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Cork oak woodlands patchiness: A signature of imminent deforestation?

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ABSTRACT

The cork oak (*Quercus suber* L.) woodlands of the agroforestry landscapes of Southwestern Iberia are undergoing drastic change due to severe natural and anthropogenic disturbances. These may eventually result in woodland loss or deforestation, the final step of an ongoing process of woodland degradation. Monitoring changes in the spatial patterns of woodlands – especially fractional canopy cover of woodlands and/or their patchiness in the landscape mosaic – potentially enables forecasting of loss and responding to it at an early stage. We examine the degradation process in two cork oak woodlands, resulting from distinct disturbances, wildfire and oak mortality, aimed at evaluating the changes, trends and deviations of the spatial attributes of these woodlands as they move from an initial (less disturbed ecosystem) to a final state (more disturbed ecosystem). While undergoing disturbances, both woodlands exhibited similar trends of decreasing fractional canopy cover and decreasing number of larger patches. Patchiness rather than fractional canopy cover seems, however, to be potentially more useful as a signature of imminent oak woodlands deforestation, given that its contrast before and after disturbance was much higher. The structural dynamics of oak woodlands is a crucial but neglected issue that needs greater attention from policy forums working toward their conservation and restoration as well as from stakeholders and society as a whole.

Introduction

Worldwide deforestation is driven by mixed natural and anthropogenic disturbances (Lambin et al., 2001). Over time, these disturbances re-shape the spatial configuration of forests (i.e., physical organization, complexity and mosaicing) and affect biotic diversity (Sala et al., 2000), climate change and vegetative carbon release to the atmosphere (Bonan, 2008; Dale et al., 2001).

Typically, in most studies on deforestation, the temporal dynamics of woodlands are assessed by applying a simple forest/non-forest classification to woodland landscape snapshots, though they often exhibit drastic variations in patch composition and structure (Grossmann & Mladenoff, 2007). However, deforestation, which denotes the definitive loss of trees, can also be interpreted as a continuous process of forest degradation, defined as tree thinning and damage to the forest canopy, which eventually end in forest loss. Yet this is a process that can be reversed, if addressed in a timely manner, as woodlands are expected to regenerate (Hosonuma et al., 2012).

The forest degradation process usually results in changes in forest spatial pattern attributes, especially woodland composition and structure, which do not immediately affect overall forest area and, consequently, remain undetected in simple land cover change assessments. Monitoring forest degradation processes can potentially help in detecting of changes and forecasting forest loss, which may enable adequate policy or management responses at an early stage (Wang, Qi, & Cochrane, 2005).

Evergreen oak woodlands are widely distributed within the Mediterranean climate-type regions (e.g. in California, Chile, Australia) and are among the most representative ecosystems in Southwestern Iberia, where they occupy about 4 million ha (Olea & San Miguel-Ayanz, 2006). Here, extensive woodlands comprised of

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Quercus suber L. (cork oak) and *Quercus ilex* ssp. *rotundifolia* Lam. (holm oak) are called *montados* in Portugal and *dehesas* in Spain. They are mainly found in oligotrophic soils. The prevailing land-use system in these areas is distinguished by a systematic combination of pastoral, agricultural, and forestry activities, with livestock raising being the dominant one that determines all other land uses. Uses are well adapted to the unpredictability of the Mediterranean climate. Oak stands are regularly cleared and thinned to densities of 10–50 trees ha^{-1} to enhance herb growth as well as to ensure maximum yields of cork and acorns. Traditionally, rotational plowing has been a common management strategy for grain cultivation and for the control of shrub encroachment.

These ecosystems have a long history of deforestation within intensive human-managed landscapes and have been shaped through time by natural disturbances and human activity (Costa, Madeira, Santos, & Plieninger, 2014). Nevertheless, it is only recently that several authors assessed the importance of disturbances in shaping woodland configuration over time in such landscapes and their consequences on ecosystem functions (Costa, Madeira, Santos, & Oliveira, 2011; Costa et al., 2014; Pinto-Correia & Mascarenhas, 1999; Plieninger, 2006; Plieninger & Schaar, 2008; Urbieta, Zavala, & Marañón, 2008), revealing many similarities to other scattered-tree savannah-type ecosystems in the world (Manning, Gibbons, & Lindenmayer, 2009). Despite their remarkable resilience, novel disturbances, sometimes acting recurrently, may surpass their ability to control important ecosystem processes, such as degradation, which eventually result in definitive change and woodland loss.

The loss of evergreen oak woodlands has been recently attributed to consistent management extensification (e.g. shrub encroachment) or intensification (e.g. livestock grazing) trends, under stressful climate conditions and "strong" soil degradation (Acácio, Holmgren, Jansen, & Schrotter, 2007; Brooker, Maestre, & Callaway, 2008; Costa, Madeira, Santos, Plieninger, & Seixas, 2014; Costa et al., 2011; Maestre, Valladares, & Reynolds, 2005; Pausas, Ribeiro, Dias, Pons, & Beseler, 2006; Plieninger, Rolo, & Moreno, 2010; Pons & Pausas, 2006; Torre & Díaz, 2004). Woodland loss also occurs abruptly, under disturbances such as oak mortality (Brasier, 1996; Costa, Pereira, & Madeira, 2009, 2010; Shifley, Fan, Kabrick, & Jensen, 2006; Wargo, 1996) or wildfire occurrence (Acácio, Holmgren, Rego, Moreira, & Mohren, 2009; Catry, Moreira, Cardillo, & Pausas, 2012; Costa, Madeira, & Santos, 2014).

In Southwestern Iberia, evergreen oak woodland loss seems hard to reverse and corresponds to a continuous process of woodland degradation. Based on observations from other sorts of vegetation in semi-arid regions, such degradation should become visible through a transition of both fractional canopy cover (Cano, Navarro, & Ferrer, 2003; Carreiras, Pereira, & Pereira, 2006; Costa, Madeira, & Oliveira, 2008, Costa et al., 2010; Plieninger & Schaar, 2008) and patchiness (patch size–frequency distribution) (Kéfi et al., 2007; Maestre & Escudero, 2009; Solé, 2007). Although canopy-cover persistence is already an important feature of woodland conservation, woodland patchiness should also be seen as far from being negligible for understanding factors affecting woodlands persistence. In fact, the concept of patchiness has been used in arid Mediterranean ecosystems, where fitted power functions (Xiao, White, Hooten, & Durham, 2011) describing the patch size–frequency relationship have been tested to predict the onset of desertification (Kéfi et al., 2007; Solé, 2007).

Given the socio-economic and ecological importance of Mediterranean evergreen oak woodlands, for timely prevention of deforestation it is important to understand how woodland degradation processes occur in response to disturbances. Monitoring changes in woodland fractional canopy cover and patch size–frequency distribution can be potentially useful tools for providing such knowledge in a cost-effective manner. However, so far no studies have compared the spatial pattern changes of oak woodlands to examine trends and deviations for initial and final ecosystem states, before and after disturbances.

The present study is therefore exploratory in nature and aims to fill this gap by analyzing the fractional canopy cover and patchiness trends of cork oak woodlands, considering distinct disturbances (wildfires and cork oak mortality, see Table 1) that may eventually result in deforestation (Costa, Madeira, Santos, Plieninger, & Seixas, 2014). We investigated the degree to which these oak woodland attributes have changed under disturbance effects by characterizing an initial state before disturbance (a less disturbed ecosystem) and a final state after disturbance (a more disturbed ecosystem) and then quantifying the deviations indicative of intrinsic ecological organization dynamics.

The study was carried out under the following three hypotheses: Firstly, we assumed that, as a result of disturbances, woodland fractional canopy cover would increase, indicating an increase of canopy gaps. Secondly, as another result of disturbances, transition in patch size–frequency distribution would occur, from a power-law function to a truncated-power-law function, indicating decrease of larger patches. Thirdly, based on the theory predicting that size–frequency distribution of spatial pattern of forests will follow a power-law distribution only if the ecosystem is not disturbed (Foster & Reiners, 1986; Marco, Montemurro, & Cannas, 2011), we assumed that, when a deviation is observed in these dynamics, the ecosystem is not at equilibrium. Therefore, based on these assumptions, we hypothesized that patchiness, rather than canopy cover, would turn out to be a more accurate signature of imminent transition toward deforestation in cork oak woodlands.

Our approach is aimed at contributing toward obtaining improved insights into the changing spatial patterns of cork woodlands. Knowledge on fractional canopy cover and patchiness is sorely needed to address landscape conservation and restoration issues (Fahir, 2003; Hill & Curran, 2001; Long, Nelson, & Wulder, 2010; Remmel & Csillag, 2003).

Material and methods

Study area

The study was conducted in two cork oak woodlands in Southern Portugal, located in the littoral region, one of the most

Table 1
Characteristics of the two study areas, Ulme (UL) and S. Bartolomeu da Serra (SB).

Study areas	Ulme (UL)	S. Bartolomeu da Serra (SB)
Location	39°23′N–08°30′W	38°04′N–08°40′W
Dominant oak species	*Q. suber*	*Q. suber*
Dominant woodland ecosystem	Dense forest	Dense forest
Oak woodland initial area (Total area) (ha)	4,489 (12,197)	4,929 (6,224)
Mean annual temperature (°C)	15.9	16.0
Annual rainfall (mm)	637	629
Average air humidity (%)	75–80	80–85
Aridity index (R/PET)	0.50–0.65	0.50–0.65
Lithology	Sedimentary formations	Schist formations
Altitude (m) a.s.l.	20–190	80–260
Slope	Flat and steeply undulating	Steeply undulating (heterogeneous)
Main disturbance	Wildfire occurrence	Oak mortality
Addressed disturbance period	1995–2007	1995–2007