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Expanding temporal resolution in landscape transformations: Insights from a landsat-based case study in Southern Chile

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ABSTRACT

Understanding temporal and spatial dimensions of land cover dynamics is a critical factor to link ecosystem transformation to land and environmental management. The trajectory of land cover change is not a simple difference between two conditions, but a continuous process. Therefore, there is a need to integrate multiple time periods to identify slow and rapid transformations over time. We mapped land cover composition and configuration changes using time series of Landsat TM/ETM+ images (1985–2011) in Southern Chile to understand the transformation process of a temperate rainforest relict and biodiversity hotspot. Our analysis builds on 28 Landsat scenes from 1985 to 2011 that have been classified using a random forests approach. Base on the high temporal data set we quantify land cover change and fragmentation indices to fully understand landscape transformation in this area. Our results show a high deforestation process for old growth forest strongest at the beginning of the study period (1985–1986–1998–1999) followed by a progressive slowdown until 2011. Within different study periods deforestation rates were much larger than the average rate over the complete study period (0.65%), with the highest annual deforestation rate of 1.2% in 1998–1999. The deforestation resulted in a low connectivity between native forest patches. Old-growth forest was less fragmented, but was concentrated mainly in two large regions (the Andes and Coastal mountain range) with almost no connection in between. Secondary forest located in more intensively used areas was highly fragmented. Exotic forest plantation areas, one of the most important economic activities in the area, increased sevenfold (from 12,836 to 103,540 ha), especially during the first periods at the expense of shrubland, secondary forest, grassland/arable land and old grown forest. Our analysis underlines the importance of expanding temporal resolution in land cover/use change studies to guide sustainable ecosystem management strategies as increase landscape connectivity and integrate landscape planning to economic activities. The study is highlighting the key role of remote sensing in the sustainable management of human influenced ecosystems.

1. Introduction

The high anthropogenic pressure on land utilization widely transformed ecosystem patterns and processes across a range of temporal and spatial scales (Ellis et al., 2013; Hietel et al., 2004; Turner, 1989; Vitousek, 1997). Therefore, land use/cover is recognized as an important driver of global environmental change (Foley et al., 2005; IPCC and Barker, 2007; Lambin and Meyfroidt, 2011; Turner et al., 2007). Land use/cover transformation has serious impacts on biodiversity as well as on ecosystem goods and services essential for human well-being (Diaz et al., 2007; Millennium Ecosystem Assessment, 2005). Furthermore, the frequency and intensity of these changes influence the current status of ecological systems impacting vegetation composition, biodiversity, biogeochemical cycles, and soil degradation (Lambin et al., 2003; Sala et al., 2000; Turner et al., 2007; Vitousek et al., 1997). Understanding landscape change trajectories in a higher temporal

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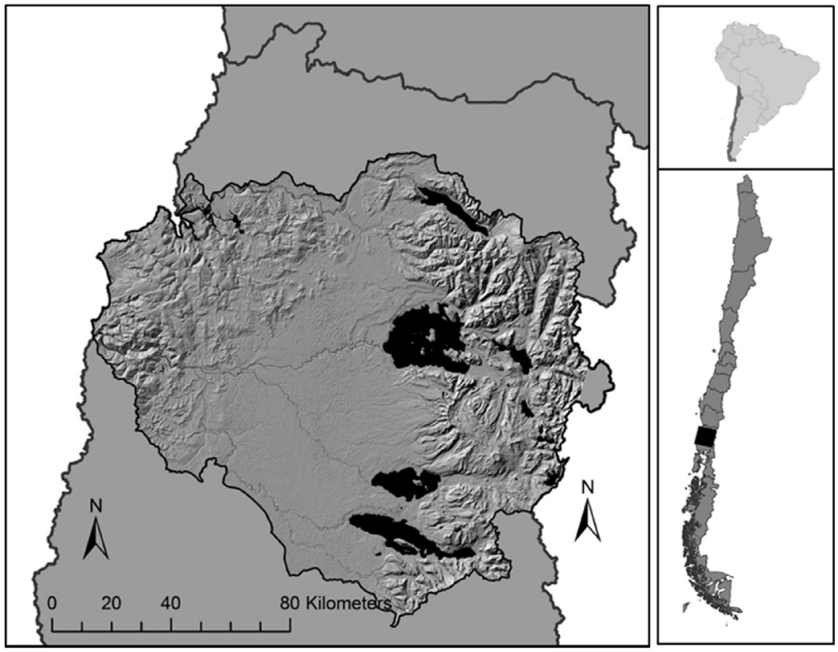

Fig. 1. Study area location within Southern Chile and South America. Topography shows the three major morphological units: Coastal mountain range, Central Valley and the Andes mountain range (from West to East). Lakes are shown in black.

frequency enable the identification of natural and anthropogenic disturbances especially in dynamic systems (Lunetta et al., 2006; Pflugmacher et al., 2012). As land use/cover change is neither uniform nor random remote sensing has become an important and widely used technique for managers and researchers, to map and monitor ecosystem modification over time (Hansen et al., 2000; Loveland et al., 2000; Zhu and Woodcock, 2012). In order to map the earth's surface, a wide range of satellites is available with different spectral, spatial and temporal characteristics (Kennedy et al., 2009; Stow et al., 2004). The Landsat program provides the largest temporal record of space-based land observations, with more than 40 years of multispectral imagery (Hansen and Loveland, 2012; Ju and Roy, 2008). In 2008, NASA (National Aeronautics and Space Administration) and USGS (U.S. Geological Survey) opened the Landsat achieve revolutionizing the use of remote sensing data (Wulder et al., 2012), offering a huge potential to monitor landscape dynamics by continuous time series analysis (Griffiths et al., 2013; Huang et al., 2010; Kennedy et al., 2010; Lambin and Geist, 2006; Roy et al., 2014; Turner et al., 2012; Zhu and Woodcok 2014). The spatial resolution (30 m) of the Landsat sensors together with its sample frequency of 16 days and the availability of relatively homogeneous measurements over a long period of time, make it a crucial dataset for monitoring dynamic landscapes (Goodwin et al., 2013; Wulder et al., 2008). A significant problem for land use/cover change detection are clouds and cloud shadow contamination, in particular in areas with high climatic variability. In these areas, multi-temporal analysis offers several advantages, including improvement of spectral variations (i.e. from topology and phenology) and allows quality enhancement of cloud-obscured images (Canty and Nielsen, 2008; Ju et al., 2012; Masek et al., 2006). However, the huge amount of information available through time series brings also methodological challenges in image processing and change detection (Rodriguez-Galiano et al., 2012). Non-parametric machine learning methods such as random forests (Breiman, 2001) provide a robust alternative to traditional image classification methods (Gislason et al., 2006; Pal, 2005; Waske and Braun, 2009). Integration of machine-learning classifier offers considerable advantages for land cover analysis, especially in dynamic systems with high cloud covers, low amount of cloud free scenes as the south of Chile. Southern Chile is a biological hotspot – it is of particular importance to conserve and protect the Valdivian temperate rain forest with its high levels of endemism (90% at species level and 34% at the genus level for woody species) and endangered species (Armesto et al., 1998; Arroyo et al., 1996). The region also has been characterized by WWF and the World Bank (Myers et al., 2000; Olson et al., 2001) as one of the most threatened eco-regions in the world. Despite its high biological importance, the area has undergone a strong land use/cover transformation similar to most regions in Chile (Armesto et al., 1998; Echeverría et al., 2006; Lara et al., 2011, 2009; Rozzi et al., 1994). In Chile – as in the entire South America – the colonization period sets the starting point of strong natural resource utilization. Agricultural conversion and the commercial logging of valuable native species were the main processes that shaped the large native ecosystem conversion from mid-1800 (Armesto et al., 2010). This land transformation resulted in one of the most rapid deforestation events in Latin America and led to severe soil erosion especially on the coastal mountain range where 59% of the surface eroded (Armesto et al., 2010; Otero, 2006; Salazar et al., 2015; Siebert, 2003). In an attempt to control the intense erosion processes, exotic forest plantations were introduced in the second half of the 20th century. However, it took until the 1970's until the forestry industry rapidly expanded, focusing on commercial plantations of *Pinus radiata*, *Eucalyptus globulus* and *Eucalyptus nitens.* Trade reforms implemented in Chile in the 1970's created large economic incentives for exotic forest plantations. Governmental economic subsidies, i.e. Law Decree 701 (DL 701), which reimbursed 75% of the afforestation expenses to the landowners after certifying an adequate rate of survival, resulted in a substitution of native ecosystems due to the economic benefits (Niklitschek, 2007). The increase of planted areas caused a dynamic land use/cover transformation that has been recognized as one of the most important drivers of deforestation in the Central-South of Chile (Díaz et al., 2011; Echeverria et al., 2006; Echeverría et al., 2008; Lara et al., 2011; Nahuelhual et al., 2012). This transformation also led to a change in composition and configuration of native forest ecosystems (Echeverría et al., 2007; Little et al.,