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Determinants of the spatial distribution of cultivated land in the North Argentine Dry Chaco in a multi-decadal study

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ABSTRACT

Deforestation in the Northern Argentine Dry Chaco (NADC) has been mainly driven by soybean expansion and, more recently, by the expansion of implanted pastures. In areas with fast land use transformations, it is important to identify variables that determine the spatial distribution of land use change. The kinds of exploratory analyses that do so contribute to understanding the logic of deforestation agents and to identifying more probable sectors for land use change. We produced maps of cultivated land in NADC for different years (1972, 1991, 1997, 2002, 2007). Based on these maps, we evaluated the importance of environmental and accessibility variables over the spatial distribution of cultivated land in NADC using multiple and simple logistic regressions. Environmental variables (soil suitability for agriculture, rainfall, topography) and accessibility variables (distance to main roads, distance to main towns) were used to fit logistic regressions to the occurrence of cultivated land at different years as dependent variable. Goodness-of-fit was evaluated by the Relative Operating Characteristic (ROC) and Pseudo R2 indices. Results indicate that the main variables explaining the spatial distribution of cultivated land in 2007 are distance to main towns (ROC = 0.76; Pseudo R2 0.12) and soil suitability (ROC = 0.72; Pseudo R2 0.11). The capacity of environmental and accessibility variables to explain the spatial distribution of cultivated land decreased through time (ROC in 1972 = 0.91 and ROC in 2007 = 0.77). Results also suggest that rainfall has not been a major restriction to cropland expansion, and that the main limitations are imposed by infrastructure and services provided from main towns. A decreasing goodness-of-fit over time suggests that initial limitations have been overcome by cropland expansion and the consolidation of productive areas. Based on these results, we suggest that cropland expansion may generate positive feedbacks in infrastructure and services (i.e. agglomeration economies) that could explain why initial limiting factors related with distance to roads and towns have been gradually overcome.

1. Introduction

Understanding patterns and drivers of land use change is important for planning the use and conservation of natural resources. The most evident requirement of information is the area affected by land use change, but some characterization of its geographical patterns is also necessary (Nelson and Geoghegan, 2002). In particular, the study of spatial patterns and their control is valuable to understanding the proximate causes of change (Muller et al., 2012). Geographical patterns of land use change are the result of interaction between biophysical (e.g rainfall, soil, slope) and accessibility factors. These factors are taken into account by socioeconomic actors, i.e. the agents who make decisions about land use change, applying a logic framed by particular experiences, cultural values and perception. In consequence, different actors under similar biophysical and socioeconomic conditions may produce contrasting geographical patterns of land use.

One of the simplest and most established models to study geographical patterns of land use is the von Thünen model (von Thünen, 1966). This model proposes that for an area with spatially homogeneous agricultural yields (i.e homogeneous biophysical conditions and technology), the localization of cultivated land is a function of the distance to the market and of transport cost. In this way, the theoretic land use pattern shows a concentric distribution around markets (cities) with a gradient from the most

Abbreviations: NADC, Northern Argentine Dry Chaco; ROC, Relative Operating Characteristic (ROC); RN, National Road; SP, standardized parameters (SP).

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intensive land use (e.g horticulture) near the market to less intensive land uses (e.g extensive cattle) in the most remote areas. The general idea of the von Thünen model is the foundation for many spatial deforestation models based in accessibility and distance to road and cities (e.g. Chomitz and Gray, 1996; Nelson and Hellerstein, 1997; Walker, 2004. For more examples see the revision: Kaimowitz and Angelsen, 1998).

The emergence of globalization and the development of interconnected regions generate a different situation, in which markets and consumption in cities are sourced by distant places (Seto et al., 2012). In this situation, the logic of a central market sourced by surrounding areas should be modified. Cities and urban centers, however, still play an important role in articulating agriculture production as centers of logistic, administrative and economic activity. Agglomeration economies has been recently suggested as a valuable concept to understand the evolution of land use change. This framework define local land use as a consequence of the concentration and diversity of various supply chain actors in the region, not just yield potential and transportation cost as predicted by Thunian theory (Garret et al., 2013). The agglomeration economies concept points out that companies that operate in geographical proximity to each other benefit from positive externalities. These are created by a range of factors that promote a more efficient activity, including better access to market information, access to technology, increased specialization in value chain, or a labor pool (Fujita and Thisse, 2013). The concept of agglomeration economies takes into account the existence of circular causality (positive feedback) which reinforces the positive externalities of agglomeration, thus promoting the incorporation of more companies. This process was proposed to explain the existence of clusters of soybean production on Brazilian deforestation frontier (Garret et al., 2013).

In the last decades, deforestation patterns in South America shifted from occurring mostly in moist tropical forests to becoming more active in deciduous dry forests and savannas (Hansen et al., 2013; Aide et al., 2013). These changes in continental patterns of deforestation were accompanied by changes in the main actors involved (Rudel et al., 2009). During the last decades, deforestation in dry forests and savannas of South America has been promoted by medium and large agribusiness companies oriented towards global market agriculture commodities (mainly soybean) and intensive cattle ranching (Gasparri and le Polain de Waroux, 2014). This type of agribusiness-driven deforestation, has been less studied compared to the spatial patterns of small scale farmer-driven deforestation in moist tropical forests. The emergence of agribusiness companies as main agents of deforestation could represent changes in the spatial patterns of deforestation in contrast to deforestation by small-scale farmers with subsistence economies. Previous works exploring geographical patterns of agribusiness deforestation in Matto Grosso in Brazil (Jasinski et al., 2005) and *Santa Cruz de la Sierra* in Bolivia (Kaimowitz et al., 2002; Muller et al., 2011) showed that distance to roads and towns are the main factors explaining the localization of cultivated land expansion, suggesting the prevalence of factors related with production logistics.

The Chaco region has turned into one of the most dynamic deforestation areas in South America (Aide et al., 2013; Graesser et al., 2015). This process has been quantified for different sectors of Paraguay (Huang et al., 2009; Caldas et al., 2013) and Argentina (Zack et al., 2004; Boletta et al., 2006; Clark et al., 2010). Some of the previous studies also explored causes of change, including rainfall increase, technology change and soybean economy (Grau et al., 2005; Zack et al., 2008; Gasparri and Grau, 2009; Gasparri et al., 2013; Hoyos et al., 2013). However, at the moment, the geographical patterns of deforestation in the Dry Chaco and their main conditioning factors have not been described. In this work, we explore the relation between biophysical and accessibility factors and geographical patterns of cultivated land expansion from 1972 to 2001 in the North Argentine Dry Chaco. We evaluate the importance of different variables through time to explain the geographical distribution of cultivated land. Based on our results, we propose alternative mechanisms to explain past and current geographical patterns of cultivated land and the implications for future research and land use planning.

2. Methods

2.1. Study area

The Dry Chaco is the largest continuous patch of Neotropical dry forest (Portillo-Quintero and Sanchez-Azofeifa, 2010). The Northern Argentine Dry Chaco (22 °S–27 °S and 59.5 °W–65 °W; Fig. 1) includes the largest part of the Argentine Chaco. The area is characterized by flat relief and soils formed by eolian and fluvial sediments. Mean annual temperature ranges between 19 and 24 °C and rainfall between 400 and 900 mm year^{-1}, distributed in rainy summers and dry winters, with higher values in the West and East borders of the study area (Minetti, 1999). Vegetation is dominated by broadleaf, deciduous or semi-deciduous trees and the region is considered by some authors as a neotropical broadleaf dry forest (Gentry, 1995; Hoekstra et al., 2010). The region undergoes fast deforestation promoted by modern agriculture, which is well documented for Argentina (e.g. Zack et al., 2004; Boletta et al., 2006; Gasparri and Grau, 2009), but generalized in the whole region (Clark et al., 2010). The main roads of the study area are the national roads (RN in Spanish) number 34, 16 and 81 (Fig. 1b). RN34 is oriented in South-North direction towards the western sector of the study area. RN16 is oriented in west-east direction, crossing the region in the southern part (provinces of Salta, Chaco and Santiago del Estero). RN81 is also oriented in west-east direction but it crosses the region in the northerner part (provinces of Salta, and Formosa).

2.2. Cartography

Variables analyzed as conditioning factors of cultivated land expansion patterns in NADC were rainfall, soil suitability, slope, distance to main roads and distance to main towns. All variables were mapped in a raster format with the same spatial resolution. Different maps and data sources were converted and resampled to preserve spatial consistence in raster formats and the pixel sizes for the logistic regression analyses. Rainfall layers from WORLDCLIM were used as reference. Sources of information and a description of each variable can be found below:

2.2.1. Land cultivated maps

In order to prepare cultivated land maps, we identified cultivated land expansion as polygons in a vectorial format by visual interpretation of Landsat images for different dates: 1972 (MSS scenes from 08/1972 t to 05/1976), 1991 (TM scenes from 03/1989 to 02/1992), 1997 (TM scenes from 04/1997 to 01/1999), 2002 (TM scenes from 04/2001 to 09/2002), 2007 (ETM and TM scenes from 07/2007 to 08/2007). Although not all the images correspond to the exact years of reference, we set the reference year based in the majority of dates acquired and the date of those images which capture the most active sectors of deforestation. A list of the images used in our study is showed in Supplementary material SI. For the mapping of cultivated land, we used the standard procedures from the National Forests Resource Assessment Program (UMSEF, 2013) to generate binary maps of cultivated and non-cultivated land. These procedures generate maps previously assessed with an