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Afforestation, agricultural abandonment and intensification: Competing trajectories in semi-arid Mediterranean agro-ecosystems

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ABSTRACT

An understanding of land use change and its drivers in semi-arid Mediterranean agro-ecosystems is important for informing ways to facilitate adaptation to future environmental and socioeconomic pressures. In this paper, we mapped and quantified land use changes in the semi-arid Mediterranean agro-ecosystem of Torrealvilla catchment between 1956 and 2008. Subsequently, we detected signs of landscape fragmentation and examined the relationship between land use change trajectories and a set of biophysical factors using Generalized Additive Models (GAMs). Finally, we qualitatively evaluated the role of socioeconomic drivers on the land use change trajectories. The study provides accounts of multidirectional land use trajectories in semi-arid Mediterranean landscapes. Our analysis shows that more than 72% of the study area has undergone significant changes over the past five decades with pronounced effects on landscape composition and structure. Both biophysical and socioeconomic factors are strongly related to the observed spatial and temporal changes in land use. Three major trajectories were observed. Firstly, rain-fed agriculture is becoming less dominant; future abandonment of rain-fed agriculture should be anticipated. Secondly, expansion of forested areas is evident in higher altitudes. The trend is still likely to continue given the possibility of further abandonment of rain-fed farming and existing subsidies for reforestation of arable land. Thirdly, intensification has been observed which has occurred mainly in lower parts of the landscape on flat to gentle slopes and near main roads. Further intensification is likely to be subject to market drivers, irrigation water availability, and future rural development and agricultural policy. Overall, the study shows that even within a given locality, contrasting land use trajectories can emerge as a result of local responses to multiple drivers of change and these need to be carefully taken into account in future policy development.

1. Introduction

Land use change occurs from local to regional and global scales and is a result of short and long term interactions of multifaceted drivers (Verburg et al., 2004; Verburg and Overmars, 2009; Sirami et al., 2010). These include the biophysical characteristics of the lands, market forces, policies and regulations, and the decision making of those managing the land (Pocewicz et al., 2008; Mottet et al., 2006). Inevitably, changes in land use and management occurring across a given agro-ecosystem affect various components and processes such as biodiversity, soil and water resources, landscape fragmentation, and land degradation with strong implications for many ecosystem functions and services and for society (Zimmermann et al., 2010; Kamusoko and Aniya, 2007; Ries, 2010; de Groot et al., 2002). Hence it is not surprising that a great deal of research has been devoted to study land use changes in diverse environmental settings extending over different spatial and temporal scales (e.g. Siwe and Koch, 2008; Wentz et al., 2008; Caldas et al., 2007). Outcomes from these studies are important for example for on-going evaluation of the effectiveness of past and current policies and for substantiating discussions on appropriate future responses (Lin et al., 2007; Brannstrom et al., 2008; Castella et al., 2007).

The nature of existing research on land use change varies (Briassoulis, 2000; Parker et al., 2003; Upadhyay et al., 2006). Some studies focus on purely identifying changes and/or investigating the drivers of changes (e.g. Zhou and Kockelman, 2008; Van Doorn and Bakker, 2007; Qasim et al., 2011). Others

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examine the environmental and/or socioeconomic impacts of changes (e.g. Garcia-Ruiz and Poesen, 2007; Bhattarai et al., 2008; Prato et al., 2007; Hubacek and Sun, 2001; Fleskens et al., 2012). Another group of research simulates past to present changes and/or future trends either based on macro-level socioeconomic scenarios or micro-level agent interactions (e.g. Manson, 2005; Valbuena et al., 2010; Verburg and Overmars, 2009). Nevertheless, often studies exclusively look at one particular land use change process or one specific aspect of drivers. Especially in the context of Mediterranean semi-arid agro-ecosystems, an individual study rarely attempts to analyse the multitude of competing processes affecting landscape scale outcomes. A comprehensive analysis would ideally examine the multiple important processes and the resulting spatial composition and evaluate the role of both biophysical and socioeconomic drivers on the observed pathways.

There is no doubt that important land use changes have taken place and are ongoing in semi-arid agro-ecosystems of South-East Spain with important impacts on the long term problem of land degradation in this area (e.g. Garcia-Ruiz, 2010). However, current empirical evidence is limited regarding the types of changes that have occurred, the spatial extent and variation of the changes, how different types of changes have progressed over time, and the drivers of these changes. Furthermore, there is often very limited information on changes in landscape fragmentation, while changes in fragmentation have important implications for biodiversity and hydrological connectivity. All this kind of information is invaluable for developing informed measures to tackle challenges associated with the management of these vulnerable agro-ecosystems. In particular, a better understanding of the inter-linkage between land use change processes and the associated biophysical and socioeconomic drivers is of high importance for drawing insights regarding the likely future land use trajectories in the studied area and potentially other similar Mediterranean agro-ecosystems, and for highlighting management implications in order to guide land use in a sustainable direction.

In this paper, we aim to undertake a multi-temporal fine scale land use change analysis in a medium sized catchment from 1956 to 2008 and thus provide insights into the evolution of a Mediterranean semi-arid agro-ecosystem of south-eastern Spain over the last decades with a potential to explore future land use trajectories. To this end, the specific objectives of the study are: (1) To evaluate multi decadal land use changes, (2) to analyse multi decadal land use patterns and landscape fragmentation, and (3) to examine the relationship between the observed land use change processes and biophysical and socioeconomic drivers.

2. Materials and methods

2.1. Study area

The study extends over 'Rambla de Torrealvilla', a sub-catchment within the Guadalentín basin (3300 km^2) in south-eastern Spain, covering a total area of about 266 km^2 (Fig. 1). The study area makes an interesting site for studying land use change in Mediterranean dryland agro-ecosystems because land use in the area has for a long time been very dynamic and ongoing human interventions have historically influenced the landscape in various directions. Soil erosion and water scarcity are among the most pressing environmental issues across the study area. The biophysical characteristics of the area are inherently susceptible to soil erosion. The Torrealvilla is characterised by a meseta-like plain and an undulating landscape with long pediments and strongly incised river terraces; soils are formed dominantly in highly erodible lithologies (marls and limestones). Dominant soil types include Gypsisols, Fluvisols, and Cambisols (FAO, 2006).

The local climatic conditions are characterised by dry summers and heavy rains in spring and autumn which aggravate the soil erosion problem (López-Bermúdez et al., 1998, 2002). The mean annual precipitation is between less than 300 to more than 500 mm. Droughts, centred during summers, commonly lasting for more than 4–5 months. The monthly temperature ranges from 12 to almost 17 °C with an average of 15 °C. Annual potential evapotranspiration rates larger than 1000 mm are common in large parts of the basin.

Most recent land uses in the study area consist of rainfed cereals, almond/olive orchards, intensively irrigated horticulture (vegetables), grapes, pig/animal farming, shrubs, and forest. *Stipa tenacissima*, *Rosmarinus officinalis* and *Anthyllis cytisoides* are among the most commonly found semi-natural vegetation in the shrubland. The forests are mainly covered by *Pinus halepensis*.

2.2. Data preparation and analysis of land use change

Land use classes were delineated on aerial photographs taken in 1956, 1986, 2004, and 2008 by digitization in ArcGIS software (ESRI® ArcMap™ 9.2). For 1956 and 1986, we sourced digitised panchromatic photos at 1 m spatial resolution (original scale 1:30,000) from the Ministry of Sustainable Development and Land Use Planning of the Region of Murcia (Spain). For 2004 and 2008, multispectral (red, green, blue, and near infrared) ortoimages at 0.45 m spatial resolution were available from the Ministry of Sustainable Development and Land Use Planning of the Region of Murcia and the NATMUR project (Ministry of Agriculture and Water of the Region of Murcia in Spain), respectively. Prior to the digitisation works, various visits to the study area were undertaken to gain familiarity with the land use classes and patterns.

Land use maps of the recent time periods were digitised first. Eleven land use classes were distinguished: cereal (CER), almond/olive (ALO), intensively irrigated horticulture (IIH), grapes (GRP), water storage (WST), pig/animal farm (PAF), solar panel farming (SPN), shrubs/gullies/non used (SGN), open forest (SFR), dense forest (DFR) and built-up area (BUA). Regular field checks of the digitized maps were performed. Following such a field check, in overall 98% of the 'tentative' classification was found to be correct. The 1956 and 1986 land use maps were corroborated by informal interviews with landowners/farmers, cross-checking with relevant past reports and data, and discussions with fellow scientists from the region. Once all the land use maps were completed and the accuracy checked, the individual maps were converted into raster format with a cell size of 2 m × 2 m. The analysis of multi temporal land use patterns and changes was carried out in ArcGIS (ESRI® ArcMap™ 9.2) by overlaying and cross tabulating the maps of the four available dates.

A detailed investigation of the spatial composition and configuration for the multi-temporal land use maps was undertaken in Fragstat software (McGarigal et al., 2002) at landscape and class levels (i.e. for the whole study area and each land use type, respectively). By undertaking such analysis at both levels we were able to examine possible differences in trends. We calculated a key set of metrics deemed essential for detecting fragmentation (Table 1). These metrics were selected as they allow effective interpretation of different aspects of fragmentation at the spatial scale of our analysis (Herzog et al., 2001). Moreover, Simpson-based indices of diversity were chosen instead of Shannon's indices since the latter is only recommended for cases with more than 100 land use types (Yue et al., 1998). For more details on the definitions of the metrics used, mathematical formulas, and guidance for interpreting the different landscape and class metrics used in this