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Temporal Analysis of Deforestation and Characterization of the Agricultural District of Suframa, Manaus-AM

CLEITON DOS SANTOS GAMA[1]
Department of Agricultural Projects
Superintendence of the Manaus Free Trade Zone – SUFRAMA
Department of Forest Sciences, Federal University of Amazonas - UFAM
ANDRÉ LUIZ ALENCAR DE MENDONÇA[2]
Department of Forest Sciences, Federal University of Amazonas - UFAM

Abstract

The Amazon forest is a world heritage and recently a central point of international discussions because of fire and illegal deforestation related to anthropic activities and regulations. We analyzed annually between 1999 to 2018 the deforestation and land-use dynamics in two local roads (ZF1 and ZF2) near Manaus city of Amazonas state - Brazil, utilizing remote sensing automatic classifications and automatic change detection algorithms and spatial analysis by GIS techniques. Additionally, we compared available classifiers, from traditional MaxVer to the object-based image analysis (OBIAs) approach to evaluate six land-use classes and develop a panorama of these local roads of socioeconomic situation. The best classifier against the better resolution and up-to-date data were OBIAS plus the maximum likelihood approach, which was applied to all 18 years of imagery data, resulting in 86 km² of complete forest loss in this area and a significant increase in area values corresponding to green

[1] **Cleiton dos Santos Gama** is a forest engineer from the Faculty of Humanities, Exact and Letters of Rondônia - Brazil, Master in Environmental and Forestry Sciences from the Federal University of Amazonas - UFAM. He is currently a forest engineer at the Manaus Free Trade Zone Superintendence - SUFRAMA. He works in research in environmental monitoring and land regularization.
[2] **André Luiz Alencar de Mendonça** is Ph.D. in Geodetic Sciences from the Federal University of Paraná - Brazil, has experience in geosciences and the environment, cartography, and remote sensing. He is currently an Adjunct Professor at the Federal University of Amazonas - UFAM in the forestry and environmental sciences course.

secondary areas. The socioeconomic analysis revealed substantial harm in the social conditions of people who live on these roadsides, including low family incomes and a lack of basic life and production infrastructure. Land conflicts increasingly open new areas, contributing to increased deforestation rates and a culture of easy money from burning and clearcutting. The multitemporal deforestation by supervised Landsat imagery classification showed changes in forest cover directly influenced by anthropic factors due to the lack of control and monitoring activities concerning the study area occupation.

Keywords: environmental monitoring; degradation of nature; land conflicts; geoprocessing; socioeconomic survey.

1. INTRODUCTION

The Amazon is an extremely intricate region, particularly when observed under the social, cultural, ecological, and economic points of view (Gutberlet, 2002). Within this context is the Superintendential of Manaus Free Zone (SUFRAMA) and its Agricultural District (DAS), a large property located in the rural area of Manaus (Amazonas state capitol), with approximately 590,000 ha, also covering part of Rio Preto da Eva and Presidente Figueiredo municipalities. The DAS is managed by SUFRAMA, a federal autarchy.

Land-use conversions related to the human presence in this area are the object of study in this work. Deforestation here is understood as a conversion of forest areas to non-forested areas and in conjunction with forest degradation (Numata et. al., 2010. As pointed out by Skole and Tucker (1993), typology related to deforestation is as important as size when we analyze biodiversity loss and long-term effects. Souza Jr. (2013) aims to the necessity to evaluate in conjunction deforestation and forest degradation process as a form to develop management policies related to land use and protected areas. However, as degradation includes any disturbance of the native state of the forest, with all phyto physiognomy being analyzed (Defries et al., 2007). Studies in the Amazon indicate that the biggest impact concerning change of land use started in the 1970s (Fearnside, 2005), and many studies show intense deforestation from the late 1970s (Fearnside,

1985) to the present day, with a slight decrease in the beginning of the present decade (Hansen et al., 2013; Aragão et al., 2014; Nepstad et al., 2014). The wide literature published over the theme aims involvement in the carbon cycles and as a consequence in the weather and biodiversity and ecological process in general (Fearnside, 1985, Skole & Tucker, 1993; Moran, 1993; Correia et al. 2006; Malhi et al. 2008, Spracklen & Garcia-Carreras, 2015) not only local, but such as regionals and even global (Werth & Avissar, 2002). Some authors argue that public environmental affirmative policies, agrarian reform, agrology, and the chain reaction of production and sustainable consumption are key to stop this process (Margulis, 2003; Barona et al., 2010; Araújo et al., 2011; Nepstad et al., 2014).

Fearnside (1997) points out that keeping large areas of forest results in the protection of four big groups of dependent activities in the forest: knowledge, biodiversity, thermal cycling, and carbon storage. Margulis (2003) shows that a socioeconomic review of deforestation needs to take at least three levels into consideration: (i) the local population, such as the perspectives more comprehensive to the population; (ii) the national level; and (iii) the global level. Celentano and Veríssimo (2007) point out a temporary economic benefit relationship, tending to future collapse, between deforestation/forest degradation and forest resource preservation. Andersen (1997) and Margulis (2003) argue that it is important to study deeply the socioeconomic relations and public and private environmental and economic benefits in order to establish a proper relation of cost and benefits.

The search for the causes of Amazon forest disturbances promoted scientific debates for years, and some hypotheses circulated in the academic community: Agriculture (Barona et al., 2010), cattle farming (Margulis, 2003), landholding (Binswanger, 1991), mining, colonization and human occupation (Moran, 1993), and roads (Alves, 2002; Fearnside & Graça, 2006; Barber et al., 2014).

This research proposed to analyze the deforestation dynamic of the road extensions (or local roads) called ZF-1 and ZF-2 in the DAS area in Manaus – AM, in the period from 1999 to 2018, with the support of remote sensing and GIS techniques and geospatial data. The purpose was to describe the social and economic dynamics of these areas, considering Autarchy and local stakeholders' points of view. Thus, image classification methods were evaluated in order to better quantify deforested areas. Spatial analysis was carried out to analyze, quantify, and explain the dynamics of the local deforestation over 18 years. Finally, characterizations of the landholding and economic situation in the DAS were used as foundations to analyze this rural area and its perspectives.

2. MATERIALS AND METHODS

2.1 Study area

This study was carried out in the DAS area on the local roads named ZF-1 and ZF-2 (Figure 1). The main road accesses to these road junctions are the BR-174 federal highway, which connects Manaus and Boa Vista cities, and the state highway AM-010 (Manaus – Itacoatiara), which are both paved. The DAS has more than 10 local roads known as ZFs, and 90% of them are not asphalt paved. Access to these roads is difficult, especially in the rainy season. As cited, the DAS is a 5,900-km² area, originally a donation from the state of Amazonas — but never the subject of land regularization — designated to agricultural projects, with a southern boundary on latitude 2º 43' 46"S, almost contiguous to the urban area of Manaus (at approximately 2º55'S).

Local roads ZF1 and ZF2 form a junction and have the following main UTM coordinates: ZF-1 (E 175293,678 and N 9711197,644) and ZF-2 (E 148569,808 and N 9707756,101), 21S zone, using SIRGAS 2000 as a geodetic reference. ZF-1 has an extension of 31 km, and the extension of ZF-2 is 39 km. ZF-1 shows a high rate of occupation, while ZF-2 shows contrasting characteristics related to ZF-1, since it has a smaller number of approved projects, and thus a smaller number of people working and living there.

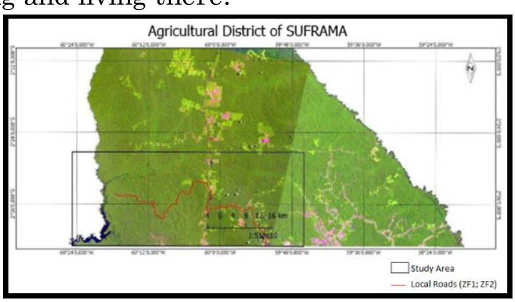

Figure 1 – DAS area –Agricultural district of SUFRAMA and study area.

Methodologically, the present work is divided by following steps, such as (a) evaluation of image classification to decide the better method for temporal analysis of the study area, using present images (Landsat 8 imagery and planet scope for validation); (b) application of the best classification method to a temporal series from 1999 to 2018 Landsat imagery data in order to quantify deforestation, (c) the main deforestation hotspots, and (d) analysis of the Autarchy database on economic activities and social characteristics in the nearby area.

In order to perform the analysis of the deforestation in the study area, we used satellite imagery from the *Landsat* 5 mission, using a TM sensor, Landsat 7 and ETM+ sensor, and *Landsat 8* and its OLI instrument, from the following years: 1999, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2013, 2014, 2015, 2016, 2017, and 2018 (Table 1). In addition, we used PlanetScope imagery, which is a commercial nanosatellite constellation (PlanetScope, 2018), for the year 2018 (Table 2), with 3-m pixel products and images featuring reflectance from visible to near infrared. The latter were used together with 2018 Landsat 8 images in order to evaluate classification methods.

Table 1 – Images following the standard: satellite-sensor/year month day/orbit-point.

Satellite imagery missions	Year/month/day	Orbit/point
LANDSAT 7	1999/10/25	231/62
LANDSAT 7	2001/08/11	231/62
LANDSAT 7	2002/08/30	231/62
LANDSAT 5	2003/08/09	231/62
LANDSAT 5	2004/10/14	231/62
LANDSAT 5	2005/08/30	231/62
LANDSAT 5	2006/09/02	231/62
LANDSAT 5	2007/08/04	231/62
LANDSAT 5	2008/07/21	231/62
LANDSAT 5	2009/09/10	231/62
LANDSAT 5	2010/08/28	231/62
LANDSAT 5	2011/08/31	231/62
LANDSAT 8	2013/10/07	231/62
LANDSAT 8	2014/08/23	231/62
LANDSAT 8	2015/09/11	231/62
LANDSAT 8	2016/10/15	231/62
LANDSAT 8	2017/07/30	231/62
LANDSAT 8	2018/09/19	231/62

PlanetScope mosaics were used as field truth, since high spatial resolution (3 m) pixels were enough to determine samples, validated by high precision (geodetic L1/L2) GNSS surveys in representative areas. Polygons for areas of interest were then defined as follows: anthropized (any constructions, exposed soil, and related human patterns), primary vegetation (forests and related phitophysiognomy), secondary or non-forest green area (including agricultural and bush formations), water, clouds, and shadows. These were needed in order to build *Kappa statistics* (Galparsoro & Fernández, 2010) and the confusion matrix, against thematic classes produced by classifiers.

Table 2 – PlanetScope images from 2018.

Year/month/day	Planet images
2018/08/31	135130_101b
2018/08/31	135131_101b
2018/08/31	135132_101b
2018/08/31	135133_101b
2018/08/31	135336_0f43
2018/08/31	135337_0f43
2018/08/31	135338_0f43
2018/08/31	135339_0f43
2018/08/31	135455_103d
2018/08/31	135456_103d
2018/08/31	135458_103d
2018/08/31	142744_104b
2018/08/31	142745_104b
2018/08/31	142746_104b
2018/08/31	142747_104b

In addition to traditional pixel-to-pixel classifiers, an object-based image segmentation (OBIAS) method was applied to the *Landsat* 8 2018 image. This method introduces a segmentation process, dividing the image in spectral regions, which can be defined as similarity areas (Borges & Silva, 2009).

The use of image segmentation as a level before the classification was a way to overcome some of the limitations that may present conventional classifiers pixel by pixel. OBIAS implementation was carried out with SAGA GIS (7.0), with bandwidth seed point generation equal to 5. The logical sequence for this classification is as follows: A) registering both images and clipping exactly the equal area of interest; B) classifier training; C) unsupervised classification

(ISODATA and K-means) (Memarsadeghi et al., 2007) and supervised classification methods: minimal distance (Meneses & Almeida, 2012) and maximum likelihood (Richard & Jia, 2006). The OBIAS method was also evaluated using minimal distance (Desclee et al., 2006) and maximum likelihood (Amaral et al., 2009). Kappa and confusion matrix were used for comparison.

After deciding the optimum method, we applied it to classifications on (July to Cctober, summer epoch) 1999-to-2018 annual Landsat imagery. We present through graphics, tables, and maps the values associated with deforested, anthropized, and secondary forests in regeneration processes and their possible causes in the increase or decrease of deforestation rates throughout the 18 analyzed years in the study area.

Forest data from older imagery were compared to land-use thematic classification from newer imagery as follows: 1999 to 2005, 2006 to 2011, and 2013 to 2018. The same analysis was carried out with thematic vector data derived from raster classification (polygons from pixels), using spatial selection. Centroids were then produced from these polygons, and they are base coordinates for producing heat map symbology, in which proximity is highlighted.

Jointly with the analysis of the ZF's study area deforestation, we carried out a socioeconomic survey through the technical inspection reports and database available from the Autarchy c*oordination of agricultural projects*. The information was collected according to the flow chart presented in Figure 2.

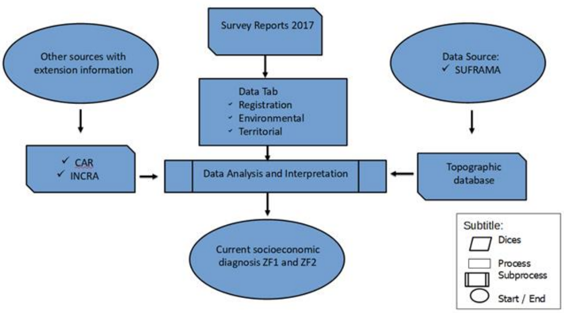

Figure 2 - Flow chart of secondary database for socioeconomic diagnosis.

This research also used other available information from public organizations, mainly data from the Environmental Federal Ministry, called the Environmental Rural Register (CAR), and the INCRA official database, which is Brazil's official land ownership, with georeferenced data.

3. RESULTS AND DISCUSSIONS

3.1 Evaluation of classification methods

For the analysis of the deforestation of the study area, six classification methods were evaluated, responding to which algorithm would be better to quantify thematic classes applied to the region. The ISODATA method (automatic, non-supervised) presented five spectral classes, and, analyzing the general aspects in these classifications, it was seen that the ISODATA classified large areas of "primary forest" as being "water". None of the predefined classes generated homogenous results in this classifier, and in general, the "view" aspect was of confusion, making it impossible to define adequate thematic classes for the classified map.

The K-means algorithm presented slightly better results in terms of separation and definition of classes. However, we identified strong failure in correctly carrying out "shadow" from "water" thematic classes. Shadows from clouds are known issues in image analysis and automatic classification, since target reflectance is less "pure" and not as easily distinguished as its "original" class. In the Amazon region and its large analysis areas and long rainy season, this issue can be significant, especially when analyzing pre-Landsat 8 and sentinel 2 data (missions with new spectral bands to automatically detect the presence of clouds).

The first supervised and pixel-by-pixel method presented is the minimal distance (MinDist). This was better evaluated than unsupervised methods according to the statistic odd accuracy and Kappa rate. It is important to highlight that, considering a visual interpretation of the classification, there is apparently an extrapolation of the areas classified as secondary forest (light green).

Through the maximum likelihood method (MaxVer), the performance of the algorithm was significantly better. However, it is important to enhance as limitations of the method the incoherencies in the classification of isolated pixels and the influence of the embossing related to the determination of some classes, mainly the secondary forest class (light green) that was overestimated by the method, even considering that a higher amount of training samples was inserted into the classification process to ensure spectral separation.

A *Landsat* 8 set of bands from the year 2018 was segmented to the classification by the region's minimal distance and maximum likelihood using the OBIAS algorithm, with a bandwidth seed point generation equal to 5. After segments were ready, they were manually designed to classes, and then the minimal distance classifier was applied. The visual interpretation of this map shows confusion, especially for the classes "water" (in blue) and "shadow" (in black), mainly in the river edges, several of which are classified as "shadow". Through the *Kappa* value, this classification is considered good.

Over the six evaluated classifiers, the maximum likelihood post-OBIAS segmentation showed the best statistic rates, considering validation against truth areas. The quality of classification according to *Kappa* rate and overall accuracy was close to 100%. Following this, this research adopted the current method for all remaining classifications, considering annual series of Landsat imagery since 1999, in order to produce thematic maps, spatial analysis, and discussion on deforestation rates for the study area.

3.2 Land-use analysis: 1999 to 2018

In order to develop better global comprehension of the results of multitemporal analysis, the following graphic (Figure 3) was produced. It aims to explain the dynamics related to the following classes: primary forest, secondary vegetation, anthropized area, and water.

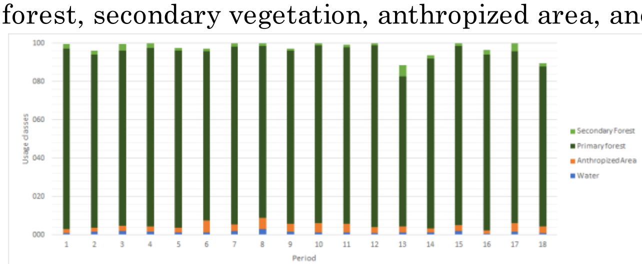

Figure 3 – Area percentage for each land-use class — 1999 to 2018 — from Landsat imagery semi-automatic classification.

In order to analyze primary forest, secondary vegetation, and anthropized area thematic classes, we also separated the temporal series into three groups, each group with a time interval of six years:

first group, 1999–2005; second group, 2006–2011; third group, 2013–2018. Thus, it was possible to view and interpret alterations in land use in the study area over 18 years clearly and briefly.

Primary forest in the study area showed localized modifications in its composition over the 18 years of study. It can be assumed that, since ZF-2 presents many established allotments that were granted to research institutions like INPA (Amazon Natural Institute of Research) and UFAM (Federal University of Amazonas), these help with the maintenance of the forest.

The occupation process of ZF-1 was carried out with little or no oficial control; consequently, this area showed larger forest disturbance, which caused environmental issues in the study area. The analysis of the Autarchy database for the year 2017 showed that large areas (usually above 10,000 ha) were granted to big companies in this area. As time passed, these areas were abandoned for economic, land ownership insecurity, and environmental legal reasons, as verified by Autarchy surveys. Portions of these parcels had no surveillance and were invaded, causing them to be divided into smaller allotments, gradually intensifying the irregular occupation in the ZF-1 roadsides, and contributing to the total amount (considering the study area as a whole) of forest loss of 86 km² in the last 18 years.

Secondary forest showed an increase from 2013 to 2018 of 61.21 km². Most people living in these local roadsides did not have the financial resources to clear large areas in the forest, and with this financial limitation they faced technical difficulties to improve land quality and start agricultural activities.Even with enough money to start their occupation projects, farmers did not have easy technical support to increase the productivity of cultivations, or they had no infrastructure for the flow of production. Road pavement was nonexistent, and consequently, traffic conditions were very poor, especially during the rainy season.

3.4 Hotspots and spatial analysis

Conversions from primary forest to anthropic activities were quantified and identified to the years from 1999 to 2005 and demonstrated on a heat map (Figure 4). The heat map shows that in the areas of greatest conversion to the anthropized areas - they were located at km 07 on the left hand side of the federal highway BR-174, in areas where mediumsized agriculture - for example, areas with approximately 25 hectares.The other area (to the south), which presented intense conversion, was located on the road close to the Brazil Institute of Environment (IBAMA), one of the institutes with areas in the DAS.

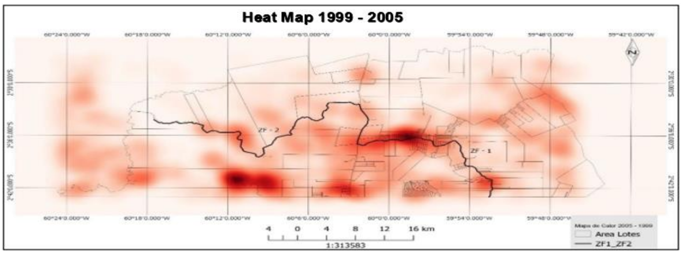

Figure 4 – Hotspots of conversion from forest to anthropized area, 1999–2005.

The total amount of area considered forest in the year 2006 is 37.350 ha; it was then converted to anthropized area in the year 2011, with double the deforestation when compared to the former period. A concentration of maximum values (Figure 5) occurs in an area of 2,000 ha, originally granted to an agricultural company (here identified as CERES).

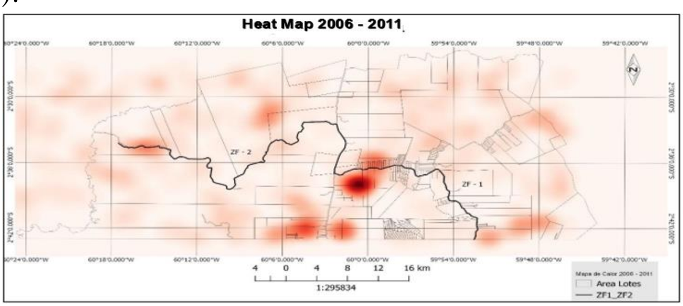

Figure 5 – Hotspots corresponding to converted forests/anthropized areas, 2006–2011.

The heat map shows that in the period of 2013–2018 the maximum concentration of conversion areas of the forest was highly distributed to the total area of this study, which means that deforestation action nowadays is generalized. In other words, deforestation is happening simultaneously in many regions, mainly because there is no control program, official zoning, or monitoring activities to stop the spread of deforestation and burnings (Figure 6).

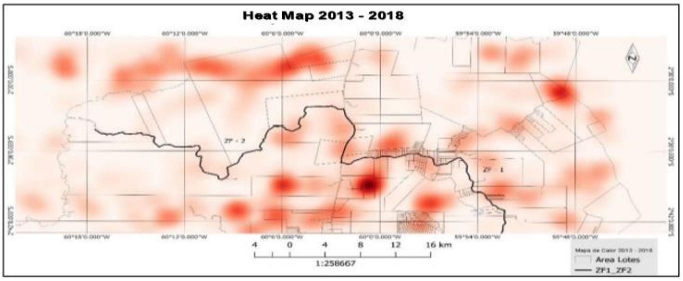

Figure 6 – Hotspots corresponding to converted forests/anthropized areas, 2013–2018.

3.5 Analysis of databases

In order to present information about actual land ownership and the social and economic situation of the ZF-01 study area, this work collected data from official Autarchy survey reports for 2017, the geospatial database of the DAS for 2018, and complementary data from (SICAR) Brazilian system on rural environmental register from the National Ministry of Environment and from (SIGEF) Brazilian official system for land ownership, by National Institute of Colonization and land reform (INCRA) from 2018.

The geospatial database shows a total of 161 occupations, in between regular occupations with some degree of implementation of agricultural projects and also irregular occupations, characterized as invasions. Since the DAS area is not measured/surveyed, technically law 10.267/2001 (Brasil, 2001) is not being enforced, and any process of dismembering or concession of use in this area can be contested.

It was possible to survey data about residents. Every allotment is assumed to be registered to a person or company/institute/university — legal entities. Among residents of the road junction area ZF-01, 55% are registered as male and 30% as female; 85% are individuals. Moreover, 4% are registered as a legal entity, and 11% are unidentified, because of a lack of information on the reports.

For 84 surveyed areas, 37% declared 2001 as the occupation year in a ZF-1 allotment; however, for subsequent years, a smaller rate (6% and 12% for 2002 and 2003, respectively) was registered as the year of regularization, which indicates that these people were not looking to regularize their occupations.

Most DAS areas went to public organizations at around 585.45 km², equivalent to 34.5% of the total area, followed by large areas (more than 1,000 ha) at around 503.93 km², equivalent to 29.7%. The institutionalized focus is noted in a large part of ZF-2, which may contribute to the maintenance of the forest. The designation of large areas to industry conglomerates and big producers is concentrated in ZF-1.

We also analyzed quantitative CARs, which is an official register of land use, for the study area. Quantification was carried out for registers within the study area (Figure 7). There were 182 identified areas registered in the CAR system (SICAR), exactly 2,415.54 ha. The largest area is a 429.63 ha parcel, and the smallest is 0.10 ha. Compared to the total area of study, a polygon of 209,000 ha, 1% is registered in the SICAR (Figure 8).

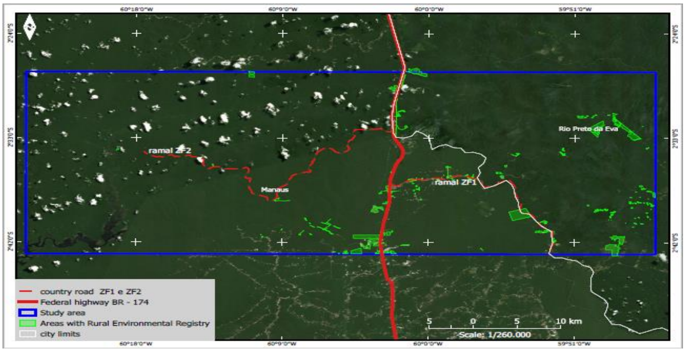

Figure 7 – ZF-1 and ZF-2 rural environmental cadastre areas (CARs).

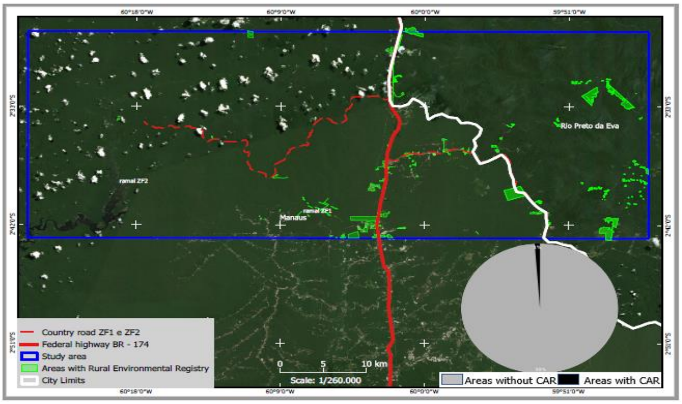

Figure 8 – CAR percentage in the study area.

Data from the SIGEF, the official land ownership database in Brazil, were gathered in order to confirm the land management situation in the ZF-1 and ZF-2 area. This made it possible to observe that, considering the total DAS area, only a few parcels appear in the SIGEF database: 13 georeferenced areas in the agricultural district as a whole and only four georeferenced areas in the ZF-1 and ZF-2 roadsides.

4. CONCLUSION

The best results from field validation and high-resolution imagery were obtained from the OBIAS, region-based, associated to the maximum likelihood algorithm. Classification quality was measured by the *Kappa index*, using Landsat images in the study area for 2018.

Internal Autarchy processes show that allotments of more than 1,000 ha in this road (ZF-1) were designated to agricultural projects, and they failed, mainly due to economic reasons and infrastructure issues. Most of these large areas were abandoned and started a very intense migratory flow inside the DAS, an area with occupations mostly by small farmers, who started chopping down forests to clear areas, build houses, and develop agricultural plantations without technical assistance.

The institutionalized areas that were granted in the roadside of ZF-2 possibly helped to preserve forest cover. Nowadays, just a few governmental institutions operate in the region, which can create irregular occupations. In the present case, some such institutions are located there and could stimulate other institutions to study the area and ensure its protection.

For people living in this region, deforestation, plantations, or cattle raising, together with forest burning or selective logging, is the only way to obtain money. Accompanied projects demonstrated issues with continuity and a lack of technical support and infrastructure, but since Autarchy has little perceived governance over the area, we need to consider the absence of regulations and zoning as an issue. Most rural properties in the district are not registered in these two Brazilian government databases. Moreover, our study detected a rise in landholding conflicts, invasion, and violence, which create problematic situations in social, economic, and environmental aspects.

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