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Establishment of oak seedlings in historically disturbed sites: Regeneration success as a function of stand structure and soil characteristics

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ABSTRACT

The establishment and development of oak (*Quercus* spp.) seedlings are frequently impaired by site heterogeneity resulting from historical anthropogenic disturbances in Mediterranean basin woodlands. In particular, the alteration of forest structure and soil biotic and abiotic components can compromise the natural regeneration of Persian oak (*Quercus brantii* Lindl.) in western Iran. This study aimed to investigate how soil properties, soil mesofauna diversity and stand structural indices differ between well and poorly regenerated areas. We sampled 105 plots in an oak woodland subjected to past disturbances but protected from human activities for the last 20 years. These 100-m^2 plots were distributed into two groups: i) poorly regenerated plots (PRP) with only 0 or 1 newly established oak seedling, and ii) well regenerated plots (WRP) with $\geq$3 seedlings. In each plot, we characterized the forest structure using three structural indices, and determined the soil properties and mesofauna diversity. Structural indices were higher in WRP than in PRP for height (0.83 and 0.23), diameter differentiation (0.74 and 0.36) and species mixture (0.90 and 0.21). Also, richness and diversity of soil mesofauna were lower in PRP than in WRP.A canonical correspondence analysis (CCA) ordination clearly separated WRP, which were characterized by a clumped spatial distribution of mature oak trees on fertile soils, from PRP that exhibited a uniform spatial distribution of trees established on soils with a higher sand content (63 and 59%) and a higher bulk density (1.7 and 1.3).The uniform spatial distribution of trees, which was less favourable to oak seedling establishment, was inherited from intensive past human disturbances. To favour oak regeneration, we recommend applying management actions in cooperation with land-users, in particular the conservation of small patches of tree clumps to act as islands of fertility and seed sources.

1. Introduction

One of the most important aspects of sustainable management and forest conservation is the assessment of natural regeneration status (Gould, 2005).This is particularly important for oak (*Quercus* spp.) woodlands of the Mediterranean basin (Schaich et al., 2015) because the establishment and development of tree seedlings are frequently impaired by various human disturbances and dry seasonal conditions, which promote changes in forest stand structure (Cierjacks and Hensen, 2004; Montserrat et al., 2009; González-Moreno et al., 2011). Oak species are especially sensitive to such disturbances which can thus jeopardize the continuity of oak woodlands over the long term (Plieninger et al., 2004; Dufour-Dror, 2007).

Although the lack of seeds can limit oak regeneration establishment, post-dispersal factors such as the availability and quality of microsites, microclimatic conditions and soil properties are important ecological filters controlling seedling emergence, growth and survival (Mendoza et al., 2009). In many Mediterranean ecosystems such as the semi-arid oak forests of the Zagros Mountains in western Iran, these factors are associated with site heterogeneity

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resulting from natural and historical disturbances (Heydari et al., 2013). A part ofthese disturbances was ccaused by windthrows but most of them were related to overgrazing and overexploitation of the forest to meet fuelwood demands or to convert forest to agriculture (Heydari et al., 2017). Such disturbancescan induce changes in the main canopy structure which, in turn, can affect various soil characteristics (Marchi et al., 2016; Košulič et al., 2016) and ultimately oak seedling recruitment (e.g. Acácio et al., 2007).

While coppicing frequently results from the imposition of natural disturbance, such as windthrows (Ghazanfari et al., 2004) or, more usually, originates from anthropogenic disturbance that may be incurred by traditional management practices (Salehi et al., 2010; Khosravi et al., 2016). Indeed, trees are frequently cut during land use conversion to agriculture and animal pastures, and for meeting fuelwood demands (Moreno et al., 2007; Salehi et al., 2010). In recent decades, grazing has been controlled by excluding livestock from most afforested areas. The coppice form of these forests alters the primary regeneration pathway, thereby reducing the opportunities for regeneration establishment by seed (Pourreza et al., 2014).

Considering the negative impact of anthropogenic disturbances on oak regeneration, forest conservation seems appealing to promote the maintenance of oak woodlands. For instance, long-term forest protection after site degradation can improve some soil properties (Heydari et al., 2013) and promote forest vegetation development compared to adjacent unprotected sites. However, these favourable conditions are not spatially distributed evenly throughout protected sites. In fact, structural heterogeneity arising from previous disturbances that occurred before the beginning of an extended period of protection (Maestre et al., 2003; Pons and Pausas, 2006; Plieninger et al., 2011) also exerts direct and indirect effects on seedling establishment (Kwit and Platt, 2003).

Stand structure refers to internal relations of living trees in a stand (Chen and Popadiouk, 2002) and their characteristics of stands, such as tree spatial patterns, are essential for understanding forest dynamics (Wang et al., 2010).For example, stand structure can be useful to assess the effects of disturbances and management activities on regeneration (Siitonen et al., 2000) and successional (Ozcelik 2009; Lalfakawma et al., 2009) processes. Therefore, it can be helpful for planning and implementing ecosystem conservation and recruitment strategies (Sapkota et al., 2009; Pastorella and Paletto, 2013). In fact, the structure of the canopy and subcanopy vegetationcan modify the biotic and abiotic conditions of both the belowground and aboveground environments of seedlings (Danner and Knapp 2001; Platt et al., 2004; Dickie et al., 2007). This includes soil nutrients, soil moisture, understory light availability (Valladares and Guzmán, 2006) and microclimatic conditions (Cuesta et al., 2010; Pérez-Ramos et al., 2010; Muhamed et al., 2013; Gavinet et al., 2016). For example, Dijkstra et al. (2005) observed that soil patches covered by trees have higher soil N availability than soils covered by grasses in a frequently burned oak savanna. In addition, Hille Ris Lambers and Clark (2003) showed that seedling establishment and survival are controlled by microsite availability, which depends on stand spatial heterogeneity and neighboring interactions.

Soil faunal community is an important component of soil ecosystems and plays an essential role in litter decomposition, nutrient release and energy flow (Meyer et al., 2011; Tan et al., 2013). Faunal diversity and composition can be significantly affected by forest structures as a result of natural disturbances (Blasi et al., 2013) and past management actions (Vanbergen et al., 2007; Košulič et al., 2016). For example, stand composition (e.g. pure vs mixed stands) or ageing (young vs mature stands) can alter the soil food web and, consequently, the soil fauna (Scheu et al., 2003). In turn, the contribution of soil fauna to litter decomposition varied depending on the carbon to nitrogen (C/N) ratio of the litter, the degree of stand mixture and the ambient temperature (Blair et al., 1990; Yang and Chen, 2009; Li et al., 2015). Li et al. (2015) showed that low temperatures during winter can limit the activities of some fauna groups more than others (Li et al., 2015). For instance, air temperature regulated by the forest structure can affect spider activities (Pearce et al., 1994) while a thick layer of litter can buffer this effect through a control of microclimate and prey abundance (Bultman and Uetz, 1982). Overall, stand structure can modify many soil properties that affect the abundance and composition of terricolous organisms which, in turn, can have a positive impact on soil productivity (Sánchez-de León and Zou, 2004) and, by extension, seedling establishment.

Our knowledge on the relationships between forest structure and soil physical and chemical properties, mesofauna diversity, and abundance of naturally established seedlings is still limited. This is particularly the case for Persian oak (*Quercus brantii* Lindl.) whose regeneration is compromised by natural and anthropogenic disturbances in western Iran (Salehi et al., 2013). To fill this gap, we have investigated how soil properties, soil mesofauna diversity and stand structural indices differ between well and poorly regenerated areas located in similar site conditions. The results of this study can be useful to characterize environmental conditions associated with well and poorly regenerated areas and to implement supplementaryrecruitment measures besides natural regeneration such as artificial seeding.

2. Materials and methods

2.1. Study area

This study was conducted in a protected area of the Zagros woodlands in western Iran (Fig. 1). The dominant tree species of these woodlands is Persian oak (*Quercus brantii* Lindl.) with coppice-with-standard form. Other tree and shrub species present in the study area are *Cerasus microcarpa*, *Crataegus pontica* and *Daphne mucronata*. The study area is relatively uniform in terms of physiographic conditions with an elevation ranging from 1100 to 1350 m above sea level and is characterized by a generally flat topography. Based on the classification system of de Martonne (1925), the climate of this region is Mediterranean with an average annual precipitation of 590 mm based on 20-year records. The average annual temperature is 17 °C with minimum and maximum monthly temperatures averaging 4.6 °C (January) and 29.9 °C (August), respectively. Mollisols (Soil Survey Staff, 2014), which are calcareous soils with a clay loamy texture, dominate the soils of the study area.

This area was previously covered by dense and high quality oak woodlands. However, the forests of this area has undergone significant natural and anthropogenic disturbances (fires, mother tree felling and lopping for firewood, farming and recreation) and was also used as shelter during the Iran-Iraq war. For the past 20 years, the area has been protected from human disturbances by closing access roads which were frequently controlled by forest rangers.

2.2. Experimental design

In autumn 2013, we initiated preliminary fieldwork in an area of 542 ha, which consisted in geo-referencing 105 points around which several acorns were present on the forest floor. The minimum distance between two adjacent points was about 145 m. At each point, we established one 1-m^2 plot within which we counted the number of acorns. The number of acorns ranged from 3 to 8, and 77 of these plots (73%) had 4 or 5 acorns. In late summer of 2014, we extended the plots to 100 m^2 to investigate the number of newly established seed-origin oak seedlings. After counting the seedlings,