergy and food production.

5. CONCLUSIONS

The percentage of pasture cover decreased between the years 2000 and 2015. However, it is still the largest land cover in São Paulo State. Together with agriculture, these categories showed more than 80% of all land cover changes during this period.

About 79.5% of pasture cover area persisted between these years. Most changes occurred from losses of pastures and gains in agriculture, mainly in the Western region. Most gains for pasture areas came from other non vegetated area and grassland categories.

Our results showed the relevance of pasture areas and highlighted the importance of this land cover change to address land use policy and plan scenarios for bioenergy and food production.

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