RA'EGA

O ESPAÇO GEOGRÁFICO EM ANÁLISE

LAND USE AND LAND COVER DYNAMICS IN MUNICIPALITIES OF THE UPPER PARAGUAY RIVER BASIN: AN ANALYSIS BASED ON THE GEOPORTAL TERRACLASS

ANÁLISE DA DINÂMICA DO USO E COBERTURA DA TERRA EM MUNICÍPIOS DA BACIA DO ALTO PARAGUAI (BAP) A PARTIR DO GEOPORTAL TERRACLASS

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ABSTRACT

The Upper Paraguay Basin (hereafter, by the Portuguese acronym BAP) has great ecological importance to Brazil since it includes the Pantanal, one of the largest wetlands in the world. Monitoring the land use and the land cover (LULC) is strategic not only for the floodplain of BAP but also for its plateau since the floods in Pantanal are affected by the actions conducted in its surroundings. Part of the BAP area placed within the State of Mato Grosso is mapped by the TerraClass Amazon Project and, therefore, the LULC dynamics in these localities can be assessed through these official data. The aim of this study was to analyze the LULC dynamics in three municipalities in the State of Mato Grosso, Brazil, using the geospatial tools provided by a Web-GIS based on data from the TerraClass Amazon Project. The results showed that in the municipalities of Denise and Barra do Bugres, between 2004 and 2014, there was a significant increase in the areas of Semi-Perennial Agriculture mainly due to the conversion from Cultivated Herbaceous Pasture. In the municipality of Santo Afonso, the class that presented the highest growth rate in the period was Annual Agriculture, with most of the areas being converted from pasture areas. The results highlight the processes of territorial dynamics that took place in the studied municipalities. The conversion from cultivated pasturelands to croplands (annual or semi-perennial agriculture) has been the main responsible aspect for the expansion of the agricultural activity in these municipalities.

Keywords: Web-GIS, mapping, Sankey diagram, territorial management.

RESUMO

A Bacia do Alto Paraguai (BAP) tem grande importância ecológica para o Brasil, uma vez que abriga o Pantanal, uma das maiores planícies inundáveis do mundo. O monitoramento do uso e cobertura da terra é estratégico não só na planície da BAP como também em seu planalto, uma vez que as cheias do Pantanal são influenciadas pelas ações realizadas no seu entorno. Parte do território da BAP na porção mato-grossense é contemplada pelos mapeamentos do Projeto TerraClass e, desta forma, a dinâmica de uso e cobertura da terra nessas localidades pode ser avaliada por meio desses dados oficiais. O objetivo deste estudo foi analisar a dinâmica do uso e cobertura da terra em três municípios de Mato Grosso a partir das ferramentas geoespaciais disponibilizadas por um Web-GIS, com base nos dados do Projeto TerraClass Amazônia. Os resultados mostraram que nos municípios de Denise e Barra do Bugres, entre os anos de 2004 e 2014, houve aumento das áreas de Cultura Agrícola Semiperene, cuja maior parte foi proveniente das áreas de Pastagem Cultivada Herbácea. Em Santo Afonso, a classe de maior crescimento foi a de Culturas Agrícolas Temporárias, cuja expansão se deu essencialmente sobre áreas de pastagem. Os resultados evidenciam processos de dinâmica territorial nos municípios estudados, sendo que a conversão entre pastagem cultivada e agricultura (temporária ou semiperene) tem sido a principal responsável pela expansão da atividade agrícola nesses municípios.

Palavras chave: Web-GIS; mapeamento; diagrama de Sankey; gestão territorial.

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1. INTRODUCTION

The Upper Paraguay Basin (hereafter, by the Portuguese acronym BAP) has approximately 60% of its area in the Brazilian territory, presenting great ecological importance for the country since it contains the Pantanal, one of the greatest floodplains of the world with rich animal and plant biodiversity. Pantanal's plain is well preserved, but the plateau has passed through anthropic alterations and the native vegetation has been replaced by livestock, croplands, reforestation, and urban buildings (SILVA et al., 2011). Despite the fact that the plain represents only a fraction of the BAP, its seasonal floods are influenced by the hydrological regime of the whole basin. Therefore, the land use and land cover (LULC) monitoring of the plateau becomes important. In this context, issues related to the environmental impacts of the human activities in the BAP, such as agricultural and livestock practices, should be considered by the managers at the different governmental levels, in order to preserve the local ecosystems.

The State of Mato Grosso has experienced fast LULC change processes in the last decades, in which extraction of wood, livestock, and farm activities have promoted large economic, social, and environmental dynamics to the detriment of the preservation of natural resources (BECKER, 2005). The occupation of the State was encouraged by federal policies that fostered the colonization of the "empty spaces" in the Midwest Region as well as by the construction of the main highways to guide the flow of production (CHIOVETO, 2014). The State of Mato Grosso presents the second highest rate of deforestation in the Legal Amazon, with an accumulated area of 142,967 km², from 1988 to 2017, estimated by the Brazilian Amazon Forest Satellite Monitoring Program (*Programa de Monitoramento do Desmatamento na Amazônia Legal por Satélite* – Prodes) (INPE, 2018). In this regard, information on the identification and characterization of the LULC history are required in order to establish strategies that promote environmental conservation and regional development (LAMBIN e GEIST, 2006).

The TerraClass Amazon Project, a cooperation between the Brazilian Agricultural Research Corporation (*Empresa Brasileira de Pesquisa Agropecuária* – Embrapa) and the National Institute for Space Research (*Instituto Nacional de Pesquisas Espaciais* – INPE) has been responsible for the implementation of the official LULC mapping of the deforested lands in the Legal Amazon, with a spatial resolution of 30 m (COUTINHO et al., 2013; ALMEIDA et al., 2016). Currently, five maps are available for the public regarding the years 2004, 2008, 2010, 2012, and 2014. The thematic classes are only identified in the deforested areas, following information from Prodes (INPE, 2017). Part of the BAP area placed within the State of Mato Grosso is included in this mapping, as the municipalities of Denise, Santo Afonso, and Barra do Bugres. Therefore, the LULC dynamics of these localities might be assessed using TerraClass data.

With the growing development of the Web applications that intend to gather and visualize geospatial data and to spread the geographical databases available in digital repositories, there is an increasing demand for more efficient instruments to access information from the TerraClass Project. Therefore, considering the strategic importance of this demand, the project's team has developed a new computational environment based on Web applications, designed to favor the access, the visualization, and the analysis of the geographical data using a Web-Geographical Information System (Web-GIS). The objective is to allow those users not acquainted with GIS tools to use the internet navigator in a simple and intuitive way in order to obtain spatial information about the results of the project as well as to perform LULC analyses using specific tools.

In this way, the aim of the present study was to analyze the LULC dynamics in three municipalities of the State of Mato Grosso using the geospatial tools provided by a Web-GIS based on data from the TerraClass Amazon Project.

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2. MATERIAL AND METHODS

2.1. Study Area

This study analyzed the municipalities of Denise, Santo Afonso, and Barra do Bugres, located in the Brazilian area of the BAP, in the State of Mato Grosso, as shown in Figure 1.
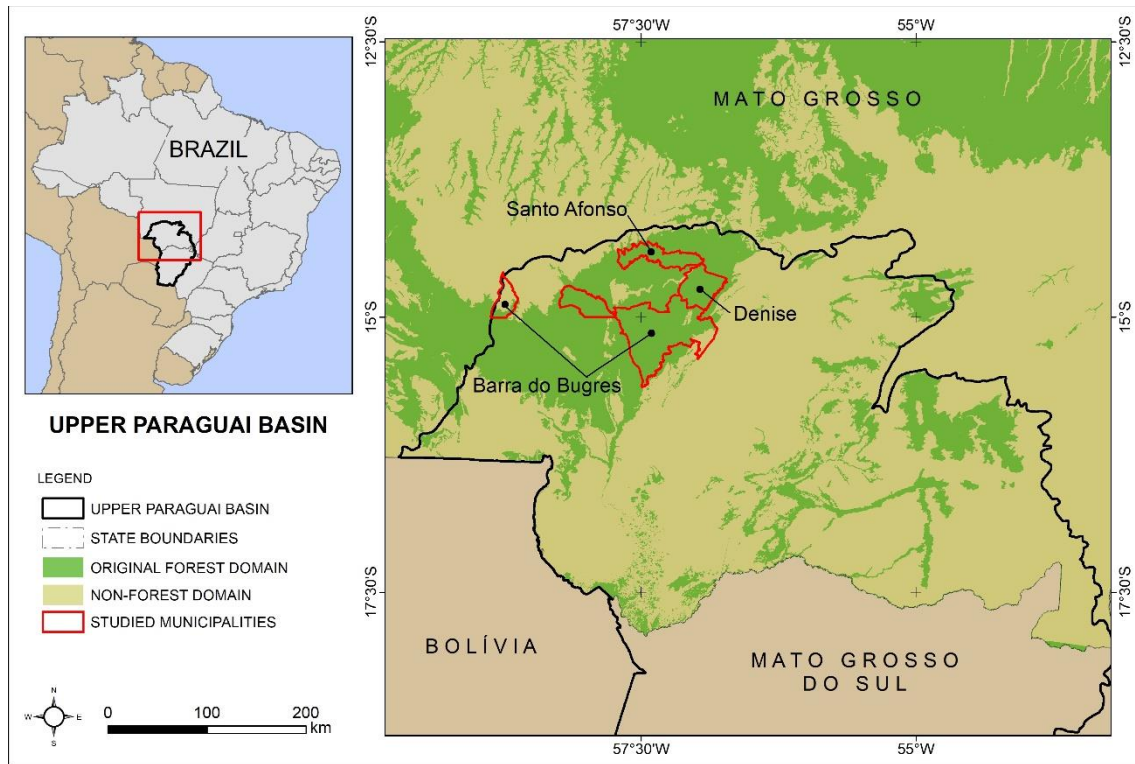

Figure 1 - The Mato Grosso State municipalities of Denise, Santo Afonso, and Barra do Bugres located in the BAP in predominantly forested areas of the Legal Amazon.

The economy of the region is based on the agribusiness, especially meat cattle, sugarcane industry, and grain crops. The area has recently passed through significant changes in the LULC, mainly related to the expansion of the sugarcane (AZEVEDO JÚNIOR et al., 2012) and grain crops, which has motivated the choice of the municipalities analyzed in this study. Other factors considered in this choice were their locations within the BAP and the fact that their areas are included in the data of the TerraClass Project.

The municipalities of Denise, Santo Afonso, and Barra do Bugres, with an area of 1,278 km², 1,174 km², and 5,984.98 km², respectively, are located in the Brazilian Legal Amazon, in areas with predominantly original forest, included in the limits of Prodes. Small portions of the territories of Denise (16.3 km²) and Santo Afonso (3.6 km²)

present non-forest vegetation and are not monitored by Prodes and TerraClass. In the case of Barra do Bugres, approximately 14% of its territory (826.72 km²) is located in non-forested areas, especially its non-continuous western area of the municipality, with its land cover being mostly related to the Cerrado, Lavrados, and Campinarana formations.

2.2. Methodological Procedures

The LULC in the three BAP municipalities was analyzed through a Web Geographical Information System (Web-GIS), available at the GeoPortal TerraClass (www.terraclass.gov.br), which shows data from historical series of TerraClass maps, providing a set of tools for a spatial analysis (Figure 2).

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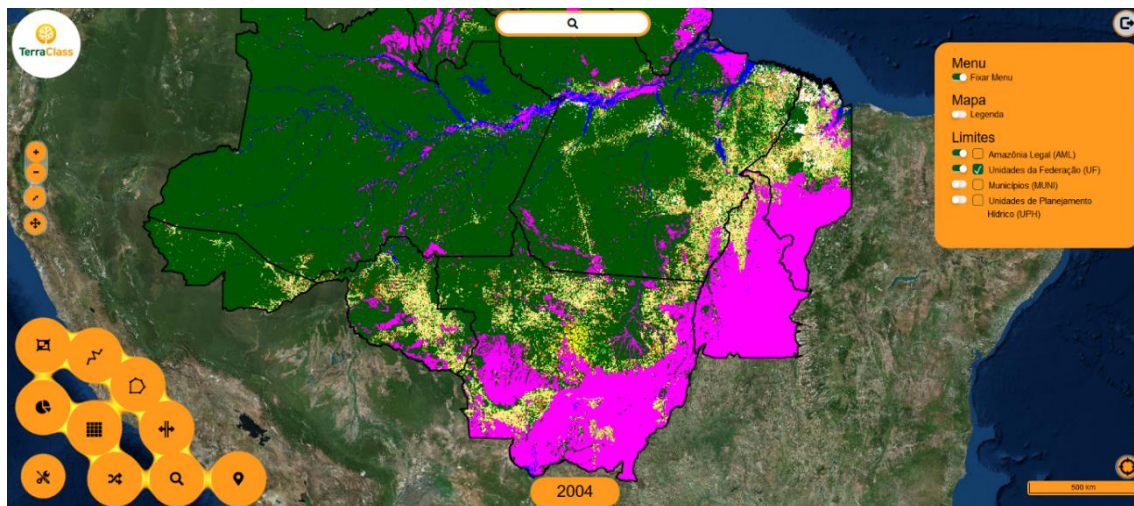AN ANALYSIS BASED ON THE GEOPORTAL TERRACLASS**

Figure 2 - The Web-GIS interface available at the GeoPortal TerraClass website.

The available maps refer to the second version of the TerraClass Amazon data, which has been improved regarding the quality of the classification and adjustments in the thematic classes according to the redefinition of the following labels: 1 - Perennial Agriculture, 2 - Semi-Perennial Agriculture, 3 - Annual Agriculture, 4 - Non Observed, 5 - Urbanized, 6 - Deforested in the Year, 7 - Mining, 8 - Others, 9 - Cultivated Shrubby Pasture, 10 - Cultivated Herbaceous Pasture, 11 - Silviculture, 12 - Secondary Natural Forest Vegetation, and 13 - Primary Natural Forest Vegetation. Essentially, the information analyzed in this study was based on the 2004 and 2014 maps; however, the analyses involving the Sankey diagram also used data from the other available years.

The Web-GIS TerraClass was designed with the data stored in the PostgreSQL database using open source tools. The features of the PostGIS extension are used to implement the spatial inquiries in an optimized way according to the methodology described by Santos et al. (2017). In addition to the function of viewing the layers per year, the system provides a set of tools which aims to facilitate the users' task when consolidating the map information from different geographical cut-offs.

The analisys of LULC changes over time can be carried out by the users through the Sankey diagram tool, available by the TerraClass Web-GIS.

According to Schmidt (2008), this diagram was initially proposed to represent energy flows and their distribution in many directions. Each one is represented by a line or arrow, whose thickness indicates its energy proportion or amount. Thicker lines represent a higher amount of energy being transmitted from that direction, while fine lines represent a smaller amount of energy being transmitted. The same concept can be applied to other types of variables and magnitudes. In the Web-GIS TerraClass case, in which the Sankey diagram was implemented through the D3 library (BOSTOCK, 2013), the adopted variable is the area and the target/end are the thematic classes. Therefore, this diagram is capable of representing the flow of the transition areas between the thematic classes along the years, allowing the visualization in the map of the areas related to the selected transition in the different geographical cut-offs.

3. RESULTS

Table 1 presents the areas of each thematic class of the Amazon TerraClass Project in the municipalities of Denise, Santo Afonso, and Barra do Bugres in km², in 2004 and 2014, whose values were exported by the Web-GIS TerraClass software.

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Thematic Class	Denise Area (km²)		Santo Afonso Area (km²)		Barra do Bugres Area (km²)	
	2004	**2014**	**2004**	**2014**	**2004**	**2014**
Primary Natural Forest Veg.	171.44	160.78	263.89	198.69	1,999.77	1,884.10
Secondary Natural Forest Veg.	106.54	127.68	88.43	139.15	424.04	486.91
Perennial Agriculture	0.00	0.00	0.00	0.00	0.00	0.00
Semi-Perennial Agriculture	366.76	493.34	17.55	1.18	448.39	568.40
Annual Agriculture	0.00	7.53	0.00	73.00	0.00	7.65
Cultivated Shrubby Pasture	50.73	81.86	52.69	109.82	499.92	406.00
Cultiv. Herbaceous Pasture	556.13	383.86	726.80	629.03	1,699.27	1,760.47
Deforested in the Year	3.52	0.00	11.84	0.84	49.82	2.62
Silviculture	0.00	0.00	0.00	0.00	0.00	0.01
Urbanized	1.64	2.68	0.55	1.00	6.03	9.58
Mining	0.00	0.00	3.42	0.00	0.00	0.00
Others	3.57	2.54	2.31	5.62	10.18	17.47
Not Observed	0.48	0.56	2.76	11.92	6.65	0.85
Water Body	1.39	1.39	0.30	0.30	14.27	14.27
Non Forest	16.33	16.33	3.69	3.69	826.72	826.72
Grand Total	**1,278.54**	**1,278.54**	**1,174.22**	**1,174.22**	**5,985.06**	**5,985.06**

Table 1 - Areas of the thematic classes mapped in 2004 and 2014 in the municipalities of Denise, Santo Afonso, and Barra do Bugres, according to the TerraClass Project maps.

3.1. Dynamics of LULC in the municipality of Denise

Figure 3 shows the charts produced directly by the Web-GIS TerraClass software, representing the relative frequency of each thematic class in 2004 and 2014 in the municipality of Denise.
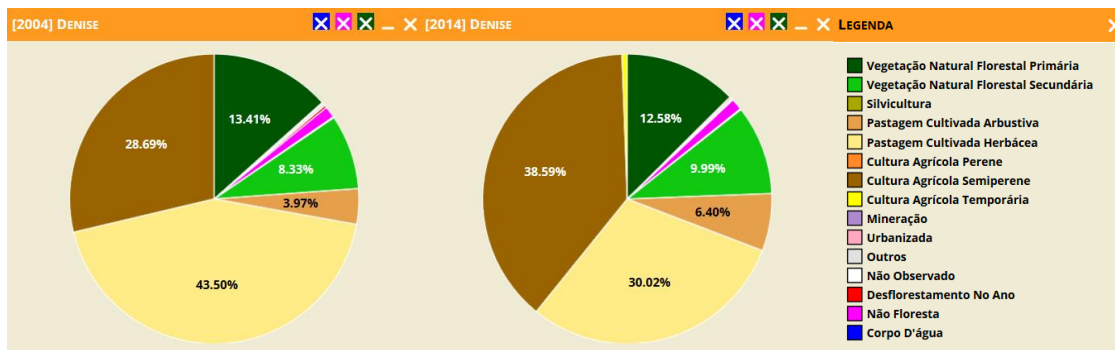

Figure 3 - Relative frequencies of the LULC in the municipality of Denise, based on the 2004 and 2014 TerraClass maps.

The data presented in **Table 1** and in **Figure 3** show that the municipality of Denise exhibited a significant increase in the Semi-Perennial Agriculture class, represented mainly by the expansion of sugarcane crops between 2004 and 2014. In 2004, this class was present in 28.69% of the municipality, changing to 38.59% in 2014, representing an increase of 126 km² of this thematic class along 10 years.

These data confirm the strong expansion of sugarcane crops in the Brazilian Midwest region in recent years, in order to supply the increasing domestic demand for alcohol fuel. According to *União da Indústria da Cana-de-Açúcar* (Unica) and Canasat Project (RUDORFF et al., 2010), in the

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State of Mato Grosso, the sugarcane planted area has doubled between 2004 and 2014. In the BAP, considering that the Pantanal plain presents some LULC particular restrictions, this extremely dynamic outlook of landscape transformation has taken place predominantly in the plateau region (SILVA & CARLINI, 2015).

During the analyzed period, the thematic class that has lost the greatest amount of area in the municipality of Denise was the Cultivated Herbaceous Pasture, decreasing from 43.5% in 2004 to 30% in 2014, that is, a reduction of 172 km² in absolute values (**Table 1 and Figure 3**). A large part of this reduction is due to the conversion of pasturelands into sugarcane croplands.

The Web-GIS TerraClass software provides a tool based on the Sankey diagram that

enables a very robust analysis of these transitions, providing a better understanding of these dynamic LULC processes. **Figure 4** depicts a static representation of the Sankey diagram generated by the Web-GIS TerraClass, with which the user might interact and select years or classes of interest, configuring it to visualize specific LULC transition flows as well as to identify their areas in square kilometers. The years of 2004, 2010 and 2014 were selected in this example. Then, the Semi-Perennial Agriculture class (the brown rectangle) was clicked in the 2014 column. Under this configuration, the system has automatically highlighted the lines of all the classes in cyan coloration in 2004 and 2010 that were converted into Semi-Perennial Agriculture class in 2014.
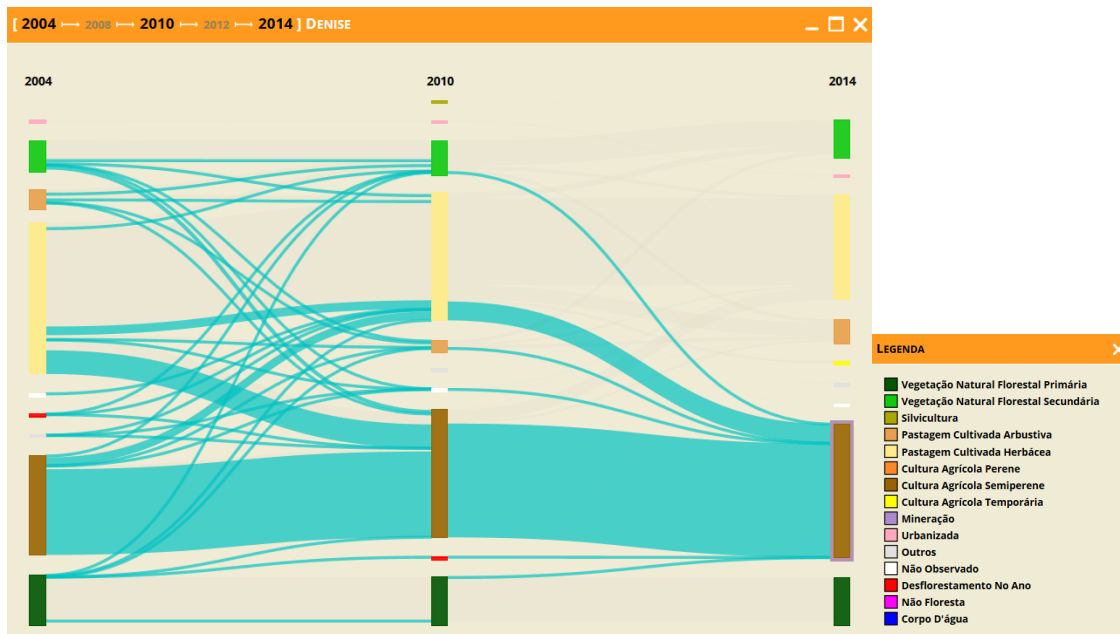

Figure 4 - The Sankey diagram applied to 2004, 2010, and 2014 in the municipality of Denise. The highlighted lines show the transitions flows of classes in 2004 and 2010 to Semi-Perennial Agriculture class in 2014.

Evidently, the major flows towards the Semi-Perennial Agriculture in 2014 originated from its own class in 2004 and in 2010. Therefore, they do not indicate transitions, but its maintenance over time. However, when the flows from their own thematic classes are discarded, Cultivated Herbaceous Pasture appears as the

class whose transitions present the thickest lines, that is, the one that has most contributed to the increase of the Semi-Perennial Agriculture areas, both in 2004 and in 2010, as well as between 2010 and 2014. By positioning the mouse pointer on any of these cyan coloration lines, the user can visualize those transitions in the map and identify

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each area in square kilometers. For example, between 2004 and 2010 the Cultivated Herbaceous Pasture has lost 87.1 km² to the Semi-Perennial Agriculture class and, between 2010 and 2014, an additional 69.5 km² was lost.

3.2. Dynamics of LULC in the municipality of Santo Afonso

Figure 5 exhibits the charts generated directly by the Web-GIS TerraClass, showing the relative frequency of each thematic class in 2004 and 2014 in the municipality of Santo Afonso.
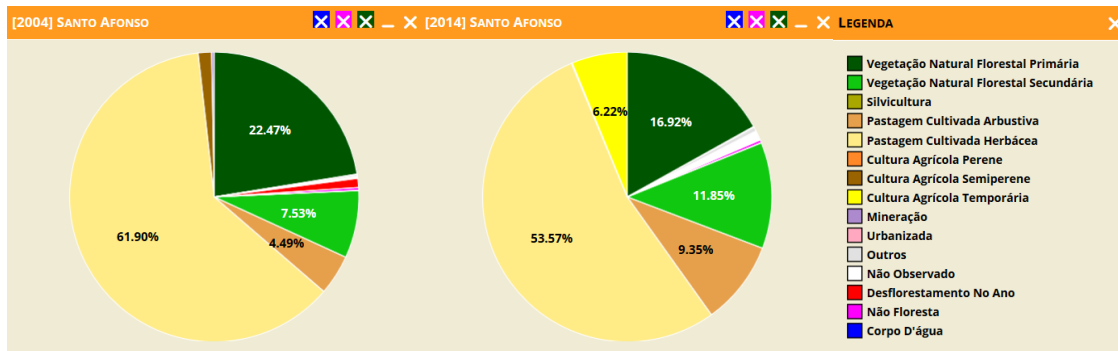

Figure 5 - Relative frequencies of the LULC in the municipality of Santo Afonso based on the 2004 and 2014 TerraClass maps.

The results presented in **Table 1** and in **Figure 5** reveal that in the municipality of Santo Afonso there was a significant increase in the Annual Agriculture class. In 2004, this class was not detected in the municipality but reached 6.24% (74 km²) in 2014. There was also a reduction in the Primary Natural Forest areas, which represented 22.5% of the municipality in 2004, changing to approximately 17.0% in 2014 due to the clear-cut deforestation. On the other hand, the Secondary Natural Forest class, which comprises areas in an advanced stage of regeneration of the original bush and/or arboreal vegetation previously cut, presented an increase in the analyzed period, going from 7.5% in 2004 to almost 12.0% in 2014, with an increase of about 50 km².

The Annual Agriculture class comprises extensive areas occupied by annual corporate farming, especially with soybean, corn, and cotton crops. The increase of this class is related to the expansion process of these crops through the conversion of traditional pasturelands. **Figure 5** shows that the Cultivated Herbaceous Pasture areas have experienced a reduction in the analyzed period, since in 2004 this class represented 62% of the municipality of Santo Afonso, decreasing to 54% of the territory in 2014.

In order to detect which classes have lost space to Annual Agriculture in 2014, a Sankey diagram was generated (**Figure 6**). In this diagram, the years 2004, 2010, and 2014 were selected and the Annual Agriculture class activated in 2014.

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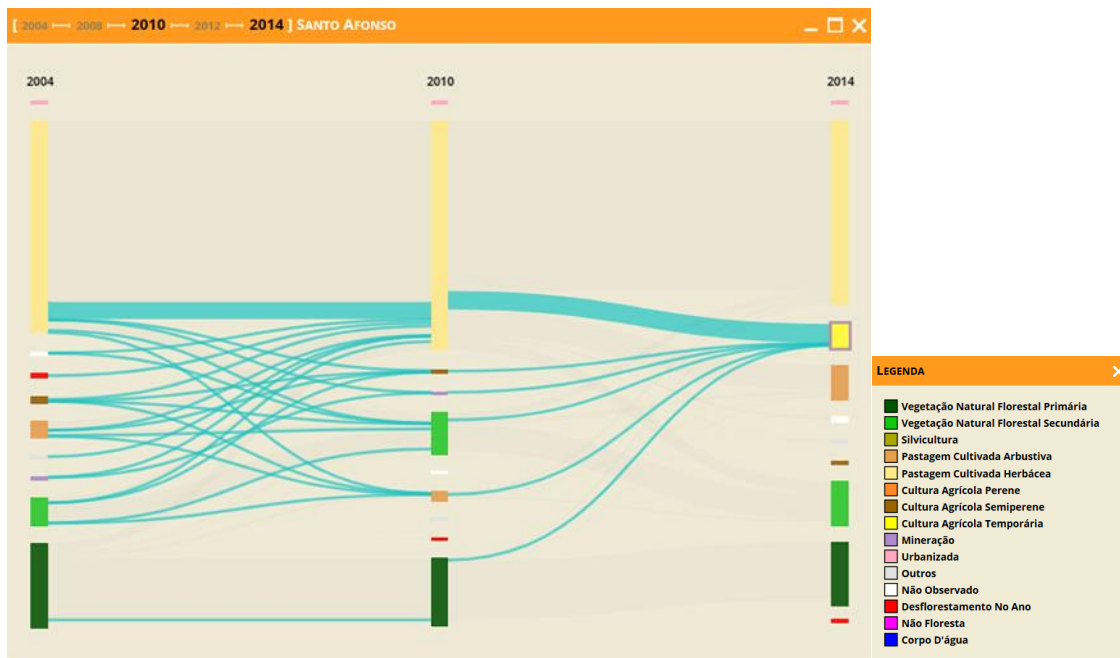

Figure 6 - The Sankey diagram applied to 2004, 2010, and 2014 in the municipality of Santo Afonso. The highlighted lines show the transition flows from classes in 2004 and 2010 to Annual Agriculture class in 2014.

In this context, the Sankey diagram depicts the transition flows towards the Annual Agriculture class in 2014. It is possible to graphically visualize that between 2010 and 2014 the flow line that extends from the Cultivated Herbaceous Pasture towards the Annual Agriculture class is the thickest and represents the most important transition between these classes in the period. By putting the mouse pointer on this line, the user finds that this flow represented an area of 63.7 km². Considering the numbers presented in **Table 1**, the area of Annual Agriculture class in 2014 was 73 km², showing that

approximately 87% of these areas came from the pasturelands/croplands conversion. The other highlighted lines represent other types of less significant transitions towards Annual Agriculture.

3.3. Dynamics of the LULC in the municipality of Barra do Bugres

Figure 7 presents the charts generated directly by the Web-GIS TerraClass, showing the relative frequency of each thematic class in 2004 and 2014 in the municipality of Barra do Bugres.
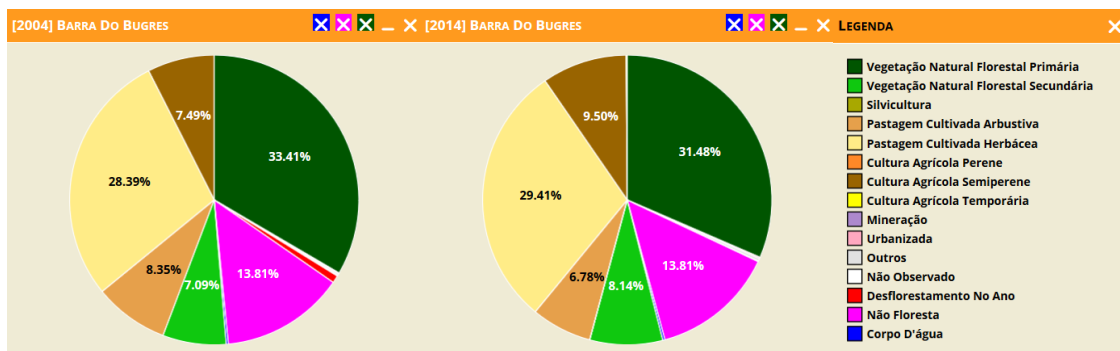

Figure 7 - Relative frequency of the LULC classes in the municipality of Barra do Bugres based on the 2004 and 2014 TerraClass maps.

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The results shown in **Table 1** and in **Figure 7** revealed that the municipality of Barra do Bugres has lost 115.66 km² (or 5.78%) of its natural primary forests from 2004 to 2014, despite a reduction of 94.74% in deforestation. The Natural Secondary Forest class presented an increase of 62.88 km², corresponding to 14.83% of the areas in regeneration.

The Semi-Perennial Agriculture class increased in 10 years, especially due to the expansion of the sugarcane industry, being the class that most increased in relative and absolute terms. In 2004, sugarcane was present in 7.49% of the municipality territory, reaching 9.50% in 2014, with an increase of 120.01 km² in area (26.76%). The data are in accordance with the work of Santos et al. (2013), which showed that the municipality of Barra do Bugres presented a large expansion of crop area in the 1990s and 2000s, due to the demand for ethanol production by the Barralcool Plant and to the tax benefits offered to the sugarcane industry. These are the major factors responsible for the increase in the volume production. On the other hand, the convertion of native vegetation into sugarcane croplands in the BAP plateau might result in environmental problems, such as soil erosion and compaction and water contamination by pesticides (NEVES et al., 2015), also affecting the Pantanal plains.

Another thematic class that decreased in area in the municipality of Barra do Bugres during the analyzed period was the Cultivated Shrubby Pasture, going from 8.35% in 2004 to 6.78% in 2014, representing a reduction of 93.92 km².

Figure 8 presents a Sankey diagram yielded by the Web-GIS TerraClass. In this example, again, the years of 2004, 2010 and 2014 were selected and the Semi-Perennial Agriculture class activated in the 2014 column. With this configuration, the system automatically highlighted the lines of all classes in cyan coloration of all classes that were converted into Semi-Perennial Agriculture in 2014.
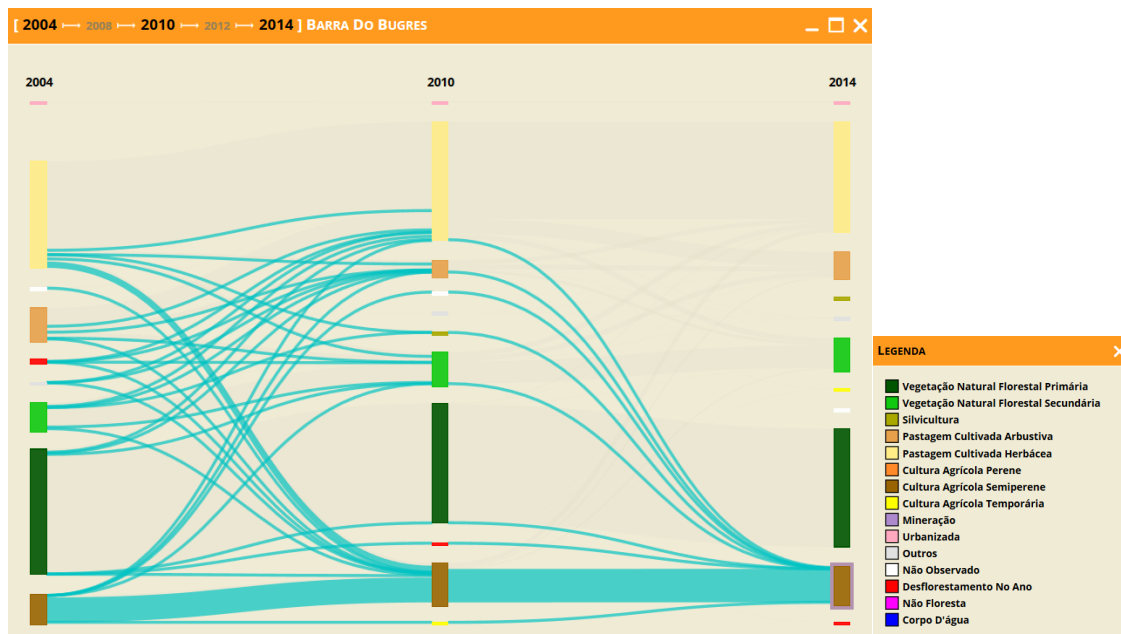

Figure 8 - Sankey diagram applied to 2004, 2010, and 2014 in the municipality Barra do Bugres. The highlighted lines show the transition flows from classes in 2004 and 2010 to Semi-Perennial Agriculture class in 2014.

As observed in the municipality of Denise, the highest flows to the Semi-Perennial Agriculture class in 2014 originated from its own class in 2004 and 2010 and do not represent any

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class change. By putting the mouse pointer on these lines, it was observed that 396.88 km² remained in this thematic class during 10 years.

Discarding the flows originated from its own class, the Cultivated Herbaceous Pasture was the class that most contributed to the increase of the Semi-Perennial Agriculture, both between 2004 and 2010 and between 2010 and 2014. By positioning the mouse pointer on these lines, it is possible to identify the area related to each transition, with the Cultivated Herbaceous Pasture giving an area of 100.70 km² to Semi-Perennial Agriculture class, from 2004 to 2010, and 24.70 km² from 2010 to 2014. This fact shows that the increase in the sugarcane production is usually associated with the inclusion of areas that were previously destined to livestock activities.

All the charts presented were quickly generated through the tools provided by the Web-GIS TerraClass. The geospatial inquiries were executed in an efficient and organized way, in a relatively simple and easy handling environment, without the need of specific technical knowledge.

Regarding the tools for the analysis of the LULC dynamics, its major function is the multi-

temporal Sankey diagram of transitions, presenting a huge potential of use. Other information can be extracted from this type of chart representation depending on both the years selected by the users and the choice of source and target classes. Moreover, by selecting any transition flow with the mouse, the user can visualize in the map the spatial representation of all the polygons related to this transition.

Figure 9 shows the screen of Web-GIS TerraClass and a Sankey diagram in which 2004, 2008, 2010, 2012, and 2014 were selected and only the Natural Secondary Forest class was chosen, for the municipality of Barra do Bugres. In this configuration, the system identified only those areas that remained as Natural Secondary Forest during the studied period, eliminating any transition between classes that occurred along the years. These areas, spatially presented in the map of the municipality of Barra do Bugres, amounted to 201.04 km² and represented areas of secondary forest with a regeneration age of at least ten years.

Figure 9 - Screen of the Web-GIS TerraClass showing the Sankey diagram applied to 2004, 2008, 2010, 2012, and 2014 in the municipality of Barra do Bugres, considering only the Secondary Natural Forest Vegetation. The areas highlighted in the map with cyan coloration represent regions of secondary forest with at least ten years of regeneration.

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4. CONCLUSIONS

The computational tools made available by the GeoPortal TerraClass allowed a faster and more intuitive visualization of the data and information about the land use and land cover and its changes between 2004 and 2014, in three municipalities of the Upper Paraguay River Basin.

In the analyzed period, there was an increase in the areas of Semi-Perennial Agriculture in the municipalities of Denise and Barra do Bugres represented by the expansion of sugarcane crops, whose increase occurred mainly in areas of Cultivated Herbaceous Pasture. In the municipality of Santo Afonso, the highest increase was found in the class of Annual Agriculture, whose expansion occurred mainly due to the conversion of pasturelands to croplands. In both cases, the Sankey diagram, a function of Web-GIS TerraClass, proved to be critical to reveal these processes.

The results herein presented showed the potential of the Web-GIS TerraClass tools for supporting territorial management by revealing the land use and land cover dynamics in the analyzed municipalities.

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