Land cover change trajectories in western Amazonia

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Abstract. This paper aims to quantify the trajectories of deforestation and degradation in Acre State – Brazilian Amazonia. For this proposed study, we used a series of remote sensing products from INPE: deforestation, degradation and land use data from PRODES, DEGRAD and TerraClass, respectively. We performed a spatial explicit pixel-by-pixel analysis to estimate the changes in trajectories between deforested and degraded areas, between 1997 and 2013. The results demonstrated that 77% of the deforested areas were replaced by pastures, 15% by secondary vegetation, 4% by other classes, 3.4% by mosaic occupations and only 0.3% by agriculture. Degraded areas between 2007 and 2013 presented 8% of conversion to pasture, 2% to other classes and 0.8% to mosaic occupations. The remaining 87% of the degraded areas were maintained as forests during this period. Therefore, in Acre state, direct forest conversion are used for pastures rather than agriculture, and forest degraded by fires or selective logging remains as degraded forests. In a long time span, it is possible that, if no further degradation reaches the impacted forests, they will recover as old growth forests with minimal or no impact in carbon emissions, but with unknown impacts on the forest structure and biodiversity.

Key-words: deforestation, degradation, land use, Acre, Amazonia.

1. Introduction

The land use and land cover change impacts the energy exchange between the surface and atmosphere, influencing local and regional balances on the elements that regulate the Earth's climate, causes biodiversity loss, forest degradation, carbon emission, among others (Foley et al., 2005; Lambin et al., 2003; Laurance et al., 2011). Thus, the most important process involving land cover dynamics is deforestation and forest degradation.

Between 2000 and 2012, it was estimated that 32% of the overall forest loss occurred in tropical forests, and almost half occurred in South America (Hansen et al., 2013). The Amazonia forest is located in this region and is the major continuous tropical forest of the planet, with a highly heterogeneous biodiversity (Fearnside, 2008). Despite being the largest tropical forest in the world, the 2004-2015 cumulative deforested area in the Brazilian Amazonia reached approximately 130,000 km² (INPE, 2016a) and forest degradation summed more than 100,000 km^2 between 2007-2013 (INPE, 2016b). This intensive anthropic intervention, converts high biomass and biodiversity forests into low biomass monoculture pasture and agriculture leading to the emission of greenhouse gases (IPCC, 2007).

The government of Acre, the westernmost state in the Brazilian Amazonia, has promoted forest conservation and sustainable forest management on its policy, being one of the pioneers in Brazil for promoting incentives for environmental services, known as SISA, passed into state law on October 22, 2010 (law number 2.308/2010). Nonetheless, uncontrolled logging and forest clearing primarily for cattle pastures have continued, particularly in eastern Acre where some municipalities have lost 20-75% of their forests (Brown et al., 2006). Between 2007-2013 the total deforested area in Acre was 1,670 km² and degraded area between this period was 847 km² (INPE, 2016a; INPE, 2016b). Despite Acre deforestation contribute only with 3% of the total deforestation of the Brazilian Legal Amazonia, these land cover changes have impacts on climates and human well-being.

The Brazilian National Institute for Space Research (INPE) performs the monitoring of Brazilian Amazonia forest through various projects, such Deforestation Monitoring Program in Legal Amazonia (PRODES). This program aims estimate the deforestation rate of Brazilian Amazonia (INPE, 2008). However, this project does not indicate the use of these deforested areas. To answer this question, a partnership project between INPE and EMBRAPA was developed to map the land use of deforested areas called TerraClass (Coutinho et al., 2013). This project mapped land use for deforested areas for the following years: 2004, 2008, 2010, 2012 and 2014 for entire Legal Amazonia. Due to the growth of forest degradation, INPE developed DEGRAD program for detect degraded areas in Amazonia. This program mapped degradation for 2007 to 2013 with the images used by PRODES program.

For presenting the lowest deforestation rates among the Legal Amazonia states, there is few studies that focus on the land use and land cover change dynamics in Acre state. Nonetheless, this region is quite unique: it has been highly impacted by the most extreme recent droughts in 2005, 2010 and 2015/16 (Marengo et al, 2008; Marengo et al, 2011; Jiménez-Muñoz et al., 2016) and two major floods (Espinoza et al., 2014); presents significant changes in its hydrological cycle (Gloor et al., 2013), and pressure for deforestation has increased in the recent years due to the Inter-Oceanic Highway (Perz et al., 2008) and due to gold mining in the Peruvian side of the border (Scullion et al., 2014). Thereby, his paper aims to quantify the trajectories of deforestation and degradation in Acre State – Brazilian Amazonia.

2. Material and Methods

The Acre state has an area of 153,194 km², which corresponds to 3% of the Brazilian Legal Amazonia, and has the states of Rondonia and Amazonia as limits in Brazil and Peru e Bolivia as international boundary (Figure 1). In the 60's began a larger process of migration and settlements implementation, attracting people from other regions of the country. This process was due in large part, to incentives from the federal and state governments for the territory occupation (Allegretti, 1992). Historically, Acre state economy was based on forest products extraction, such as rubber, wood and non-wood products. However, this economic base has been replaced by cattle ranching activities since late 1960's. This change in the economic activity has resulted in environmental and socio-economic problems. The environmental problems are related to deforestation of large primary forest areas, biodiversity loss and increase degraded pasture areas after few years of use. The socio-economic problems are related to decline of rubber production and abandonment of settlements causing increase of urban population and suburbs (Becker, 2001; Lorena, 2001; Fearnside, 2005).

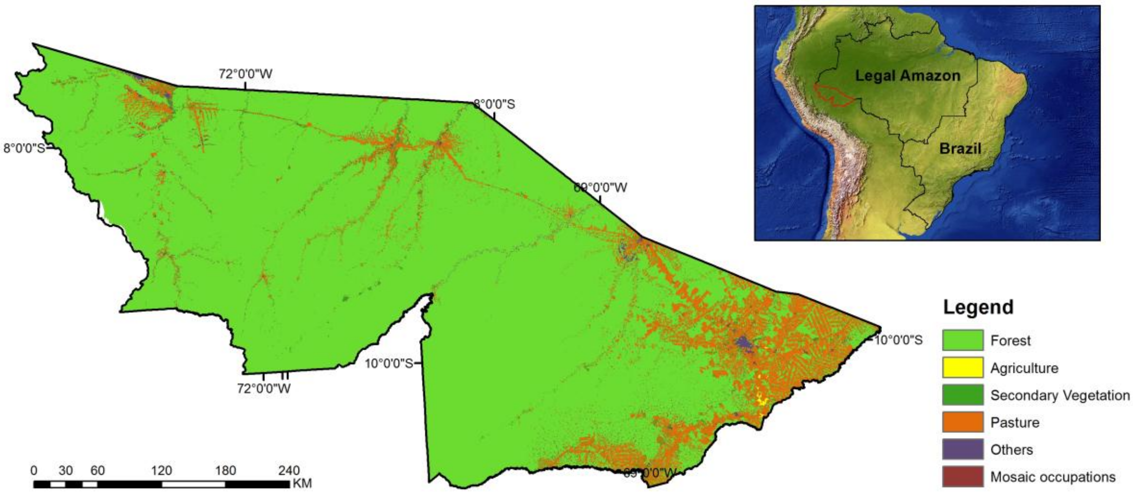

Figure 1. Study area. Land use of Acre state in 2014.

The data used in this work was annual deforestation between 1997 and 2013 provided by PRODES/INPE. Degradation data from 2007 to 2013 was provided by DEGRAD/INPE. The DEGRAD data refers to remote sensing detection of forests impacted by logging and/or fire. Land use and land cover data was obtained from TerraClass/INPE for the years 2004, 2008, 2010, 2012 and 2014.

The methodology used by TerraClass mapped the following classes: annual agriculture, mosaic of occupations, clean pasture, dirty pasture, pasture with regeneration, pasture with exposure soil, secondary vegetation, reforestation, urban, others, mining, non-forest, hydrography and unobserved areas. To simplify the analysis we aggregate some classes, in pasture class we join all pasture classes and in other class we join non-forest, hydrography, urban and unobserved areas. The data used in this work is presented in Table 1.

Table 1. Data and years used in this work

Data/Source	Years
DEGRAD/INPE	2007 - 2013
PRODES/INPE	1997 - 2013
TerraClass/INPE	2004, 2008, 2010, 2012 e 2014

To analyze the fate of the deforested area, we accumulated deforestation data for the following periods: 1997-2003, 2004-2007, 2008-2011 and all deforestation between 1997-2013. For degradation data, we processed 2007, 2008-2009, 2010-2011, 2012-2013 and all degradation which occurred in the period from 2007-2013. We used the TerraClass data which followed the year for each period. For example, to analyze the fate of the deforested area from 1997 to 2003, we used TerraClass data for the year 2004. Then, we carried out a pixel-by-pixel analysis to calculate the area of each land use class in both deforestation and degradation data, in order to track the changes in land cover and land use.

Finally, a zonal analysis with the land tenure data (Table 2), provided by the State Office of Climate Change and Regulation of Environmental Services (IMC-AC). This analyze provided the quantification of land use and degraded area in each land tenure type.

Table 2. Land tenure data

Land tenure type	Number of registered areas	% State area
Non-discrimatory study	11	9.08
Public Land	22	1.91
Settlement	109	9.95
Discriminated	40	13.71
Particular	158	19.49
Indigineous Land	30	14.5
Conservation Unit	19	31.36

3. Results

In figure 2 is presented the changes in land use classes throughout the analyzed period. These results demonstrate that approximately 77% (13,548 km²) of the deforested areas were converted to pasture from 1997-2013, followed by secondary vegetation (15%), other classes (4%), mosaic occupations (3.5%) and agriculture (0.4%). This same pattern is observed in all periods of analysis, showing that the agrarian structure of Acre is based on cattle ranching.

Studies demonstrated that in Acre state, areas have been deforested for cattle ranching since the decadence of rubber extraction in the late of 1960's (Lorena, 2001). Thus, sometimes pastures are stablished as a means to increase the value of the land or in order to rent it to other farmers, providing an incentive for forest clearance (d'Oliveira, 2000). This justifies the high percentage of deforested areas converted to pasture.

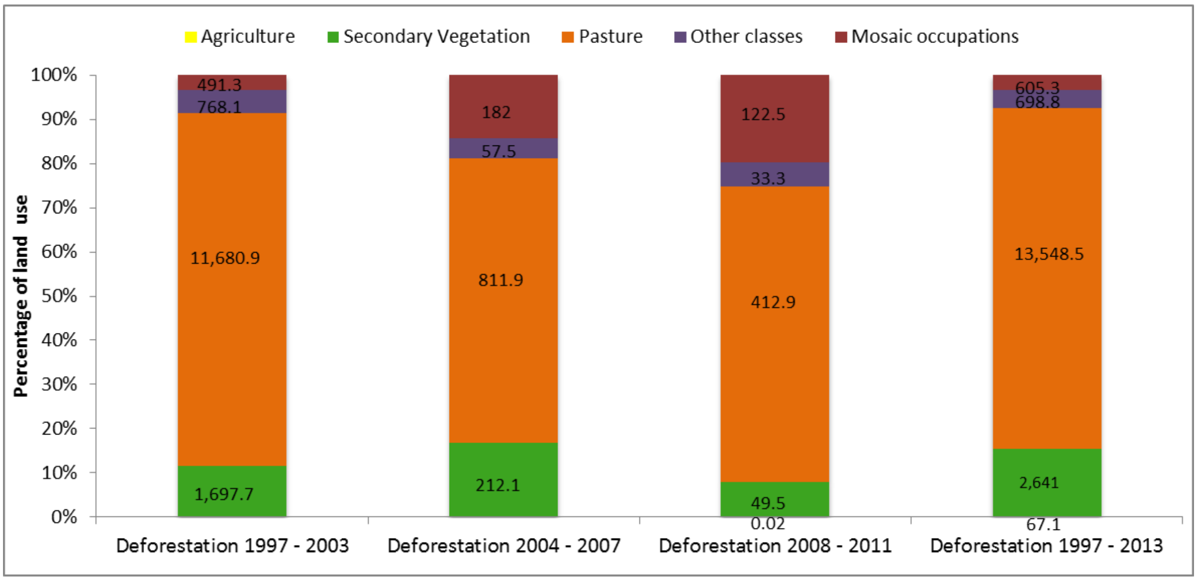

Figure 2. The fate of deforested areas. In the bars are presented the area in km².

In figure 3 is presented the fate of the forest degraded areas in the period studied. Between 2007-2013, approximately 734 km² (87%) of the degraded forests remained as forests until the last year evaluated, 2014. It was observed that 8% of the degraded forests changed to pastures, 2% to secondary vegetation, 1.85% to other classes and 0.75% to mosaic occupations. These results demonstrated that, in total, 12.7% (100 km²) of degraded areas between 2007-2013 was completely converted to other land use by 2014.

As we can see in figure 3, the period between 2010-2011 presented higher conversion compared with other periods of analysis, with 25 km² of degraded areas was deforested and converted to another use. The 2012-2013 period presented the small conversion, with 4.7 km². Compared with Legal Amazonia states Acre presents low degradation rates, but follow the cyclic pattern of increase and decrease of degradation and presents a decrease between 2011 and 2013.

Although most of the degraded forests remained as forests, the degradation process itself has many implications. For example, it causes decline in biodiversity, disruption of ecosystem process and turn forest more susceptible to fire spread (Cochrane et al., 1999; Pereira et al., 2010; Rands et al., 2010; Haddad et al., 2015). Moreover, if the degraded forests are submitted to a continuous degradation, carbon loss and species composition changes occurs (Barlow and Peres, 2008).

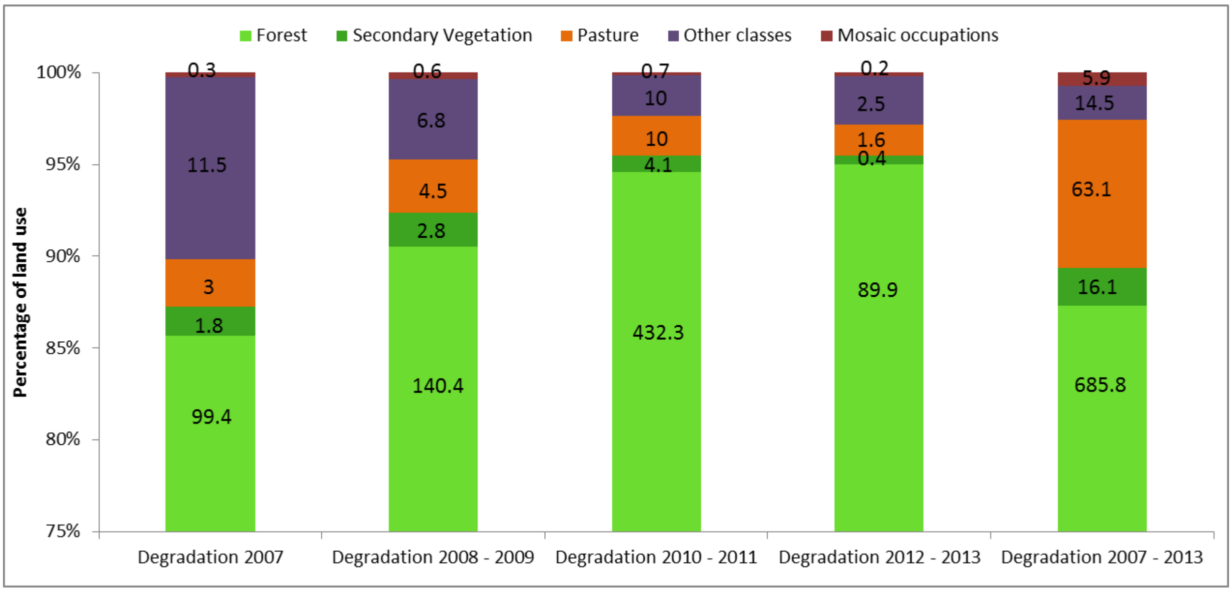

Figure 3. The fate of degraded areas. In the bars are presented the area in km².

In table 3 is presented the land tenure data status for 2014 related to the areas deforested and converted to other land use between 1997-2013. Areas that became agriculture are located in settlement (1.2 km²) and particular lands (65.8 km²). Particular, settlement and discriminated lands together presented 77% of secondary vegetation and 91% of pasture. Compared with all classes, particular has 98% of agriculture areas (65.8 km²) and this indicate that they are more productive. Settlement exhibits 83% of deforested area occupied by pasture and is more dependent of this activity.

A comparison among all classes of land tenure showed that indigenous lands had the lowest deforested area in the period (182 km²) corresponding to 0.8% of the total indigenous area. Approximately 56% of the total area deforested in indigenous land became secondary vegetation in 2014, 24.8% became pasture and 6.8% and 12% change to other classes and mosaic occupations, respectively. Conservation units presented 54% of deforested areas converted to pasture, 27% to secondary vegetation, 14% to mosaic occupations and 4% to other classes.

These results suggest that Indigenous land can be more effective to preserve forest cover than Conservation areas. This result is in accordance with evidences that forests managed by indigenous communities can be more effective in maintaining forest cover than those managed under solely protection (Porter-Bolland et al., 2012; Nepstad et al., 2006).

Table 3 – Land use classes in 2014 in areas deforested between 1997 and 2013 (km²).

Area type	Agriculture	Secondary Vegetation	Pasture	Other classes	Mosaic occupations
Non-discriminatory study	0.0	203.8	414.9	49.8	44.5
Public Land	0.0	49.2	212.4	10.9	16.9
Settlement	1.2	663.4	4,900.0	196.5	164.8
Discriminated	0.0	559.0	2,645.9	207.3	120.3
Particular	65.8	803.7	4,449.8	182.4	100.5
Indigenous Land	0.0	102.2	45.2	12.4	22.2
Conservation Unit	0.0	256.2	512.1	38.8	138.5

In table 4 there is land ownership and land use classes in 2014 of the degraded areas between 2007 and 2013. Particular lands presented the greatest degraded area with 227.6 km², followed by settlements with 180.4 km² and conservation unit 161 km². In these types of land 94%, 92% and 94.4%, respectively, remained as forest cover in 2014, respectively. The land tenures with the smallest degraded forest areas were public lands, lands with non-discrimatory study and indigenous territories. Indigenous and public lands had the smaller area (1.5 km²) of change from degraded forests to other land uses. On the other hand, settlement and particular lands had the highest area of change from degraded forest to other land uses, with 14.3 km² and 11.5 km², respectively.

These results indicates that indigenous and public lands are less susceptible to have its forests degraded by logging or fire and that forests in settlement and particular lands are impacted, and present the higher change rate in degraded forest cover to a land use.

Table 4 – Land use classes that substituted degraded forests (km²) from 2007 to 2013, by land tenure.

Area type	Secondary Vegetation	Pasture	Other classes	Mosaic occupations	Forest
Non-discriminatory study	1.3	0.7	0.8	0.3	19.4
Public Land	0.6	0.3	0.3	0.2	5.3
Settlement	4.0	4.0	5.2	1.1	166.1
Discriminated	2.8	0.9	2.3	0.5	93.3
Particular	4.1	1.6	4.2	1.6	216.1
Indigenous Land	0.6	0.4	0.1	0.4	34.5
Conservation Unit	2.9	2.5	1.7	2.0	152.0

4. Conclusion

The result of this work supports the conclusion that on Acre state, pasture areas are advancing over deforestation and degradation areas rather than agriculture and land abandonment, detected here as secondary forests. Most of forests degraded by fires or selective logging remain as degraded forests. In a long term, it is possible that, if no further degradation reaches the impacted forests, they will recover as old growth forests with minimal or no impact in carbon emissions, but with unknown impacts on the forest structure and biodiversity.

Thus, conservation units, that is supposed to protect forests and stop deforestation, present 54% of deforested area converted to pasture when compared to indigenous land that presents

25% of deforested area converted to pasture. So, it indicates that conservation units administration may not be effective to avoid deforestation. Indigenous land data demonstrated that more than 50% of its deforested area became secondary vegetation because shift cultivation. This suggests that indigenous land is more effective to control the advance of deforestation.

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