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Transformation dynamics of the natural cover in the Dry Chaco ecoregion: A plot level geo-database from 1976 to 2012

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A B S T R A C T

The aim of this work was to characterize the spatial and temporal dynamics of the transformation of the natural cover in the Dry Chaco ecoregion from 1976 to 2012. Dry forests in this region have one of the highest deforestation rates in the world. We analyzed 44 Landsat scenes, including part of Argentina, Paraguay and Bolivia. The analysis was based on tracking individual transformed plots of the entire Dry Chaco region for over more than three decades using the same protocol. Until the end of 2012 15.8 million ha of the original habitats of the Chaco were transformed into croplands or pastures. Our study showed that the greater annual rates of transformation were observed in Paraguay, where deforestation increased dramatically in the last decade, reaching values higher than 4.0% in 2010, the highest historical value in the entire region. The size of the transformed plots increased significantly through the studied period both in Argentina and Paraguay, while in Bolivia decreased. At the landscape level, the use of several fragmentation indices showed the disruption of the continuity and connectivity of the original vegetation. The spatially explicit description of the dynamics of transformed areas is an indispensable tool for natural resources management, territorial planning and deforestation impacts assessment. The developed geo-database is available online at http://monitoreodesmonte.com.ar/ for further analyses and use.

1. Introduction

South American Dry Chaco is going through a new phase of agricultural expansion and intensification that is increasing exponentially the production of commodities, but that may also compromise the provision of ecosystem services (Paruelo et al., 2011). Clearance of xerophytic forests and other native vegetation types for agriculture or cattle ranching is the dominant transformation of the landscape (Gasparri and Grau, 2009; Volante et al., 2012; Caldas et al., 2013; Volante and Paruelo, 2015). Deforestation rates are one of the highest in the world (Hansen et al., 2013), which generates a worldwide concern on the conservation of the woodlands and on the sustainability of the production systems. Land use and land cover changes in Dry Chaco forests have become a major issue for policymakers and an area of intense political dispute (Paruelo et al., 2011; Seghezzo et al., 2011; García-Collazo et al., 2013; Redaf, 2012).

Different governmental and non-governmental organizations of South American countries promote the sanction of legal instruments aimed to regulate the use of natural resources, and to support forest conservation. In December of 2004 the Congress of Paraguay sanctioned the Law No. 2524, also known as Zero Deforestation Law, which banned forest transformation in the eastern part of the country. Argentina issued Law No. 26,331, Native Forest Protection Act in November 2007, to promote the territorial planning and regulate the conservation and management of native forest (García Collazo et al., 2013). The Law No. 1700 of the Plurinational State of Bolivia, New Forest Act (issued in July 1996), was aimed to regulate property rights on forest areas for local actors. Despite these regulation attempts through legal mechanisms

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deforestation in the region follows. Moreover, there is a widespread concern on illegal deforestation and logging in Argentina (Redaf, 2012), Paraguay (Fundación Avina, 2012) and Bolivia (Andaluz and Mancilla, 2006). The ongoing land transformations generate, on the one hand, a loss of natural habitats and on the other, a fragmentation of the landscape (Gasparri and Grau, 2009). Both, in turn, have large impact on ecosystem functioning (Volante et al., 2012; Alcaraz-Segura et al., 2013a). The degree of fragmentation provides critical information to infer ecosystem characteristics (O'Neill et al., 1997). Changes in the landscape structure have direct consequences on biodiversity (Fahrig, 2003), biogeochemical cycles (Saunders et al., 1991), atmospheric dynamics (Pielke and Avissar, 1990) and water exchange (Briant et al., 2010). Land clearing increase carbon emissions (Gasparri et al., 2008), groundwater recharge and onset salt mobilization in areas where forests are replaced by annual croplands (Amdan et al., 2013).

There is a great international pressure to monitor long-term changes in forest cover (GCOS, 2004; GOFC -GOLD, 2007) and the main efforts are focused on tropical rainforests (Achard et al., 2002; Shimabukuro et al., 2004; INPE, 2008). Nevertheless, deforestation rates are particularly high in subtropical dry forests areas (FAO, 2009; Hansen et al., 2013). Several studies evaluated forest cover transformation in the Dry Chaco ecoregion (Supplementary material Table S.1); however, most of these studies had low temporal resolution or extension. A plot level geo-database for the entire Dry Chaco region that covers long term periods −more than three decades− based on the same protocol is not available. Such database is an essential input not only for basic research on the characteristics and consequences of land use and land cover change, but also for applied issues related to law enforcement or land planning.

In this paper we characterized the spatial and temporal dynamics of natural cover transformation in the South American Dry Chaco ecoregion from 1976 to 2012, using a geo-database developed with Landsat satellite imagery observation. Changes were quantified at the individual plot level. We analyzed land transformation dynamics focusing on the total transformed area, the plot size patterns and the landscape patterns of the transformed land. The developed geo-database is available for further analyses and use at http://monitoreodesmonte.com.ar/.

2. Study area and methods

2.1. Study area

The South American Dry Chaco is a vast plain comprising northwestern Argentina, western Paraguay and southeastern Bolivia, integrating an area of approx. 787,000 km^2 (Olson et al., 2001). The South American Dry Chaco ecoregion includes 3 countries (primary administrative units, Argentina, Bolivia and Paraguay), 18 secondary political and administrative units (called provinces in Argentina and departments in Bolivia and Paraguay) and 175 tertiary administrative units (called departments in Argentina, municipalities in Bolivia, and districts in Paraguay). Of the total area of the Dry Chaco, 62% is located in Argentina, including part of the provinces of Salta, Santiago del Estero, Jujuy, Tucumán, Formosa, Chaco, Catamarca, Córdoba, Santa Fe, La Rioja, San Juan and San Luis; 22% in Paraguay, including part of the departments of Alto Paraguay, Boquerón and Presidente Hayes; and 16% in Bolivia, including part of the departments of Santa Cruz, Chuquisaca and Tarija.

The Chaco region is one of the flatter plains of the planet (Jobbágy et al., 2008). This region is part of the Rio de la Plata Basin and is crossed by the Pilcomayo, Bermejo, Juramento and Salado rivers. The climate of the Chaco is semiarid and is characterized by a strong seasonality, with high temperatures in summer and winter frost. Annual mean temperature varies from 18 °C in the southern part of the ecoregion to 26 °C in the north, and annual mean rainfall varies from 400 mm/year in the center to1000 mm/year in the eastern and western extremes (Minetti, 1999). Because of its continental climate there are large variations in temperature between winter and summer. The months of maximum precipitation coincide with those of higher temperatures (Berbery and Barros, 2002). Rains occur in summer, from October to March, and the driest months are July and August. The predominant natural vegetation of the Chaco is open woodland or thorn forest, interspersed with grasslands (Morello et al., 2012).

This region has a significant productive potential (Lambin et al., 2013), a large biodiversity and cultural richness (TNC, 2005), but also presents high levels of poverty and inequality (Bolsi and Paolasso, 2009; Paolasso et al., 2012). Around 7.5 million people live in the Chaco, coexisting aboriginal populations with descendants of European immigrants (*Criollos*) (Naumann, 2006). Indigenous people and “*criollos*” practice a subsistence economy, including small scale agriculture, extensive ranching, hunt and gathering (Leake and De Economo, 2008). In the last decades, the area is undergoing into a rapid transformation to agribusiness (Grau et al., 2005; Gasparri et al., 2008).

2.2. Image processing and database development

Landsat satellite images were examined in order to identify land-clearing transitions in the period 1976–2012. Images were obtained from CONAE (National Commission on Space Activities, from Argentina), INPE (National Institute for Space Research, from Brazil) and USGS (U.S. Geological Survey, from USA). The whole area includes 44 Landsat scenes. For years prior to 2000 three periods were analyzed: 1976–1986, 1986–1996 and 1996–1999. From 2000 to 2012 land transformation dynamics was evaluated annually. We selected images with low presence of clouds, preferably corresponding to December (because most of the clearings occur during the driest winter months). Images were selected, georeferenced, ordered by date and displayed in high contrast false color composite (RGB band combination: 4-5-3) in Quantum GIS 1.8.0-Lisboa. About seven hundred Landsat images have been analyzed. A list of the used images is available at http://monitoreodesmonte.com.ar/metodologia.

Landsat Multispectral Scanning (MSS) 1–3 imagery (launched at 1972 and terminated at 1983, with 60 m spatial resolution and 4 spectral bands) was used to detect land transformations before 1976. Scene size and path-row designations from Landsat MSS 1–3 imagery differs from that of subsequent releases. Landsat Thematic Mapper (TM) 4–5 imagery (launched at 1982 and terminated in 2013, with 30 m spatial resolution and 7 spectral bands) was used to detect transformations at 1986, 1996, and from 2000 to 2012. Images from Landsat Enhanced Thematic Mapper Plus (ETM+) 7 (launched at 1999 and still active, with 30 m resolution and 8 spectral bands, operating with scan line corrector disabled since 2003) were used to detect transformations from 2000 to 2012, as an alternative to the use of Landsat 5.

The transformed plots were manually digitalized by visual interpretation of the last Landsat image of the study period (2012). Each individual plot was incorporated as a polygon shape into the GIS. The criterion to define plots by visual interpretation was the disruption of spatial continuity with strong evidences of human action. Transformed plots by human action are regularly shaped and have defined limits, while transformations due to natural agents (e.g. fire) are irregularly shaped. In some cases where the size of the patches was significantly large but with small defined plots inside, without hedgerows presence between them (e.g. plots