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Integrated planning for landscape diversity enhancement, fire hazard mitigation and forest production regulation: A case study in central Portugal

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ABSTRACT

Forest fires and forest biodiversity are related issues of major concern in Mediterranean countries and require an integrated approach to landscape planning. The aim of this study was to develop a GIS approach for regulating forest production while promoting landscape diversity and mitigating fire hazard. A study area located in the centre of Portugal was chosen. The area was primarily occupied by maritime pine and had a high fire hazard, low tree species diversity and an extensive protection area. The classical area control method was used to assist in forest production regulation. Species suitability maps were produced for 21 recommended species for afforestation in the study area. Maritime pine management compartments were defined, and a 50-year harvesting plan was proposed. In each harvested compartment, protection areas were identified for species conversion (e.g., native oaks and/or broadleaves). Afforestation species were proposed according to the species suitability maps produced earlier. Low flammability species that produce high-quality wood, non-wood products and landscape enhancement were preferred. A comparison of the land cover in the study area in 2007 to that anticipated in 2064 via the proposed plan showed that a more fragmented landscape structure could be achieved by introducing 16 species of lower flammability than maritime pine into the study area. This study proved the usefulness of this methodological approach for guiding sustainable changes in homogeneous, unmanaged forest landscapes prone to fire. Further research is needed regarding integrated planning approaches that incorporate environmental, economic and social dimensions (e.g., human desertification of rural areas).

1. Introduction

In the Mediterranean region, changes in land use patterns and the impacts of socioeconomic factors on land management practices have resulted in major modifications to forest ecosystems during the second half of the 20th century (Piussi and Farrell, 2000; Fernandes et al., 2014; Seijo et al., 2015). Many rural areas have experienced substantial population decreases, leading to the abandonment of agricultural land and a reduction in the consumption of forest fuels (Piussi and Farrell, 2000; Nunes et al., 2005; Jones et al., 2011). Additionally, a prominent feature of forest policies in the Mediterranean region is large-scale afforestation and subsequent reforestation with fast-growing pioneer conifers for wood production and land restoration (Jones et al., 2011; Fernandes et al., 2014). As biomass removal has decreased with afforestation, fire hazards have increased (Fernandes et al., 2014). Throughout this period, fires have destroyed many large forest areas (Piussi and Farrell, 2000; FAO, 2013), particularly in southern Mediterranean countries (e.g., Greece, Italy, Portugal and Spain).

The relationships between landscape structures and fire regimes are interactive (Loepfe et al., 2010). Generally, when agricultural land is abandoned, vegetation growth inevitably occurs and leads to spontaneous forest regeneration, often transforming from a mixture of fragments of different ages and sizes to an integrated

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homogenization of the forest landscape (Geri et al., 2010). Homogenous landscapes with high fuel loads and high connectivity favour high fire intensity and considerable potential for spreading (Loepfe et al., 2010; Fernandes et al., 2014). However, fires also increase landscape homogeneity by reducing fuel loads and changing land use/cover types (e.g., forests into scrublands), thereby increasing fire propagation (Loepfe et al., 2010). Fires are selective, with small fires exhibiting stronger land cover preferences than large fires. In general, forests are usually more fire prone than agricultural areas, but less susceptible than scrubland (Nunes et al., 2005; Moreira et al., 2011; Oliveira et al., 2014). From a management perspective, land cover is the only landscape variable that influences fire behaviour and can be manipulated. In that context, the development of land use policies that conserve landscape diversity by promoting a fragmented landscape structure, namely, combining the effects of strategically placed area-wide fuel treatments, fire resistant forest types and agricultural mosaics, are recommended (Badia et al., 2002; Loepfe et al., 2010; Fernandes et al., 2014).

The environmental consequences associated with land cover/land use changes due to the abandonment of agricultural areas and/or the afforestation intensification may occur as a result of gradual decreases in landscape diversity and complexity and an increase in vulnerability to certain hazards such as forest fires (Serra et al., 2008). Therefore, analyses of landscape patterns (e.g., composition and structure) are essential for forest conservation and should be a priority in forest management programmes (Teixido et al., 2010). Multiple contributions can be made to the diversity and complexity of the landscape matrix: (1) at the landscape level, by considering the spatial arrangement of different-aged plantation stands with respect to other landscape components, especially native forest remnants (Brockerhoff et al., 2008), and (2) at the stand level, by considering appropriate management choices regarding composition, structure (e.g., age structure, vertical structure, spatial heterogeneity and trees species), rotation lengths and harvesting approaches (Kerr, 1999; Brockerhoff et al., 2008). Introducing species and age diversity throughout a forest can increase its resilience to pests, diseases and fire and expand the associated economic opportunities. Replanting can also offer the opportunity to establish woodland replacement that responds to new markets and is potentially more resilient to climate change and fire. Moreover, promoting diversity in forests is essential to preserving biodiversity and expanding habitats, as well as contributing to enhanced landscape quality and recreational opportunities (Grant et al., 2012).

One way of introducing age diversity into a homogeneous, unmanaged forest landscape is by regulating forest production. In that context, the area control method (Davis and Johnson, 1987) is one of the easiest approaches to ensure the progression of stand age classes. This approach requires that those areas in the oldest age class are harvested and regenerated each year, thereby becoming the areas in the youngest age class the following year. All other age classes are treated as a prescribed and annually increase one age class. The structure of the forest remains constant from year to year. The same number of hectares is cut each year, the same approximate harvest is produced each year, and harvest equals growth, which ensures the sustainability of the exploited resource (Davis and Johnson, 1987).

Currently, the Portuguese landscape is predominately occupied by forests (3,154,800 ha; 34%) and scrubland and pastures (2,853,228 ha; 32%). Only 24% of the country is currently maintained as agricultural areas (2,114,278 ha). Portuguese forests are chiefly composed of planted eucalyptus forests (*Eucalyptus globulus* Labill.; 811,943 ha; 26%) and maritime pine forests (*Pinus pinaster* Aiton; 714,445 ha; 23%) (ICNF, 2013). Portuguese forest stands are differentially prone to fire, with mature forests of broadleaved deciduous and mixed forests having a lower fire hazard compared to pure pine forests, eucalyptus plantations, or mixed pine and eucalyptus stands (Fernandes, 2009; Moreira et al., 2009; Silva et al., 2009; Fernandes et al., 2010). Accordingly, a more prominent role should be given to the expansion of deciduous broadleaved and mixed forests rather than pine stands or exotic species plantation forests in fire-prone landscapes. In addition, regarding afforestation policies, the creation of non-contiguous forest patches smaller than 30 ha is advisable (Fernandes et al., 2010; Moreira et al., 2011). In fact, the fragmentation of a fire-prone landscape with patches in different succession stages, the introduction of narrow corridors between wooded patches and the promotion of convoluted perimeters are effective measures to reduce the potential fire size (Moreira et al., 2011). Therefore, the definition of landscape-level management rules is important for promoting landscapes that are less fire prone where the species, stand variables (e.g., stand density and stand height) and topographic variables (e.g., slope and aspect) of contiguous patches can be used to predict fire spread and severity (Fernandes et al., 2010; Moreira et al., 2011).

Although Portugal has a significant legal framework regarding forest policies (FAO, 2013), which was developed in consideration of complexly related issues such as climate change, forest health, fire and forest multifunctionality, obtaining concrete results is a challenge that requires an integrated landscape planning approach (Tortora et al., 2015). This paper presents a GIS methodology for an integrated landscape planning approach supported by existing methods to promote landscape diversity enhancement, fire hazard mitigation and forest production regulation in homogeneous unmanaged forest landscapes prone to fire. In that context, a study area that is mainly occupied by maritime pine and has a high fire hazard, low tree species diversity and an extensive protection area was chosen. The objectives of the study were as follows: (1) to investigate land cover change trends from 1990 to 2007; (2) to produce a suitability map for 21 recommended species for afforestation in the study area; (3) to determine the appropriate management compartments using the area control method to regulate maritime pine forest areas over a 50-year rotation period (both to assist in the regulation of this forest and to identify the compartments associated with the protection area); (4) to compare the landscape structure (patch number and size by species), composition (area by species) and flammability (fire hazard prediction) in 2007 and 2064; and (5) to discuss the application of these planning methods in terms of Portuguese forest policy.

2. Materials and methods

2.1. Study area

The study area (3100 ha) is located in the centre of Portugal (Fig. 1a) and is primarily occupied by continuous areas of maritime pine forest. In 2003, this area was severely devastated by a wildfire (1516 ha; 49%; Fig. 1b). In 2007, the study area landscape was dominated by maritime pine forest (1817 ha; 59%; Fig. 1c), with mature stands in the south and young regenerated stands in the north. This study area has low species diversity, as 92% of the land cover is composed of maritime pine, eucalyptus and shrubs (Fig. 1c). Therefore, regarding both study area land cover and topography (based on a digital elevation model (DEM); Fig. 1d), it is not surprising that the vast majority of this area is classified as extreme to very extreme fire hazard (2868 ha; 95%; Fig. 1e) according to the official fire hazard map from 2011 (DGT, 2016). Furthermore, this area also comprises a vast protection area (1822 ha; 59%; Fig. 1f) (DR, 2015a) due to its topography and network of rivers and streams (Fig. 1g). Additionally, the mountain area to the west (Fig. 1d) is included in the Geopark of "Naturtejo da Meseta Meridional", which has been considered a UNESCO Global Geopark since 2006.