Linkages between soybean and neotropical deforestation: Coupling and transient decoupling dynamics in a multi-decadal analysis

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A B S T R A C T

Soybean expansion, driven by growing global meat demand, has accompanied neotropical deforestation in past decades. A recent decoupling between soybean production and deforestation in Brazil is taken as evidence of efficient deforestation regulation. Here, we assessed the relationships between soybean economy, livestock production and deforestation from 1972 to 2011 in Northern Argentina Dry Chaco. We used Panel Analysis to evaluate the relationship between soybean cultivated and deforested area in different periods and we used high resolution time series analysis of a deforestation hotspot, to explore links between soybean economy, cattle ranching and deforestation. In northern Argentina, 2.7 millions ha were deforested from 1972 to 2011, 56% of which occurred after 2002. The results of the Panel analysis indicate a strong link between soybean expansion and deforestation but with variation among periods mediated by the links between soybean and livestock productions. Deforestation was strongly coupled with soybean expansion during the 1972–1997 and 2002–2011 periods; but was largely decoupled between 1997 and 2002, when strong increments in production were accompanied by low deforestation. The high resolution analysis also indicated contrasting levels of association after and before 1997. The soybean deforestation decoupled periods in Brazil and Argentina shared similarly weak economic incentives for soybean production, rapid technological innovation and preceding high deforestation periods. In the Argentine case, when economic incentives turned positive after a 5-years decoupled period, new government measures were unable to regulate deforestation. Our study suggests that macroeconomic factors can be a much stronger deforestation force compared with domestic legal frameworks. Effectiveness of neotropical deforestation regulation should be carefully monitored and interpreted with caution paying special attention to global economic context for soybean expansion.

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1. Introduction

By harboring some of the most biodiversity and biomass rich forest ecosystems, and being a major net food exporter, Latin America faces an urgent need to compromise the conservation of valuable forest ecosystems and to increase food production (Grau and Aide, 2008). A key question regarding this conservation–production compromise is weather increases in food production are achieved though increases in land use efficiency (e.g. higher yields, expansion into underutilized areas) or if instead they translate into deforestation with the resulting destruction of valuable ecosystems (Foley et al., 2011; Ramankutty and Rhemtulla, 2012).

Tropical forest was the primary source of new agriculture land in the 80s and 90s (Gibbs et al., 2010) and deforestation in Latin America during the 21st century closely accompanied exports of soybean and beef (Aide et al., 2013). This evidence suggests that, particularly in South America, deforestation has strong links with the global commodities market, and more specifically with the growing global demand of meat resulting from growing population and changing diets (Godfray et al., 2010; Kastner et al., 2012). In particular, soybean crops (mostly used for animal feed) became a major deforestation driver in Latin America (Fearnside, 2001; Grau et al., 2005; Killeen et al., 2008). However, despite the prominent role of soybean agriculture and cattle ranching on Latin America deforestation, there are few studies quantifying this link, and most of them are restricted to Brazil (e.g. Morton et al., 2006; Ewers et al., 2008; Barona et al., 2010; Macedo et al., 2012).

Studies in Brazil based on detailed remote sensing analyses of the spatial association between land uses and deforestation showed that some deforested areas were occupied with croplands, but most recently cleared land was transformed into pastures

(Morton et al., 2006; Macedo et al., 2012). Soybean production variables were strongly correlated with deforestation rate between 2000 and 2005 (Morton et al., 2006) but this was followed by a decoupling of soybean expansion and deforestation between 2006 and 2010 (Macedo et al., 2012). Longer time series analyses did not find strong associations between the economy of soybean and annual deforestation in the Amazon (Ewers et al., 2008); and a recent, more extensive study recorded periods differing in the strength of the soybean-deforestation association (Barona et al., 2010). The recent decoupling of soybean and deforestation in Southern Amazon (Macedo et al., 2012) has been interpreted as an example of effective government measures that allowed increasing agriculture production without sacrificing forests and the biodiversity and biomass they harbor (Macedo et al., 2012; Malingreau et al., 2012). These studies provided valuable insights on the behavior of the soybean-deforestation. But they had two main limitations: (i) by being geographically restricted to Brazil, they are potentially affected by the country's idiosyncratic characteristics and this could limits its level of generality; (ii) by focusing mostly on soybean as proximate cause during short periods (5–6 years) they can only identify direct and immediate relationships (or their absence), neglecting longer term lagged or indirect associations.

To help overcoming these limitations, we analyzed the links between different agriculture and livestock productions in Argentina and deforestation of the Argentine Dry Chaco during a four-decade period. Argentina's Chaco is a rapidly expanding agriculture frontier (Clark et al., 2010; Gasparri et al., 2008) and is currently the second most active deforestation front in South America after the Amazon rainforest (Aide et al., 2013). In

consequence, it provides the opportunity to explore the soybean-deforestation system under a political and socioeconomic context different from the Brazilian Amazon, but also with broad-scale ecological relevance (Viglizzo et al., 2010). Argentina is the third largest global soybean producer and exporter after USA and Brazil, and the top exporter of soybeans oil and cake (FAO, 2013). Soybean expansion has been pointed as the key driver of Argentina's deforestation (Gasparri and Grau, 2009; Zak et al., 2008) but without rigorous quantification of the association (Pincén et al., 2006; Viglizzo, 2011).

We designed this study with the following specific objectives: (i) to quantitatively analyze the role of soybean as driver of deforestation in Northern Argentine Dry Chaco (NADC); and (ii) to explore the coupling-decoupling soybean-deforestation dynamics during four decades in association with national socioeconomic conditions. We analyzed changes in soybean production, livestock and deforestation between 1972 and 2011, considering different spatial resolutions (region, provinces and departments); and explored temporal relationships between soybean crop economy and annual deforestation rate in NADC, including a focal analysis of hotspot of soybean expansion and deforestation (Anta sector in the Salta province).

2. Materials and methods

The Dry Chaco is the largest continuous patch of Neotropical dry forest (Portillo-Quintero and Sanchez-Azofeifa, 2010). Northern Argentina Dry Chaco (22° S–27° S and 59.5° W–65° W; Fig. 1) includes the largest share of the Argentine Chaco. The area is
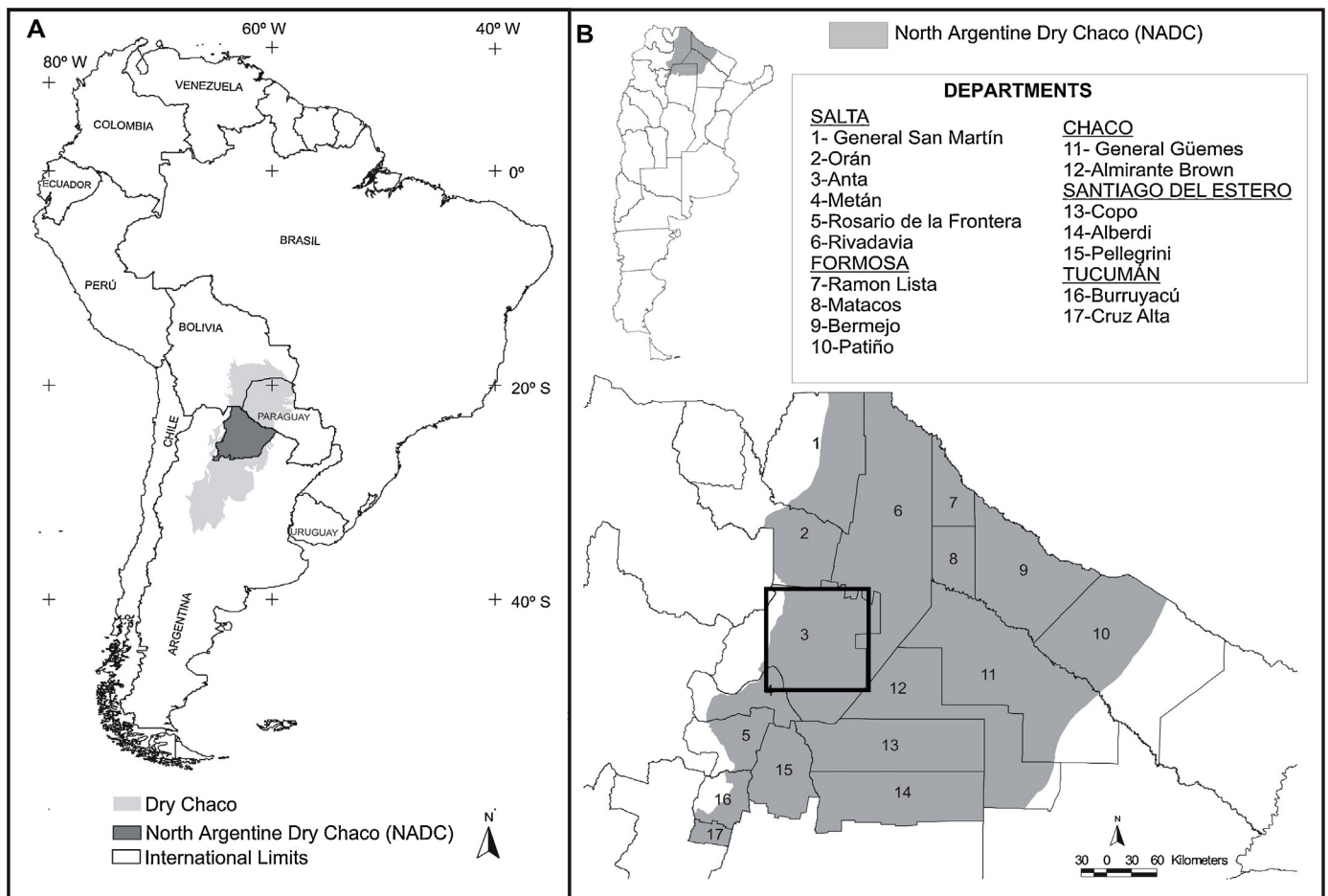
Fig. 1. Study area and departments includes in analysis for the North Argentine Dry Chaco. (A) Dry Chaco and NADC in South America. (B) References for departments in the NADC and location of the Anta sector (black-border square).