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Fragmentation patterns of evergreen oak woodlands in Southwestern Iberia: Identifying key spatial indicators

Augusta Costa [a,b,*], Manuel Madeira [c], José Lima Santos [c], Tobias Plieninger [d], Júlia Seixas [a]

[a] Center for Environmental and Sustainability Research (CENSE), Faculdade de Ciências e Tecnologia (DCEA), Universidade Nova de Lisboa, Campus de Caparica, 2829-516 Caparica, Portugal

[b] Instituto Nacional de Investigação Agrária e Veterinária, I.P., Quinta do Marquês, Av. da República, 2780-159 Oeiras, Portugal

[c] Centro de Estudos Florestais, Universidade de Lisboa, Instituto Superior de Agronomia, Tapada da Ajuda, 1349-017 Lisbon, Portugal

[d] Department of Geosciences and Natural Resource Management, University of Copenhagen, Rolighedsvej 23, 1958 Frederiksberg C, Denmark

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ABSTRACT

Mediterranean evergreen oak woodlands (composed of *Quercus suber* L. and *Quercus rotundifolia* Lam.) are becoming increasingly fragmented in the human-modified landscapes of Southwestern Portugal and Spain. Previous studies have largely neglected to assess the spatial changes of oak woodlands in relation to their surrounding landscape matrix, and to characterize and quantify woodland boundaries and edges. The present study aims to fill this gap by analyzing fragmentation patterns of oak woodlands over a 50-year period (1958–2007) in three landscapes. Using archived aerial imagery from 1958, 1995 and 2007, for two consecutive periods (1958–1995 and 1995–2007), we calculated a set of landscape metrics to compare woodland fragmentation over time. Our results indicated a continuous woodland fragmentation characterized by their edge dynamics. From 1958 to 2007, the replacement of open farmland by shrubland and by new afforestation areas in the oak woodland landscape surrounding matrix, led to the highest values for edge contrast length trends of 5.0 and 12.3, respectively. Linear discriminant analysis was performed to delineate fragmented woodland structures and identify metric variables that characterize woodland spatial configuration. The edge contrast length with open farmland showed a strong correlation with F1 (correlations ranging between 0.55 and 0.98) and may be used as a proxy for oak woodland mixedness in landscape matrix. The edge dynamics of oak woodlands may result in different patterns of oak recruitment and therefore, its study may be helpful in highlighting future baselines for the sustainable management of oak woodlands.

1. Introduction

Habitat reduction and fragmentation are major drivers of biodiversity loss (Cooper and Walters, 2002; Fahrig, 2003; Villard et al., 1999). Habitat fragmentation can result in a decrease of core area habitats, an increase of the number of habitat fragments (Fahrig, 2003; McGarigal and Cushman, 2002), decreasing habitat connectivity (Grashof-Bokdam et al., 2009) and increasing habitat edges. Such changes may drastically alter a range of ecological functions and ecosystem services at landscape level (Brooks et al., 2002; Bugalho et al., 2011).

Forest habitat fragmentation (and loss) is a consequence of land-use pressure and landscape management changes worldwide. It has been extensively studied in temperate forests, often in relation ecological processes (Cardille et al., 2012; Echeverria et al., 2006; Riiters et al., 2002), and in tropical forests (Dewit et al., 2013; Fahrig, 2003), where annual forest loss rates are extremely high – in some cases larger than 2% yr^{-1}, compared to a global forest net loss of 0.2% yr^{-1} (FAO, 2006). Fragmentation patterns and processes becomes particularly relevant for conservation science when applied to forest-fragment mosaics that are located within landscape matrices dominated by open areas, such as grasslands or shrublands (Teixido et al., 2010). Such landscape matrices may constitute barriers for many species that are not able to cross open areas and/or forest-fragment edges. Although many landscapes of the Mediterranean-climate regions fit this description, there is a

* Corresponding author. Center for Environmental and Sustainability Research (CENSE), Faculdade de Ciências e Tecnologia (DCEA), Universidade Nova de Lisboa, Campus de Caparica, 2829-516 Caparica, Portugal. Tel.: +351 21 4463740; fax: +351 21 4463701.

E-mail addresses: augusta.costa.sousa@gmail.com, augusta.costa@iniav.pt (A. Costa), mavmadeira@isa.ulisboa.pt (M. Madeira), jlsantos@isa.ulisboa.pt (J. Lima Santos), tobias.plieninger@ign.ku.dk (T. Plieninger), mjs@fct.unl.pt (J. Seixas).

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clear lack of data on rates of forest habitat fragmentation in these areas (Brooks et al., 2002).

Substantial losses of oak woodlands growing in the Mediterranean Basin (named *dehesas*, in Spain, and *montados*, in Portugal) have been reported, resulting from (cumulative) disturbances such as drought or climate change effects (Giorgi, 2006), wildfires (Acácio et al., 2009; Barbero et al., 1990; Catry et al., 2012; Costa et al., 2012; Underwood et al., 2009) and shrub encroachment (Costa et al., 2009, 2010; Plieninger, 2006; Plieninger and Schaar, 2008; Plieninger et al., 2011; Regato-Pajares et al., 2004; Urbieta, 2008). At the same time, oak woodlands in the Mediterranean Basin depend on human management for the persistence of their savannah-like physiognomy (Bugalho et al., 2011; Santos and Thorne, 2010). The management practices (e.g. livestock grazing, shrubland management, tree pruning, oak afforestations or cork harvesting) need to be changed to counteract tree loss and lack of natural regeneration (Plieninger et al., 2011; Ramírez and Díaz, 2008).

Fragmentation of the oak woodlands in the Mediterranean Basin may find expression not only in the isolation, connectivity, shape and size of their fragments (Ramírez and Díaz, 2008), but also in the type of edges and landscape matrices that surround nested woodland fragments (Cadenasso et al., 2003; Cayuela et al., 2006; Grossman and Mladenoff, 2007). Potentially negative fragmentation impacts have been reported on the occurrence of oak recruitment (Acácio et al., 2007; Brotons et al., 2004; Maltez-Mouro, 2007; Pons and Pausas, 2006; Reino et al., 2009; Urbieta et al., 2011) and on biodiversity loss (Martínez et al., 2010; Pereira and Fonseca, 2003). Yet, no study, so far, has quantified landscape changes in terms of oak woodland boundaries and edges dynamics with surrounding matrices or reported what roles these may play in inhibiting or enhancing the movement of organisms, such as oak seed dispersal agents or abiotic fluxes like moisture and light.

To deepen the understanding on oak woodlands fragmentation, an analysis of patterns and dynamics of oak woodland fragmentation was performed in three landscapes of Southwestern Iberia, where long-standing loss of evergreen oak woodlands loss has been reported (Costa et al., 2011). Considering the importance of spatial configuration for the description of landscape pattern changes (Remmel and Csillag, 2003) and characterizing forest fragmentation dynamics (Long et al., 2010), our goals have been to investigate the degree to which spatial configuration of oak woodlands changed between 1958, 1995 and 2007 and to assess the usefulness of edge indexes as surrogates for their fragmentation within the landscapes. We formulated the following three hypotheses: Firstly, oak woodland fragmentation occurs concomitantly with loss. Secondly, the development of such fragmentation patterns would differ strongly over time as oak woodland changes often occur in episodic pulses (Acácio et al., 2009; Plieninger, 2006). Finally, we assumed that woodland edge features would turn out to be key variables, rather than size or isolation, in addressing recent oak woodlands pattern changes. This information is needed for interpreting landscape consequences of policy measures such as the legal protection of oak woodlands (since the late 1980s, in Portugal) and afforestation schemes (since 1992 throughout the EU) (Costa et al., 2011; Plieninger and Schaar, 2008).

2. Material and methods

2.1. Study areas

Our three study areas of *montado* landscapes in Southern Portugal comprised the civil parishes of Ulme (UL), São Bartolomeu da Serra (SB) and Alcoutim (AL). They have a Mediterranean climate, in which rainfalls mostly occur from late autumn to early spring, but exhibit great annual irregularities. Closest to the Atlantic Ocean, the SB and UL sites show similar rainfall and temperature patterns; they contrast with AL, located in the inner Guadiana basin, which has a drier and hotter climate (Table 1).

Taken together, these three locations provide representative rates and scenarios of landscape change in Mediterranean oak woodland systems. The common element shared by each of the study areas is that the economic value of *montado* relies on relatively large farm sizes and low intensity farming systems (Moreno and Pulido, 2009). However, the areas differ drastically in the dynamics of their landscape matrix, i.e., the landscape surrounding the nested oak woodlands (Costa et al., 2011). AL experienced a strong abandonment of cereal cultivation in the gently undulating peneplain, where Haplic Leptosols (*sensu* WRB, 2006) are predominant. The arable land was transformed into shrubland and, more recently (since the late 1990s), into pine afforestation area. At UL, the tendency was to increase the eucalypt plantation on the less productive arable land, on the top of the Pliocenic terraces, and on Stagnic Luvisols (*sensu* WRB, 2006) and to intensify the rainfed cultivation in the more productive areas of the flat in valley bottoms, on Gleysols and Fluvisols (*sensu* WRB, 2006). The oak woodlands became therefore, restricted to the steeper areas in-between, mostly with Regosols and Cambisols (*sensu* WRB, 2006), and to the gullies that densely incise the Pliocenic terraces associated with a dendritic drainage pattern. At SB, the cereal cultivation has persisted on the flatter and richer land with Luvisols (*sensu*

Table 1
Biophysical characteristics of the Ulme, São Bartolomeu da Serra and Alcoutim study areas.

Study areas	Ulme	São Bartolomeu da Serra	Alcoutim
Location	39°23′N – 08°30′W	38°04′N – 08°40′W	37°31′N – 07°35′W
Oak woodland habitat	*Q. suber*	*Q. suber*	*Q. rotundifolia*
Area (ha)	12,179	6224	13,152
[a]Utilized Agricultural Area (ha)	22.2	70.2	11.2
[a]Livestock Units (#) [% sheep]	4492 [14.0]	15,791 [27.4]	1472 [93.0]
[b]Open farmland transition	Eucalypt plantation	–	Shrub encroachment, Pine plantation
[c]Mean annual temperature (°C)	15.9	16.0	16.5
[c]Annual rainfall (mm)	637	629	505
[c]Air humidity (%)	75–80	80–85	75–80
Litology	Sedimentary formations	Schist formations	Schist formations
Slope	Flat and steeply undulating	Steeply undulating (heterogeneous)	Steeply undulating (heterogeneous)
[d]Burnt area (ha), 1990-2008	8,108 (2001–2005)	11 (2003)	39 (1991); 1,728 (1996–2007)

[a] National Institute of Statistics (1999/20000) (*in* Costa et al., 2011).
[b] Costa et al. (2011).
[c] INAG (2010).
[d] Burnt Area Map of Portugal (1990–2008)(AFN, 2010).