Population densities and deforestation in the Brazilian Amazon: New insights on the current human settlement patterns

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ABSTRACT

This paper provides the first analysis at the sub-municipality scale of the relationships between population densities and deforestation in the Brazilian Amazon between 2000 and 2010. We use the database on deforestation published by the Brazilian space research center (INPE) and the population census data released by the federal geographical and statistical agency IBGE at their finest scale: the census tract level. By crossing the population density and deforestation variables, we identify ten human settlement patterns in the Amazon. There are low-low and high-high classes of population density and deforestation, but also low-high and high-low classes. This analysis helps understand the low overall relations in the Amazon for population and deforestation. We emphasize the expansion of large-scale agriculture and cattle ranching as causing the depopulation of rural areas while in many regions of the Amazon quite strong population densities coexist with relatively low extents of deforestation. Such findings stress the need to implement case-specific public policies in these regions in order to encourage human presence compatible with the conservation of forest cover and biodiversity. We also confirm the importance of the Amazon urbanization process, including the 'discrete urbanization' of rural areas, and the need to better recognize the distinct social and environmental problems of urban areas.

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1. Introduction

The impact of population settlement on natural resources has been a central issue in population and environmental studies. In the tropical forests, a number of case studies have shown a positive relation between population density and deforestation (Ehrhardt-Martinez, 1998; Laurance, Sayer, & Cassman, 2014; López-Carr & Burgdorfer, 2013). However, since the 2000s, this paradigm has been changing, and human population density is no longer pointed out as the principal determinant of tropical deforestation in land-use change studies. Instead, it is viewed as a factor interacting with complex social, economic, and political processes at local and global levels (DeFries, Rudel, Uriarte, & Hansen, 2010; Geist & Lambin, 2002; Pacheco et al., 2011; Rudel, Defries, Asner, & Laurance, 2009).

For the Brazilian Amazon, which represents 40% of the world's remaining tropical rainforests (FAO, 2011) and supplies important

ecosystem (Foley et al., 2005) and climate (Malhi, Roberts, Betts, Killeen, Li, & Nobre, 2008; Nobre, 2014, p. 42) services, such insights may be of great relevance, since the demographic growth during the last decades has been impressive: the overall population of the Legal Amazon rose from about 2.5 million in 1960 to over 24,3 million today, a 10-fold increase (IBGE, 2010). In the same period, almost 71 million hectares were deforested, equivalent to 18% of the original forest cover, with important annual rates of deforestation, even if since 2009 the phenomenon has been lowered to about 5000 km^2 per year (Le Tourneau, 2016; Nepstad et al., 2009; INPE, 2015). If a lot of studies have shown the influence of different factors on deforestation, like the presence of roads (Kirby et al., 2006; Laurance et al., 2002; Perz et al., 2008) and land tenure issues (Araujo, Bonjean, Combes, Combes Motel, & Reis, 2009; Ostrom & Nagendra, 2006; Paneque-Gálvez et al., 2013; de Espindola, de Aguiar, Pebesma, Câmara, & Fonseca, 2012), few recent studies have addressed the relationships between population densities and deforestation in the Brazilian Amazon.

This paper investigates the mixed relationship between human population density and deforestation in the Amazon for the 2000 to 2010 period. Our research hypothesis is that there is a low overall

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relation in the Amazon for population and deforestation because local conditions vary widely. For example, strong deforestation rates may be observed in areas of low population densities because of expansion of large-scale agriculture and cattle ranching. This issue of the heterogeneity of population settlement patterns and their impacts on natural resources in the Amazon is critical for policy makers concerned with land-use planning.

First, we examine the partition of urban and rural population and its variations across the Amazon, identifying human settlement patterns (from dispersed rural population to dense city centers). Then, we investigate the transformations of such settlement patterns between 2000 and 2010 and analyze possible relationships between such transformations and the evolution of deforestation during the same period.

The basis of our analysis are the database on deforestation released by the Brazilian space research center (INPE) (INPE, 2015) and the population census data at the census sector level published by the federal geographical and statistical agency IBGE (IBGE, 2010). Using such fresh data at the sub-municipality scale, we aim at bringing an accurate vision of the human occupation of the Amazon both in the land use frontier and in its remotest parts.

2. State of the art

2.1. Deforestation processes and human settlements in the Brazilian Amazon

The large-scale colonization process of the Brazilian Amazon since the 1960s resulted in different human settlement patterns with different combinations of population density and deforestation.

2.1.1. In-migration and Amazonian land use frontier consolidation

In the 1960s and 1970s, the military government began to promote rural colonization of the Amazon in order to populate and to integrate it to the Brazilian economy. Several public policies were implemented to accelerate immigration and economic development in the region and have contributed to the appearance of large-scale deforestation (Fearnside, 2005). Construction of major transport infrastructures began and ambitious colonization programs (both private and state sponsored) tried to attract smallholders in the region under the motto "Lands without men for men without lands" (Le Tourneau & Bursztyn, 2011). Hundreds of thousands of families arrived in the region and began to convert the forest into agricultural lands (Morton et al., 2006). In these areas of small-scale family farming, the underlying human settlement pattern tends to be a combination of medium to high population density and medium to high deforestation, except where land speculation takes place, giving way to the installation of *latifundios*.

In the 1970s and 1980s, generous fiscal incentives were also implemented in order to attract large firms into the Amazon, leading in a vast majority of cases to the establishment of large-scale cattle ranching and to the conversion of forest areas to pasture (Carvalho et al., 2002). Last, several big infrastructure projects (Tucurui dam, Transamazônica highway, etc.) were also responsible for the migration of workers to the Amazon and the further installation of these in public lands and local towns (Browder & Godfrey, 1997).

In the 1980s, forest conversion to pasture continued to expand because of land speculation: creating pasture in forest areas was a cheap way to create "productive land", to claim land titles and to sell the new properties with high profits in a context of rapid rise of land prices (Nepstad, Stickler, & Almeida, 2006). This system of extensive, low-input cattle ranching motivated by land speculation resulted in creating large areas of degraded land (Bowman, Soares-Filho, Merry, Nepstad, Rodrigues, & Almeida, 2012; Carvalho et al., 2002) with few human settlements. Indeed, large scale ranching has contributed to the evolution of the human settlement pattern with the emergence of large areas with relatively low population density and high deforestation.

2.1.2. Deforestation driven by distal demand for agricultural products

In the 1990s, soybean began to expand into the Amazon thanks to the development of new adapted technologies (Fearnside, 2001) and to the rise of soybean prices on the international market. With the growing international demand for soybean, large-scale mechanized agriculture expanded into the southern and eastern extent of the Brazilian Amazon and modified the rural dynamics of the region. The soybean industry expansion contributed to a new valorization of land, leading ranchers to sell their properties and seek new areas further north where land prices were lower, participating to the land use frontier advance (Nepstad, Stickler, et al., 2006) and to a trend toward depopulation of the rural areas (Lapola et al., 2014). Thus large-scale crop production has added a new pressure on the forest due to direct deforestation for cropland implantation and to intensified use of lands previously cleared for cattle ranching (Arvor, Meirelles, Dubreuil, Bégué, & Shimabukuro, 2012; Morton et al., 2006). Thereby, the human settlement pattern consisting in low population density and high deforestation has been expanding through the Amazon frontier.

Moreover, as for the big infrastructure projects of the 1970s and 1980s, the magnitude of investments for the commodities production and exportation led to a rapid growth of the cities located along one of the Amazon's export corridors (Richards & VanWey, 2015). This has contributed to the attraction of rural population and to the multiplication of quite densely populated urban areas.

2.1.3. Toward the conciliation of forest conservation and human settlement: the progressive recognition of the land rights of Amazonian "traditional" peoples

In parallel, since the 1990s, the "traditional" peoples of the Amazon, including Indigenous peoples, but also *Quilombolas* communities (communities formed by descendant of fugitive slaves) and other communities whose subsistence historically depends of non-timber forest products (ex. Rubber-tappers) have gained collective land rights on relative large portion of their ancestral territories. Today, about 21.7% of the Brazilian Amazon is classified as Indigenous land and 14.5% is under diverse protected areas aiming at conciliating the presence of rural communities and the conservation of the Amazon forest (Veríssimo, Rolla, Vedoveto, Futada, & de, 2011, p. 87). In these areas of forest extractivism and slash and burn agriculture, the underlying human settlement pattern is a combination of low to medium population density and low deforestation.

Adding to this, 8.9% of the Amazon is under integral protected areas where human presence is forbidden (therefore theoretically registering zero population and zero deforestation).

As this quick historical description shows, the Amazon consists in a vast mosaic of diverse land tenures and human settlement pattern, both terms having influenced each other (Nasuti, Tritsch, & Eloy, 2015).

2.1.4. New trends of Amazonian deforestation

Since 2009, the efforts of the Brazilian government to curb deforestation induced a spectacular diminution on the annual deforestation rates and the progressive decoupling of agricultural expansion and deforestation (Gollnow & Lakes, 2014; Le Tourneau, 2016; Macedo, DeFries, Morton, Stickler, Galford, & Shimabukuro,