Science of the Total Environment 610–611 (2018) 926–936

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

The effect of grazing exclusion over time on structure, biodiversity, and regeneration of high nature value farmland ecosystems in Europe

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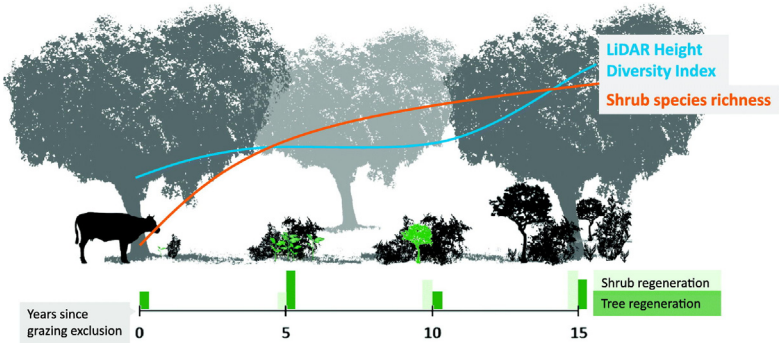
HIGHLIGHTS

- Grazing exclusion has direct impact of the *montado* forest structure.
- Structural and compositional diversity increase with post-exclusion time.
- 3-D spatial arrangement of structural elements represents forest dynamics.
- A structural diversity index is validated as a surrogate of ecosystem function.
- 5-Year exclusion enhances shrub diversity and regeneration and tree establishment.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 14 April 2017
Received in revised form 18 July 2017
Accepted 2 August 2017
Available online xxxx

Keywords:
Forest structure
Structural biodiversity index
LiDAR
Cork-oak forest
Montado
Recruitment

ABSTRACT

Climate change and increasing socio-economic pressure is placing many ecosystems of high ecological and economic value at risk. This is particularly urgent in dryland ecosystems, such as the *montado*, a multifunctional savannah-like system heavily modeled by grazing. There is still an ongoing debate about the trade-offs between livestock grazing and the potential for ecosystem regeneration. While it is consensual that overgrazing hinders the development of the shrubs and trees in this system, the effects of undergrazing or grazing exclusion are unclear. This study provides the unique opportunity to study the impact of grazing on compositional and structural biodiversity by examining the ecological chronosequence in a long-term ecological research site, located in Portugal, where grazing exclusion was controlled for over 15 years. As the threat of intensification persists, even in areas where climate shifts are evident, there is a critical need to understand if and how the *montado* might recover by removing grazing pressure. We evaluate succession on structural and compositional diversity after grazing pressure is removed from the landscape at 5, 10, and 15 years post-cattle exclusion and contrast it with currently grazed plots. A LiDAR-derived structural diversity index (LHDI), a surrogate of ecosystem structure and function first developed for the pine-grassland woodland systems, is used to quantify the impact of grazing exclusion on structure and natural regeneration. The distribution of the vegetation, particularly those of the herbaceous and shrub strata (>10 ≤ 150 cm), presents statistically significant changes. The LHDI closely mimics the compositional biodiversity of the shrubs, with an increase

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http://dx.doi.org/10.1016/j.scitotenv.2017.08.018

in diversity with increased years without grazing. Under present climate conditions, both shrub regeneration and the establishment of tree saplings were strongly promoted by grazing exclusion, which has important management implications for the long-term sustainability of *montado* systems.

1. Introduction

Climatic changes have increased environmental pressure on dryland ecosystems (Costa et al., 2011a), a particularly troubling fact for Mediterranean high biodiversity systems. By 1990, over 70% of the original extent of Mediterranean woodlands and scrublands has been converted to other land uses by longstanding human footprint (MEA, 2005). Although rural abandonment has allowed a gradual recovery of certain forested ecosystems, the evergreen oak forests of the Iberian Peninsula are consistently losing spatial coverage (Plieninger, 2006), consequently impacting their ability to provide ecosystem services and conserving biodiversity (Ferraz-de-Oliveira et al., 2016).

Montados (in Portugal) and *Dehesas* (in Spain) cover ca. 3.5 million ha (Pinto-Correia et al., 2011) and are multifunctional savannah type systems with highly variable evergreen canopy densities (*Quercus suber* or *Quercus ilex* spp. *rotundifolia*) and semi-natural grassland undercover (Sales-Baptista et al., 2016), currently dominated by grazing as a land-use (Bugalho et al., 2011a). The Montado is an agro-pastoral system that originated from natural forests following the removal of trees by human activities such as clearing, burning and grazing (Pulido et al., 2001). When the agricultural practices are removed or reduced, the succession leads to increases in woody plants (Castro and Freitas, 2009). Unlike other systems, the montado has been shaped by human activities for centuries (in fact close to a millennium or more in some areas) and is structurally kept as a savannah by human and not by natural factors. The succession of woody vegetation with decreasing land use intensity, including undergrazing, is well accepted for this particular ecosystem; common shrub control strategies such as shrub clearing and rotational ploughing are used to control woody succession (Pulido et al., 2001; Plieninger et al., 2003, 2004; Calvo et al., 2005), and even manmade fire (Godinho et al., 2016).

Managing the spatial patchiness, and multifunctionality of the traditional landscape (Tenhunen et al., 2009) of the montado is crucial to maintain the ecosystem services and associated socio-economic impact of the region (Concostrina-Zubiri et al., 2017). These ecosystems, critical for providing both high social value and biodiversity, are classified as High Nature Value (HNV) and their sustainable management is reliant on appropriate low intensity use (agricultural or animal stocking rates) and appropriate monitoring to ensure biodiversity levels (Beaufoy and Cooper, 2009). Even though the *montado's* high conservation value is protected by the European Union (Habitats Directive 92/43/EEC), these systems are facing significant threat from a shift from the traditional low intensity land use to either abandonment or intensification of land use (Sales-Baptista et al., 2016). Overgrazing is suspected to contribute to the long-term degradation of montados, reducing biodiversity and natural oak regeneration (Plieninger et al., 2010, Ribeiro et al., 2010; Bugalho et al., 2011a, 2011b, Concostrina-Zubiri et al., 2017). Land abandonment is also reported to have a strong effect on the vegetation composition with decreases in species diversity with decreasing land use intensity as a direct consequence of the replacement of short-lived herbaceous species with the dominant shrub *Cystus ladanifer* (Castro et al., 2010). As the land degradation of these systems accelerates, as evidenced by tree decline symptoms since the 1980s (Costa et al., 2011a) these economically vital ecosystems might cease to function (Doughill et al., 2010).

Grazing ecosystems evolved with and depend upon herbivory, heavy hoof action, nitrogen deposits, and decomposing carcasses of large migratory herbivorous. When introduced into ecosystems that did not evolve with frequent grazing, these forces can alter biological communities and ecosystem function. In human-controlled grazing systems, such as the *montado*, the detrimental or beneficial effects of grazing are largely determined by how and where grazing is used. The ecological impacts of grazing depend on the type of ecosystem, plant community, and conditions of a particular site. One of the ecological impacts of grazing is overgrazing, which is widely known to have an effect on composition and structure of plant communities and of biological soil crusts (Concostrina-Zubiri et al., 2017), by reducing biomass, soil nutrient enrichment and overall regeneration (Yan and Lu, 2015; Zhou et al., 2005).

Grazing exclusion is actively being used as a management strategy to prevent ecosystem degradation, promote high function, or even for restoration of degraded areas (Mata-González et al., 2007, Mofidi et al., 2013, Wei et al., 2012). For *montados*, both the overuse, in fertile areas, and abandonment of grazing, in less fertile and peripheral areas, pose a significant threat of ecosystem degradation (Pinto-Correia and Godinho, 2013; Bugalho et al., 2011b). Even though grazing exclusion is widely used for managing certain ecosystems, the impact of this land management strategy on plant structure, biomass, and biodiversity in the *montados* is still unclear. For some degraded grassland ecosystems, grazing exclusion appears to improve herbaceous cover, biomass and biodiversity including biological soil crusts (Mata-González et al., 2007, Modifi et al. 2013; Concostrina-Zubiri et al., 2017); other studies found no significant change in biodiversity with grazing exclusion (Yan and Lu, 2015) or even a decrease in species richness and biodiversity with exclusion (Bugalho et al., 2011b, Mayer et al., 2009, Shi et al., 2013). Many of these studies have focused on short-term exclusion (><6–8 years) and ecological processes that led to functional and biodiversity changes are longer term. Our study focuses on the progression from grazing to longer term grazing exclusion (from 0 to 15 years), focusing on the impact to the forest structure, biodiversity and regeneration.

Even though grazing is well accepted as a major ecological driver of the *montado* ecosystem, there is still a critical shortage of information on how to use grazing as a tool to promote biodiversity (Bugalho et al., 2011a; Azeda et al., 2014). Even more surprising is the lack of information on the regeneration of the tree stratum, particularly the cork oak, and the dynamics of its succession stages (Pausas et al., 2009) in the *montado* ecosystems. Most of the *montados* present an even-sized class distribution (Pausas et al., 2009) with few, if any, young trees. Lack of tree regeneration indicates that these ecosystems with high biodiversity potential are not currently being managed with sustainability in mind. Exclusion from grazing, particularly short-term (2–5 years) has been suggested as a land management technique in the *montado* ecosystem to allow tree regeneration (Bugalho et al., 2011a; Ramírez and Díaz, 2008), but this needs further testing in different situations for different components of the ecosystem.

There are other important consequences of removing grazing pressure in the montado ecosystem that must be managed as well. Removal of grazing pressure yields an increase in total above-ground biomass and net primary productivity, increasing the overall carbon storage of the system while making the system more likely to burn at higher intensity (Castro and Freitas, 2009). While cork oak is a pyrophyte, intensive wildfires can