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Different times, same story: Native forest loss and landscape homogenization in three physiographical areas of south-central of Chile

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ABSTRACT

Temperate forest represents the smallest area among the main world's forest biomes, but is one of those most threatened by forest loss. Chile contains most of the temperate forest in South America and more than half of the temperate forest in the southern hemisphere. Chilean temperate forest is considered to be one of the world's biodiversity hotspots. In this study we assessed the rate of land use and land cover (LULC) change over time, identified the main LULCs replacing native forest, and described how changes have evolved in contrasting physiographical conditions and through different historical phases of the landscape over the last 40 years. To achieve this, we analysed LULC change with particular focus on forest cover in three areas representing different physiographical conditions and histories of human occupation in the Araucanía Region of Chile, namely the Central Valley, the Coastal range, and the Andean range. We found substantial differences in temporal and intra-regional patterns of forest loss and LULC change. In the Central Valley, forest loss started long ago, and the area occupied by native forest nowadays is less than 5% of the landscape. In the Coastal range, rapid land cover change has taken place since 1973, with an increasing rate of forest loss over time. We detected a similar but less intense pattern in the forests of the Andean range. Overall, the general pattern points to a process of landscape homogenization in all three physiographical areas. Exotic tree plantations have spread over large geographical areas, becoming the dominant land cover. Land cover change in the Araucanía Region reflects a model of change in which areas with better environmental conditions and accessibility are occupied first for productive activities. As the availability of suitable areas for the expansion of productive activities diminishes, these activities start to move into physiographical areas which were previously "protected" by adverse environmental conditions or poor accessibility. This model of production growth could lead to the complete deforestation of areas outside national protected areas, and other areas which still remain inaccessible due to technological restrictions on exploitation.

Introduction

The most serious current and future threats to the conservation of biodiversity in terrestrial ecosystems, even more than climate change, are land use and land cover (LULC) change, and habitat fragmentation (Pereira et al., 2010; Sala et al., 2000). In many ecosystems these changes have already occurred, or are currently occurring, affecting the original ecosystems (Millennium Ecosystem Assessment, 2005). Preventing this rapid

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transformation should be of special interest for the design of public policies, particularly in developing countries, since it is expected that in such countries the frontier of agricultural and/or productive activities will continue to expand (Sala et al., 2000). This will affect the original forests and may lead to a loss of biodiversity, diminishing the capacity of forests to provide a large number of ecosystem services.

Temperate forest represents the smallest area (16%) among the world's principal forest biomes. This biome has suffered the second largest loss of forest (3.5%) in recent years (2000–2005), greater even than that of the tropical rainforests of Brazil, Indonesia and Malaysia, and surpassed only by the loss of boreal forest in North America, where big fires and mortality due to pests are major drivers of land cover change (Hansen, Stehman, & Potapov, 2010). At the same time, the regions dominated by temperate forest typically sustain a greater human population per unit of area than significantly more extensive biomes, and also contribute more substantially to global biodiversity than colder and drier biomes (Ellis, 2011). Due to their high productivity, temperate forests have been the preferred biome for land conversion for agriculture and pasture (Ellis, 2011). This has resulted in one of the largest habitat losses in the world (Hoekstra, Boucher, Ricketts, & Roberts, 2005). Chile contains most of the temperate forest in South America and more than half of temperate forest in the southern hemisphere (Donoso, 1993). Chilean temperate forest is also considered to be one of the world's 35 biodiversity hotspots, due to the high concentration of endemic species and high level of threat (Mittermeier et al., 2004; Myers, Mittermeier, Mittermeier, da Fonseca, & Kent, 2000).

The general trends reported for native forest loss, local spatial patterns and drivers of change mainly result from human settlement, which is ultimately related to the predominant biophysical conditions (Rodríguez, Armenteras, Retana, & Molowny-Horas, 2011). In general, population pressure and shifting areas of cultivation are the main factors for deforestation (Geist & Lambin, 2002). In the Latin America and Caribbean Region, environmental conditions (i.e. climate and elevation) and the percentage of original vegetation cover explain better than human density the variation in woody vegetation change (Aide et al., 2013). Native forest loss can be seen at different scales; this process interacts with the individual social and political histories of each administrative region, which vary as a function of the region's economic and social development (Rudel, 2007). In Colombia for instance, the annual deforestation rate varies considerably between regions, differing by a factor of up to four or more (Armenteras, Cabrera, Rodríguez, & Retana, 2013). At the national level, rural population density, cattle, protected areas and slope were the most important variables; however significant differences were also found at local level (Armenteras et al., 2013).

Various studies have reported changes to native Chilean temperate forest, large areas of which have been lost during recent decades (Aguayo, Pauchard, Azocar, & Parra, 2009; Altamirano, Aplin, et al., 2013; Altamirano & Lara, 2010; Altamirano, Salas, Yaitul, Smith-Ramírez, & Ávila, 2013; Echeverría et al., 2006; Echeverría, Newton, Nahuelhual, Coomes, & Rey-Benayas, 2012). Only half of the forest existing in the second half of the sixteenth century remains (Lara, Solari, Prieto, & Peña, 2012), most of it confined to inaccessible parts of the Andean range or the southernmost parts of the country. These losses are considered to be related principally with land-clearing for agro-food production and replacement by exotic tree plantations for pulp and paper production (Aguayo et al., 2009; Altamirano & Lara, 2010; Altamirano, Aplin, et al., 2013; Altamirano, Salas, et al., 2013; Echeverría et al., 2006), and also with severe degradation of primary forest (Echeverría et al., 2012).

Several studies, carried out in different geographical areas of Chilean temperate forest over a similar time period, have shown differences in the intensity of forest loss, and in the principal land covers modifying the landscape (Aguayo et al., 2009; Altamirano, Aplin, et al., 2013; Altamirano & Lara, 2010; Altamirano, Salas, et al., 2013; Echeverría et al., 2006). However, with the exception of Echeverría et al. (2012), these studies have analysed patterns of landscape change but have not considered intra-regional differences. Echeverría et al. (2012) establish a theoretical model for landscape change by studying the spatial-temporal dynamic of real landscapes in three different areas in the same region, but with contrasting proportions of primary forest present at the start of the study. The model establishes different phases in the process of landscape change, where forest loss is high when the proportion of original primary forest is categorised as intermediate rather than high or low. This model was established in landscapes where the predominant driver of change was forest degradation, i.e. where the primary forest is replaced by degraded forest or arborescent shrubland. According to Echeverría et al. (2012), the current state of landscape conservation may strongly influence patterns of land use change and the predominant drivers of that change. We hypothesized that the physiographical conditions and the historical phases of the landscape will influence the intensity of landscape change (Altamirano, Aplin, et al., 2013; Altamirano, Salas, et al., 2013; Rodríguez et al., 2011; Rodriguez, Armenteras, & Retana, 2012). In other zones of southern central Chile it has been shown that land cover change is heterogeneous across time and space, as significant relationships have been found between the spatial distribution of land cover types and different biophysical variables; these relationships also change over time (Echeverria, Coomes, Hall, & Newton, 2008; Nahuelhual, Carmona, Lara, Echeverría, & González, 2012; Schulz, Cayuela, Rey Benayas, & Schröder, 2011). This information is very important for establishing conservation strategies and guiding public policies based on differing territorial conditions.

Since the principal cause of landscape change in southern central Chile is related with the expansion of the agricultural frontier and the establishment of exotic tree plantations (Aguayo et al., 2009; Altamirano, Aplin, et al., 2013; Altamirano & Lara, 2010; Altamirano, Salas, et al., 2013; Echeverría et al., 2006), favourable conditions for the expansion of such productive activities may also determine the patterns of landscape change. Considering the changes observed in other areas of Chilean temperate forest (Aguayo et al., 2009; Altamirano, Aplin, et al., 2013; Altamirano & Lara, 2010; Altamirano, Salas, et al., 2013; Echeverría et al., 2006; Echeverría et al., 2012), it is quite likely that the same process has occurred in the Araucanía Region in the last 40 years (Altamirano, Aplin, et al., 2013; Altamirano, Salas, et al., 2013).

The aims of this study are to assess the rate of land cover change over time, quantify native forest loss over the last 40 years, and investigate how rates of change vary depending on the different physiographical conditions and historical phases of the landscape. To achieve these goals we compared the annual rate of forest loss, and the main land covers which replaced native forest in the landscape over time, in three different areas presenting biophysical differences and differing histories of human occupation.

We expect patterns of land cover change and native forest loss in recent periods to occur in response to historical processes which are strongly influenced by the physiographical conditions of the region. We hypothesize that land cover change and native forest loss will be more intense where physiographical conditions favour the expansion of the principal productive activities (e.g. flat areas). The forest loss rate in Chile has usually been reported to be higher in earlier periods than in recent years (Echeverría et al., 2006; Schulz, Cayuela, Echeverria, Salas, & Rey Benayas, 2010).