Land Use Policy 49 (2015) 35–42

Contents lists available at ScienceDirect

Land Use Policy

journal homepage: www.elsevier.com/locate/landusepol

Potential land availability for agricultural expansion in the Brazilian Amazon

Denise Zanatta Martini[a,*], Mauricio Alves Moreira[a], Luiz Eduardo Oliveira e Cruz de Aragão[a], Antônio Roberto Formaggio[a], Eloi Lennon Dalla-Nora[b]

[a] National Institute for Space Research-INPE, Remote Sensing Division-DSR, Avenida dos Astronautas, 1758, Jardim da Granja, 12227-010 São José dos Campos, SP, Brazil
[b] National Institute for Space Research-INPE, Earth System Science Center-CCST, Avenida dos Astronautas, 1758, Jardim da Granja, 12227-010 São José dos Campos, SP, Brazil

ARTICLE INFO

Article history:
Received 27 October 2014
Received in revised form 25 June 2015
Accepted 7 July 2015

Keywords:
Brazilian Amazon
Agricultural expansion
Sustainable development
Deforestation
Biomass

ABSTRACT

The Amazon hosts one of the largest stocks of arable land in the world. However, little is known about the available extent of agricultural land in conformity with legal, agronomical and environmental requirements. This study aims to identify and quantify potentially available areas for agricultural expansion in the Brazilian Amazon considering the extent of: (i) legally available forested lands, (ii) previously converted lands with suitable productive capacity and (iii) previously converted lands free of land use conflicts. This analysis was carried out by integrating georeferenced information on land use, soil fertility, terrain slope, biomass, protected areas and land use policies (e.g. Brazilian Forest Code) into a conditional decision support procedure, based on Boolean inference techniques. Our results showed that 11.69% (493,103.03 km^2) of the Brazilian Amazon would be potentially available for agricultural expansion in the year 2010. This area was essentially dominated by forests (59.37%), followed by previously converted lands (40.63%). The extent of this area was equivalent to 75.86% of the total cultivated area in Brazil in 2010. However, the effective usage of these areas would have direct political and environmental implications. First, it is expected that the effective usage of available forests would detract recent achievements of the Brazilian Action Plan for Prevention and Control of Deforestation in the Amazon, which has reduced deforestation by 79% from historical rates. Moreover, the conversion of these areas could result in a committed emission of 13 ± 1 Pg CO_2eq to the atmosphere which is equivalent to the total emissions from land cover change registered in Brazil during the 2000–2010 period. Therefore, the compensation of environmental liabilities stands as the most consistent destination for the available forests mapped in this study. To minimize environmental impacts, agricultural expansion in the Brazilian Amazon should be restricted to already converted areas. This land cover class totalizes 200,000 km^2, which could support agricultural expansion without promoting the advance of deforestation.

1. Introduction

Available land for agricultural expansion has become an increasingly scarce resource across the globe (Lambin and Meyfroidt, 2011; Lambin et al., 2013). In practice, the expansion of the agricultural frontier is currently concentrated in the tropical regions (Gibbs et al., 2010; Hansen et al., 2009). The Brazilian Amazon (considered here as the Amazon biome within the political limits of the Brazilian Legal Amazon, excluding *Cerrado* areas) in particular, stands as one of the major stocks of arable land remaining in the world (Ramankutty et al., 2008; Cai et al., 2011; Lambin et al., 2013). However, from a legal, agronomical and environmental point of view, little is known about the real availability of land and the practicability of agricultural expansion in this region.

Since mid-2000s, the Brazilian government has adopted several measures to reduce deforestation in the Amazon, which has dropped 79% from 2004 to 2013 (INPE, 2014). The strengthening of command and control strategies, as well as the adoption

* Corresponding author.
E-mail addresses: denise@dsr.inpe.br (D.Z. Martini), mauricio@dsr.inpe.br (M.A. Moreira), laragao@dsr.inpe.br (L.E.O.e. Cruz de Aragão), formag@dsr.inpe.br (A.R. Formaggio), eloi.dallanora@inpe.br (E.L. Dalla-Nora).

http://dx.doi.org/10.1016/j.landusepol.2015.07.005
0264-8377/

of conditional credit policies, have become important mechanisms for combating illegal deforestation (Assunção et al., 2012; Macedo et al., 2012). Moreover, the rapid expansion of the protected areas network in recent years lowered the availability of unallocated public lands, a historical source of deforestation and land appropriation in this region (Boucher et al., 2013; Dalla-Nora et al., 2014). All of these measures, together with previous land use policies (e.g. Brazilian Forest Code) have imposed major restrictions on the traditional agricultural expansion model adopted in the Amazon.

Beyond the recent political and legal issues, the agricultural potential of this region can also be influenced by environmental, logistical and technological constraints, such as temperature and precipitation regimes tolerated by specific crops, infrastructure availability and the agricultural capacity of the soil. These factors are directly related to the economical viability of agricultural expansion in the Amazon, as well as the sustainable development of this sector (Nepstad et al., 2006; Lambin et al., 2013). Therefore, the potential for agricultural expansion in the Brazilian Amazon is dependent on a series of poorly understood or underestimated direct and indirect driving factors.

Previous studies attempted to estimate the land availability for agricultural expansion under different perspectives (IIASA/FAO, 2012; Alexandratos and Bruinsma, 2012; Lambin et al., 2013; Spera et al., 2014). Generally, these assessments were either based on biophysical parameters such as temperature, precipitation and soil type (IIASA/FAO, 2012) or on the identification of specific land use classes which could be used for agriculture, such as pasturelands or abandoned lands (Campbell et al., 2008; Cai et al., 2011). Nevertheless, in both cases, the analyses adopted limited number of parameters and provided low level of detail once they were primarily based on global datasets. Recent studies addressed this topic more carefully, but their results were focused only on forestland availability (Soares-Filho et al., 2014) or converted lands suitable for soybeans expansion specifically (Gibbs et al., 2015). Moreover, such studies did not consider the interplay between important land use and conservation policies acting in this region, which can strongly influence land availability and be decisive for supporting decision making.

To complement this discussion, in this paper we ask: what is the extent and location of available areas for agricultural expansion in the Brazilian Amazon, taking into account the complex and interrelated forces observed in this region? To answer this question we aim to carry out a detailed assessment of the availability and location of the land with potential for agricultural expansion in the Brazilian Amazon, based on: (i) legally available forested lands, (ii) previously converted lands with suitable productive capacity and (iii) previously converted lands free of land use conflicts. This study also addresses the political and environmental implications related to farming within the mapped areas in the context of the Brazilian Action Plan for Prevention and Control of Deforestation in the Amazon-PPCDAm (Brazil, 2004), the Brazilian National Plan for Climate Change-NPCC (Brazil, 2009) and the Brazilian Forest Code-BFC (Brazil, 2012). Ultimately, we aim to subsidize the debate about new policies for territorial planning and sustainable development, by critically assessing the role of the agricultural sector in the Brazilian Amazon region.

2. Material and methods

2.1. Study area

The Brazilian Amazon covers an area of approximately 4,200,000 km^2, corresponding to 49% of the Brazilian territory (IBGE, 2004). The Brazilian Amazon biome, within the Brazilian Legal Amazon encompasses totally or partially the states of Acre (AC), Amapá (AP), Amazonas (AM), Pará (PA), Roraima (RR), Rondônia (RO) Mato Grosso (MT), Maranhão (MA) and Tocantins (TO) (Fig. 1a). According to Köppen and Geiger (1928) the climate of the region is tropical (type A), but three sub-climates can be identified: tropical rainforest (Af), tropical monsoon (Am) and tropical wet and dry (Aw) (Fig. 1b). The average annual temperature is 25 °C with small variations throughout the year. Predominant soil types in the Brazilian Amazon are Latosols (~50%) and Podzols (~30%) (Fig. 1c) and the terrain is mostly flat with gently sloping areas with low susceptibility to erosion. The main vegetation types (Fig. 1d) that are found in the Brazilian Amazon are Ombrophilous Dense Forest, Ombrophilous Open Forest, Seasonal Evergreen Forest and *Campinarana* – a typical Amazonian phytophysiognomy (IBGE, 2012). The Amazon biome also represents nearly 30% of the world's remaining tropical forests, and is considered the greatest reservoir of plant and animal species in the globe (Sayre et al., 2008).

The territorial occupation of this region has been historically associated with different motivations, directly linked to political and economical contexts (Machado, 2002). Until the 1960s, government actions in the Amazon had not significantly impacted forested areas (Serra and Fernadez, 2004). With the start of the military government in 1964, the region received considerable attention and experienced a demographic boom primarily linked to settlement projects, migration incentives and implementation of major infrastructure projects (Becker, 2001). More recently, land use change processes in the Brazilian Amazon have also been influenced by external factors such as the increased demand for agricultural commodities such as meat and grains from international markets (Rudel et al., 2009; DeFries et al., 2010). Along this trajectory, approximately 18% of the biome's forests were converted for human use, especially for agriculture and livestock (INPE, 2014).

2.2. Data acquisition and processing

The identification of Potentially Available Areas (PAAs) for agricultural expansion in the Brazilian Amazon was undertaken based on the integration and analysis of different spatially explicit driving factors, compiled in a GIS (Geographic Information System) environment and organized in a Geographic Database (Fig. 2). A conditional decision support procedure based on Boolean inference techniques (Rosa, 2011) was developed and used for the logical combination of binary maps (Fig. S1). This mapping approach shares to a large extent the premises adopted by Soares-Filho et al. (2014) and Gibbs et al. (2015). Nevertheless, this study took into account the interplay between important land use and conservation policies (e.g. BFC, PPCDAm, NPCC) that affect land availability, but were not considered in previous studies.

Land use and cover data, the basis for the identification of PAAs from different land use sources, were adapted from the TerraClass mapping project (INPE, 2010). This project classified deforested areas within the Brazilian Legal Amazon into different land use and land cover classes for 2010. This map was reclassified to aggregate the classes of interest as explained here and illustrated in Fig. S2 and Table S1:

- *Forest:* native primary forested areas in climax stage;
- *Secondary Vegetation:* previously deforested areas (clear cut), in different regeneration stages;
- *Degraded Pasture:* areas of abandoned or underused pasture, showing signs of regeneration, erosion and with low productivity;
- *Others:* consolidated (urbanized zones, mining, occupation mosaics), productive (annual agriculture, managed pastures) or marginal (rock outcrops, sand dunes, river beaches, water bodies) lands.