Public LiDAR data are an important tool for the detection of saproxylic insect hotspots in Mediterranean forests and their connectivity

Patrik Rada a, Ascensión Padilla b,c, Jakub Horák a,d, Estefanía Micó b,*

a Faculty of Science, University of Hradec Králové, 500 03 Hradec Králové, Czech Republic
b Instituto de Investigación CIBIO (Centro Iberoamericano de la Biodiversidad), Universidad de Alicante, 03690 San Vicente del Raspeig, Alicante, Spain
c Instituto Interuniversitario de Geografía, Universidad de Alicante, 03690 San Vicente del Raspeig, Alicante, Spain University of Alicante
d Faculty of Forestry and Wood Sciences, Czech University of Life Sciences in Prague, 165 21 Prague, Czech Republic

A R T I C L E   I N F O

Keywords:
Habitat suitability
Old growth forest
Threatened species
Remote sensing
Mediterranean forest
Dehesa

A B S T R A C T

Light Detection and Ranging (LiDAR) is a remote sensing technique with multiple uses throughout scientific fields. It can also be used to transfer point data measured in the field to broader spatial scales, which might enable the evaluation of habitats over large areas and define biodiversity hotspots. Our study took place in Cabañeros National Park, which is situated in the Mediterranean, namely, central Spain, and its vegetation is dominated by forest and impenetrable scrubland. LiDAR was used to detect veteran trees as key elements for a highly diverse saproxylic community. The saproxylic beetle community inhabiting tree hollows was studied among different forest types and habitats to determine its preferences. We identified potential hotspots for the saproxylic beetle community of tree hollows both inside and outside of the park, as well as the connectivity of suitable habitat patches. This was based on the species response to the spatial partitioning of the landscape. We found that not all potentially suitable forest types hosted the same saproxylic diversity or similar species compositions. In addition, forest distribution and connectivity inside and outside of the park also varied highly among forest types and habitats, where the most diverse deciduous oak forest was also the least connected together with the riparian forest. The evergreen oak forest could act as a habitat linkage for most of the threatened and less mobile species in the park. However, the low connectivity of the most diverse forest types in the park surroundings can compromise the persistence of saproxylic diversity in the near future. We concluded that LiDAR data were an effective tool for estimating saproxylic beetle diversity distribution over large-scale areas in the context of landscapes with low accessibility. Additionally, this tool allowed us to identify the most threatened forest types and critical patches for connectivity persistence where management practices capable of accelerating tree veteranisation could help to increase adequate forest connectivity in the region.

1. Introduction

Satellite images, airborne scanning or field measurements are widely used techniques to acquire data about natural habitats (Hinsley et al., 2002; Varela et al., 2008; Coops et al., 2016). Currently, there are multiple data sources where it is possible to obtain data with low or moderate resolution for large-scale analysis (Raimond, 2015). Nevertheless, precise publicly available data with high resolution are still scarce (Sánchez, 2018). Recently, some European countries made some of their data accessible (Instituto Geográfico Nacional, 2009; National land survey of Finland, 2022). One of the data sources with high potential is Light Detection And Ranging (LiDAR): a remote sensing technique with multiple uses throughout scientific fields (Dassot et al., 2011; Jaboyedoff et al., 2012; Guan et al., 2016). One of the possible uses is for habitat modelling (Hyde et al., 2005; Zellweger et al., 2014). However, the number of applications in habitat modelling is still relatively low (Vierling et al., 2008; Hagar et al., 2020).

The main advantage of LiDAR is that it allows the sampling of habitat characteristics at a large spatial scale (Hyde et al., 2005; Zamora-Martínez, 2017). The maximum tree height derived from the canopy height model provides information about tall and usually old growth trees, which are surrogates of habitat continuity (Ohlson et al., 1997). Additionally, the LiDAR technique provides a means for estimating plant species richness or composition to an appropriate extent (Hyde et al.,...
2005; Müller and Brandl, 2009). In addition, remote sensing techniques can provide valuable tools for the transfer of field-measured point data to broader spatial scales (Müller and Brandl, 2009, Zellweger et al., 2014). This may enable the evaluation of habitats over large areas and define diversity hotspots (Zellweger et al., 2014; Zamora-Martínez, 2017). This is especially important in the context of landscapes with low accessibility due to impenetrable vegetation cover where field measurement is complicated (Müller and Brandl, 2009) and which is common in the Mediterranean area (Gutiérrez-Marco et al., 2011).

Mediterranean forest vegetation is very diverse (Quézel et al., 1999; Mazzoleni et al., 2004). Typical examples are sclerophyllous forests dominated in the western Mediterranean by Quercus ilex Linnaeus, 1753 and Quercus suber Linnaeus, 1753 (Barbero et al., 1992; Reille and Pons, 1992; Mazzoleni et al., 2004). Nevertheless, Mediterranean broadleaved forests present a high degree of variability (Mazzoleni et al., 2004). This has been due to survival during glacial periods on the one hand and to the long-lasting management of forests with the diffusion of other tree species on the other hand (Scarascia-Mugnozza et al., 2000). LiDAR applications in the Mediterranean basin showed the ability to estimate vertical vegetation structure and community type (Morsdorf et al., 2010; Simonson et al., 2012; Lopatin et al., 2014). Forest plant species diversity has also been successfully estimated (Simonson et al., 2012), but applications for the estimation of animal species richness are rather scarce (Torre et al., 2022). However, an appropriate link between tree species diversity, tree-forest structure and animal forest diversity would allow the use of LiDAR to predict animal diversity distribution in a region.

In this way, old growth trees are key elements for forest diversity; they provide resources and refuge for a highly diverse saproxylic community – those depending, either directly or indirectly, on dying or dead wood (Ulyshen, 2018) – that include fungi, vertebrates and invertebrates, mostly represented by insects (Speight, 1989). LiDAR application can therefore help to identify different potentially suitable forest habitats for saproxylic communities as well as to estimate their vulnerability based on the distribution and connectivity of the different forest types and habitats.

One target group to test this tool is saproxylic beetles. Not only do they make up approximately one-third of the world’s insect diversity (Ulyshen and Sobotnik, 2018), but they are also easy to sample using certain types of traps that allow an association between them and the forest types and microhabitats they use. Among the saproxylic beetles, we selected tree hollow assemblages for the following reasons: (i) tree hollows are a key microhabitat in the Mediterranean region that hosts a rich and functionally diverse saproxylic community, (ii) the presence of tree hollows is associated with LiDAR-detectable veteran trees and is also favoured by tree management, and (iii) they can be surveyed with emergence traps, an absolute and quantitative method highly effective for monitoring beetle diversity (Quinto et al., 2013). In addition, we selected a protected area that represented the Mediterranean landscape as a mosaic with habitat patches that are different in size, spatial configuration and structure (Mico et al., 2013).

Within this framework, we used a LiDAR application to identify different potential suitable forest types (riparian, deciduous and evergreen oak forests) and habitats (forest and dehesa1) in the Cabaneros National Park (Spain) and to estimate their extension and connectivity.

Our aims were to (i) identify old growth forests as potential hotspots for saproxylic beetle species, (ii) assess the saproxylic beetle preferences for forest type and habitat, with special emphasis on the threatened species, (iii) calculate the optimal spatial scale for saproxylic beetles in the national park and the connectivity of suitable habitat patches, and (iv) identify potentially suitable habitats in the surroundings of the national park.

---

1 Savannah-like open woodland with scattered old trees, result of former traditional agrosilvopastoral practices.

We hypothesized that the results would be able to predict biodiversity hotspots within the national park as well as beyond its border. We also hoped that connectivity analyses would be able to reveal those patches of forests critical to maintaining continuity between each forest type for conservation purposes.

2. Methods

2.1. Study site

This study took place in Cabaneros National Park (henceforth Cabaneros NP), which is situated in central Spain within the orographic system of Montes de Toledo. Altitude in the park varied between 560 and 1448 m. a. s. l. The territory is rugged (i.e., with diversified topography), especially in the northern half, where narrow and steep valleys predominate. In contrast, the southern sector is more open with Plio-Quaternary sediments, known as “raina” (Gutiérrez-Marco et al., 2015).

The climate is moderate Mediterranean with rainfall between 500 and 700 mm and an average temperature of approximately 14 °C. Precipitation peaks in the spring and autumn, with more than 650 mm per year compared to water stress in summer. Winters have frequent frosts and occasional snowing. The vegetation is defined as Mediterranean forest and scrubland adapted to the lithological, geomorphological and, fundamentally, climatic conditions. It is dominated by Luso-Extremena holm oak groves, characterized by holm oak (Quercus ilex subsp. ballota). In the shady valley areas, there is an abundance of gall oak (Quercus faginea Lamarck, 1785), and in siliceous lithology, there is cork oak (Quercus suber). Around the rivers and streams, most of which are temporary, there are riparian forests made up of ash trees (Fraxinus angustifolia Vahl, 1804) and willows (Salix sp. Linnaeus, 1753). Quercus pyrenaica Willdenow, 1805 and Q. faginea, as not typical riparian trees, accompany the above. Therefore, in very narrow watercourses, we can find a diversity of tree species (Vaquero, 1997; Gutiérrez-Marco et al., 2011; García-Herrera et al., 2011; García and Aparicio, 2013).

The national park was established in 1995, and its area is nearly 41 000 ha (Seoane Calvo, 2018). In this area, well-preserved Mediterranean ecosystems from grasslands and scrublands to diverse woodlands can be found (Vaquero, 1997). This is due to strict Ordinances of Use and the very low levels of economic performance compiled in the 16th century (Ministerio para la Transición Ecológica y el Reto Demográfico, 2021a). Many forests in the park were managed in the past for different traditional uses (wood, charcoal, and cork). Some of them were also pollarded for firewood. This resulted in a higher number of hollows on the tree trunks, which supported the high diversity of saproxylic species. However, many old growth trees are located in small areas scattered around national park and impenetrable scrubland is dominant (Mico et al., 2013; Quinto et al., 2014).

2.2. Studied taxa

The saproxylic beetle community was studied in 2009 and 2015 using hollow emergence traps. Tree hollows were covered with black acrylic mesh and sealed up with staples. Emerged beetles came into a white collecting pot with ethylene glycol as preservative. Traps were placed in the field for the whole study year and emptied every month (for more details see Quinto et al., 2013). Hollow emergence traps (99 in total) were placed into nine different locations across Cabaneros NP. Proportional stratified sampling was used (Hirzel and Guisan, 2002). Two localities represented deciduous oak forest (29 traps), one locality represented riparian forest (25 traps), one evergreen oak forest (6 traps) and four evergreen oak dehesa (39 traps). Thus, habitats with higher percentage coverage in NP were more sampled (i.e., more traps) than less extensive ones. Additionally, our sample coverage (SC) was high, with 100% for deciduous forest, 99% for riparian forest, and 99% for both evergreen forest and dehesa (see 2.5. Statistical analysis section). In
Fig. 1. Structure of the different vegetation types and habitats. Deciduous forests dominated by (a) *Quercus pyrenaica* and (b) *Quercus faginea*. (c) Riparian forest dominated by *Fraxinus angustifolia*. Evergreen forest dominated by (d) *Quercus ilex* and (e) *Quercus suber*. (f) Dehesa of *Q. ilex*. (g) Deciduous forest of *Q. pyrenaica* with canopy height lower than 10 m and (h) areas with lower vegetation (i.e., scrubland) are examples of areas excluded from the study.
Table 1
Canopy height model thresholds for every vegetation type. Note that vegetation with lower heights was excluded from the analyses due to the absence of hollows.

<table>
<thead>
<tr>
<th>Type of vegetation</th>
<th>Height threshold (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deciduous oak forest</td>
<td>10</td>
</tr>
<tr>
<td>Riparian forest</td>
<td>9</td>
</tr>
<tr>
<td>Evergreen oak forest</td>
<td>7</td>
</tr>
<tr>
<td>Evergreen dehesa</td>
<td>6</td>
</tr>
</tbody>
</table>

Table 2
Summary of potential saproxylic species hotspots in the context of all Cabañeros National Park. Note that the percentage of habitat shows what area of that selected habitat was suitable, and the percentage of NP shows the percentage of this suitable habitat in the total area of NP.

<table>
<thead>
<tr>
<th>Type of vegetation</th>
<th>Tree species</th>
<th>Total area (ha)</th>
<th>Area of potential hotspots (ha) (%)</th>
<th>Percentage of NP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deciduous oak forest</td>
<td>Quercus pyrenaica</td>
<td>2056.31</td>
<td>559.06 (27.19%)</td>
<td>1.37%</td>
</tr>
<tr>
<td></td>
<td>Quercus faginea</td>
<td>2785.97</td>
<td>708.62 (25.44%)</td>
<td>1.73%</td>
</tr>
<tr>
<td>Riparian forest</td>
<td>Fraxinus angustifolia</td>
<td>262.71</td>
<td>239.62 (91.21%)</td>
<td>0.59%</td>
</tr>
<tr>
<td>Evergreen oak forest</td>
<td>Quercus suber</td>
<td>424.66</td>
<td>137.39 (32.35%)</td>
<td>0.34%</td>
</tr>
<tr>
<td></td>
<td>Quercus ilex</td>
<td>2347.2</td>
<td>178.39 (7.60%)</td>
<td>0.44%</td>
</tr>
<tr>
<td></td>
<td>Q. suber + Q. ilex</td>
<td>8252.83</td>
<td>803.24 (9.73%)</td>
<td>1.96%</td>
</tr>
<tr>
<td>Deciduous dehesa</td>
<td>Quercus faginea</td>
<td>210.1</td>
<td>209.25 (99.60%)</td>
<td>0.51%</td>
</tr>
<tr>
<td>Evergreen dehesa</td>
<td>Quercus suber</td>
<td>318.14</td>
<td>305.33 (95.97%)</td>
<td>0.75%</td>
</tr>
<tr>
<td></td>
<td>Quercus ilex</td>
<td>1691.09</td>
<td>1514.11 (89.53%)</td>
<td>3.70%</td>
</tr>
<tr>
<td></td>
<td>Q. suber + Q. ilex</td>
<td>301.1</td>
<td>279.74 (92.91%)</td>
<td>0.68%</td>
</tr>
</tbody>
</table>

addition, Sc ranged between 93% and 99% at the 9 sampling sites.

2.3. Public LiDAR and vegetation data

Publicly available LiDAR data whose origin was associated with the National Observation Plan was used for the territory of Spain (Instituto Geográfico Nacional, 2009). The point density was 0.5 points per square metre, and points were automatically classified based on orthophotos from the National Plan for Aerial Orthophotography (PNOA) with a pixel resolution of 25 or 50 cm. The studied region was recorded during 2009. We created a canopy height model (CHM) based on LiDAR points using QGIS 3.22.0 and LAStools. Specifically, CHM was obtained as a difference between digital surface model (DSM) and digital terrain model (DTM) (for more details, please see Rapidlasso, 2014). The canopy height model pixel resolution was 2.5 m.

The second data source used in our analyses was the vector layer of natural systems of the Network of National Parks in Spain (Ministerio para la Transición Ecológica y el Reto Demográfico, 2021b). This layer contained information about vegetation on a scale of 1:10 000. The layer was created in combination with the mapping and interpretation of aerial orthophotographs and terrain surveys. This layer was publicly available and was a part of the Monitoring and Evaluation Plan of the National Park Network (Ministerio para la Transición Ecológica y el Reto Demográfico, 2021b).

2.4. Field measured data and their use

Saproxylic species inhabiting tree hollows are generally associated with old growth trees and with veteran trees, in which traditional management in the past has accelerated the formation of cavities. Therefore, interest lied in the following vegetation types: deciduous forest (dominated by Quercus pyrenaica (Fig. 1a) or Quercus faginea (Fig. 1b)); riparian forest (dominated by Fraxinus angustifolia (Fig. 1c)); evergreen forest (dominated by Quercus ilex (Fig. 1d), Quercus suber (Fig. 1e) or their mixture) and dehesa (former agricultural habitat with scattered deciduous or evergreen trees called “dehesa”, Directive 92/43/EEC: 6310-Dehesas of evergreen Quercus spp.) (Fig. 1f).

In 2021, a field survey was performed in Cabañeros NP to access the height threshold values of veteran trees of every vegetation type. The survey heights were measured using a SUUNTO PM-5 height and clinometer with a height scale accuracy of ± 2%. The mean and maximum tree heights for every sampling plot (40 in total) of 20 m radius were recorded. Additionally, the presence of hollows in both the highest- and average-height trees of every studied plot was of interest to determine the potential of trees for saproxylic species. Canopy height model thresholds were set as the minimum height of the tree of every species that could most likely support the presence of hollows as key habitat for the saproxylic community (Table 1).

Based on these threshold values, areas with lower vegetation were excluded (Fig. 1g, 1 h). Additionally, these values were used for vectorization of the surrounding landscape at a scale of 1:4500. This vectorization was based on the canopy height model, and all suitable habitats were included. Pine plantations were easily differentiated thanks to their regular structure and were excluded from vectorization, as they lack hollows and are of marginal importance for saproxylic beetles (Fierro et al., 2017). The surrounding landscape in a three-kilometre radius around national park borders was vectorized.

A three-kilometre radius was chosen to cover even the maximum distance between suitable habitats inside of the national park (maximum distance = 2533.27 (m); mean distance = 230.78 (m)) and to enable calculation of suitable habitats in surroundings of sampling plots, as one locality was distant only one kilometre from the national park border.

The percentage of suitable habitats was calculated for every studied locality at six spatial scales with radii of 125, 250, 500, 1000, 2000 and 4000 m. Each radius was twice the size of the previous radius (e.g., Horák, 2014). Spatial scales were terminated with a radius of 4000 m, as it was expected to be a higher distance than recommended as a general guideline for saproxylic beetles (Holland et al., 2004; Jackson and Fahrig, 2012). These spatial scales (landscapes) were subjected to subsequent analyses to reveal the optimal spatial scale for saproxylic beetles (Horák et al., 2013; Schmidt et al., 2008). The optimal spatial scale was also used in connectivity analyses separately for forests or habitats that varied in terms of species diversity.

2.5. Statistical analysis

The sample completeness of each site, forest type and habitat was measured by sample coverage (the proportion of the total number of individuals who belong to the species detected in the sample) that was calculated with iNEXT Online (Chao et al., 2016).

To analyse the saproxylic diversity preferences, the type of forest (deciduous oak/riparian/evergreen oak) and type of habitat (forest/evergreen dehesa) were used as independent variables (hereafter selected independent variables). Deciduous dehesa was very rare in the park, therefore, it was not included in the analysis. Species richness and abundance at the trap level were used as dependent variables. Their normality was tested using the Shapiro–Wilk test. Species richness was square root transformed, and abundance was transformed by decimal logarithm to achieve normal distribution. A general linear model (glm) was performed for every dependent variable and selected independent variables. Statistical analyses were performed in R 3.6.3.

Canonical correspondence analysis (CCA) was used for all saproxylic species using the lattice (Sarkar, 2008), permute (Simpson, 2019) and vegan (Oksanen et al., 2019) packages to obtain interactions between species and selected independent variables. These analyses revealed the
Fig. 2. Map comparing overall forest and dehesa in Cabañeros NP and those that were potentially suitable for saproxylic communities. The upper panel shows a map of all forest and dehesa habitats, while the lower panel shows only potentially suitable habitats.
dependency of species composition on selected independent variables. A separate significance test of each term was performed, and their p values were calculated.

Indicator species analysis was used to test differences in the abundance and frequency distribution of species (Dufrene and Legendre, 1997). Only species with at least 10 individuals were considered in this analysis (Mupepele et al., 2014). Package Labdsv was used (Roberts, 2010).

To calculate habitat connectivity, the optimal spatial scale of suitable habitats was tested at the locality level. The generalized linear mixed effect model (glmmTMB), package glmmTMB (Brooks et al., 2017), was used for every radius. Species richness was used as the dependent variable. The type of forest and percentage of suitable habitats in the selected radius were used as independent variables. The number of traps in a locality was used as a random factor to generalize the results due to the unequal number of traps within localities. The spatial scale with the highest Akaika information criterion (AIC) was considered optimal.

3. Results

3.1. Old growth forests as potential hotspots for saproxylic beetle species

Our results showed that even though more than 45 percent of the national park consisted of sclerophyllous forest, broad-leaved forest and dehesa, only 12.06 percent was suitable for saproxylic species inhabiting tree hollows (for suitable areas of every type of vegetation, please see Table 2). The rest of the forest consisted mainly of Mediterranean shrub species such as Erica sp. Linnaeus, 1753 and Arbutus unedo Linnaeus, 1753 with occasional presence of young oak trees. The only exceptions were forests formed by a mixture of Q. ilex and Q. suber species in which mature Q. suber trees occasionally occurred. Although large, isolated trees can act as a reservoir of saproxylic species (Mico et al., 2020), it is difficult to quantify their role in the continuity of insect populations, as the presence of these trees in such habitats is only anecdotal. For this reason, we did not include this formation as a possible diversity hotspot.

The distribution of suitable habitats across the national park was rather uniform, with dehesa dominating in the southeast. Remarkable were valleys in the western part of the park, mainly in the northwest, where the terrain was more diversified than in the rest of the park. The central part of the park provided rather small forest fragments except for the Q. faginea forest complex in the south (Fig. 2).

3.2. Saproxylic beetle diversity distribution within forest types and habitats

The study included 126 species and 4179 individuals belonging to 27 beetle families (Table S1).

Saproxylic species richness indicated a preference for deciduous oak forests over evergreen oak forests (t = -3.36, P < 0.01) and over riparian forests (t = -2.99, P < 0.01). There was no significant difference between riparian and evergreen forests (t = -1.52, P = 0.13) or between forest habitat and evergreen dehesa (t = -0.04, P = 0.97). The abundance of saproxylic species was also higher in deciduous oak forests than in riparian (t = -2.76, P < 0.01) and evergreen oak forests (t = -3.14, P < 0.01). There was no difference between riparian and evergreen forests (t = -1.45, P = 0.15) or between forest habitat and evergreen dehesa (t = -0.21, P = 0.84) (for the summary of generalized linear models, please see Table S2).

Species composition was significantly influenced by selected independent variables (F = 2.18, P < 0.001). It varied based on forest type (F = 2.38, P < 0.001) and habitat type (F = 1.78, P < 0.05) (Fig. S1).

In addition, we found 16 indicator species of deciduous oak forest, 7 indicator species of riparian forest and 2 of evergreen oak forest and dehesa (Table 3).

A total of 6 threatened species were found following IUCN criteria (Nieto and Alexander, 2010): one endangered species (Limonius viciculus Mümmer, 1821) also included in Annex II of the Habitat Directive, one vulnerable species (Ischnodes sanguinicollis Panzer, 1793) and four near threatened species (Cercambyx welensis Küster, 1846; Ectameognous mantonandi Buysson, 1881; Elater ferrugineus Linnaeus, 1758; and Megapenthes lugens Redtenbacher, 1842) L. violaceus was found in riparian and evergreen oak forests; C. welensii was found in deciduous oak forests; E. mantonandi and E. ferrugineus were found in deciduous and riparian forests; and I. sanguinicollis and M. lugens were found in all forest types.

3.3. Connectivity of suitable habitat patches inside and outside of the NP

Connectivity was tested separately for deciduous oak, riparian and evergreen oak habitats, as the previous analyses revealed a higher importance of deciduous oak habitats for saproxylic species. Additionally, species composition varied between these habitats.

The optimal spatial scale for saproxylic species was found on a radius of one kilometre (Table S3).

The distribution of suitable habitats was rather heterogeneous in the

<table>
<thead>
<tr>
<th>Landscape radius</th>
<th>Total area (ha)</th>
<th>Deciduous oak forest (ha)</th>
<th>Riparian forest (ha)</th>
<th>Evergreen oak forest (ha)</th>
<th>Evergreen dehesa (ha)</th>
<th>Total percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 km</td>
<td>15 839.97</td>
<td>259.13</td>
<td>34.37</td>
<td>306.19</td>
<td>169.69</td>
<td>4.83%</td>
</tr>
<tr>
<td>2 km</td>
<td>30 818.61</td>
<td>537.08</td>
<td>66.59</td>
<td>456.55</td>
<td>771.40</td>
<td>5.94%</td>
</tr>
<tr>
<td>3 km</td>
<td>45 275.40</td>
<td>755.52</td>
<td>106.76</td>
<td>559.42</td>
<td>1762.64</td>
<td>7.03%</td>
</tr>
</tbody>
</table>
park surroundings, with the only exception of the east, where suitable habitats were rather rare. The area of suitable habitats considerably decreased outside of the national park in a one kilometre radius, being <5% (Table 4). However, this effect was lower with increasing distance from the park border, with the highest value at three kilometres (Table 4).

The role of suitable deciduous oak forest was smaller with a higher distance from the park border, but the area of evergreen dehesa increased. Suitable habitats in the south consisted mainly of dehesa, while in the north, deciduous oak forests dominated. Riparian forest was rather scarce at all landscape radii. The evergreen oak forest consisted mainly of small suitable fragments that were rather uniformly scattered around all park borders (Fig. 3).

Connectivity analyses revealed moderate connectivity of suitable habitat fragments inside the park in the case of deciduous oak habitats (Fig. 4). Fragments of riparian forests, presented mainly in the northwest area of the park, were rather connected. However, their abundance was low, and fragments in other parts were isolated (Fig. 5). In contrast, suitable evergreen oak habitats were well connected due to their scattered distribution (Fig. 6).

4. Discussion

Our results confirmed that LiDAR data in combination with field measurements are an effective tool for estimating saproxylic beetle species diversity distribution over large-scale areas, which was especially useful in the context of low accessibility due to impenetrable vegetation in the studied area (Müller and Brandl, 2009; Gutiérrez-Marco et al., 2011). In the case of Cabañeros NP, this tool allowed us to predict suitable forest types and habitats for the tree hollow beetle assemblages. Additionally, our results revealed that all suitable forest and habitat types hosted different saproxylic diversity and species compositions. Forest distribution and connectivity also vary highly among forest and habitat types, which can unequally jeopardize the prevalence of certain assemblages in the long term (e.g., Oleksa et al., 2013).

4.1. Detected suitable habitats and their species diversity

Field detection of old growth forests within the Cabañeros NP is very complicated due to low accessibility. Vegetation is formed by impermeable scrublands with limited patches of old growth trees. LiDAR data have proven to be useful for the detection of old growth forests over this large area. This has been essential for the estimation of possible hotspots of saproxylic diversity, as it profits from large-diameter trees with heterogeneous microhabitats (Kolstrom and Lumatjärvi, 2000) and a range of decay stages (Grove, 2002). These characteristics were even deepened by forest management of the past, which resulted in a higher number of hollows on old-growth tree stems (Sebek et al., 2013; Quinto et al., 2014).

All detected suitable forests with old-growth trees did not host the same species richness or the same assemblage composition. The type of forest (dominated by different tree species) drives those differences. Deciduous oak forest was the most diverse, which might be caused by the presence of larger hollows with a greater volume of wood mould in stems of deciduous trees than evergreen ones (Quinto et al., 2014). However, every forest type hosted some threatened species and its own indicator species (Table 3), contributing to a high gamma diversity in the park (Micó et al., 2013).

There were no differences in species richness regarding habitat openness (i.e., between forest and dehesa habitats). This was an
interesting finding, as higher canopy openness is believed to positively affect saproxylic species richness (Ramilo et al., 2017), as it provides higher light accessibility (Aragón et al., 2010;). However, forests in Cabaneros NP are rather open in comparison with dense forests of central or northern Europe (Verdú et al., 2011; Kopecký et al., 2013). This is the result of past management practices such as pollarding (e.g., Müllerová et al., 2014), which led to lower differences in light conditions between the studied forest and dehesa and possibly resulted in no difference in species richness.

4.2. Connectivity and distribution of fragmented suitable habitats

Analyses of the optimal spatial scale revealed the general response of saproxylic beetles on the scale of one kilometre. This corresponded to findings of Franc et al. (2007), who indicated the same optimal spatial scale of saproxylic beetles in temperate mixed oak forests. Therefore, it seems that saproxylic species reacted on the same scale in the case of both Mediterranean and temperate oak forests. Other studies from similar environments, such as hollow assemblages of oak forests (Bergman et al., 2012) or saproxylic communities of traditional fruit orchards (Horák, 2014), indicated rather smaller spatial scales.

Deciduous oak forest was situated mainly in valleys or rather isolated forest blocks with few interconnecting fragments (Fig. 4). This structure led to a higher degree of isolation, which even multiplied outside of the park, where this type of forest was even rarer. Therefore, it seems that this national park is acting as an island for this forest type and its biota. This habitat isolation might threaten species diversity (Oleksa et al., 2013), which would be critical, as this forest type was the most diverse in the park. This is very important in regard to the preservation of current nature protection and the support of developing a system of habitat protection beyond park borders. The indication of patches essential for habitat connectivity is also important for conservation measures (e.g., Pascual-Hortal and Saura, 2006; Wintle et al., 2019). These patches were mainly valleys in the central part and, to a lesser extent, the east valleys. Only the northwest part was rather well connected. The presence of red-listed species such as C. welensii, E. montandoni and E. ferrugineus could thus be compromised, in the near future, in certain areas of the park as well as of the rich saproxylic community associated with these forests with more than 16 indicator species.

The evergreen oak forest was rather well connected both inside and outside of the park. This was enabled because evergreen trees are more drought tolerant and can grow in places where deciduous trees cannot

![Fig. 4. Connectivity map of suitable deciduous oak forests and dehesa with an optimal spatial scale radius of one kilometre in Cabaneros NP, Spain.](image-url)
Evergreen trees hosted the least diverse community and only two indicator species. This may be caused by their hard wood and smaller hollows, which are less suitable for saproxylic species (Quinto et al., 2014). However, the distribution and continuity of this forest type might help to preserve certain red-listed species, such as L. violaceus (mostly found in riparian forests but also registered in evergreen oak forest), I. sanguinicollis and M. lugens (both found in all forest types). This indicates the importance of evergreen forest as a habitat linkage; it might connect preferable forest types of lower coverage and help to create habitat networks.

In general, the dispersal capacity of red-listed saproxylic species is expected to be lower than the dispersal of other saproxylic species (Brunet and Isacsson, 2009). The dispersal possibilities of L. violaceus, as the most threatened species collected, are not known, but they are considered to be limited (Gouix et al., 2015); the same applies in the case of I. sanguinicollis, which often shares the same environment with L. violaceus (Rattu and Massarone, 2017). C. welensii is known to have a low dispersal tendency and rather sedentary behaviour, but some adults disperse to distances greater than one kilometre (Torres-Vila et al., 2017). E. ferrugineus dispersal activity does not overcome a distance of 700 m (Zauli et al., 2014; Oleksa et al., 2015). However, based on models, approximately 1% of individuals might have a flight distance of 1 600 m (Zauli et al., 2014).

Based on our connectivity analyses, it seems that dispersal of less mobile saproxylic species is rather restricted to the national park itself, and connectivity with the park surroundings is rather low. This is a general problem of protected areas that are at risk of becoming islands in the surrounding unhostile environment (Gimmi et al., 2011). This underlines the importance of conservation activities within the park, which might be the last suitable habitat for many species (even threatened ones) in this region. Additionally, management activities such as tree maintenance, thinning and soft pollarding in park surroundings would also be beneficial, as they may promote both forest suitability and connectivity of existing patches.

5. Conclusions

Remote sensing techniques proved to be a powerful tool for data acquisition and extrapolation of field measured data over large-scale areas, which might help conservationists and researchers focus their activities on the most valuable reservoir areas or on those that are rather marginal, but their conservation is critical due to their connectivity value. Additionally, knowledge of habitats with the possible presence of the red-listed species might better target future conservation management even in the form of tree veteranisation.

All management in the park was abandoned since its establishment. Nevertheless, traditional management practices such as pollarding may be reconsidered to provide future hollow-rich stands suitable for saproxylic species, mainly in the central part of the park with lower connectivity and the presence of younger deciduous tree stands.

In the same way, the management of limited suitable habitats outside of the park would be beneficial to improve forest connectivity in the future. The management of limited deciduous oak forests and riparian forests might considerably improve future conditions for saproxylic species.
fauna inhabiting tree hollows.

CRediT authorship contribution statement

Patrik Rada: Methodology, Software, Validation, Formal analysis, Investigation, Data curation, Visualization, Writing – original draft, Writing – review & editing. Ascensión Padilla: Methodology, Data curation, Writing – review & editing. Jakub Horáček: Writing – review & editing. Estefanía Micó: Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Supervision, Project administration, Funding acquisition, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

We are very grateful to the staff of Cabañeros National Park for their help during this study and for providing the vegetation maps. Financial support was provided by the Ministerio de Ciencia e Innovación, Spain (PID2020-115140RB-I00) granted to EM. This study was also supported by the programme Erasmus+ and by UHK specific research project (2116/2020) granted to PR.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.foreco.2022.120378.


Zamora-Martínez, M.C., 2017. La tecnología LiDAR, herramienta útil para el estudio de la biodiversidad. Rev. mex. cienc. forestales 8, 4–6.
