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A plantation-dominated forest transition in Chile

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ABSTRACT

As one of the few countries in Latin America to have reversed persistent losses in tree cover, Chile may hold important insights for forest transition theory. However, existing studies have not provided methodologically consistent analyses at sufficient temporal and spatial scales to properly assess the state of Chile's forest transition. In the current study, we generate high-resolution maps of Chilean land use change between 1986, 2001 and 2011. We couple remote sensing with a review of historic assessments of Chile's forest resources to document long-term trends in forest extent. This historical review identifies multiple discrete forest transitions throughout Chile's history. These fluctuations in forest clearing emphasize that the cultural, economic and political forces that precipitate forest transitions can all be reversed. The remote sensing analysis calls into question official statistics indicating an expansion of native forests between 1986 and 2011. We find that increases in forest cover were largely driven by the expansion of forest plantations, rather than through native forest regeneration. Plantation forests directly displaced native forests in many locations, especially during the 1986–2001 period. Nevertheless, declines in the rate of forest conversion during the 2001–2011 period suggest that plantations are beginning to ease pressure on native forests.
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1. Introduction

Over the past decade, decelerating deforestation and forest expansion in some countries have fostered growing public optimism that the world may be discovering ways to end deforestation (Meyfroidt & Lambin, 2011; Nepstad et al. 2009; Rosenthal, 2010). In response, land systems scientists have shown a great deal of interest in understanding the processes that give rise to forest expansion. In particular, forest transitions – national shifts from extended periods of deforestation to periods of forest expansion – seem to be an important factor in current global forest trends (Mather, 1992). Early studies of forest transitions sought to describe historical changes in the extent of temperate forest cover in Europe and North America (Mather, Fairbairn, & Needle 1999; Mather & Fairbairn, 2000). However, a growing literature focuses attention on more recent transitions in Asia and Latin America (Bruggeman, Meyfroidt, and Lambin 2016; Meyfroidt & Lambin, 2008; Nagendra & Southworth, 2009). Developing countries that have successfully reversed longstanding trends of deforestation may hold insights to guide more sustainable land use practices.

However, forest transition analyses that aggregate distinctly different types of tree-covered landscapes under a single definition of forests may obscure the ecological impacts of continued changes in forest composition and location (Perz, 2007). China, for example, has added nearly three million hectares of forest annually over the past decade as result of aggressive reforestation efforts (FAO, 2011). Although FAO statistics indicate that the extent of primary forests has not declined, diverse native forests are being converted to plantation monocultures (Li et al., 2006). Furthermore, much afforestation has taken place without consideration of the local suitability of planted species (Xu, 2011). Such examples highlight the importance of assessing the ecological quality of forest transitions (Lambin & Meyfroidt, 2010).

An increasingly important determinant of the ecological quality of forest transitions is the relative share of plantation and natural forests (Hall, Van Holt, Daniels, Balthazar, & Lambin, 2012). Due to rapid growth over the past two decades, plantations now constitute more than 7 percent of global forest area (FAO, 2010b). This rapid growth in plantation area has been associated with a variety of

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political, demographic and economic drivers (Rudel, 2009). This expansion has allowed the world to meet rapidly growing demand for timber and fiber; by 2020, plantations are estimated to provide 44 percent of global industrial roundwood production (Carle, Vuorinen, and Del Lungo 2002). Plantation forests also serve as an important component of global strategies for carbon emissions mitigation (Favero & Mendelsohn, 2014; Strengers, Minnen, and Eickhout 2007). However, while plantations may reduce harvest pressure on natural forests, they also directly compete for scarce land (Heilmayr, 2014). When plantations displace native forest ecosystems, they can reduce biodiversity (Barlow et al. 2007; Stephens and Wagner 2007), introduce invasive species (Richardson, 1998, p. 199), negatively affect local hydrology (Jackson et al. 2005; Little, Lara, McPhee, & Urrutia, 2009) and increase erosion (Oyarzun & Peña, 1995). As a result, it is important to understand the types of ecosystems forest plantations replace.

The ecological differences between plantations and naturally occurring forests have inspired the term “tree-cover transition” as a more general variant of the traditional “forest transition” (de Jong 2010; van Noordwijk and Villamor, (2014). Such terminology enables clear differentiation between “natural” forest regrowth (forest transitions) and more anthropogenically driven tree-cover expansion (tree-cover transition). However, to maintain consistency with the original literature on forest transitions, we choose to follow the FAO definition of forests in which “forest area” includes both naturally occurring and plantation forests. We nevertheless strive to provide a more nuanced description of Chile's forest transition by differentiating “plantations” from “native forests” throughout our analysis. We choose to use the term “native forests” to refer to non-plantation forests in order to maintain consistency with Chilean terminology. Following this convention, we use the term native forest transition to refer to increases in native forest area, and forest transition to refer to increases in the sum of plantations and native forests.

The objective of this study is to analyze forest expansion in Chile, one of the few countries with net gains in tree cover that has rarely been explored through the lens of forest transition theory. Whereas government datasets (CONAF, CONAMA, & BIRF, 1999; CONAF, 2008) and the UN FAO's Global Forest Resource Assessment (FRA) (FAO, 2010b) indicate that Chile has undergone a forest transition, several regional analyses emphasize the continued loss of native forests (Clapp, 2001; Echeverria et al. 2006; Echeverría, Newton, Nahuelhual, Coomes, & Rey-Benayas, 2012; Lara, Eugenia Solari, Del Rosario Prieto, & Peña, 2012). In order to reconcile these inconsistencies, we undertake the most spatially and temporally comprehensive, methodologically consistent analysis of land use change in Chile to date. The results overturn the existing understanding of Chile's forest transition by identifying net losses in native forests between 1986 and 2011. In addition, a review of Chile's historic forest extent underscores the precarious nature of forest transitions. Finally, this study adds nuance to forest transition theory by differentiating changes in the area of native forests and plantation forests.

1.1. Study area

Chile has many characteristics that make it a particularly important subject for forest transition research. Historical isolation, shaped by geographic influences of the Andes, Atacama Desert and Pacific Ocean, has endowed Chile with exceptionally high levels of endemism (Smith-Ramírez, 2004). Extreme gradients in elevation and latitude have further contributed to the country's impressive biodiversity (Armesto, Villagrán, and Arroyo 1996). However, timber harvests and agricultural expansion from the 18th until the early-20th century led to significant degradation of forest ecosystems (Armesto et al. 2010).

As one of very few Latin American countries to have seemingly reversed persistent losses in forest cover, Chile may hold important lessons to guide the creation of effective mechanisms to slow global deforestation. Rising incomes, labor diversification and government policies have all influenced forest expansion (Diaz, Ignacio, Nahuelhual, Echeverria, & Marin, 2010; Modrego, Barrera, and Charnay 2004). Due to the rapid growth of plantations, Chile can also inform our understanding of the environmental impacts associated with forest-sector intensification. Plantations provide nearly 95 percent of the country's timber production on 15 percent of its forested lands (FAO 2010; FAO 1997). Such intensive production has the potential to reduce pressures on native forests. However, plantation expansion has also been an important direct driver of native forest clearing (Clapp, 2001; Echeverria et al. 2006). As a result of these competing interactions, the ecological impacts of Chile's forest transition are unclear. Careful consideration of Chile's experience may give forest transition theory greater nuance in describing the range of possible ecological consequences of forest expansion.

Due to the forest sector's connections to the neoliberal economic policies of the 1970's, Chile's experience holds significant relevance in a steadily globalizing economy. In contrast to other countries undergoing forest transitions, Chilean forest expansion has occurred with relatively little import-based displacement of land use to other countries (Meyfroidt, Rudel, and Lambin 2010). With timber products and pulp counting among its top exports, Chile can provide insights into trade's impacts on natural resource protection. The recent expansion of the Chilean forest industry into countries such as Argentina, Brazil and Uruguay further highlights the potential importance of the Chilean forestry model for the rest of the world.

1.2. Historical transitions

Over the course of its human history, Chile has undergone a series of alternating periods of deforestation and forest expansion. By the time Spanish explorers reached Chile's shores, agricultural mosaics existed in many of the more fertile regions of the country (Camus & Solari, 2008). Although the ‘original’ extent of Chilean forests may have approached 30 million hectares (Bryant, Nielsen, and Tangley 1997), archeological reconstructions indicate that indigenous populations had converted nearly 891,000 ha of forests over much of Central and Southern Chile to agricultural mosaics (Lara et al. 2012). However, Spanish conquest and the associated introduction of disease devastated the indigenous population throughout this region. The ensuing three hundred years of Spanish colonialism mark Chile's first native forest transition. By the middle of the 19th Century, Chile's native forests had reclaimed many abandoned agricultural areas and covered approximately 24 million hectares (Otero, 2006).

After the Chilean War of Independence (1810–1826), the newly established government began to shift its attention towards consolidation of its territory. Through a combination of incentives, immigration reforms and infrastructure investments, the government encouraged widespread colonization during the second half of the 19th century. According to Federico Albert, the first Chilean Inspector General of Forests, Hunting and Fishing, 13 million hectares (approximately half) of Chile's forests were cleared during this period of colonization. Although Albert claims the total forested area in 1914 was 15.7 million hectares, his estimates for the Patagonian region of Magallanes is considered an overestimate by several million hectares. Albert's revised numbers indicate that the total area of forests fell from between 24 and 29 million hectares in the mid-1800s to between 11 and 16 million hectares by 1914 (Albert, 1901, 1913; Otero, 2006). Despite the uncertainty of Albert's estimates, the observation of significant Chilean deforestation during the Southern colonization is confirmed by the country's first aerial inventory of forest resources. The maps created by the US

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