Sylvopastoral management and conservation of the middle spotted woodpecker at the south-western edge of its distribution range

Hugo Robles a,*, Carlos Ciudad a, Rubén Vera b, Pedro P. Olea c, Francisco J. Purroy a, Erik Matthysen d

a Department of Animal Biology, University of León, Faculty of Biological and Environmental Sciences, Campus de Vegazana s/n, E-24071 León, Spain
b Department of Agro-forestry, Unit of Zoology, University of Valladolid, Av. Madrid 44, Campus La Yutera, E-34004 Palencia, Spain
c Department of Biology and Environmental Sciences, Faculty of Experimental Sciences, SEK University, Campus de Santa Cruz La Real, Cardenal Zúñiga 12, E-40003 Segovia, Spain
d Laboratory of Animal Ecology, Department of Biology, University of Antwerp (UIA), Universiteitsplein 1, B-2610 Antwerp, Belgium

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Abstract

Anthropogenic changes in forest structure threatens the persistence of numerous organisms. In Spain, Pyrenean oak (Quercus pyrenaica) forests are mainly subjected to three sylvopastoral management systems which determine variations in the forest structure: (i) “young forests” subjected to frequent disturbance by fires and clear-cuttings; (ii) “Pyrenean oak dehesas”, subjected to a traditional sylvopastoral system exclusive to Spain which favours the development of both old oaks and pasture; (iii) largely undisturbed “mature forests”. We examined the effects of these sylvopastoral management systems on habitat use and reproduction of the middle spotted woodpecker (Dendrocopos medius), a forest specialist bird, at the south-western edge of its distribution range. Habitat use was examined at multiple spatial scales. Within the territories, woodpeckers preferred large diameter oaks for foraging and decay oaks with holes for nesting. Within the forest tracts, no significant relationships between territory density and habitat structure in the forest tracts were found. At the landscape scale, dehesas and mature forests, both with high densities of important foraging and nesting trees, were occupied by woodpeckers. Young forests, with low densities of those trees, were avoided. No significant differences in territory density or reproductive success were found between dehesas and mature forests. The maintenance of viable woodpecker populations requires conservation actions at several spatial scales. Within the territories, woodpeckers preferred large diameter oaks for foraging and decay oaks with holes for nesting. Within the forest tracts, no significant relationships between territory density and habitat structure in the forest tracts were found. At the landscape scale, dehesas and mature forests, both with high densities of important foraging and nesting trees, were occupied by woodpeckers. Young forests, with low densities of those trees, were avoided. No significant differences in territory density or reproductive success were found between dehesas and mature forests. The maintenance of viable woodpecker populations requires conservation actions at several spatial scales. Within the forest tracts, suitable densities of important foraging and nesting trees must be maintained. At the landscape scale, management decisions must consider the maintenance of traditional sylvopastoral systems in dehesas and mature forests. At the regional scale, taking into account a habitat cover in the landscape of the 7% for the Cantabrian Mountains, we estimated an area of 285,000 ha to be included in the conservation planning unit for the middle spotted woodpecker.

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1. Introduction

Most forests in Europe have been or are being subjected to some type of anthropogenic activity (Bradshaw, 2004). Forest uses by humans varies from hunting and extensive traditional grazing to intensive wood production in plantations (Luis-Calabuig et al., 2000; FAO, 2001; Plieninger et al., 2003; Duriez et al., 2005). These different uses determine variations in the structure and composition of the forest and, in consequence, in habitat structure of forest organisms. Habitat alteration due to anthropogenic activity threatens the persistence of numerous forest organisms (Ranius and Jansson, 2000; Luck, 2002; Erickson and West, 2003; Bütler et al., 2004). An essential step towards the development of effective conservation strategies is to examine responses in the habitat use and reproductive success of species to changes in anthropogenic forest use.

An important tool for maintaining biodiversity is the use of keystone and umbrella species (Mikusinski, 1997; Simberloff, 1999; Roberge and Angelstam, 2004). In the temperate deciduous forests of the western Palaearctic, the presence of the non-migratory middle spotted woodpecker (Dendrocopos medius...
mediums) is associated to a high richness of other forest bird species (Roberge and Angelstam, 2006), acting as an umbrella species (Angelstam et al., 2004). As an excavator of holes in trees, the middle spotted woodpecker is considered a keystone species in forests, providing breeding opportunities for secondary hole-nesting birds (e.g. Wesolowski, 1989). Its habitat requirements are associated with characteristics of the mature forests, such as large diameter trees for foraging (Pasinelli and Hegelbach, 1997; Weib, 2003) and dead wood for excavating breeding cavities (Wesolowski and Tomiałojć, 1986; Pasinelli, 2003; Kosiński and Winiecki, 2004). The alteration and destruction of its habitat has caused a reduction in numerous populations of this woodpecker (Pasinelli, 2003). Examples of such habitat destruction are a reduction in the tree ages, the elimination of old oaks and of dead and decaying trees (Pasinelli, 2003). Middle spotted woodpecker is therefore potentially sensitive to changes in forest structure, the effects of which may be representative for other forest organisms (Roberge and Angelstam, 2006).

Several studies have been carried out on habitat use of the middle spotted woodpecker in central and northern Europe (e.g. Pettersson, 1984; Pasinelli and Hegelbach, 1997; Fauvel, 2001; Michalek et al., 2001; Hertel, 2003; Weib, 2003; Kosiński and Winiecki, 2004), but there is little information on southern populations. Spanish population of middle spotted woodpecker represents the south-western edge of its distribution range (Pasinelli, 2003). In Spain, they mainly occupy Pyrenean oak Quercus pyrenaica forests in the Cantabrian Mountains and the Basque Mountains (Purroy et al., 1984; Arrambide and Rodríguez, 1996; García-Fernández et al., 2002; Robles and Olea, 2003; Orrubia et al., 2004). Pyrenean oak forests are endemic of the western Mediterranean region (Tárrega and Luis, 1990; Calvo et al., 1991) and have high bird species richness (Álvarez, 1989). Although the Iberian Peninsula has the largest Pyrenean oak forest area in its distribution range, it is the least protected forest in Spain, with only 2.21% of its surface protected (Maldonado et al., 2001). Moreover, it has been historically altered by human activities such as charring, grazing, fires and clear-cuttings (Calvo et al., 1991; Luis-Calabuig et al., 2000; Maldonado et al., 2001). Three types of sylvopastoral management determine variations in Pyrenean oak forest structure: (i) heavily disturbed “young forests” subjected to frequent fires and clear-cuttings; (ii) “Pyrenean oak dehesas”, subjected to a traditional sylvopastoral system exclusive to central and northern Spain which favours the development of old trees and pasture interspersed (Luis-Calabuig et al., 1993; Blanco et al., 1997; Camprodón, 2001); (iii) “mature forests” with scarce human activities. Data are necessary to assess the potential impact of these management systems on the conservation of the middle spotted woodpecker.

During a 5-year study period (2000–2004), we examined the effects of sylvopastoral management in Pyrenean oak forests on habitat use and reproductive success of the middle spotted woodpecker in the south-western edge of its distribution area (Cantabrian Mountains in NW Spain). Habitat use was examined at multiple spatial scales for two reasons: (i) different factors may influence habitat use at different scales (Wiens et al., 1987; Luck, 2002); (ii) habitat structures (e.g. foraging and nesting substrates) selected on a spatial scale may be driving habitat use decisions at a larger spatial scale (Orians and Wittenberger, 1991; Walters et al., 2002). First, we compared the distribution and abundance of the middle spotted woodpecker in forest tracts subjected to different sylvopastoral management system (landscape scale). Second, we analysed foraging and nesting tree use within the territories (territory scale), as the densities of these trees may influence selection processes on a larger spatial scale (see Pasinelli, 2000). Based on the results of tree use, we examined the relations between habitat structure and woodpecker distribution and abundance in the forest tracts (forest tract scale). Last, we compared reproductive success from territories with different habitat structure and sylvopastoral management. Based on the obtained results, management measures for the conservation of the middle spotted woodpecker were proposed, with implications for other forest bird species.

2. Study area

The study was conducted in a landscape dominated by Pyrenean oak forests (Q. pyrenaica) of approximately 24,800 ha situated on the southern slope of the Cantabrian Mountains (NW Spain), between Leon and Palencia provinces (centred on 42°43'N, 5°11'W). It is located in the transition area between the Eurosiberian and Mediterranean bioclimatic regions (Penas, 1995), at altitudes from 900 to 1 350 m a.s.l. Approximately the 85% of the study area is formed by Pyrenean oak forest (i.e. the potential habitat for the middle spotted woodpecker in the Cantabrian Mountains, see Orrubia et al., 2004). A small proportion of other Quercus species (Q. faginea, Q. petraea and Q. pubescens, see Penas, 1995; Penas et al., 1997) may also be mixed together with the Pyrenean oak, and less frequently (<1%) other non-oak species (e.g. Fagus sylvatica, Pinus sp., Populus sp., Salix sp.). Other forest habitats (2%) are pine plantations (Pinus pinaster and P. sylvestris), beech (F. sylvatica), riverside (Populus sp., Salix sp. Fraxinus sp.) and holm oak (Q. rotundifolia) forests. The remaining 13% is formed by non-forest habitats, such as pastures, scrublands, cereal croplands, roads and urban areas.

Three different sylvopastoral management systems are used in Pyrenean oak forests (Table 1). Firstly, “young forests” maintained in that seral stage by frequent disturbances. They have frequently been burnt and/or subjected to repeated clear-cuttings within the last decades, so the oaks are mostly young trees regenerated from shoot on the rhizome or the stem of subterranean roots (Tárrega and Luis, 1990; Luis-Calabuig et al., 2000). They have high shrub cover (mainly Erica sp., Genistella tridentata and Halimium sp.) and low livestock pressure. Secondly, the “dehesas” are associated with traditional extensive grazing, mainly sheep and goats. They have low shrub cover and are often cleared by selective cutting to create pastures and to favour the development of large oaks (Díez et al., 1991; Luis-Calabuig et al., 1993; Blanco et al., 1997). These oaks are pruned to make their crowns larger, providing shade in summer and abundant acorn production for
livestock. The low used or abandoned dehesas may have greater shrub cover (Diez et al., 1991) and a bimodal age structure, i.e. with both large old trees and small young ones originated from resprouting. Finally, the largely undisturbed “mature forests” maintain a wide variety of tree ages, a high richness of undergrowth species (Prunus spinosa, Ilex aquifolium, Sorbus aria, S. aucuparia, Crataegus monogyna, Rosa sp., etc.), low livestock pressure and little firewood extraction by selective cutting. These three sylvopastoral management systems make up a mosaic landscape with patches subjected to different degrees of anthropogenic forest use and forest maturity.

3. Methods

3.1. Sylvopastoral management and woodpecker distribution and abundance

From 2000 to 2004, the distribution and abundance of the woodpeckers were determined in 49 randomly chosen forest tracts (n = 17 young forest tracts, 9 dehesa tracts and 23 mature forest tracts) of 21–40 ha, as most of dehesa patches had this size range. Forest tract size did not differ significantly between forest tracts (Kruskal–Wallis test: \( \chi^2 = 1.667, \) d.f. = 2, \( p = 0.435 \)). Woodpecker distribution (presence/absence) was determined in each tract during three visits suitably distributed between March and the beginning of May each year, when intra-specific aggressive interactions (i.e. territorial activity) are most common (Pasinelli et al., 2001). During each visit the entire forest tract was covered approximately at 20 ha/h. We stopped every 100 m to use a playback technique, alternating 30 s of species calls (kweek and rattle calls, see Pasinelli, 2003) with 45 s listening, and repeating one more time this operation when the species was not detected (Robles and Olea, 2003). Given that not all the forest tracts were sampled during the 5-year study period, we considered the species as being present when we detected birds for at least 2 years, and absent when no birds were detected in none of at least 4 years.

Forest tracts with woodpecker presence were visited five times per year to estimate woodpecker abundance. Once the presence of woodpeckers was detected we stopped using the playback technique, trying to avoid attracting birds from nearby territories (Kossenko and Kaygorodova, 2001). Woodpecker were followed and signs of activity (visual and auditive) recorded on maps elaborated ad hoc to a 1:4000–1:10,000 scale (Robles and Olea, 2003). Territory density in each forest tract was estimated from the mean number of territories observed during the study period.

3.2. Foraging and nesting tree use

In the next step, we analysed foraging and nesting tree use within the territories. The densities of these trees interact to influence home range sizes in the middle spotted woodpecker (Pasinelli, 2000), and may influence distribution and abundance at a forest tract scale.

3.2.1. Trees used for foraging

We collected data on foraging tree use based on visits to middle spotted woodpecker territories in March and April 2002–2004, coinciding with the peak of territorial activity during the pre-breeding period (Pasinelli et al., 2001). We recorded the species, diameter (dbh, measured at 1.3 m from the ground), condition (alive or dead) and height of each tree used, and the condition of the foraging substrate (alive or dead). In order to reduce dependence between observations only one observation per tree and those distanced at least 10 min were considered (Rudolph et al., 2002). We collected information in 10 breeding territories, 5 in dehesas and 5 in mature forests, with a total of 160 trees (10–24 trees per territory). No data were collected in young forests as they were not occupied by woodpeckers (see Section 4.1).

Foraging tree availability was determined by establishing a network of circular plots of 0.04 ha (11.2 m radius) 100 m apart in each territory (Fig. 1). The species, diameter and condition of all the trees were recorded in each plot. Only oaks measuring ≥13 cm dbh were classed as available, as other species and smaller oaks were not used by the woodpeckers. We also measured the mean height of 1–3 randomly-chosen trees ≥20 cm dbh in each circle (96% of the trees used had ≥20 cm dbh).

3.2.2. Trees used for nesting

From May to July 2000–2004, we carried out intensive searches to locate nests in 26 territories. We found 49 trees with breeding cavities. We defined breeding cavities as those excavated during the breeding season by territorial pairs if we observed adults inside for longer than 20 min (i.e. incubating) and/or feeding the nestlings. As multiple nesting trees used within the same territories across years might be dependents,
we only considered one tree per territory randomly chosen. We measured 26 nest-trees and 26 non-used trees randomly-situated within the territory limits. We only considered oaks >22 cm dbh as available, because other tree species and smaller oaks were not used by the woodpeckers. We recorded the species, diameter (dbh), condition (alive, decay: trunk partially debarked and/or with polyporous fungi, or dead: with no living parts), height and presence/absence of holes >4 cm wide (i.e. the minimal size required by this woodpecker for nesting) for each tree, differentiating between natural holes and those excavated by woodpeckers.

3.2.3. Data analysis

Unless otherwise stated, statistical analyses in this paper were conducted in SPSS 12.0. Comparisons between the characteristics of the trees used and available for foraging were carried out with paired and unpaired t-tests. We used unpaired t-tests and Mann–Whitney U-tests for the comparison of the trees used for foraging and nesting between the sylvopastoral management systems. Comparisons between nesting trees and randomly chosen trees were made with Wilcoxon singed-rank tests for continuous variables, and $\chi^2$-tests for categorical variables. Fisher exact tests were used to compare categorical variables of nesting trees between the sylvopastoral management systems. Bonferroni correction was applied for multiple tests performed on the same data set (Rice, 1989).

3.3. Habitat structure and woodpecker distribution and abundance

3.3.1. Field methods

Based on the results of foraging and nesting tree use, we examine the relations between habitat structure and the distribution and abundance of the middle spotted woodpecker in the forest tracts. For this aim, we recorded data on vegetation structure in the forest tracts using the same procedure as described in Section 3.2.1, that is, by establishing a network of 0.04 ha circular plots 100 m apart (Fig. 1). Habitat variables are described in Table 2. We took two measurements of foraging tree availability: (1) the density of oaks with a diameter from 13 to 37 cm, the minimum diameter used and the lowest mean of the diameter used in a territory, respectively (see Section 4.2); (2) the density of large oaks (dbh ≥ 37 cm). We calculated the density of potential cavity trees (i.e. oaks ≥ 22 cm dbh, dead or decay and/or with holes, see Section 4.3). As dead wood may be an important foraging substrate in winter for the middle spotted woodpecker (Pettersson, 1983), the density of dead and decay oaks was calculated. We also estimated the density of small oaks (dbh < 10 cm and at least 1.5 m high) because dense hardwood midstory has been shown to have a negative influence on habitat use of other woodpecker species (e.g. Conner et al., 1999; Rudolph et al., 2002). This was done by counting its number in four $2 \times 2$ m squares 5 m from the centre of each plot on each cardinal axis. Finally, altitude was measured in the centre of each plot.

3.3.2. Data analysis

Habitat variables that did not meet assumptions of normality were log$_{10}$ or square root transformed (Kolmogorov–Smirnov normality test: all $p > 0.05$ after data transformation). The differences in habitat structure between the forest tracts occupied and non-occupied by territories and between the sylvopastoral management systems were tested using analysis of variance (ANOVA).

The relations between territory density of the forest tracts ($n = 32$) and habitat characteristics (Table 2), including also the forest tract size and the sylvopastoral system, were analysed by multiple linear regression. All continuous habitat variables, with the exception of the density of small oaks and the forest tract size, were significantly correlated (Pearson correlations: all $p < 0.05$). The highly correlated variables were reduced in principal components analysis using varimax rotation to generate new variables non-intercorrelated. Composite variables of the principal components and the low correlated habitat

Table 2

<table>
<thead>
<tr>
<th>Variables</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density of small oaks</td>
<td>Number of oaks &lt;10 cm dbh and &gt;1.5 m height per ha</td>
</tr>
<tr>
<td>Density of middle oaks</td>
<td>Number of oaks from ≥13 to &lt;37 cm dbh per ha</td>
</tr>
<tr>
<td>Density of large oaks</td>
<td>Number of oaks ≥37 cm dbh per ha</td>
</tr>
<tr>
<td>Density of potential cavity trees</td>
<td>Number of oaks ≥22 cm dbh dead (with no living parts) or decay (partially debarked trunk and/or with polyporous fungi) and/or with holes &gt;4 cm wide per ha</td>
</tr>
<tr>
<td>Density of dead/decay oaks</td>
<td>Number of dead and decay oaks</td>
</tr>
<tr>
<td>Altitude</td>
<td>Metres above sea level</td>
</tr>
</tbody>
</table>

Fig. 1. Network of circular plots of 0.04 ha (11.2 m radius) 100 m apart established to estimate foraging tree availability in the territories (white area) and habitat structure in the forest tracts.
variables were analysed by backward stepwise multiple linear regression.

3.4. Reproductive success

3.4.1. Field methods

From 2000 to 2004, breeding success was determined for 49 pairs in 26 territories. Pairs were scored as successful if they produced fledglings or large nestlings (easily told from the changes in the begging calls of the young, see Pasinelli, 2001, 2003) or unsuccessful if they failed before producing large nestlings. In a subsampling of accessible nests ($n = 27$ nests in 18 territories from 2001 to 2004), the number of nestlings 7–3 days before fledging were counted using a dentist mirror and a lamp. We checked some nests for one more time before fledging, but we did not find any differences in brood sizes. As we found no dead young inside the nest after fledging date ($n = 18$ nests), the number of large nestlings was assumed as an adequate estimation of reproductive output.

3.4.2. Data analysis

The relations between brood size and territory habitat characteristics (Table 2, including also the sylvopastoral management system) were analysed using generalized linear mixed models (GLMMs) with a Poisson error distribution in R statistical software (available at URL http://www.R-project.org). GLMMs allow both fixed and random terms to be fitted. Random term in our models take into consideration multiple sampling units (Shall, 1991). Thus, territory identity was fitted as a random term. All continuous habitat variables, with the exception of the density of small oaks, were significantly correlated (Spearman rank correlations: all $p < 0.05$). The highly correlated variables were reduced in principal components analysis. Composite variables of the principal components, the density of small oaks, the sylvopastoral management system and year were fitted as fixed terms. Model selection was performed simplifying the maximum model by backward elimination of the least significant terms in order to get the minimal adequate model (Crawley, 2005). Because of the small sample size, no interaction or quadratic terms were added.

Given the low number of breeding failures ($n = 6$), it was not possible to use GLMM analysis to examine the relationships between breeding success and habitat characteristics. Thus, the differences in breeding success between the dehesas and mature forests were analysed using the Fisher exact test. As the year had no significant effect on breeding success (Fisher exact test: $p > 0.5$ for all the possible combinations between years), the data of all the years were pooled.

4. Results

4.1. Sylvopastoral management and woodpecker distribution and abundance

Middle spotted woodpecker was found in all dehesas and mature forest tracts, but not in any of young forest tracts. Mean territory density was $0.52/10$ ha ($\text{range} = 0.15–0.92$, S.E. = $0.04$, $n = 32$ forest tracts), with no significant differences between dehesas and mature forests (mean ± S.E. dehesas versus mature forests: $0.46 ± 0.09$ versus $0.54 ± 0.04$, unpaired $t$-test: $t = -1.050$, $p = 0.302$, $n = 9$ and 23, respectively).

4.2. Trees used for foraging

All trees used for foraging were oaks. Non-oak trees ($I. aquifolium, C. monogyna, Malus sp.$) were very scarce in the analysed territories ($2.4/1000$ trees). Diameter of used trees was
significantly greater than that of the available trees (mean ± S.E.: 50 ± 4 cm versus 34 ± 2 cm, paired \( t \)-test: \( t = -4.882, \ p = 0.001, \ n = 10 \) territories), with significant values for 8 of the 10 territories (Table 3). Diameter of the used trees was greater in dehesas than in mature forests (unpaired \( t \)-test; \( t = 3.157, \ p = 0.013, \) Fig. 2a), but the diameter of available trees did not differ between both forest types (\( t = 1.690, \ p = 0.130, \) Fig. 2a). The height of the used trees did not differ significantly from that of the available ones (mean ± S.E. used versus available: 12.8 ± 0.8 m versus 12.8 ± 0.6 m, paired \( t \)-test: \( t = 0.215, \ p = 0.834, \ n = 10 \) territories). The height of the used and available trees was greater in mature forests than in dehesas, with differences being marginally significant (unpaired \( t \)-test; used: \( t = -2.208, \ p = 0.058; \) available: \( t = -2.239, \ p = 0.056 \) (Fig. 2b).

Only a very small proportion of dead oaks was available (1.8/1000 oaks), and was not used. Woodpeckers foraged mainly in live parts of the trees (mean of observations in live substrate in 10 territories: 81.4%, S.E. = 3.5, range = 66.7–100.0%), with no significant differences between dehesas and mature forests (median dehesas versus mature forests: 76.5% versus 84.6%, Mann–Whitney \( U \)-test: \( U = 7.50, \ p = 0.295 \)).

4.3. Trees used for nesting

All nest-trees were oaks. Non-oak trees (\( I. \) aquifolium, \( C. \) monogyna, \( M. \) sp., \( S. \) sp.) were very scarce (1.8/1000 trees) in the analysed territories. Woodpeckers excavated cavities in oaks \( \geq 22 \) cm diameter, using a significantly higher proportion of decay trees (76.9% of the used trees) and trees with holes (84.6%) than non-used ones (all \( p \leq 0.005 \), see Fig. 3). 88.5% of the used trees were decay and/or had holes (\( n = 26 \) nest-trees). Neither used trees nor random non-used trees were dead. However, one nest-tree non-considered for the analysis was dead (2.0%, \( n = 49 \) nest-trees).

No significant differences between used and non-used trees were found in the diameter (median and range, used versus non-used: 39 cm [22–87] versus 39 cm [22–75], Wilcoxon signed-rank test: \( Z = -0.794, \ p = 0.427, \ n = 26 \)) and the height (median and range, used versus non-used: 11 m [3–18] versus 12 m [6–20], Wilcoxon signed-rank test: \( Z = -0.776, \ p = 0.438 \)) of the trees. In dehesas, birds nested in trees with larger diameter (median and range: 46 cm [35–87] versus 38 cm [22–66], Mann–Whitney \( U \)-test: \( U = 39.5, \ p = 0.046; \) \( n = 9 \) and 17 trees, respectively) and lower height (median and range: 12.8 m [9–20] versus 13.0 m [6–20], Mann–Whitney \( U \)-test: \( U = 31.0, \ p = 0.035; \) \( n = 9 \) and 17 trees, respectively).

Table 4

Results of the ANOVA for comparing the habitat variables (mean ± S.E.) between sylvopastoral management systems (\( n = 17 \) young forest tracts, 9 dehesa tracts and 23 mature forest tracts)

<table>
<thead>
<tr>
<th>Variables</th>
<th>Woodpecker absence</th>
<th>Woodpecker presence</th>
<th>( F )</th>
<th>( p )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Young forests</td>
<td>Dehesas</td>
<td>Mature forests</td>
<td></td>
</tr>
<tr>
<td>Density of small oaks( ^a )</td>
<td>2945 ± 432 a</td>
<td>855 ± 249 b</td>
<td>2341 ± 1168 ab</td>
<td>6.902</td>
</tr>
<tr>
<td>Density of middle oaks</td>
<td>152 ± 33 a</td>
<td>57 ± 12 a</td>
<td>389 ± 47 b</td>
<td>15.292</td>
</tr>
<tr>
<td>Density of large oaks</td>
<td>1 ± 1 a</td>
<td>54 ± 11 b</td>
<td>57 ± 8 b</td>
<td>21.061</td>
</tr>
<tr>
<td>Density of potential cavity trees</td>
<td>2 ± 1 a</td>
<td>23 ± 4 b</td>
<td>29 ± 3 b</td>
<td>26.330</td>
</tr>
<tr>
<td>Density of dead and decay oaks( ^b )</td>
<td>21 ± 9 a</td>
<td>9 ± 3 a</td>
<td>48 ± 8 b</td>
<td>12.055</td>
</tr>
<tr>
<td>Altitude</td>
<td>1057 ± 22 a</td>
<td>1015 ± 15 a</td>
<td>1164 ± 23 b</td>
<td>10.851</td>
</tr>
</tbody>
</table>

The letters a and b indicate homogenous groups for each variable (post hoc analysis by Tukey’s HSD test). See text and Table 2 for a description of the habitat variables.

\( ^a \) Square root transformed.

\( ^b \) \( \log_{10} \) transformed.
range: 11 m [7–12] versus 14 m [3–18], Mann–Whitney U-test: \( U = 40.5, \ p = 0.050 \) than in mature forests. We found no significant differences between dehesas and mature forests with regard to the remaining tree characteristics (all \( p \geq 0.1 \), see Fig. 4).

4.4. Habitat structure and woodpecker distribution

Forest tracts occupied by woodpeckers (i.e., dehesas and mature forests) had significantly higher density of large oaks and of potential cavity trees than unoccupied ones (i.e., young forests) (Table 4). Density of middle oaks, of dead/decay oaks, and tree height were significantly greater in mature forests than in dehesas and young forests. Young forests had significantly more small oak density than dehesas, whilst mature forests had intermediate values (Table 4).

4.5. Habitat structure and woodpecker abundance

Principal components analysis of the continuous habitat variables gave two independent components that accounted for 78.5% of cumulative variance in the data. Density of large oaks, of potential cavity trees and altitude had high factor loadings with the first component (0.682, 0.850 and 0.760, respectively). This component was interpreted as a measurement of forest maturity (older oaks are generally larger and more suitable for excavating), and was called OLDOAK. Density of middle oaks and of dead/decay oaks had high factor loadings with the second component (0.904 and 0.914, respectively). This component was difficult to interpret.

The final habitat variables (two composite variables, two untransformed variables and the sylvopastoral management system) were analysed using backward stepwise multiple linear regression. Regression analysis did not show any significant effect of habitat variables on territory density of the forest tracts (\( p > 0.2 \) for all models).

4.6. Reproductive success

Overall, 87.8% of the pairs (\( n = 49 \)) were successful, with no significant differences between the dehesas and mature forests (dehesas: 85.7% of 21 nests, mature forests: 89.3% of 28, Fisher exact test: \( p > 0.999 \)).

Mean brood size was 2.96 (range = 1–5, S.E. = 0.22, \( n = 27 \)). Principal components analysis of the continuous habitat variables gave two independent components that accounted for 75.8% of cumulative variance in the data. Similar to previous analyses, density of large oaks, of potential cavity trees and altitude had high factor loadings with the first component (0.889, 0.778 and 0.881, respectively). Density of middle oaks and of dead/decay oaks had high factor loadings with the second component (0.905 and 0.869, respectively). The final habitat variables (two composite variables, the density of small oaks and the sylvopastoral management system) were analysed using GLMMs. GLMM analysis did not show a significant relationship between brood size and habitat structure, including the sylvopastoral management system (all \( p > 0.3 \)).

5. Discussion

5.1. Geographical variation in the habitat use by the middle spotted woodpecker

Middle spotted woodpecker has been considered as a habitat specialist mainly associated to mature deciduous forests rich in oaks (Pasinelli, 2000). In combination with other European studies, our results on habitat use support the idea that, in landscapes dominated by oaks, the middle spotted woodpecker exhibits similar habitat requirements in different areas of its distribution range. Woodpeckers selected oaks with greater diameter for foraging in our study area, in accordance with the only previous study carried out on this topic in oak forests by Pasinelli and Hegelbach (1997) in Switzerland. Our results also confirm observations of studies carried out in central Europe finding that middle spotted woodpeckers build their nests in dead parts of the tree, preferring those with old cavities and polyporous fungi (Wesołowski and Tomialojc, 1986; Kosiński and Winiecki, 2004).

Recent studies have found that middle spotted woodpecker also occupies non-oak forests with a high proportion of rough-barked deciduous trees (Hertel, 2003; Pasinelli, 2003; Weib, 2003). Conditions in different parts of the range of a species may, depending on its ability to adjust to changes, lead to geographical variation in habitat selection (Rolstad et al., 2000). In old beech (F. sylvatica) forests in Germany, dead wood plays an essential role as foraging substrate (Hertel, 2003), unlike the observations for populations in oak forests, where this woodpecker forages mainly in live parts of trees (Pasinelli and Hegelbach, 1997; present study). Also, in a riverine-oak forest in Poland, Kosiński and Winiecki (2004) found that middle spotted woodpecker preferred to nest in dead trees, most of which not oaks but ash (Fraxinus excelsior), alder (Alnus glutinosa) and birch (Betula verrucosa). However, in our study area, where the availability of other non-oak species was very limited, woodpeckers did not prefer dead trees for nesting. So, the use and preference of the middle spotted woodpecker on the characteristics of trees for foraging and nesting vary geographically depending on the availability of the tree species in the forest. This shows that this species exhibit certain plasticity in its habitat use on a regional scale (Pasinelli, 2003).

Despite this plasticity in habitat use, middle spotted woodpeckers exhibit common characteristics for foraging and nesting in different habitats of its distribution range. They normally forage on large diameter and rough bark trees, which are thought to provide high food abundance (i.e. arthropods) for this woodpecker (Pasinelli, 2003). With regard to nesting, the presence of soft and decaying wood seems to be more important for cavity construction than tree species (Pasinelli, 2003) or tree condition.

5.2. Sylvopastoral management and conservation of the middle spotted woodpecker

Middle spotted woodpeckers avoided young forests, preferring dehesas and mature forests. We found no significant
differences in both territory density and reproductive success between dehesas and mature forests. Thus, both dehesas and low disturbed mature forests seem to be appropriate habitats for the middle spotted woodpecker, showing that a highly altered habitat (i.e. dehesas) can be also a suitable habitat for a forest specialist bird. Pyrenean oak dehesas also enable local economy to be maintained, and preserve a cultural heritage exclusive to central and northern Spain (Luis-Calabuig et al., 1993; Blanco et al., 1997; Camprodon, 2001). This highlights the conservation value of the traditional dehesa system in allowing the reconciliation of agroforestry and biodiversity.

Availability of suitable foraging and nesting substrate limits the habitat use in many bird species (Newton, 1994; Walters et al., 2002; Luck, 2002). In sedentary birds that occupy all-purpose territories, such as the middle spotted woodpecker (Pasinelli et al., 2001), the choice of territory is of great importance, and must provide suitable foraging and nesting habitat (Pasinelli, 2000; Luck, 2002). Forest tracts occupied by middle spotted woodpeckers (i.e. dehesas and mature forests) had significantly higher densities of large oaks (dbh > 37 cm) and potential cavity trees densities than unoccupied ones (i.e. young forests). Large oaks and potential cavity trees provide the middle spotted woodpecker with suitable substrate for foraging and nesting, respectively (Pasinelli and Hegelbach, 1997; Pasinelli, 2000; Kosiński and Winiecki, 2004; present study). Thus, a low availability of suitable substrate for foraging and nesting could be limiting the distribution of the middle spotted woodpecker in young forests.

Another potentially influential factor in habitat selection is competition (Mac Nally, 1990). Pasinelli (2000) did not find an effect of great spotted woodpecker (Dendrocopos major) density on home range sizes of middle spotted woodpeckers. In our study area, all the dehesas and mature forest tracts were occupied by great spotted woodpeckers, green woodpeckers (Picus viridis) and spotless starlings (Sturnus unicolor), whereas such potential competitors were lacking in some young forests (pers. obs.), suggesting that inter-specific competition is unlikely to influence the distribution pattern of middle spotted woodpeckers.

Territory quality has been shown to be one of the influencing factors of reproductive success in birds (Catchpole and Phillips, 1992; Luck, 2003). Similar to Pasinelli (2001), we did not find a relationship between breeding success or brood size and the structural habitat variables, which may be seen as measurements of territory quality (Pasinelli, 2001). As a possible explanation of this unexpected result, Pasinelli (2001) suggests that, as middle spotted woodpeckers adjust the home range size to the available resources (Pasinelli, 2000), differences in habitat quality may already be compensated, so that these differences do not translate into reproductive success. On the other hand, although no relationships between territory density and habitat structure in the forest tracts were found, habitat quality does seem to be an important factor influencing territorial occupation by middle spotted woodpecker (see above). Thus, the factor limiting the reproductive output could be the choice of a habitat with sufficient quality to allow the birds to settle in a territory. Traditional management systems in dehesas and mature forests, which maintain high densities of important old oaks for foraging and nesting, enable territorial settlement and reproduction of the middle spotted woodpecker in this area.

An important consideration for habitat conservation of the middle spotted woodpecker is related to the even age distribution of the trees in the highest intensively-used dehesas. These dehesas are formed exclusively by very old oaks. Some old trees fall on the ground each year and, as no younger trees are available, long-term sustainability of the Pyrenean oak dehesas is limited. A similar situation threatens the sustainability of the holm oak (Quercus ilex) dehesas, a habitat included within the EU Habitats Directive (see Pulido et al., 2001, and references therein). Following the recommendations of Pulido et al. (2001), a sustainable dehesa system must include periods of long-term exclusion of livestock to allow the tree regeneration and its long-term sustainability. Once grazing pressure has been limited, Pyrenean oaks are able to resprout at very high densities by vegetative regeneration (resprouting from shoot on the rhizome or the stem of subterranean roots) or regenerating sexually (Tárrega et al., 2006). Indeed, the high density of small oaks in abandoned (without livestock) dehesas indicates the existence of regeneration. Also, a similar situation has been shown to limit habitat regeneration of species specialised on old trees inhabiting forests subjected to past coppice-with-standard management practices in Europe and North America, including the middle spotted woodpecker (see Pasinelli, 2000, and references therein). Conservation of species specialised on old trees requires maintaining an adequate proportion of all age strata of the trees, allowing in this way the future regeneration of its habitat (Pasinelli, 2000; Onrubia et al., 2004). Mature forests, which maintain all age stages of the trees, represent a suitable habitat for the persistence of such forest specialist species.

Historically, oak forests in Cantabrian Mountains have been cleared, felled, ploughed and burnt to increase the area used for agriculture, livestock and mining (Purroy et al., 1984; Blanco et al., 1997; Luis-Calabuig et al., 2000; Onrubia et al., 2004). Large areas of oak forest have been replaced by exotic plantations of conifers and eucalyptus (Purroy et al., 1990; Luis-Calabuig et al., 1993). In recent decades, the intensification of the livestock production systems promoted by the European Union’s Community Agrarian Policy (CAP) has brought about a reduction in extensive sheep and goat grazing systems (Serrano et al., 2002). All of these changes in land use have resulted in a decrease in the area occupied by dehesas and mature oak forests, to such an extent that the largest surface of Pyrenean oak forest in Cantabrian Mountains is made up of highly-disturbed young forests (Tárrega and Luís, 1990; Luis-Calabuig et al., 2000; Calvo et al., 2003), which are not occupied by this woodpecker. Thus, it is reasonable to expect that distribution of the middle spotted woodpecker in Spain has been reduced over recent decades due to a decrease in habitat availability (Onrubia et al., 2004).

The maintenance of viable populations requires conservation actions at several spatial scales (Angelstam et al., 2004). Within the forest tracts, suitable densities of important foraging
and nesting trees must be maintained (Pasinelli, 2000). As reference values, 51 territories in our study area had a mean density of 66 large oaks (≥37 cm dbh) and 30 potential cavity trees per ha, similar to the 63 oaks ≥36 cm dbh found in Switzerland (Pasinelli, 2000) and the 26 potential cavity trees in Switzerland and Poland (Pasinelli, 2000; Kosiński and Winiecki, 2004). At the landscape scale, management decisions must take into account the maintenance of traditional silvopastoral systems in dehesas and mature forests, which support high densities of old trees essential for foraging and nesting. At the regional scale, the area requirements for a population of 100 middle spotted woodpecker females range from 20,000 to 130,000 ha, depending on whether it is a pure-nesting. At the regional scale, the area requirements for a population of 100 middle spotted woodpecker females range from 20,000 to 130,000 ha, depending on whether it is a pure-nesting. At the regional scale, the area requirements for a population of 100 middle spotted woodpecker females range from 20,000 to 130,000 ha, depending on whether it is a pure-nesting. At the regional scale, the area requirements for a population of 100 middle spotted woodpecker females range from 20,000 to 130,000 ha, depending on whether it is a pure-nesting. At the regional scale, the area requirements for a population of 100 middle spotted woodpecker females range from 20,000 to 130,000 ha, depending on whether it is a pure-nesting.

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Díez, C., Luis, E., Tárrrega, R., Valbuena, L., 1991. Degradation process in traditional systems of silvopastoral managements in dehesa landscapes required for this woodpecker (15%, Angelstam et al., 2004). This is because only 7% of a 880 km² landscape in a wider area of the Cantabrian Mountains is covered by woodpecker habitat (unpublished data), we estimate an area requirement of 285,000 ha to be included in the conservation planning unit for the middle spotted woodpecker. Moreover, as 7% is lower than the minimum proportion of suitable habitat patches in the landscape required for this woodpecker (15%, Angelstam et al., 2004), we expect habitat fragmentation, through an increment of isolation among habitat patches and a reduction in patch sizes, to have negative effects (e.g. Pettersson, 1984) in this population of the Cantabrian Mountains.

The middle spotted woodpecker is one of the best indicators of the bird species richness in the temperate deciduous forests of the western Palaearctic (Roberge and Angelstam, 2006) and is considered an umbrella species (Angelstam et al., 2004). This is because the middle spotted woodpecker is a high demanding species very sensitive to changes in forest structure, the effects of which may be representative for other forest birds (Roberge and Angelstam, 2006). In fact, dehesas and mature forests (Q. pyrenaica, Q. faginea and Q. humilis), i.e. the potential habitat for this woodpecker, maintain great bird species richness, significantly higher than in oak forests with few large trees (i.e. young oak forests) (Campodóñ, 2001). Therefore, management and conservation measures previously proposed for the middle spotted woodpecker may have also implications for many other forest bird species. Nevertheless, because a single species would not suffice for ensuring the protection of all co-occurring species, combinations of species with complementary habitat requirements should be used for biodiversity conservation in the forests (Angelstam et al., 2004).


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