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Complex land cover change processes in semiarid Mediterranean regions: An approach using Landsat images in northeast Spain

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ABSTRACT

In this study we used Landsat images to analyze land cover change processes since 1984 in the middle Ebro valley (Spain). The purpose was to identify abrupt changes suggesting modification of the land cover category, and gradual changes not associated with a change in the land cover type but potentially indicative of significant changes in natural areas. The results showed that: i) in analysis of land cover change the seasonality of vegetation cover is an important factor that must be taken into account in identifying the various change processes that may affect a region; ii) the major land cover changes in the study area were related to very diverse processes including urban expansion, industrial activities, the establishment of land irrigation, land extensification, natural revegetation following rural abandonment, forest fires, and changes in natural vegetated areas related to global warming and drought. With the exception of the occurrence of forest fires, the changes in natural areas (forest, shrubs and steppes) tended to be gradual with respect to both positive (forest colonization following rural abandonment and land extensification) and negative (land degradation and forest decline) processes. These areas showed rates of change that were lower in magnitude than those directly transformed by human activities. We found that time series of high spatial resolution satellite images and the application of change statistics provided a useful approach to the identification of abrupt changes, and gradual land cover change processes that are not commonly revealed using classical analytical approaches.

1. Introduction

Land cover and land use changes are important indicators of global change (Crutzen & Stoemer, 2000; Lambin & Geist, 2006), and are a general feature of Western Europe, where human activities have modified the landscape structure in time and space (Jongman, 2002; Vos & Meekes, 1999). These changes have generally been driven by societal adaptation to environmental conditions. In some cases the changes enabled sustainable use of resources, and increased the landscape and biological diversity (Bernués et al., 2011; Gibon, 2005; Sayadi et al., 2009; Vos & Meekes, 1999).

Land cover and land use changes accelerated during the second half of the 20th century in response to general (economic globalization and climatic change) and local (urbanization, rural exodus, land abandonment and agricultural intensification) driving forces (Klijn & Vos, 2000; Riebsame et al., 1994; Van Eetvelde & Antrop, 2003; Vitousek et al., 1997; Wood & Handley, 2001). In Western Europe the regional management systems and public policies (mainly the European Agricultural Policy) are central to understanding the recent land cover changes (García-Martínez et al., 2009; Laguna & Lasanta, 2007; Olesen & Bindi, 2002). These factors explain the increased number of studies in recent years concerning land cover and land use in various countries and ecosystems of Western Europe (Mertens & Lambin, 1997; Pan et al., 1999; Ramankutty & Foley, 1999; Rogan et al., 2003; Serneels & Lambin, 2001). Most of these have been focused on mountain areas since the rural population exodus that began during the 20th century. This exodus caused generalized land abandonment, which triggered widespread revegetation processes that have had significant environmental and socioeconomic impacts (Bielsa et al., 2005; Chauchard et al., 2007; Koulouri & Giourga, 2007; Lasanta et al., 2005; MacDonald et al., 2000; Mouillot et al., 2005; Vicente-Serrano et al., 2004). However, the majority of studies have involved small areas, such as municipalities, small basins or valleys (Lasanta et al., 2001; Poyatos et al., 2003; Pueyo & Beguería, 2007; Taillefumier & Piégay, 2003; Vilá et al., 2009).

The studies of land cover change in Western Europe have commonly reported the changes that have occurred between two time points, using data from the land registry (Mottet et al., 2006), old postcards (Debussche et al., 1999) or aerial photographs (Lasanta et al., 2005; Sluiter & de Jong, 2007; Van Eetvelde & Antrop, 2003). These studies have commonly involved long time periods and used a static approach based on the information available for two different dates, and thematic maps of various land cover categories (Hietel et al., 2004; Parmenter et al., 2003; Thomlinson et al., 1996). Although this approach is useful for determining the main landscape changes, it is not able to distinguish

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some processes characterized by gradual landscape-scale modifications, or changes that result in modification of the cover conditions but not the cover type. Amongst these are gradual land degradation or desertification, a decline in forest activity, revegetation processes as a consequence of natural vegetation successions, or the rapid recovery of vegetation following a disturbance, such as wildfire. These processes do not necessarily result in changes in land cover category, but are very important as they can markedly affect soil fertility, carbon sequestration, biodiversity and the general quality of the environment. However, they are very difficult to identify using traditional methods because in most cases they are not visually apparent. Hill et al. (2008) and Del Barrio et al. (2010) recently identified various land cover change processes in Spain that were not possible to identify using thematic maps. They used sequential time series of satellite images and trend statistics to show that most of the changes identified did not modify the type of cover, but changed the biophysical conditions of the cover. The changes were related to the rural population exodus (increase of vegetation density), degradation processes (loss of vegetation cover) and forest fires.

The studies noted above were based on low spatial resolution satellite images obtained from the polar National Oceanic and Atmospheric Administration–Advanced Very High Resolution Radiometer (NOAA-AVHRR) satellites. High spatial resolution images enable detection of land cover change processes with a greater degree of detail than do low resolution images, as well as other processes that cannot be identified using the latter. The available long-term data image collections from Landsat satellites are a major resource for understanding change processes affecting the earth (Cohen & Goward, 2004), and have been widely used to analyze land cover changes (e.g. Lenney et al., 1996). A common approach using Landsat data has been to use images to classify land into differing categories, and to quantify changes in categories between different dates (Romero-Calcerrada & Perry, 2004; Shalaby & Tateishi, 2007; Yuan et al., 2005). Few studies have used time series of high resolution images to analyze gradual non-categorized change processes, and most have involved the identification of specific process such as desertification (Hostert et al., 2003; Röder et al., 2008), trends in forests after disturbances (Huang et al., 2010; Kennedy et al., 2010; Vogelmann et al., 2009) and forest recovery after fire (Díaz-Delgado et al., 2002; Vicente-Serrano et al., 2011). Very few studies have used the full potential of Landsat time series to fully classify land cover change processes that may occur in a single region (e.g., Stellmes et al., 2010).

In Western Europe, human intervention is a greater determinant of land cover changes in flat areas than in mountainous areas (Nogués-Bravo, 2006), because the influence of the markets, the political actions and the urbanization processes. For a variety of reasons the central Ebro valley (northeast Spain) is an appropriate region for analyzing land cover change processes, and assessing the use of high resolution satellite image time series and trend statistics to detect them. i) The central Ebro valley is one of the most dynamic economic areas in Spain because of its strategic location between the main Spanish cities of Madrid, Barcelona, Valencia and Bilbao, a consequence of which has been the establishment of large industrial and service activities. ii) There has been intensive urbanization of the city of Zaragoza (675,121 inhabitants in 2010) involving an expansion of residential and industrial areas. iii) The region is semiarid, which has resulted in the establishment of large areas of irrigated land. The semiarid nature of the climate has favored the intensification of agriculture in some areas, but extensive agriculture and/or abandonment in others, particularly dryland areas with large hydrological deficits and low fertility soils. iv) The European Agricultural Policy has promoted the setting aside of some areas, while adjacent irrigated land is very intensively cultivated. v) The diverse climate of the study area causes spatial and temporal variability in precipitation and temperature, which differentially impact on the dynamics of the natural vegetation (Vicente-Serrano, 2007; Vicente-Serrano et al., 2010). In summary, this is a highly dynamic region where diverse land cover changes may occur over short periods, providing the opportunity to assess how physical factors and/or human management processes are driving change.

In this study we analyzed various land cover change processes that have occurred in the central Ebro valley since 1984 (the year Landsat 5-TM satellite was launched), using a high spatial resolution (30 m.). The objectives were to use time series of Landsat images to identify both abrupt landscape changes, involving a change in land cover category, and gradual changes that may have significantly affected natural areas without a change having occurred in the land cover type.

2. Study area

The central Ebro valley is a topographic depression surrounded by mountain chains (the Pyrenees and the Iberian range). The structural platforms are the dominant relief on both sides of the Ebro River, which is the main watercourse in the valley and crosses it from west to east. There are mountain chains to the north and south of the study area: the Pre-Pyrenees (maximum altitude approximately 2000 m a.s.l.) to the north, and the Iberian range (approximately 1300 m a.s.l.) to the south.

The central Ebro valley is one of the most arid regions of Europe. The climate is Mediterranean with major continental influences. Precipitation rates are low and highly variable, with average values ranging from 800 mm in the north near the Pre-Pyrenees to less than 300 mm in the central areas of the Ebro valley. Most of the study area has a negative water balance (precipitation minus potential evapotranspiration, PET; Fig. 1). Thus, in the most arid parts of the valley the deficit is >900 mm (Cuadrat et al., 2007). The winters are cold and long with very frequent frost episodes, which restrict the development of cultivated agriculture and natural vegetation. In the center of the valley four months have mean temperatures <10 °C, with frequent daily extremes <−10 °C. Heat waves with maximum temperatures up to 40 °C are common in summer. The average temperature during the warmest month (July) is approximately 24 °C (Cuadrat, 1999).

Due to aridity, shrubs and pastures are the dominant vegetation in the center of the valley (25.7% of total surface), while a smaller area (10.1%) is occupied by forests of mainly *Pinus halepensis*, and small degraded savin forests (Braun-Blanquet & Bolòs, 1957; Pueyo & Alados, 2007; Pueyo et al., 2007; Vicente-Serrano et al., 2010). In the Pre-Pyrenees and the Iberian range pure mountain conifer forests or mixed conifer–hardwood forests dominate the landscape. In these areas the forested landscapes comprise stands of *P. sylvestris* L., *P. pinea* L., *P. nigra* subsp. *salzmannii* (Dunal) Franco, *Quercus faginea* Lam., and *Q. ilex* L. subsp. *ballota* (Desf.) Samp.

Dryland cultivation covers 38.9% of the total surface area (Fig. 1). Winter cereals (wheat and barley) alternating with fallow dominate the cultivation regime. Irrigated agriculture increased during the second half of the 20th century, and now represents 20.8% of the total surface area. Cereals (wheat, barley, rice and corn) and alfalfa are the main crops cultivated under irrigation, with fruit and vegetables comprising small areas (Lasanta, 2009). The European Agricultural Policy has promoted the setting aside of some lands from agriculture, and this has affected parts of the study area, mainly on gypsum slopes, the bottom of valleys affected by salinity, and small fields (Lasanta et al., 2000).

Urban and industrial areas occupy 5% of the area, mainly corresponding to the city of Zaragoza and adjacent areas within a 50 km radius. This highly dynamic area shows constant land cover changes indicative of the transformation of natural and cultivated areas to industrial, commercial and residential areas, and transport infrastructure including roads, airports and high speed railways. The