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What to save, the host or the pest? The spatial distribution of xylophage insects within the Mediterranean oak woodlands of Southwestern Spain

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ABSTRACT

The Mediterranean oak forests are currently in severe decline. Although the oak decline has been mainly related to *Phytophthora* sp. and extreme climatic conditions, there are other biotic factors - such as the beetle *Cerambyx "complex"* - which are also implicated. The future climate change scenarios might aggravate this situation but also might enhance the dispersal and establishment of new beetle populations. We used the Andalusian forest health monitoring network (SEDA Network) to assess the current distribution of the beetles, using the Kernel Density Estimation approach, and the current and future distributions using ensemble Species Distribution Models. Model predictions revealed that dasometric (normal diameter and frequency of oak trees) and climatic (number of days with mean temperature above 30 °C) variables were important to estimate the distribution of the *Cerambyx "complex"*.

The model performance was analyzed by K, TSS, and AUC, which gave accurate (K > 0.56; TSS > 0.59 & AUC > 0.87) to very accurate (K > 0.63; TSS > 0.64 & AUC > 0.89) results for the models developed only with dasometric variables and with the combination of climatic and dasometric variables, respectively. We found four main regions where the xylophage beetles occur in Andalusia and a larger area which satisfies the environmental requirements of these beetles. The current potential habitat suitability of the xylophage beetles might increase under future climate scenarios, which might enhance the dispersal, colonization, and establishment of new populations of xylophage beetles in Andalusia.

1. Introduction

The broad-leaf evergreens Holm oak (*Quercus ilex* L.) and Cork oak (*Quercus suber* L.), and - to a lesser extent - the semi-deciduous Portuguese oak (*Quercus faginea* Lam.) are widely distributed within the Mediterranean Basin and are the main tree species in the southwest of the Iberian Peninsula (Costa et al., 1998). They are usually found in a savannah-type ecosystem known as "Dehesas" or "Montados", Mediterranean oak woodlands hereinafter (Campos et al., 2013). The Mediterranean oak woodlands are complex, man-made ecosystems characterized by an open, heterogeneous tree canopy cover with shrub or annual herbaceous understories, with an historical combination of land uses involving several forms of pastoral, agricultural, and forestry activities (Acacio et al., 2016). The varied land uses of the Mediterranean oak woodlands together with multiple land ownership - e.g. private, corporate, cooperative, and public ownership - have left these woodlands as a very diverse ecosystem (Esselink and Vangils, 1994; Bugalho et al., 2011). The Mediterranean oak woodlands are highly protected ecosystems, rich in endemic species, and are included in the Red Natura 2000. Moreover, they also contribute to the economy of the region - with valuable products such as cork, acorns, livestock, and wildlife - and provide ecosystem services like carbon sinks, ecotourism, and prevention of soil erosion and desertification (Campos et al., 2013).

However, the Mediterranean oak woodlands are currently endangered due to low regeneration and the "oak decline" (de Sampaio e Paiva Camilo-Alves et al., 2013; Sallé et al., 2014). The low regeneration is linked not only to the inherent difficulty faced by *Quercus* sp. with regard to their regeneration from seedlings in the Mediterranean climate (Leiva and Vera, 2015) on nutrient depleted soils (Esselink and Vangils, 1994), but also, and most importantly, to high acorn predation (e.g. pig pastoralism), seedling browsing, trampling by ungulates (e.g. by cattle and livestock), and elevated early seedling mortality due to severe summer drought (Campos et al., 2013; Leiva and Vera, 2015). The oak decline can be defined as a complex syndrome, caused by the multiple interactions of different biotic and abiotic factors, which weakens the tree and causes a severe decline and, occasionally,

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death (de Sampaio e Paiva Camilo-Alves et al., 2013). The impact of this decline in Mediterranean oak woodlands has been observed as a reduction of the fractional canopy cover and the appearance of patchiness (measured as the patch size-frequency distribution). Although oak decline has been mainly related to *Phytophthora* sp. (Moreno et al., 2009) and extreme climatic conditions (severe drought, prolonged flooding, rapid fluctuation of soil water levels, and cold winters; Lindner et al., 2014), other biotic factors - such as xylophage insects - are also involved and are considered as secondary pests (Sallé et al., 2014), but have received less attention (but see López-Pantoja et al., 2011, 2016; Torres-Vila et al., 2016).

These xylophage insects are those included in the beetle *Cerambyx "complex"* (Coleoptera, Cerambycidae; López-Pantoja et al., 2011; Vitali and Schmitt, 2016), which feed, during some part of their life cycle, on fresh, dead, dying, or physiologically decaying oak trees. The female beetles lay eggs in the bark cracks, often through wounds caused by inappropriate management - such as thinning of large branches, incorrect cork extraction, or rotational plowing (Tiberi et al., 2016). The larvae feed on the tree wood for 3–5 years, creating galleries. The colonized trees can be identified by their dead wood structures, the typical oval exit holes on the trunk or thick branches, and the wood meal on the fresh exit holes (Sallé et al., 2014; Tiberi et al., 2016). The damage caused by the larvae of xylophage insects weakens the trunk and branches of the tree, which are easily broken by the effect of wind, heavy rain, or their own weight (López-Pantoja et al., 2011). Moreover, xylophage insects can play an important role as vectors for fungi and other pathogens (Sallé et al., 2014; Tiberi et al., 2016), which may convert these species into a serious pest (Ramírez-Hernández et al., 2014). These species can be found in Europe, mostly in the Mediterranean countries and warm regions of central Europe, and in the Middle East. Oaks, especially *Q. ilex*, *Q. robur*, and *Q. suber*, host the richest fauna of xylophage insects in Europe, but these insects can also develop in carob trees, willows, and poplars (Sallé et al., 2014; Lieutier and Paine, 2016). Their habitat preference fits the structural features of Mediterranean oak woodlands, such as low tree density and sun exposure, since xylophage beetles preferentially breed in sun-exposed wood located in the woodland understorey (Vodka et al., 2009).

The *Cerambyx "complex"* involved in the decay of Mediterranean oak woodlands mainly comprises *Cerambyx welensii* Kuster, *Cerambyx cerdo* L., and *Prinobius myardi* Mulsant (López-Pantoja et al., 2011; Tiberi et al., 2016). These three xylophage insects receive different levels of protection. *Cerambyx cerdo* is protected by the Habitats Directive, with the goal of maintaining existing populations and establishing its long-term survival (Navarro Cerrillo et al., 2004). On the other hand, *C. welensii* and *P. myardi*, the most common drilling insects in the southwest of Spain, are not protected and very little is known about their distribution, biology, and behavior (López-Pantoja et al., 2008, 2011, 2016). Thus, the conservation of the beetle *Cerambyx "complex"* within Mediterranean oak woodlands is linked to the conservation of its habitat; therefore, we are facing the dilemma of whether to safeguard the host or the pest.

In addition, climate change scenarios for Andalusia forecast an increase in drought frequency, duration, and intensity, which might decrease the distribution areas suitable for oak forest (Lindner et al., 2014; Acacio et al., 2016) and enhance the performance of oak-related pests (Sallé et al., 2014; Lieutier and Paine, 2016). The habitat of these insects might be reduced but climate change might improve their performance, converting the xylophage insects into important pests within Mediterranean oak woodlands (Sallé et al., 2014; Lieutier and Paine, 2016; Tiberi et al., 2016). Forest damage, such as that caused by the beetles of the *Cerambyx "complex"*, has been monitored in Europe since the early 1980s (Michel et al., 2014). In Andalusia, the forest health has been monitored by the forest health monitoring network (hereinafter, SEDA Network) since 2001 (Junta de Andalucía, 2016). The SEDA Network was established with the aim of assessing the phytosanitary status of the Andalusian forests across time (Ferretti et al., 2010). The network is distributed over 8 × 8 km grids and is evaluated annually according to the European forest health monitoring schemes. The analysis of its data provides relevant information to study processes of increasing complexity such as oak decline (Fernández-Cancio et al., 2012).

The data distribution of the SEDA Network is a powerful tool to study the spatial distributions of, and the spatial relationship between, forest health and the abiotic and biotic factors involved in forest decay; that is, the relationship between the host (*Quercus* sp.) and the pest (the beetle *Cerambyx "complex"* sp.) under both the current climate and climate change scenarios. The spatial relationship between species occurrence and climate data can be studied using Species Distribution Models (SDMs). The SDMs find statistical relationships between gridded environmental data and the occurrence records of the target species, and extrapolate the predictions to assess the future distribution of the species under climate change scenarios (Prasad et al., 2013). The possibility of forecasting the potential habitat suitability of the species makes SDMs a relevant tool for biodiversity conservation and management (van Gils et al., 2008, 2012, 2014). Moreover, the dispersal of the habitat suitability of xylophage insects through time can be assessed by distant methods for point pattern analysis (Liebhold et al., 2013).

The aim of this study was to investigate which drivers influence the spatial distribution of the xylophage insects within Mediterranean oak woodlands at the landscape level. We hypothesized that the probability of occurrence of xylophage insects within Mediterranean oak woodlands would vary with the stand characteristics (i.e. dasometric variables such as the tree fraction of the canopy cover or the tree to tree distance), but also would be determined by climatic factors, such as temperature and precipitation. The main objective was divided into three specific objectives: (i) to define/describe the current spatial distribution of the xylophage insects in Andalusia, using Kernel Density Estimation (KDE), (ii) to assess the potential current and future spatial distribution of the xylophage insects, using SDM techniques, and (iii) to identify the areas which have the potential to host the xylophage insects, according to both dasometric and climatic variables. With the help of Geographical Information Systems and our own results concerning the environmental requirements of the xylophage insects, we intended to highlight the areas on which conservations plans should focus and stress the actions that should be taken in relation to the future colonization areas of xylophage insects, in order to conserve the endangered Mediterranean oak woodlands.

2. Material and methods

2.1. Study area

Andalusia is a characteristic region of the Mediterranean Basin with an area of 87,268 km^2, located in the South of the Iberian Peninsula, between 36° and 40° N latitude. Its climate is typically Mediterranean, with hot and dry summers and precipitation concentrated in the spring and fall. Mediterranean oak woodlands dominate this region, covering 1.4 million hectares, 51.5% of the total area. Holm oak (*Quercus ilex* L.) is distributed throughout Andalusia, but is less common in the more arid eastern zone. Cork oak (*Quercus suber* L.) occupies sites of lower elevation (<800 m.a.s.l) in the western oceanic edge, over acidic soils or sandy substrates, while Portuguese oak (*Quercus faginea* Lam.) has a minor distribution in Andalusia; it occurs below 1500 m.a.s.l. over moderate