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DOI: 10.14393/SN-v32-2020-45146
Received: 27 September 2018 | Accepted: 30 October 2019

Papers

Land use and land cover dynamics in a sustainable development project in the Transamazon highway region, Pará state, Brazil

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Abstract
The Transamazon highway region in the state of Pará is critical for Amazon deforestation due to socioeconomic transformations it has undergone. This work analyzes spatial and temporal changes in land use and its impacts on land cover in the Virola-Jatobá Sustainable Development Project (PDS) in Anapu-Pará, from 1984 to 2015. The study was mainly conducted through processing and analyzing Landsat scenes using the Spring platform. Very modest rates of deforestation were registered in the initial years analyzed. More substantial increments were reached seven years after the formation of the PDS, but nevertheless still at a low level. Consequently, forest is the predominant land cover in the PDS, followed by pasture, because agricultural areas are modest. In general, forested land presented high stability rates. Among other land use classes, pastures also presented significant stability, although the class weedy pasture showed some instability.
Keywords: Landscape dynamics; Geotechnology; Spatial analysis; Settlement project.

Introduction

Land use and land cover change processes are an important topic on the global environmental research agenda. They modify the energy balance and influence the climate, by altering terrestrial albedo, the chemical composition of the atmosphere, and biogeochemical cycles (FOLEY et al., 2005; VERBURG et al., 2009; LAURANCE et al., 2011). Global deforestation is one of the most impacting factors for these processes. Hansen et al. (2013) assessed that between 2000 and 2012, 32% of global losses of vegetation cover affected tropical forests, near half of which in South America.

Since the 1970s, land use and land cover dynamics in the Amazon comprises the conversion of primary forest to other land uses, particularly in the critical region known as the “Arch of

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Deforestation". According to Sorrensen (2009), this process usually begins with successive episodes of selective logging with the elimination of adult individuals of commercial tree species. The use of fire is a common practice to prepare the land for agricultural systems, especially pasture, the most relevant anthropogenic land use in terms of area in the Amazon (TERRACLASS PROJECT, 2014; MAPBIOMAS PROJECT, 2019). With productivity loss due to improper land management, many of these pastures are abandoned, and natural vegetation succession occurs.

Growing needs for environmental adequacy to global climate change demand reductions in Amazon's deforestation rates and fire use. Public policies and programs for environmental conservation have been implemented in the region, many led by the Brazilian Ministry of Environment (MMA). One of these initiatives was established by the National Colonization and Land Reform Institute (Incra), which established the land tenure modality known as Sustainable Development Project (PDS), through Incra's Ordinance 477/1999 (INCRA, 1999), modified by Ordinance 1040/2002 (INCRA, 2002). The PDS modality was also a response to restrictions for the creation of land reform settlement projects in Amazonian forested areas, determined by Law No. 11.284 of 2006 (BRASIL, 2006).

According to Incra (1999) and Porro et al. (2015), the PDS constitutes a settlement modality whose land tenure is issued through Real Use of Rights' Concession Contracts (CCDRU), which could be on behalf of one or more associations representing beneficiary families. Compared to other land tenure modalities, such as Extractive Reserves, PDS beneficiaries, whose main activity does not need to be extractive, may include family farmers' featuring profiles and practices with greater market integration.

In each PDS there are Legal Reserve Areas (LRA) and Alternative Use Areas (AUA). The LRA in a PDS can be used only collectively, based on sustainable forest management plans that must be approved by environmental agencies. The AUA are explored on a family basis, in plots allocated by Incra to each beneficiary family. The PDS is an environmentally differentiated modality of land reform in the Amazon, with settlers' subsistence based on family farming, extractivism and other activities with low environmental impact (PORRO et al., 2015). The integration of these activities would contribute to reduce deforestation's magnitude in land reform settlements.

The implementation of this tenure modality is a great challenge, particularly in critical regions with land struggles related to the occupation of and dispute over forested areas. This is the case of the area under the influence of the Transamazon Highway (BR-230), in the state of Pará (BRATMAN, 2011; DE SARTRE et al., 2012; PORRO et al., 2015). In the municipality of Anapu, the development of a proposal that articulates land reform and environmental conservation resulted mainly from the work of sister Dorothy Stang and the Pastoral Land Commission (PORRO et al., 2015).

Environmental studies can assist the proper understanding of processes of occupation in areas pressured by the expansion of pioneer frontiers in the Amazon. In such studies, the deployment of remote sensing and geoprocessing products and techniques, by providing spatial and temporal dimensions, has the potential to subsidize policies, especially those regarding the political and economic planning of natural resource use (WATRIN et al., 2011). Working on rural settlement projects in Southeast Pará, Watrin et al. (2005) found that anthropizing processes in landholdings tend to present distinct trajectories according to specific migration features and land adjudication strategies. Forest clearing is favored in areas of older colonization and smaller average plot size, thus restricting the availability of natural resources to landholders.

Working in watersheds sites in the Lower Tapajós region, Pará state, Rozon et al. (2015) observed complex and heterogeneous changes in the spatial and temporal dynamics of land use and land cover. According to these authors, events observed in five watershed groups can be in part explained by the proximity of roads and villages.

Based on the use of geotechnology, this paper analyzes issues related to spatiotemporal changes in land use and their impacts on vegetation cover in PDS Anapu III and IV, in the state of Pará. The purpose of the paper is to understand the dynamics of land use and land cover in the PDS land reform modality, considering the selected settlement as a pilot area.

Study site

The study area corresponds to the 39,486.01 hectares of the Sustainable Development Project (PDS) Anapu III and IV, known as PDS Virola-Jatobá (PDS-VJ), located in Anapu municipality, Altamira microregion, state of Pará (Figure 1). Created by Ordinance SR01 39/2002 (INCRA, 1999), the PDS is a mosaic of 3,000-hectare land lots, previously intended for rural entrepreneurs who signed public land sale agreements with the federal government. As contract clauses were not fulfilled, the land returned to the Union. The PDS-VJ comprises two modules, PDS Anapu III, intended exclusively for forest management, while PDS Anapu IV also houses 160 alternative use plots. These plots correspond to an average of 20 hectares, intended for the development of agricultural activities by beneficiary families.

The PDS-VJ is drained by tributary streams of the Anapu and Pracurú rivers, and the existing road network is subordinated to the BR-230 (Transamazon) highway, which runs south of this area. According to Rodrigues et al. (2007), regional soils include Dystrophic Yellow Latosol (flat to soft-hilly landscapes), Dystrophic Yellow Ultisol (soft to strong-hilly landscapes) and Dystrophic Red-Yellow Latosol (hilly to strong-hilly landscapes). These soils share good physical properties (deep, well drained, good porosity and aeration), and low chemical fertility (high acidity, low base sum and low exchangeable base saturation). Such chemical limitations for agriculture are easily corrected with chemical inputs, whose cost is, however, inaccessible to the vast majority of local landholders.

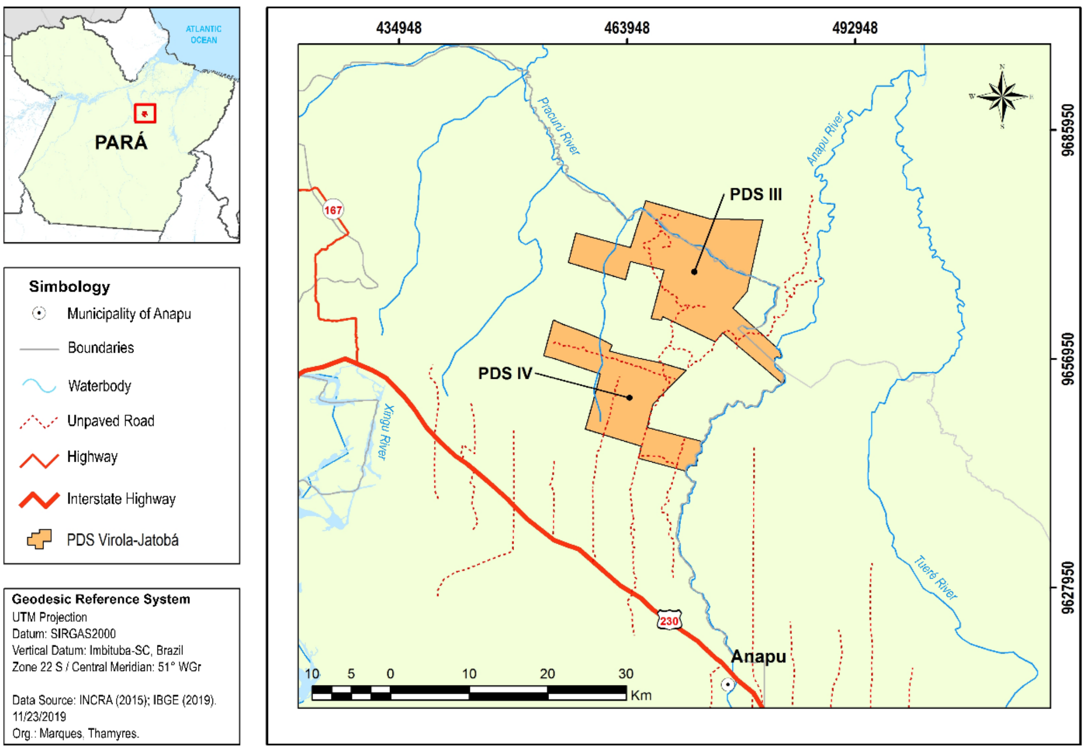
Predominant land cover in PDS Virola-Jatobá is still forest, even in areas of alternative use, where 2015 forest cover was about 70% of the total. Pastures predominate in cleared areas, despite the presence of small fields of annual crops with low diversification, mostly with cassava and maize. Exceptionally, small orchards and cocoa fields are observed. In areas of abandoned agricultural use, secondary succession vegetation with variable structure and density is observed.

Material and methods

The georeferenced data of interest were treated and analyzed within a spatial database built in the SPRING 5.3 platform (INPE/DPI, 2015), considering IBGE's cartographic base at the 1: 50,000 scale, and Sirgas' 2000 projection system. Existing boundaries for the study area, obtained from a digital map provided by Incra, were also stored in the database.

Land use and land cover patterns were mapped used Landsat images, orbit/point 225/62, on the dates of 06.23.1984, 11.28.1989, 07.21.1994, 08.04.1999, 11.19.2003, 01.08.2004, 04.08.2005, 06.06.2006, 06.23.2007, 11.07.2008, 11.19.2009 and 07.04.2011 (Landsat 5 TM bands 3, 4 and 5; spatial resolution 30m); 06.17.2002, 07.25.2010, 02.21.2012 and 10.21.2013 (Landsat 7, ETM+ bands 3, 4 and 5; spatial resolution 30m); and 03.12.2014 and 07.15.2015 (Landsat 8, OLI bands 4, 5 and 6; spatial resolution 30m). The images were not submitted to the preprocessing phase given the large number of currently available images that are orthorectified (GUTMAN et al., 2013) and atmospherically corrected (MASEK et al., 2006). The latter are Landsat 8 OLI / TIRS Level 2 data products, obtained for free from USGS (2015). Images acquired through USGS are referenced to the north, which makes necessary their reprojection to the southern hemisphere.

Figure 1 - PDS Virola-Jatobá location.



Source: INCRA, 2017; IBGE, 2017. Org.: by the Authors, 2019.

Selected images were classified with the region-supervised method, after being submitted to the segmentation process, in this case considering the similarity and area thresholds of respectively 400 and 11. After the generation of context files, statistical attribute regions were extracted in order to allow their classification. Image classification was performed by the Bhattacharya algorithm, based on the previously generated segmentation grid. Preliminary thematic products were analyzed in a field survey and subsequently subjected to thematic editions to reduce omission and commission errors.

A thematic caption was generated in the image classification process, comprising, besides Water and Cloud/Shade classes, nine mapping units, including Dense Forest and two stages of secondary vegetation (Old and Young Fallow). The separation of these classes is due to internal shading promoted by their structural differences, such as stratification and canopy height (WATRIN et al., 2005). The definition of other land use classes considered stages of development and various cultural and management practices adopted in the region. The Clean Pasture class refers to newly installed areas or areas with low weed infestation, which are features opposite to the ones in areas defined as Weedy Pasture. Agricultural areas were named as Annual and Perennial Crops, according to their cycle, while areas under agricultural preparation were mapped as Burnt and Exposed Soil classes.

Area quantification of mapped classes and analysis of land use and land cover dynamics in the studied years were performed upon obtaining thematic images of interest. The analysis of land use and land cover dynamics was possible by comparing images of all consecutive dates (cross-tabulation), totaling 16 temporal contrasts. Transition matrices were then generated based on the spatial distribution of thematic information.

Four phases were established considering equidistant intervals for the purpose of analyzing the selected series of images, taking the date of PDS establishment as reference: pre-installation (1984, 1989, 1994 and 1999; PRE), post-installation I [2002 to 2006; POST (1)], post-installation II [2007 to 2011; POST (2)] and post-installation III [2012 to 2015; POST (3)].

The analyzes considered both the temporal contrasts and the aggregation of these contrasts in the four phases. The general linear model (GLM) was adopted for the tests, considering the effect of the phases, with a significance level of 5%. Both tests and graphical representations were obtained with the aid of the Statistica software.

Results and discussion

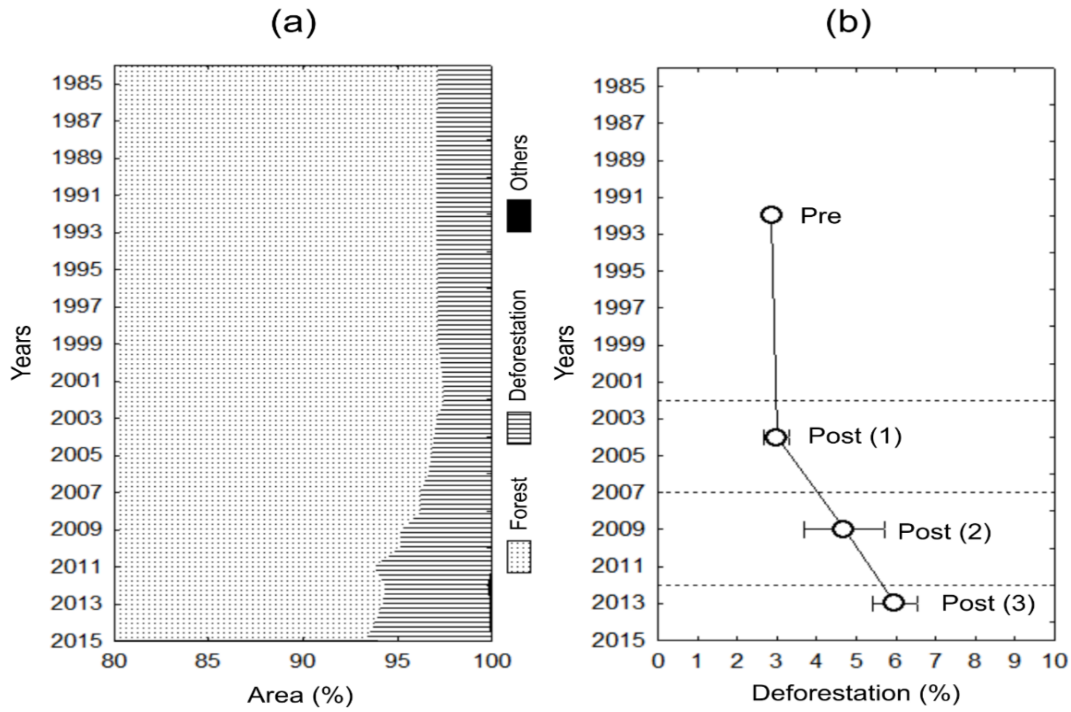
Deforestation Process

Figure 2 depicts the pattern of deforestation in the PDS-VJ, almost entirely concentrated in the Alternative Use Area. Deforestation remained practically stable during the pre-installation phase (period 1984-1999), reaching around 1,100 ha, a situation not unlike the POST (1) phase, in which annual increments of less than 100 ha were recorded. These patterns were in part due to the fact that, in the 1984-2005 period, gradual conversions were observed in Lot 129 from Old Fallow to Dense Forest, resulting from the natural process of plant succession in anthropized areas.

Total deforestation reached a rate greater than 4% of the total area (or 1,875.5 ha) from the inflection point observed in 2009 [POST (2) phase], seven years after the creation of the PDS. This pattern denotes that an unusual strategy of land appropriation is seen in this land tenure modality. Watrin et al. (2005) argue that rural settlement projects are expected to have higher deforestation rates during the initial years of implementation, a period of land use consolidation in the plots. Over time, the expansion of agricultural activities tends to deplete forest reserves, and deforestation rates steadily decline.

Considering the total deforested area already existing at the time of the establishment of the PDS, an equivalent deforestation rate in the post-installation period was only reached in 2011 [end of the POST (2) phase], when deforested areas comprised 6.24% (2,467.4 ha). Although the last phase analyzed (2012-2015) was affected by clouds, it showed a tendency for deforestation to decrease in magnitude. Part of the family plots reached the use of the 20 ha agreed upon with Incra for the establishment of agricultural activities. Another factor that may have contributed to a reduced deforestation rate during this period is the existence of the forest management initiative between 2008 and 2012. The highest deforestation value in the PDS was verified in 2015, corresponding to only 6.72%. of the total area (2,652.8 ha).

Figure 2 - Deforestation during the 1984-2015 period for PDS Virola-Jatobá, Anapu, PA. (a) Percentage values of forested and deforested areas; (b) Average percentage values and standard deviation of deforested areas considering phases of PDS establishment.



Source: by the Authors, 2019.

As expected, it should be noted that deforestation did not advance homogeneously in the PDS. Deforestation was more intense in the area of alternative use, near the main access of the settlement and with better infrastructure (Lots 128, 129 and 130). It was also greater in the sector corresponding to access road 115 (Lots 128 and 130), where residents contest the PDS modality and do not adopt land use practices recommended by Incra. The proximity of settlement villages and roads is increasingly recognized as a catalyst for spatiotemporal changes in land use and land cover in Amazon colonization areas (ROZON et al., 2015). However, according to Oestreicher et al. (2014), although such factors partly explain changes in land use and land cover, they alone cannot explain the observed phenomena. In fact, for the same authors, land use and land cover change reflect the economic, environmental, topographic and sociocultural factors of studied areas.

Throughout the series analyzed, the pre-installation and early installation [POST (1)] phases presented equivalent deforestation rates, respectively 2.86±0.05% and 3.00±0.32%. On the other hand, these phases were significantly different ($p < 0.01$) from the deforestation of the POST (3) phase (5.97±0.56%), while the POST (2) phase presented intermediate values (4,69±1.01%). It was thus observed that significant changes in PDS landscape were only manifested after the initial post-installation phase (Figure 2b). This pattern of landscape change related to deforestation is unusual, as in the vast majority of cases such changes occur immediately, as opposed to the later pattern observed in the PDS.

Deforestation Qualification

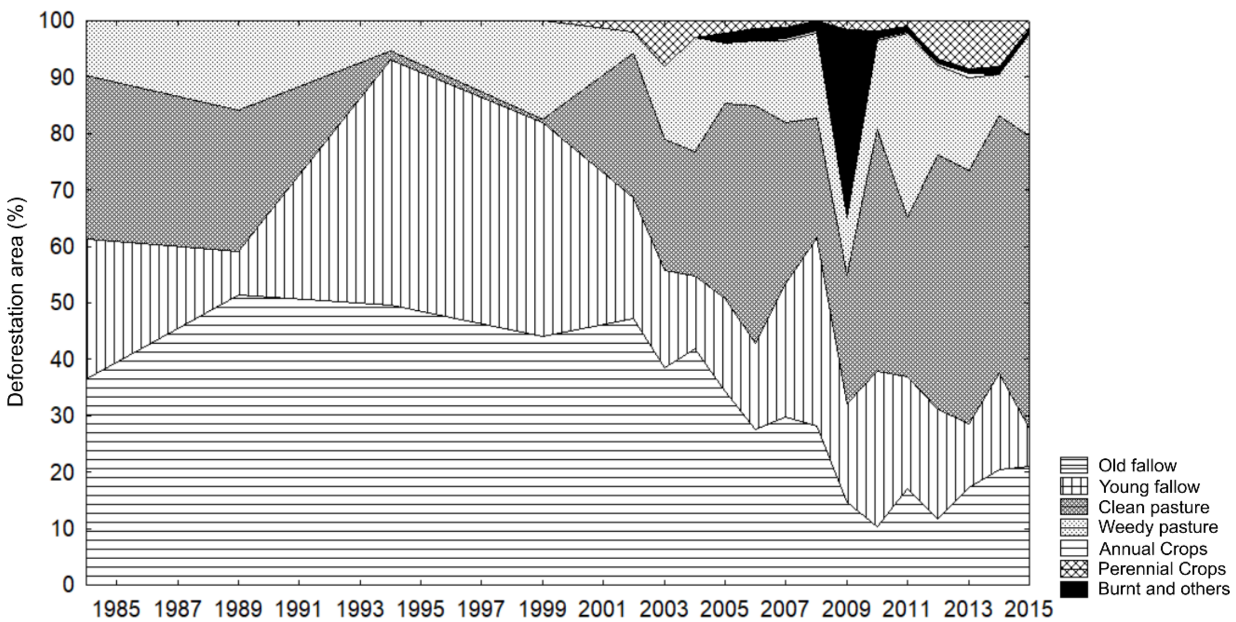
Dense Forest predominates in the studied landscape in all analyzed years, comprising from 97.46% (2002) to 93.25% (2015). This denotes a landscape of initial transformation, typical of the agricultural frontier where it is inserted (Transamazon highway). Figure 3 shows the percentage of classes associated with the qualification of deforested areas over the years being analyzed.

During the pre-installation phase of the PDS and most of the POST (1) phase, the predominant anthropized class consisted of secondary succession (Old and Young Fallow), arising from occupation prior to the establishment of the PDS. Since then, the share of these classes decreased, due to the advance of productive activities. The lowest rates of these classes were observed in 2015, during the POST (3) phase, contributing to only 27.78% of anthropized landscapes, probably due to natural succession resulting from the reclassification of these areas as dense forest. Worthy of note is the progressive reduction of the Old Fallow area, so that in the POST (2) and (3) phases the share defined for this class would be equivalent to the Young Fallow one.

Pasture areas reached over 60% of the total anthropogenic areas in 2011, last year of the post-installment phase II. With the exception of 1994 and 1999 (pre-installment phase), the Clean Pasture class always presented higher rates than those registered for Weedy Pasture, particularly in the last analyzed phase [POST (3)]. This is surprising given the low level of intensification of agricultural systems in the area, and contradicts rural settlement projects in Southeast Pará (WATRIN et al., 2005).

In contrast to results presented for cultivated pastures, areas classified as agriculture are practically insignificant during all post-installment phases and even absent during the pre-installment one. Perennial Crops, mainly cocoa fields, had greater expression, contributing up to 8.23% of the total cleared areas in the PDS. On the other hand, the minor expression of Annual Crops consists of intercropped cassava, maize and rice, always with rates below 1%. It should be noted that the mapping of this class was greatly hampered not only by the small size presented (annual fields around 1 ha), but especially by the mismatch between the field cultivation phase (first semester of the year) and the availability of Landsat images (second semester). Availability of images in drier months (October and November) also implied the possibility of classifying areas to be prepared through burning. Therefore, it is possible that part of the areas spectrally classified as Weedy Pasture in these months refers to Annual Crops after being harvest (which, for maize and rice, occurs in May-June), whose remains are associated with cassava and emerging secondary vegetation.

Figure 3 - Representation of the qualification of deforested areas during the 1984-2015 period for PDS Virola-Jatobá, Anapu, PA.



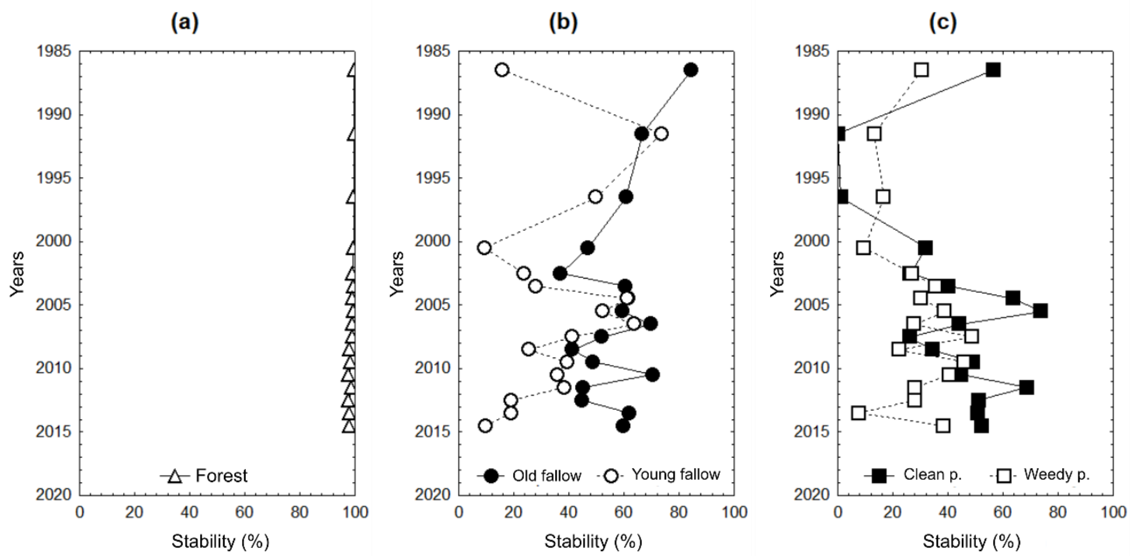
Source: by the Authors, 2019.

Land use and land cover dynamics

Reflecting the low impact of human-related activities in the PDS, Dense Forest areas presented high stability rates throughout the period of the analysis, with lowest values observed during post-instalment phases 2 and 3, and a minimum of 97.79% for 2012-2013 (Figure 4a). As observed by Metzger (2002) on former colonization sites in northeastern Pará state, such pattern is common in areas with already consolidated landscapes, where modest forest remnants, for the most part, are circumscribed to the margins of the drainage network, in unfavorable locations for the development of productive activities. Areas that did not remain stable were preferentially converted to pasture, the dominant use in cleared land, and particularly to Clean Pasture, which, with the exception of the pre-installment phase, had its origin in forested areas. The average rates of Pasture stability ranged from 49.7% to 55.2%. Field observations indicate, however, that direct conversion of forest to pasture rarely occurs in PDS plots, resulting rather from a first year in which, after deforestation, annual fields are cropped (during the first semester of the year), while sowing of pasture grass concurrently occurs with the last weeding of the crops.

Secondary succession areas denoted comparatively lower stability rates (Figure 4b), as their presence is actually associated to fallow periods in agricultural production units. Having said that, the two succession classes presented rather distinct behavior, with much higher stability rates observed for Old Fallow than for Young Fallow, matching findings of Watrin et al. (2005) and Rozon et al. (2015). However, considering the low level of human interventions in the study area, the highest conversion rates between vegetation cover units occurred among these classes (Dense Forest, Old Fallow and Young Fallow).

Figure 4 - Stability rates presented over the 1984-2015 period by main land use and land cover classes at PDS Virola-Jatobá, Anapu, PA.



Source: by the Authors, 2019.

There is a tendency for farmers to leave areas with the most advanced stages of succession to continue natural regeneration. That explains the reclassification of many Old Fallow fragments to Dense Forest observed especially in the pre-installment and POST (1) stages of the PDS. The lower stability rates observed for areas classified as Young Fallow, whose minimum value reached 9.67% in 2014-2015, are due to the fact that these areas are preferably converted to agricultural use, and in particular, to pastures. Potentially, such a choice results to a great extent from the enforcement of legal restrictions for agricultural use in forested landscapes, even in the alternative use areas of the PDS. Such restrictions compel PDS farmers to prepare their fields in Young Fallows, despite negative returns obtained from the traditional slash-and-burn system in these areas.

Among anthropized land use classes, pastures (Figure 4c) portrayed the most significant stability rates. These rates, were, however, distinguished between the Clean and Weedy Pasture classes. Clean Pasture presented the highest stability rate during all post-installment phases, with a maximum value of 68.67% observed in 2011-2012, as opposed to very low rates observed in some years of the pre-installment phase, with a minimum of 0.16%. Lower stability rates verified for Weedy Pasture are linked to the fact that they have been partially converted back to Clean Pasture, based on the practice of reforming degraded pastures with the use of fire. While some Weedy Pasture areas that did not remain stable were converted to Clean Pasture, another share of them might have been converted to Young Fallow due to continued abandonment and the unavoidable progression of the vegetation succession process.

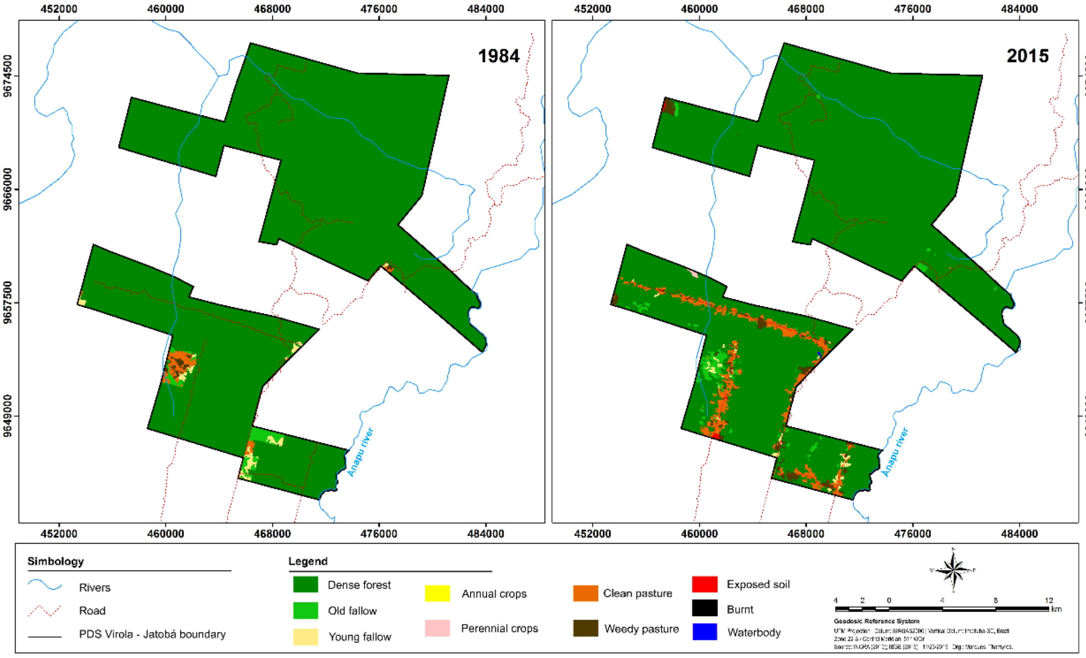
Finally, the smaller share of land classified as agriculture (Annual and Perennial Crops) consisted of fields preferably established in Dense Forest areas, taking advantage of the higher natural fertility of the organic layer. As the adopted production system is shifting cultivation, the stability of the Annual Crop class in the analyzed periods was quite variable.

These results suggest that the settlement modality in the study area constrained the disorderly deforestation process observed in other Amazon regions. However, such an outcome is accompanied by a complex socioeconomic burden that is a major challenge to be overcome by public policies in sustainable development projects. Figure 5 shows the spatial distribution of the main land use and land cover classes in 1984 - phase [Pre] and 2015 - phase [Post (3)].

Final considerations

During the early stages of the analysis, deforestation remained practically stable, occasionally registering very modest annual increments. A more prominent rate was only recorded seven years after the installation of the PDS. This performance is linked to an unusual strategy of land occupation in this land tenure modality. The expected pattern was the highest deforestation rates already occurring in the first years of settlement. In the last phase analyzed, deforestation rates tended to decrease, as some lots reached the 20-ha limit previously defined for agricultural use.

Figure 5 – Land use and land cover classification for 1984 and 2015, PDS Virola-Jatobá, Anapu, PA.



Source: by the Authors, 2019.

The Dense Forest class predominates in the study area landscape, denoting a state of incipient transformation, typical of agricultural frontiers. Dominant land use classes in cleared areas are pastures in different stages, with the Clean Pasture class being more frequent. Agricultural areas were absent in the pre-installation phase, and almost irrelevant during all post-installation phases.

Dense Forest areas were found to have high rates of stability over the period being assessed. Such level of stability is more often seen at consolidated landscapes of former colonization sites, or in areas of lower anthropogenic pressure, such as extractive reserves or indigenous lands. Comparatively, the areas of secondary succession presented lower stability rates, as they are an active component of agricultural fallows in family farming, especially the Young Fallow stage.

For cleared areas, pastures presented the higher stability rates, with Clean Pastures presenting the highest values, as opposed to Weedy pastures, which showed some variation. As the adopted agricultural systems predominantly consist of shifting cultivation, stability rates of the Annual Crop class were generally low.

Acknowledgments

This work was carried out under the project "Local governance and sustainability of community-based forest management in Sustainable Development Projects in Anapu, Transamazon - AutoManejo". It was supported by Embrapa's Macroprogram 6 and Native Forest Resources Portfolio, as well as by the Fundação Amazônia Paraense de Amparo à Pesquisa - Fapespa (Icaaf 104/2014). The authors would like to thank Funcate's geographer João Felipe Cerqueira Pinto for his support in the satellite image classification

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