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Research paper

Monitoring land use and land cover change in mountain regions: An example in the Jalca grasslands of the Peruvian Andes

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HIGHLIGHTS

- The Jalca grasslands decreased at 1.5%/yr, faster than in other Andean regions.
- Agriculture increased at 1.2%/yr and new agriculture mainly at 3600–3800 m a.s.l.
- Mining and tree plantation expanded most quickly despite the low absolute values.
- Mining increased at 9%/yr while tree plantation at 12.3%/yr.
- Agriculture may be preferably established near areas of high Jalca fragmentation.

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ABSTRACT

Mountains are rich in biodiversity and provide ecosystem services for their inhabitants. These regions are currently threatened by land use and land cover changes (LUCC), therefore an efficient monitoring is required to capture such changes. The aim of this study is to test a landscape change analysis in a mountain region to guide landscape management by including: (1) LUCC trends, (2) LUCC trends across the elevation gradient and (3) changes in spatial configuration. This framework was applied to the Peruvian Jalca grasslands (>3000 m a.s.l.), located in the Tropical Andes for the period 1987–2007. We used object-based classification of Landsat TM and patch metrics for each land cover class. Our results show an overall loss of Jalca (−1.5%/yr) and montane forest and shrubland (−2.8%/yr) with higher rates than other Andean regions. Furthermore, fragmentation is observed for the Jalca while montane forest and shrubland class is not fragmenting but the largest patches are vanishing, potentially affecting the connectivity between natural areas. Agriculture has replaced the Jalca, especially in the upper zones of the Andes showing an upward expansion of crops. However tree plantation and mining had increased more dramatically than agriculture (>9%/yr). Upper and less fragmented Jalca areas may be suitable for conservation purposes while agriculture may better expand in already degraded natural areas. Records of changes across the elevation gradient and in spatial patterns result in useful information for decision makers and may improve ecosystem management not only in the Tropical Andes but also in other mountain regions.

1. Introduction

Mountain ecosystems are characterized by their topographic variety and climatic gradients. As a consequence, it is not a surprise that they are rich sources of biodiversity (Brooks et al., 2006) and host high plant endemism (Kruckeberg & Rabinowitz, 1985). At the same time they also provide many ecosystem services to human populations such as water supply and energy availability (Körner & Spehn, 2002). Despite their importance, mountains are continuously subjected to rapidly changing environmental factors of which land use change is the most important one (Körner & Spehn, 2002). The loss of traditional land use practices and transformation into modern agricultural areas are threatening mountain biodiversity and their ecosystem services (Spehn, Liberman, & Körner, 2006). Therefore it is of utmost importance to understand temporal land use and land cover changes in order to guide management strategies for both human activities and potential conservation (Seijmonsbergen, Sevink, Cammeraat, & Recharte, 2010).

Remote sensing technology provides instruments for monitoring land use and land cover change (LUCC) and the development of a

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coherent categorization of land cover units has been a main focus. Traditional classifiers, such as the *K*-nearest neighbour (KNN) or maximum likelihood (ML), may perform well on Landsat-TM data sets (Smits, Dellepiane, & Schowengerdt, 1999). Most of these algorithms are pixel-based classifications, where each pixel is labelled in an image as representing particular ground cover types or classes. In the last 10 years the use of object-based image analysis has increased (Blaschke, 2010). This approach seeks to detect clusters of similar pixels that together form an 'object' instead of single pixels as an analysis unit (Benz, Hofmann, Willhauck, Lingenfelder, & Heynen, 2004). This method proved to be useful especially in heterogeneous regions (Burnett & Blaschke, 2003; Lucas, Rowlands, Brown, Keyworth, & Bunting, 2007) such as mountain areas.

A further consideration in mountain ecosystems, related to the topographic heterogeneity, is the change in vegetation across the elevation range. Among other factors, mean annual temperature is the main factor determining the range of different plants (Guisan, Theurillat, & Kienast, 1998). In the last decades many authors have suggested that there is an upward displacement of some mountain biomes due to climate change (Peñuelas & Boada, 2003; Sanz-Elorza, Dana, & Gonzales, 2003). Crops may follow the same pattern; therefore the inclusion of land use and land cover change analysis along an elevation gradient may improve our understanding of LUCC in the mountains.

LUCC analyses based on changes in land cover classes alone might not be sufficient information in monitoring mountain regions. The heterogeneity and related functions of these fragile regions emphasize the need to integrate stratified LUCC information along with temporal landscape metric changes. For instance, ecosystems limited to mountain summits can be considered as naturally fragmented (Riebesell, 1982) and this fragmentation may increase over time by human activities such as agriculture (Andrén, 1994; Ewers & Didham, 2006). Many studies have incorporated LUCC analysis and landscape metrics which seems promising for analyzing LUCC in mountains (i.e. Kintz, Young, & Crews-Meyer, 2006; Zomeni, Tzanopoulos, & Pantis, 2008).

In this context, the objective of this study is to test a more comprehensive landscape change analysis in a mountain region by addressing four research questions: (1) What are the main land use and land cover changes? (2) Is there any upward shift in the main land cover classes? (3) How is the spatial pattern of land cover classes changing? And finally (4) How to apply the results in a management context? This framework is applied to the Tropical Andes, which is recognized as a biodiversity hotspot (Myers, Mittermeier, Mittermeier, Fonseca, & Kent, 2000). This region provides a wide range of ecosystem services (Buytaert, Cuesta-Camacho, & Tobón, 2011) to about 100 million people living in both elevated areas and in the surrounding lowlands. Despite the coexistence of human and natural areas dates back to pre-Inca periods (Ellenberg, 1979) it is evident that human activities have seriously encroached natural areas in the last century (Spehn et al., 2006). For example in the Northern Andes, changes in agricultural practices have triggered extensive degradation of vegetation (Sarmiento, Llambi, Escalona, & Marquez, 2003) and intensive grazing and burning caused typical native species to disappear (Premauer & Vargas, 2004). Transformation of landscape functions may also affect its hydrological regulation, severely reducing the water retention capacity of e.g. tropical mountain grassland ecosystems (Buytaert et al., 2006; Podwojewski, Poulenard, Zambrana, & Hofstede, 2002).

The proposed framework is tested in the Peruvian Jalca, a tropical alpine grassland ecosystem located between the Northern and Central Andes, above 3000 m for the period 1987–2007. The analysis is based on an object-based classification of Landsat TM images since there is not only evidence of good performance in heterogeneous regions but also in allowing applications in vegetation patchiness or landscape complexity and habitat fragmentation studies (Blaschke, 2010; Newman, McLaren, & Wilson, 2011).

2. Materials and methods

2.1. Study area

The study area is located approximately between the 6°30′ S and 7°30′ S in the south of the Cajamarca region, Peru. It covers an elevation range between 3000 and 4200 m and encompasses 6307 km^2 (Fig. 1). This region is known as Jalca, a tropical alpine grassland ecosystem where natural vegetation typically consists of bunch grasses (Weberbauer, 1945). Climate conditions are drier than the paramos of the Northern Andes but more humid and lower than the punas of the Central Andes (Sánchez-Vega et al., 2005). In fact, many authors consider the Jalca as a transition area between the paramos and the punas as some vegetation from both regions can be found here (Luteyn, 1999; Sánchez-Vega, 1996). However, the Jalca also has more than 40 endemic species of plants (Hensold, 1999) such as *Laccopetalum giganteum*, *Ascidiogyne sanchezvegae*, *Calceolaria caespitosa*, *Chuquiraga oblonguifolia* and *Belloa plicatifolia* (Sánchez-Vega, 1996). The Jalca is limited naturally in the lower border by montane forest and shrubland, especially in the western part of the study area. The montane forest (a broad-leaf evergreen forest) is part of the last continuous montane cloud forest of the Peruvian western Andes and it presents high endemism of plants (i.e. Asteraceae, Solanaceae, Loasaceae) and birds (Weigend, Rodriguez, & Arana, 2005). In the study area, total annual precipitation ranges from 650 mm in the west to 1370 mm in the east and mean annual temperature ranges from 5.7 °C in the upper areas to 16.3 °C in the lower areas (Hijmans, Cameron, Parra, Jones, & Jarvis, 2005).

A main effect of human occupation in this area is that agriculture has largely replaced the natural Jalca vegetation (Sánchez-Vega et al., 2005), however this has not yet been quantified. Land tenure has been suggested as one of the main drivers of land use change for the tropics (van Gils & Loza Armand Ugon, 2006). In our study area, changes in land tenure such as those promoted by the agrarian reforms of 1963 and 1970 have lead to more occupancy of the Jalca (Sanchez, 2003). As a consequence of these reforms and before forced expropriation, the former owners of large farms sold smaller pieces to peasants, especially those areas with less productive value, which include the Jalca. New owners used these areas, mainly for intensive grazing of beef cattle (Sanchez, 2003). Later on, the presence of two important dairy factories in Cajamarca triggered intense overgrazing of Jalca areas as well (Sanchez, 2003) and promoted the sowing of pastures. Nowadays croplands typically consist of crop fields of potatoes, wheat, barley, and peas among others. Parcels are either irrigated or rainfed and fallow agriculture is a common practice. According to the last agricultural census of 1994, sowed pastures represent 5.4% of the cropland area of the Cajamarca's highlands (INEI, 2012) but it is very likely that this number has increased considerably in the last years. Nearly 60% of the farmers from the Cajamarca region own parcels of less than 2 ha with low scale production (Zegarra & Calvelo, 2006) and for 1994, only 51% of Cajamarca's farmers had legal land titles (INEI, 2012). For the remaining area, farmers are currently gaining titles or they belong to a traditional form of tenure (communal lands) or cooperatives. For 2001, 79 of the 107 recognized peasant communities had land titles (Owen, Morelli, & Hernández, 2007).

More recently, two other human activities have affected the Jalca integrity in the study area. Mining has developed more intensively since the beginning of 1990 (Sanchez, 2003). Some mountain tops above 3600 m are being exploited as opencast mining for gold extraction. A first impact is an extensive land use and land cover change, and a second one is the use of cyanides for leaching. The