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Linking land cover dynamics with driving forces in mountain landscape of the Northwestern Iberian Peninsula

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ABSTRACT

The mountainous areas of the northwestern Iberian Peninsula have undergone intense land abandonment. In this work, we wanted to determine if the abandonment of the rural areas was the main driver of landscape dynamics in Gerês–Xurés Transboundary Biosphere Reserve (NW Iberian Peninsula), or if other factors, such as wildfires and the land management were also directly affecting these spatio-temporal dynamics. For this purpose, we used earth observation data acquired from Landsat TM and ETM + satellite sensors, complemented by ancillary data and prior field knowledge, to evaluate the land use/land cover changes in our study region over a 10-year period (2000–2010). The images were radiometrically calibrated using a digital elevation model to avoid cast- and self-shadows and different illumination effects caused by the intense topographic variations in the study area. We applied a maximum likelihood classifier, as well as other five approaches that provided insights into the comparison of thematic maps. To describe the land cover changes we addressed the analysis from a multilevel approach in three areas with different regimes of environmental protection. The possible impact of wildfires was assessed from statistical and spatially explicit fire data. Our findings suggest that land abandonment and forestry activities are the main factors causing the changes in landscape patterns. Specifically, we found a strong decrease of the 'meadows and crops' and 'sparse vegetation areas' in favor of woodlands and scrublands. In addition, the huge impact of wildfires on the Portuguese side have generated new 'rocky areas', while on the Spanish side its impact does not seem to have been a decisive factor on the landscape dynamics in recent years. We conclude rural exodus of the last century, differences in land management and fire suppression policies between the two countries and the different protection schemes could partly explain the different patterns of changes recorded in these covers.

Introduction

During the last century Europe's landscape has undergone major changes (Gerard et al., 2010). Some of these changes are a result of territory homogenization processes due to rural areas being abandoned and agricultural intensification (Navarro and Pereira, 2012; Suárez-Seoane et al., 2002). Many mountain rural areas in the northwestern Iberian Peninsula have been abandoned, and therefore, the agro-pastoral activities linked to the traditional rural lifestyle have vanished (Gómez-Sal et al., 1993; Stellmes et al., 2013). These land cover and landscape changes affect biodiversity (Navarro and Pereira, 2012; Regos et al., in press; Sirami et al., 2007) and are a major causative component of global change (Verburg et al., 2011; Vitousek et al., 1997). It is essential to detect and quantify these potential changes in order to carry out the appropriate planning and management actions for conserving the environment in general and protected areas in particular. Furthermore, this type of analysis can be used in subsequent studies to assess the effect that these land cover and landscape changes have on biodiversity and ecosystem services (Suárez-Seoane et al., 2002; Regos et al., in press; Sirami et al., 2007; Navarro and Pereira, 2012).

Multispectral classification and photointerpretation of remote sensing data can be used to map vegetation and land cover (Cohen and Goward, 2004; Gerard et al., 2010). These data are particu-

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larly useful in mountainous areas where accessibility is limited (Shrestha and Zinck, 2001; Álvarez-Martínez, 2010). Over the past 40 years the images captured by Landsat satellites have been widely used to monitor these covers both at the landscape and regional scales (Chuvieco, 2008). The availability of long time-series, an appropriate spatial resolution for research at these scales and adequate spectral resolution for estimating vegetation properties make Landsat data very advantageous compared to other satellite data. Consequently, they have been widely used in a myriad of applications in ecology and other Earth sciences (Cohen and Goward, 2004).

However, in areas with strong topographic variations, the results obtained from the classification of Landsat images may not be good enough (Shrestha and Zinck, 2001; Xie et al., 2008). The main causes are illumination variations (topographic shadows and self-shadows) and atmospheric effects, among others. It is therefore necessary to preprocess the images, including appropriate topographic and radiometric corrections to substantially improve the outcome of the classification (Pons, 1990; Pons and Solé-Sugrañes, 1994; Salvador et al., 1996). Misclassification due the mixed pixels is also another important source of uncertainty when applying traditional hard classification techniques, especially in mountain areas characterized by highly fragmented and heterogeneous landscapes (Álvarez-Martínez et al., 2010). In addition, topographic variations affect microclimates, which may influence vegetation patterns (McGrath et al., 2012). In fact, a recent study have demonstrated that ecological processes behind forest expansion at the boundary between Eurosiberian and Mediterranean biogeographic regions is a complex undertaking because the influence of land use may be reinforced or constrained by abiotic factors such as climate (Álvarez-Martínez et al., 2014). It is therefore, necessary to introduce topographic and climate variables as ancillary information to improve the classification of vegetation classes (Shrestha and Zinck, 2001). In addition, the temporal resolution of Landsat images and the meteorological conditions of the study region, which has a lot of cloud cover on many days, reduce the availability of this satellite imagery. Two more important limitations are the Scan Line Corrector (SLC) problems of Landsat 7 Enhanced Thematic Mapper Plus (ETM+) from 2003 and the reduced availability of Landsat 5 Thematic Mapper (TM) before 2001 (NASA, 2013; Wulder et al., 2011). The incorporation of ancillary variables during the classification process could compensate for the lack of additional spectral information, thus improving the thematic accuracy of the resulting cartography (Campbell, 2008).

In this work we evaluated the land cover and landscape dynamics from 2000 to 2010 in a mountainous region of the northwestern Iberian Peninsula based on a post-classification comparison of Landsat-derived maps after taking into account all above mentioned shortcomings. Previous research based on the analysis of time-series of remote sensing data or aerial photography have already showed that land abandonment is one of the main drivers affecting the spatio-temporal dynamics during the second half of the 20th century (pre and post-1990's period) in marginal areas of Northwestern Iberian Peninsula (Calvo-Iglesias et al., 2009; Pôças et al., 2011; Stellmes et al., 2013). However, these previous studies do not address the potential impact of other driving forces that might be also affecting to these dynamics at regional levels. In our understanding, filling these gaps is essential to provide guidance to policy makers for developing coherent policies for effective land planning. New studies in early 21th century are also needed to test whether land abandonment processes are dominant in landscapes or whether, by the contrary, changes in natural disturbance regime, land planning, or forest policies are nowadays modulating these reported trends. Romero-Calcerrada and Perry (2004) demonstrated that the probability of fires occurring is higher in areas submitted to agricultural land abandonment. Increased fire hazard is expected where land cover changes have promoted an increase in fuel load, such as those resulting from rural abandonment (e.g., vegetation succession on abandoned lands, pastures, or woodlands) or from afforestation activities (Loepfe et al., 2010; Moreira et al., 2011). During the second half of the last century most afforestation and reforestation processes that occurred in the Iberian Peninsula were the result of forest programs (Calvo-Iglesias et al., 2009; Moreira et al., 2011; Pausas et al., 2004). In our study region, oak forests are represented exclusively by native species and result from a natural succession process, while the pine plantations are a consequence of previous forestry management plans with social and economic interests (Macedo et al., 2009). Several of these native forestry species, together with some scrub communities and pastures, are protected by the conservation measures implemented for the protected sites. The main objective was therefore, to determine whether the abandonment of rural areas was the main driver of land cover and landscape dynamics in our study region, or whether other factors, such as wildfires or forest management were also directly affecting these spatio-temporal dynamics. We hypothesized that differences in forest management and fire suppression policies as well as different protection schemes may have caused different spatial patterns in the temporal dynamics of the land covers. To test this we conducted our study in three areas with different protection and territorial management regimes.

Material and methods

Study areas

We carried out the study in three areas included in the Gerês–Xurés Biosphere Reserve (about 176,000 ha in total). All of them are located in the NW Iberian Peninsula (Fig. 1), between latitudes of 41°38′51″ and 42°8′58″ and longitudes 7°38′39″ and 8°25′43″. The first area is the Peneda Gerês National Park (PGNP) in Portugal, and the second is the Baixa Limia–Serra do Xurés Natural Park (XNP) in Galicia (NW Spain). The third area is the unprotected areas (UAA) adjacent to XNP (Fig. 1). The topographic relief is complex with an elevation ranging from 15 m to 1513 m, with an average slope of 13° (ranging between 0° and 66°). The region is located in the transition between the Mediterranean and Eurosiberian biogeographic zones close to the Atlantic coast. The climate is temperate oceanic sub-Mediterranean (Ninyerola et al., 2005). The most common type of vegetation is scrub communities. Forests are very fragmented and dominated by oaks and pines (Pulgar, 2005).

The study areas are representative of the mountainous landscapes in the northwestern Iberian Peninsula. Although this landscape has been intensely affected by human activity, the current density of the human population is quite low (29.4 inhab/km^2) (Macedo et al., 2009). The population settlements are administratively organized into six municipalities of Galicia and five of Portugal. The population dynamics have been largely influenced by the migrations of the past century, the low birth rate, and high mortality, especially in the early 1950s. As a consequence, the study region lost more than 14,000 inhabitants in the Galician municipalities included in the reserve since 1900. Nowadays, the current population is only 41% of the population in the year 1900. From 1991 to 2007 this area lost about 3000 inhabitants, mainly since 2001 (www.ine.es). The depopulation of the area has been accompanied by the abandonment of traditional agricultural and livestock activities.

Satellite imagery and ancillary data processing

The analysis described in this study (Fig. 2) spans a ten-year time period (2000–2010). The main data source consisted of five Landsat