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Changes and interactions between forest landscape connectivity and burnt area in Spain

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ABSTRACT

The spatial structure, functionality and dynamics of forest landscapes in peninsular Spain and the Balearic Islands were compared over the last five decades. Two particular features were studied in the sample sites: forest connectivity for wildlife and areas burnt by wildfires. 191 Squares, each 4 km × 4 km, were selected from the SISPARES (the monitoring framework designed to evaluate the trends in the structure of Spanish rural landscapes) environmental strata. Aerial photographs from 1956, 1984, 1998 and 2008 were interpreted and 11 land cover categories mapped and checked in the field, using a minimum mapping area of one hectare. The Equivalent Connected Area Index was used to assess forest connectivity over the sampling period. Social and economical factors were assessed using indicators of farm intensiveness. The Spanish forest connectivity has improved in the last five decades although two different trends can be identified: the first 40 years are characterized by positive rates of growth whereas the 10 last years are characterized by their stability. Nevertheless the area of burnt land was higher along the first 25 studied years and decreased significantly over the last decade.

Our results show the climate is the main driver in the evolution of forest connectivity and burnt area in the forest landscapes, playing a direct role on forest biomass production and wildfire ignition and propagation, as well as an indirect role by keeping vertical and horizontal forest continuity through the landscape spatial pattern. Social and economic factors are very important drivers as well: Rural population density and farm size average have been tested as good indicators of landscape artificiality, highly correlated to wildfire hazard and forest connectivity.

Finally, we have pointed out the evolutionary path followed by SISPARES framework as a tool for monitoring rural landscapes. It emphasises on the requirement of a 30 years time window for building-up reliable dynamic multifunctional model.

1. Introduction

The spatial pattern of Landscapes is the result of complex interactions among biophysical, biological, social and economic forces. Their evolution over time is the outcome of the dynamical relationship between landscape structure and the ecological functional processes that occur therein (Burel and Baudry, 2002; Forman, 1995; Forman and Godron, 1986; Hulshoff, 1995; Neel et al., 2004; Turner, 2005). Monitoring landscape dynamics has become essential for a better knowledge of the complex interactions that take place between social, environmental and geophysical processes (Munroe and Müller, 2007).

Traditionally, forest ecological processes have been studied at the ecosystem level (e.g. Dunning et al., 1992) but increasing concern about loss of biodiversity has encouraged the development of guidelines for forestry practices at the landscape level (García-Feced et al., 2010). The advances of remote sensing and Geographic Information Systems (GIS) which have occurred in the last two decades have made these analyses possible (Kumar, 2011; McGarigal and McComb, 1995; O'Neill et al., 1997; Wiens, 1989).

Recent research efforts have enhanced a better understanding of the causes and consequences of landscape heterogeneity, and how they condition the management of natural and human dominated landscapes (Black et al., 2003; Turner, 2005). Particularly, the new advances produced in landscape ecological research have

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improved the way forest systems are managed (Lafortezza et al., 2008; McGarigal and Marks, 1995).

Here we aim to model the spatial structure, functionality and dynamics of Spanish forest landscapes during the last half century, building on recent developments on landscape ecology and monitoring systems. Two particular features of relevance for Mediterranean forest management are studied: forest connectivity for wildlife and areas affected by wildfires.

Forest connectivity is defined as the characteristic of the landscape that facilitates the movement and dispersal of species, genetic exchange and other ecological flows through patches of forest within a given land area, and is essential for the survival and viability of many wildlife species (Crooks and Sanjayan, 2006). Conserving or promoting forest landscape connectivity is considered a key management objective due to its capacity to sustain many relevant ecological fluxes and interactions in forest ecosystems (Bailey, 2007; Forman, 1995; Saura et al., 2011b). However, in some cases, an excessive forest connectivity might trigger the spread of pests, diseases or wildfires; therefore, knowledge and management of the spatial pattern of forests within the landscape will help to halt or reduce the expansion of these undesired processes.

Wildfires are a major source of concern not only because of ecological reasons but also for economic and social problems (Inbar et al., 1998; Naveh, 1989). From an ecological point of view, fire is also a key factor that helps to determine the diversity and dynamics of vegetation in time and space (Bajocco et al., 2010). Authors such as Forman (1995), Krumel et al. (1987) and Turner (1989) emphasize that a complex combination of wildfire disturbances of varying frequency, intensity and extension are probably the main contributor to landscape diversity by interspersing land cover mosaics. Each year, wildfires affect millions of hectares of forests around the world, especially in the Mediterranean biome where forest fires are the main cause of natural resource destruction (Merino-de-Miguel et al., 2010).

The configuration of the landscape is often underestimated or misunderstood as one of the factors that affect connectivity for wildlife and wildfire occurrence. Analysis of the interactions between forest connectivity and fire events requires long term data on forest landscapes which has been absent until recently. Currently, several national monitoring initiatives have been developed in Europe, which deliver national figures for representative landscapes, habitats, and vegetation, such as the United Kingdom Countryside Survey (Smart et al., 2010; Bunce et al., 1996) (www.countrysidesurvey.org.uk) and the National Inventory of the Landscapes of Sweden (Ståhl et al., 2011).

The evolution of landscapes throughout Spain has not been well studied although there are several studies at local levels (Álvarez-Cobelas et al., 2007; Schoorl and Veldkamp, 2001). However, a monitoring system, termed SISPARES, has been designed to evaluate trends in the structure of rural landscapes (Elena-Rosselló et al., 2005). This system was conceived with an appropriate size of sampling sites, a homogeneous spatial scale, and a timescale long enough to record changes from 1956 to 2008. SISPARES data therefore provide us the opportunity to undertake a novel in-depth study the correlations between landscape pattern and both geographical and environmental factors. The data make it possible to assess both the evolution of the Spanish forest connectivity and the trends in its internal features that make the landscape susceptible to wildfire.

The general aim of this paper is to assess the spatial and temporal patterns of forest connectivity and wildfire hazard at the forest agriculture interface across Spain in the last half century. The specific objectives are (1) to provide statistical estimates of forest connectivity and areas affected by wildfire at a landscape level in Spain from 1956 to 2008 and (2) to explore the existence of spatial and temporal links (interactions or interferences) between two key landscape features: forest connectivity and burnt areas.

2. Materials and methods

2.1. Study area and landscape data

This study was carried out in the Spanish regions of the Iberian Peninsula and the Balearic Islands, covering about 497,000 km^2. The geographical position of Spain, together with its high mean elevation and the abundance of mountain ranges, are responsible for its climatic diversity (Oceanic, Mediterranean, Continental and Alpine). Spain also contains a high geological variability, resulting from rock types dating from almost every geological period. These biophysical factors have also given rise to a high diversity of plant species and vegetation types (Fernández-González et al., 2005).

Landscape structure data were recorded in a spatially and temporally consistent way at four different dates (1956, 1984, 1998 and 2008) through the SISPARES monitoring framework. SISPARES consists of 206 stratified sampling plots with an area of 4 km × 4 km distributed throughout Spain (Elena-Rosselló et al., 2005, www.sispares.com). The sampling intensity, considering the plot size and the total extension of the study area, is about 1/146. Landscape data are derived from the interpretation of aerial photographs in the first two dates and from digital photographs in 1998 and 2008. Field visits were also made to check and correct the delineations (in 1994, for the 1956 and 1984 data, in 2000/01 for the 1998 data, and in 2010/11 for the 2008 data). Each sample unit was photo-interpreted in each date with a minimum mapped area of 1 ha. The differentiated types of cover were forest, forest plantations, riparian woodlands, *dehesa*, scrub, grazed land, crops, bare land, water bodies and urban areas. For the present study, we selected those samples with a forest cover of at least 20% in order to quantify the changes that have occurred over the three periods (from 1956 to 1984, from 1984 to 1998 and from 1998 to 2008), resulting in a total of 191 sample sites.

The SISPARES sample plots are fully representative of the bio and geo-climatic structure of Spain. They were selected according to a stratified sampling procedure based on the CLATERES land classes (Elena-Rosselló et al., 1997). Consequently, each sample represents one of the CLATERES classes, ecological zones with similar biotic and abiotic factors such as topography, vegetation, lithology and climate (Elena-Rosselló et al., 1997). Subsequently, the CLATERES classes were aggregated along two main axes: the first being climatic aridity which identifies five climatic strata (humid, sub-humid, sub-arid, arid and hyper-arid) and the second soil acidity, which differentiates three lithological strata. These axes defined a total of 14 geoclimatic strata (each one corresponding to a continuous region with homogeneous bio and geo-climatic conditions and represented by several SISPARES plots) in mainland Spain and the Balearic islands.

The Spanish rural landscape typology based on vulnerability to wildfire according to land cover and use was developed by Ortega et al. (2012) and was used as the basis of the analysis. This paper classified rural landscapes into six types depending on the relative proportion of forest and agricultural land and the type of spatial mixtures and interfaces established between them. Spanish Forest Agriculture Interface types (FAI) range from pure agriculture (type I) to pure forest (type VI), through a gradient of Agricultural-Forest interface (AGFO) from type II to type V. These four agro-forestry landscape types are characterized by the relative importance of the two main land covers and the grain of the patches that determine them. Type V is defined as containing predominant patches of fully integrated agro-forestry systems, termed *dehesas*. In comparison, types II, III and IV are distinguished by containing an intermixed pattern of purely agricultural and forest patches: type II corresponds to fine-grained landscapes, type III to more dense forest landscapes (medium-grained) and type IV to coarse-grained landscapes.