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Habitat selection, density and breeding of Great Spotted Woodpecker *Dendrocopos major* in a protected natural area in northern Italy

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Abstract - Woodpeckers have a strong affinity to forests and woodlands, even though they can also occur in man-made environments such as tree plantations, where they assume the role of keystone species thanks to their ability to create cavities, used as nests or refuges by other animals. However, it remains unclear how the spreading of man-made environments influences the occurrence and distribution of local populations. This study aimed to investigate the macrohabitat and microhabitat selection of the Great Spotted Woodpecker during the breeding season in a protected area in northern Italy, focusing on plantations and woodland habitats. We additionally provided some data on breeding biology and estimated the density in this area. As macrohabitat characteristics, we compared the cover of woodlands (three types: oak, black locust, and willow woodlands) and tree plantations (two types: poplar plantations and reforestations). To define the microhabitat selection, we compared environmental variables around nesting sites and around an equal number of random locations in their proximity. The Great Spotted Woodpecker selected oak and black locust woodlands, but also reforestation and poplar plantations. The results of the microhabitat analysis showed that for breeding, Great Spotted Woodpeckers require food resources, but also a rather dense arboreal vegetation and large trees. We estimated a density of 7.61 ind./km^2 ± 1,13 (ES), indicating a good state of conservation. In conclusion, the Great Spotted Woodpecker occurs in both natural woodlands, where it also selects the non-native black locust, and tree plantations, despite the latter possibly being used only for foraging. Even though it is a generalist species, the woodpecker may play an important role as ecosystem engineer in both tree plantations and black locust woodlands, due to the scarcity of natural cavity in these habitats. To favour the presence of the species it is advisable to (1) increase the surface of tree vegetation of any type, (2) favour the maintenance of mature trees, (3) avoid silvicultural interventions during the breeding season (late January-late July).

Keywords: Woodpecker, cavity nester, poplar plantations, black locust, silviculture.

INTRODUCTION

Woodpeckers have a strong affinity to forests and woodlands and are considered the most demanding group among European forest birds in terms of ecological requirements (Angelstam & Mikusiński 1994, Mikusiński et al. 2001). They are very susceptible to habitat changes; most woodpecker species depend on dead wood for foraging and digging cavities (Mikusiński et al. 2001). Furthermore, woodpeckers' ability to dig holes in wood leads them to play a key role for numerous other animals, which can exploit these cavities as nests or shelters (Johnsson et al. 1993, Martin & Eadie 1999, Gorman 2004, Drever et al. 2008). For this reason, they can be considered important keystone species (Johnsson et al. 1993, Angelstam & Mikusiński 1994, Remm et al. 2006). Indeed, in a habitat where natural cavities are a limiting resource, the secondary nesters depend on the primary ones that produce cavities (Martin & Eadie 1999, Virkkala 2006). The usefulness of these sites should not be underestimated, in fact, in some locations, such as in intensely managed forests and in arboriculture, the scarce presence of suitable sites for the nesting of the woodpeckers, limits the density of other species nesting in cavities (Gorman 2004). The strong interdependencies among the members of the cavity-nesting bird community have led some authors to propose the concept of a "network of nests", analogous to food webs (Martin & Eadie 1999).

One of the most important European primary-cavity nesters is the Great Spotted Woodpecker *Dendrocopos major* (Linnaeus, 1758). It is the most abundant, the most widespread and the largest generalist among the European woodpeckers (Scherzinger 2001, Michalek & Miettinen 2003, Ćiković et al. 2008). Its vast range includes most of Europe, the north-west of Africa, the mid-latitudes of western and eastern Asia and further east it is also widespread in the north-tropical areas of Myanmar and Indochina (Cramp 1985, del Hoyo et al. 2000). This species inhabits most of the wooded environments between the sea level and the upper limit of woodlands, avoiding treeless environments. It prefers forests due to the presence of dry wood and mature plants used to feed and to dig holes as night shelters and nests; however, it can successfully occupy artificial and man-made environments (e.g. parks, gardens, tree plantations) (Cramp 1985, Brichetti & Fracasso 2020). It is potentially present from the Arctic taiga to the Mediterranean scrub, as well as in central European temperate forests, in alpine forests, and in other wooded habitats with trees large enough to host cavities (Cramp 1985). Despite being the most omnivorous of European woodpeckers, insects (both wood-dwelling and surface-living) are its main food sources in all season (Cramp 1985, Gorman 2004). The Great Spotted Woodpecker is a monogamous species even if the pairs usually only last for one breeding season. The nests are excavated annually by both sexes in spring and consist of cavities in the trunks of living or dead trees and a wide variety of tree species (Gorman 2004, Matsuoka 2008). In general, the population trend in Europe appears to be decreasing (BirdLife International 2021), but with a European population estimated at around 17,200,000-27,300,000 individuals, the conditions for classification within one of the threat categories are not met. The main threats are the fragmentation of the nesting and feeding habitat, the removal of dry or perishable trunks and the use of pesticides (Keller et al. 2020, BirdLife International 2021). In Italy it is a sedentary and breeding species, with higher densities in the northern regions and in Sardinia, as well as in the altitudinal range below 2000 m (Fornasari et al. 2010), with range gaps in Tuscany, Puglia and Sicily (Brichetti & Fracasso 2020). The Italian population is estimated to be composed of 70,000-150,000 pairs (Brichetti & Fracasso 2020) and is classified as Least Concern (Gustin et al. 2019). In fact, Italian populations show a good state of conservation, thanks to the remarkable ecological plasticity and the tolerance to anthropogenic disturbance on a large part of the national territory (Fornasari et al. 2010, Brichetti & Fracasso 2020).

This study was aimed to investigate the status and ecology of the Great Spotted Woodpecker during the breeding season in an area of the Ticino Valley Regional Park, in northern Italy. Specifically, the study was designed with three aims: (i) to analyze the habitat selection at two levels (macrohabitat and microhabitat) across woodlands and tree plantations, (ii) to provide data on the breeding biology of the species in this area, and (iii) to obtain an estimate of the density of the species. In this area, the species is a sedentary breeder (500-700 breeding pairs are estimated; Casale 2015), well distributed, except for more urbanized areas or agricultural environments with little or no presence of tree elements (Casale 2015).

This study is important firstly to understand better the role of both woodlands, also composed of non-native tree species, and tree plantations on the ecology of this species. Indeed, both these habitats are generally associated with low bird diversity (Laiolo et al. 2003, Hanzelka & Reif 2015, FAO 2020), even though they are used by the Great Spotted Woodpecker (Chiatante et al. 2019b, Porro et al. 2021). However, it is unclear how strong the selection for these habitats is, and it is important to quantify the effect of anthropogenic disturbance on its population viability. As a matter of fact, it was suggested that tree plantations could act as ecological traps: although they might appear to be suitable natural woodlands for woodpeckers, they can be associated with low nesting success and a high predation rate (Camprodon et al. 2015, Porro et al. 2021). Furthermore, in areas with many small non-native trees and tree plantations such as the one here in consideration there is a lack of natural tree cavities (Lindenmayer & Franklin 2002, Hartley 2002, Remm & Lõhmus 2011). Therefore, the role of the Great Spotted Woodpecker as ecosystem engineer could be essential for the conservation of secondary-cavity nesters and other forest species that rely on the holes excavated by it (Hardin et al. 2021, Catalina-Allueva & Martín 2021).

MATERIALS AND METHODS

Study area

The present study was carried out in Lombardy (Northern Italy), in an area of 1652 ha located in the western Po Plain, specifically in the Ticino Valley Regional Park (Fig. 1). This area represents the Special Area of Conservation (SAC) IT2080014 “Boschi Siro Negri e Moriano” and the southern portion of the SAC IT2080002 “Basso corso e sponde del Ticino”, and it is included in the Special Protected Area SPA IT2080301 “Boschi del Ticino”. The study area is crossed from NW to SE by the Ticino River, which originates in the Alps and flows into the Po River. The climate in this area is temperate-humid continental type, characterized by hot and sultry summers (mean temperatures between 25°C and 30°C) and cold winters (mean temperatures between -1°C and + 5°C). Natural vegetation covers 38.5% of the study area, corresponding mainly to meso-hygrophilous deciduous forests (19.9%) and riparian forests (12.2%), with a rich and well-structured undergrown. The dominant tree species are oaks *Quercus robur*, poplars *Populus alba*, *P. nigra*, *P. canescens*, the elm *Ulmus minor*, and willows *Salix alba* and *Salix fragilis*. Also, very abundant are non-native species, such as the black locust *Robinia pseudoacacia*, the tree of heaven *Ailanthus altissima* and the American maple *Acer negundo*. Arable lands occupied 40.8% of the study area and tree plantations is also well represented, occupying 13.3% of the study area, and dominated by traditional poplar plantations. The Ticino River and other water bodies represent 15.0% of the study area, whereas roads and built-up areas occupies 2.0% of the study area.

Fieldwork and data collection

Occurrence and abundances of Great Spotted Woodpecker

During the breeding period, we counted the Great Spotted Woodpecker with the linear transects method (Bibby et al. 2000). From February to May 2021, we walked 16 transects corresponding to paths and unpaved roads of the study area (Fig. 1), once a month, for a total of 36.5 km per month, along which every individual seen (using a binocular 10×40) or detected due to its song/call was recorded. To obtain a representative sample of the environment investigated, a stratified sampling design was planned (Krebs 1999, Sutherland 2006). In particular, the covers of each land use type in a 100 m buffer around transects (the distance at which the detection

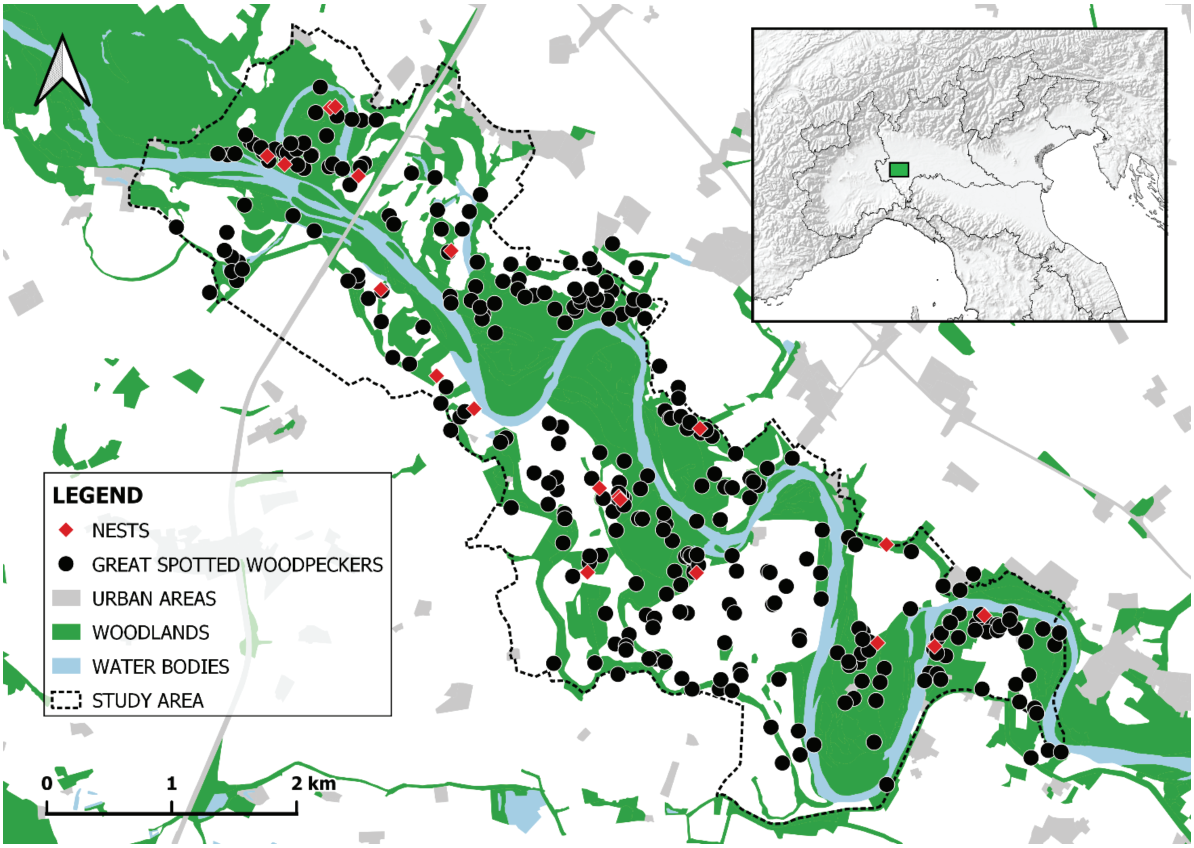

Figure 1. Study area surveyed to investigate the habitat selection and density of the Great Spotted Woodpecker in northern Italy. Observations and nests of the Great Spotted Woodpecker are shown.

probability is higher; see Results, paragraph "Abundance and Density") is proportional to those of the whole study area. Counts were conducted in the morning between dawn and 12 a.m., avoiding windy and rainy days. The data collected, including the distance and direction of each contact, were noted and subsequently entered in a Microsoft Excel spreadsheet (Microsoft Corporation 2016).

Breeding: nest search, tree and cavity variables

Starting from the first week of May to the first week of June we searched for woodpecker nests walking the 16 transects previously described and some of the wooded areas adjacent to them. The seeking of cavities was conducted mainly in the morning, walking at a slow pace to visually inspect almost all trees, carefully checking snags and alive broken trees, since strongly selected for nest excavation by the Great Spotted Woodpecker (Olsson et al. 1992, Wiktander et al. 1992, Gorman 2004, Smith 2007). In addition, the begging call of the nestlings was exploited, since it can be heard even from a distance (Ferguson-Lees et al. 2011, Ćiković et al. 2014, Porro et al. 2021). Rainy days and strong winds were avoided. When an active nest was found, the following data were collected: (1) the nest coordinates, (2) the species of the tree, (3) the integrity of the tree (possible levels: alive, alive and decaying, dead, dead and broken), (4) the diameter of the trunk (DBH, diameter at breast height), (5) the height of the tree, (6) the height of the nest, (7) the orientation of the nest. A tree was considered decaying if at least one large dead branch was present. The height of the tree and the nest was calculated through trigonometric principles (van

Laar & Akça 2007) after we measured distance from eye level to tree crown and to tree top by a laser rangefinder (Leica Rangemaster 900; Leica, Solms, Germany). In the absence of obstacles and if the nest was at a height of less than about 12 m, the internal cavity was inspected with the help of a handcrafted pole-mounted camera system, consisting of a small infrared camera (SQ11 Mini DV, China) and a telescopic pole 8 m long (Porro et al. 2021). In this case, the (8) number of eggs/juveniles in the nest was counted.

Environmental variables

Macrohabitat

To assess the habitat selection of the Great Spotted Woodpecker in the study area, we explored the effect of the percent cover of both woodland types, i.e. oak woodland (dominated by *Quercus robur*), black locust woodland (dominated by *Robinia pseudoacacia*), and willow woodland (dominated by *Salix alba*) and tree plantations (poplar plantations and reforestations). The values of the environmental variables were obtained with the support of the QGIS 3.14.16 software using a land use map ad hoc built by us. Specifically, combining information from the regional land use map DUSAF 6.0 (ERSAF 2021), the regional forest map "Carta dei tipi forestali reali della Lombardia" (ERSAF 2012), and Google Satellite imageries (Map data ©2021 Google) from the QGIS plugin QuickMapServices (NextGIS 2019), we digitalized all polygons composing the land use map of the study area. Then, we attributed the land use type to each polygon with a visual check during the study period.

Nest site selection

During the period between the second week of June and the last week of July, microhabitat data were collected. In particular, the environmental variables were measured in a plot with a radius of 10 m (0.03 ha) around the nests and around points (in equal number with respect to the nests) randomly located within a radius of 50 m from the nest (Barrientos 2010) and at a minimum distance of 20 m from them (Kosiñski & Winiecki 2004, Pasinelli 2007, Hebda et al. 2017). Specifically, in each plot (nest or random), 18 variables were measured (Tab. 1) (Porro et al. 2021). Among them, we counted the number of trees with entrance and emergence holes of saproxylic beetles larvae in the wood in the first 2 m above ground, as an indirect measure of insect prey abundance (Nappi et al. 2003). Among trees, we considered only trees with the diameter of tree trunk at breast height (DBH) ≥ 18 cm because 18 cm is considered the minimum size of a tree suitable to dig a nest (Smith 1997). For the analysis, we also separately considered trees with DBH > 50 cm as this size range was the most frequent nesting substrates selected to dig nests (Kosiński et al. 2006, Touihri et al. 2015).

Data analysis

Habitat selection: macrohabitat

The habitat selection at a macroscale was investigated applying a use versus availability approach (Manly et al. 2002), calculating the covers of macrohabitat within both the presence and the availability cells of the Great Spotted Woodpecker. These cells were obtained by overlapping on the study area a grid with cell size equal to that of the home-range of the species. In particular, the home-range of the Great Spotted Woodpecker has an average size of 10 ha (del Hoyo et al. 2000) and for this reason a grid with cells of 316 m per side was generated (Chiatante et al. 2019b).

We computed an exploratory analysis verifying the existence of significant differences between the covers of land use types between presence and availability cells through both the non-parametric Mann-Whitney U test and the Kruskal-Wallis test (Legendre & Legendre 1998). Then, we investigated the habitat suitability through binary logistic regression analysis (Manly et al. 2002, Boyce et al. 2002). We used a presence-availability approach basing on the assumption that the certainty of the presence of the species, obtained during the data collection phase, cannot be matched by an equal

Table 1. Variables used to investigate the microhabitat selection of the Great Spotted Woodpecker in northern Italy. All measures were related only to trees with DBH > 18 cm

Variable	Description
Tree cover	Estimated visual coverage of the tree crowns (%)
Shrubs cover	Estimated visual coverage of shrub vegetation (%)
Dead wood	Abundance of dead wood on the ground (four levels: 1 absent or very rare, 2 rare, 3 abundant, 4 very abundant)
Tree species	Number of trees of each species
Tree diversity	Shannon-Wiener Diversity Index of tree species
Tree vegetative state	vegetative state of each tree (four classes: alive, more alive than dead, more dead than alive, dead)
N. whole trees	number of whole trees
N. broken trees	number of broken trees
Tree DBH	average DBH of trees (cm)
Tree DBH > 50 cm	average DBH of trees with DBH > 50 cm (cm)
N. tree DBH > 18	number of trees with DBH > 18 cm
N. tree DBH > 50	number of trees with DBH > 50 cm
N. dead tree DBH > 18	number of dead trees with DBH > 18 cm
N. dead tree DBH > 50	number of dead trees with DBH > 50 cm
N. tree with ivy	number of trees with ivy
N. tree with ivy DBH > 18	number of trees with ivy with DBH > 18 cm
N. tree with ivy DBH > 50	number of trees with ivy with DBH > 50 cm
N. tree with beetles' holes	number of trees with holes of saproxylic beetles

certainty of its absence, even if the area has been subject to data collection (Boyce et al. 2002, Johnson et al. 2006). Therefore, the dependent variable was binary (1 = presence, 0 = availability) whereas as independent variables we used the coverage of the land use type inside cells previously described. The variables included in the models were selected through an Information Theoretic Approach, and in particular we used the multimodel inference using the second-order Akaike's Information Criterion (AICc) as an evaluation parameter (Burnham & Anderson 2002). This is a quantitative selection method based on maximum likelihood and on the number of parameters, in which low values indicate better adherence to the distribution of the collected data (Burnham & Anderson 2002). Then, using data dredging, all the models with independent variables were formulated and for each of them the AICc was calculated (Burnham & Anderson 2002). Therefore, we selected as the best models with ΔAICc<2, as they are attributed with greater information (Burnham & Anderson 2002); for each of them we calculated also the Akaike's weight wi. Based on the set of best models, we have carried out the model averaging, calculating the partial regression coefficients of each variables and their relative importance (Burnham & Anderson 2002). The absence of collinearity of the variables present in the model set was verified through the Variance Inflation Factor (VIF), using a threshold equal to 3.00 (Fox & Monette 1992, Zuur et al. 2010). The predictive capacity of the average model was tested through the AUC of the ROC curve (Receiver Operating Characteristic) (Pearce & Ferrier 2000, Boyce et al. 2002) and as the value for the estimate of the explained variance, we calculated the explained deviance D^2 (Boyce et al. 2002, Zuur et al. 2007). Finally, based on the models obtained, we created a prediction map of the probability of presence of the species in the entire study area, using a grid with cells of the same size as those used for the formulation of the models. The software R 4.1.1 (R Core Team 2021) and the package MuMIn (Bartoń 2018) were used for the statistical analyses.

Habitat selection: nest site selection

For the analysis of the microhabitat selection of the Great Spotted Woodpecker, we used a comparative approach between the variables measured in the plots around the nests and those collected in the random plots. First, we ran some exploratory analyses with the non-parametric Mann-Whitney U test and the χ^2 test with contingency tables, to verify the existence of significant differences between the variables measured in the plots around the nests and those around the random points. Then, similarly to the macrohabitat selection, we investigated the nest site selection through binary logistic regression analysis, using as dependent variable the nests (1) and the random plots (0) and as independent variables, the environmental characteristics previously described (Tab. 1). The variables were standardized by normalization, that is, each variable had a mean of zero and a standard deviation of one (Zuur et al. 2007). We performed model selection through the Information Theoretic Approach, using data dredging and calculating for each model with a different set of variables the AICc. Considering the small sample size (n = 39, see Results), to reduce bias, we considered only models with a maximum of four predictors, basing on the rule of thumb "one in ten" which states that one predictive variable can be studied for every ten events while keeping the risk of overfitting low (Harrell et al. 1984, Peduzzi et al. 1996). Based on the set of best models (ΔAICc<2), we carried out the model averaging, calculating the partial regression coefficients of each variable and their relative importance. The absence of collinearity of the variables present in the model set was verified through the VIF, the predictive capacity of the average model was tested through the AUC of the ROC curve and we calculated the explained deviance D^2 to estimate the explained variance.

Abundances and density

The abundances of the species along linear transects were calculated through the Kilometric Abundance Index (Bull 1981, Czeszczewik et al. 2013). To verify the existence of significant differences between abundances of each months, we used the non-parametric Kruskal-Wallis test (Legendre & Legendre 1998). The density of Great Spotted Woodpecker was estimated through the distance sampling method (CDS) (Buckland et al. 1993). After a visual inspection of distances distribution, we transformed the distance data into equal intervals of 50 m. Moreover, the probability of detecting a bird depends not only on distance but also on many other factors, such as habitat, weather, period and bird behaviour (Buckland et al. 1993), a circumstance that could exist, at least in part, in this research due to the spatio-temporal variability of our data. Therefore, ignoring all these other factors, besides distances, could cause some bias in the estimate (Beavers & Ramsey 1998, Bas et al. 2008, Anderson et al. 2015). Indeed, a graphical exploratory analysis and the Kruskal Wallis test have shown that the month could bias our estimate because the detection distance changed with it (χ^2 = 22.261, df = 3, P <0.001). For this reason, to obtain the best model, we used multiple covariate distance sampling (MCDS) (Marques et al. 2007), an extension of CDS that allow modelling the detection probability as a function of variables other than distance. Accordingly to these considerations and as advised by Buckland et al. (1993) and by Thomas et al. (2010), in this study the detectability function was calculated using three models: (1) half-normal with cosine-based correction factor, (2) half-normal with Hermite-based correction factor, and (3) hazard-rate with correction factor based on simple polynomials. To select a model among those obtained, we used the second-order Akaike Information Criterion (AICc) and the goodness of fit of the models was assessed by χ2 tests, comparing the frequencies of the observed and expected contacts (Buckland et al. 1993). Finally, we calculated the detection probability and the Effective Strip Width (ESW), i.e. the distance within which the number of individuals not observed is equal to the number of individuals observed beyond (defined as the distance within which the probability of contact individuals is maximum). For each estimate, both the coefficient of variation (CV) and the 95% confidence intervals (CI) were calculated. The analyses were performed using the statistical software R v.4.1.1 (R Core Team 2021) and the package Distance (Miller 2020).

RESULTS

Habitat Selection

Habitat selection: macrohabitat

In the study area, the Great Spotted Woodpecker is present as a sedentary and nesting species. During the breeding season, 299 observations were collected, in particular 106 in February, 80 in March, 72 in April and 41 in May. As can be seen from Fig. 1, the Great Spotted Woodpecker appears well distributed in the study area. The exploratory analysis showed that for all five wooded types were found significant differences between cases of presence and controls (Supplementary Materials, SM Tab. S1). In general, there were significant differences between each wooded type within presence cells (Kruskal-Wallis test, χ^2 = 29.049, df = 4, P < 0.001), with the highest cover in woodlands and poplar plantations (SM Tab. S1, SM Fig. S1). The multimodel inference showed that two models best explained the occurrence of the Great Spotted Woodpecker (SM Tab. S2). The average model showed that all the wooded types positively affected the species and that the most important ($\Sigma w_i \geq 0.90$) were reforestations, poplar plantations, oak woodlands and black locust woodlands (Tab. 2, Fig. 2). The estimate of reforestations' effect was slightly higher than those of both oak and black locust woodlands. On the other hand, the importance of willow woodlands was very low. The Variance Inflation Factor (VIF) confirmed the absence of collinearity between the variables in the model set (Tab. 2). The ROC curve showed a good discriminatory capacity of the model, with an AUC equal to 0.809 (P <0.001), and the mean explained deviance was 17.9%. The probability of the presence of the Great Spotted Woodpecker in the study area was 0.51 ± 0.232 (SD), with a minimum of 0 and a maximum of 0.99 (SM Fig. S2).

Habitat selection: nest site selection

During breeding season 2021, we found 19 Great Spotted Woodpecker nests, all in the woodlands (Fig. 1). The exploratory analyses showed that in plots with nest sites occurred a higher abundance of whole trees (U = 110.5, P = 0.042), with an average DBH greater than 18 cm (U = 103.5, P = 0.025) and with saproxylic beetles' holes on the trunk (U = 110.5, P = 0.026) than in control plots. For all other variables, we did not find significant differences between nest and control plots (SM Tab. SM3). The multimodel inference showed that four models best explained the nest site selection of the Great Spotted Woodpecker (SM Tab. S4). The average model, composed of five variables, showed that the most important covariate was the number of trees with saproxylic beetles' holes, which associated positively with presence of the Great Spotted Woodpecker (Tab. 3, Fig. 3). In addition, the number of trees with DBH > 18 cm positively affected the nest site selection; dead wood, tree diversity and number of whole trees, entered the model but did not explain much variation. The VIF confirmed the absence of collinearity between the variables in the model set (Tab. 3). The ROC curve showed a good discriminatory capacity of the model, with an AUC equal to 0.878 (P <0.001), and the mean explained deviance was 30.8%.

Abundances and density

The average Kilometric Abundance Index (KAI), related to the 299 observations collected between February and May, was equal to 2.02 ± 1.68 (SD) individuals per km. The abundance decreased from a maximum of 2.98 in February to a minimum of 1.06

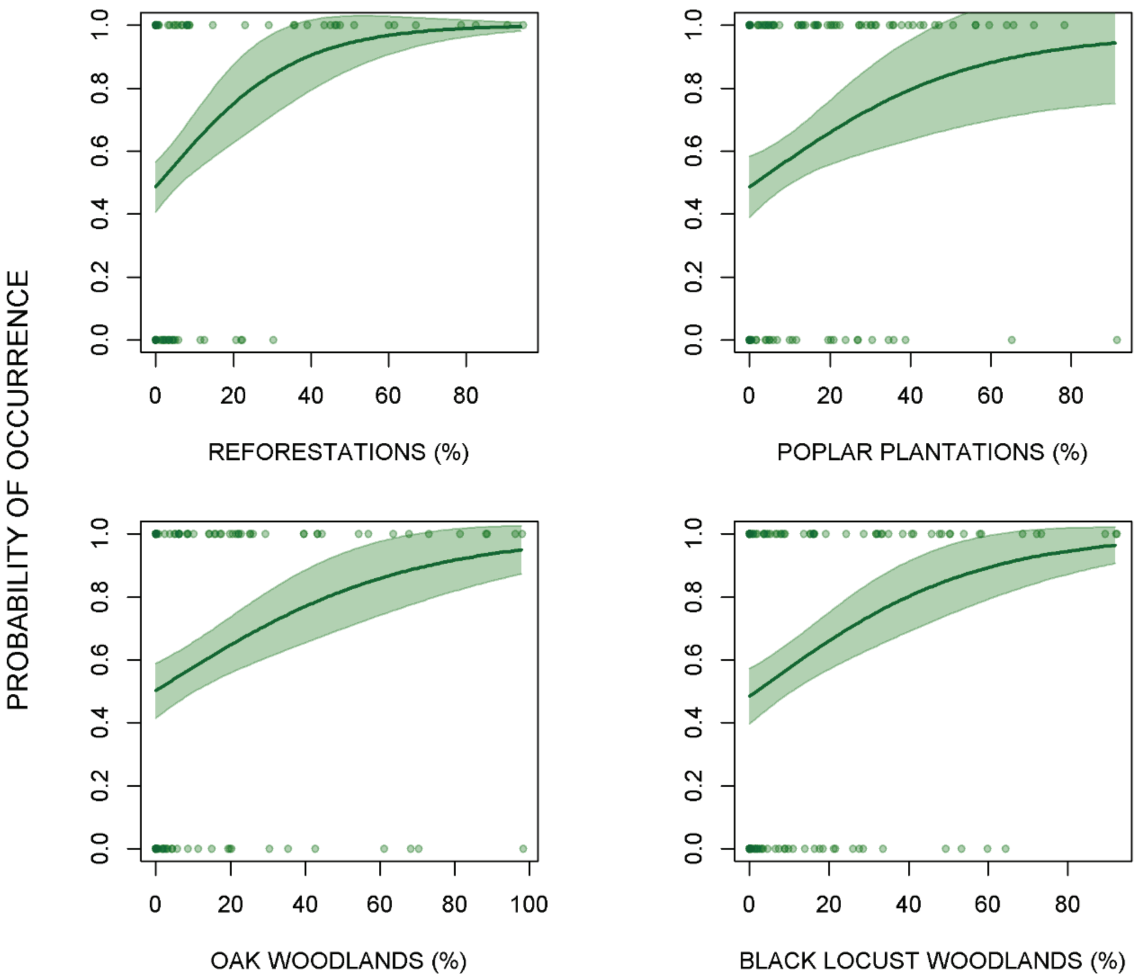

Figure 2. Estimates of the probability of occurrence as a function of increasing coverage of the most important environmental variables (Σwi >0.90) selected in the average binary logistic regression to investigate the occurrence of the Great Spotted Woodpecker in northern Italy.

Table 2. The average logistic regression explaining the occurrence of the Great Spotted Woodpecker in northern Italy. In bold are the most important variables ($\Sigma w_i > 0.90$).

Variable	β	SE	LCI	UCI	Σw_i	VIF
Intercept	-1.003	0.225	-	-	-	-
Reforestations	**0.058**	**0.017**	**0.024**	**0.092**	**1.00**	**1.02**
Poplar plantations	**0.038**	**0.011**	**0.017**	**0.059**	**0.94**	**1.01**
Oak woodlands	**0.030**	**0.009**	**0.012**	**0.048**	**1.00**	**1.08**
Black locust woodlands	**0.036**	**0.010**	**0.017**	**0.056**	**1.00**	**1.06**
Willow woodlands	0.029	0.009	0.011	0.047	0.06	1.08

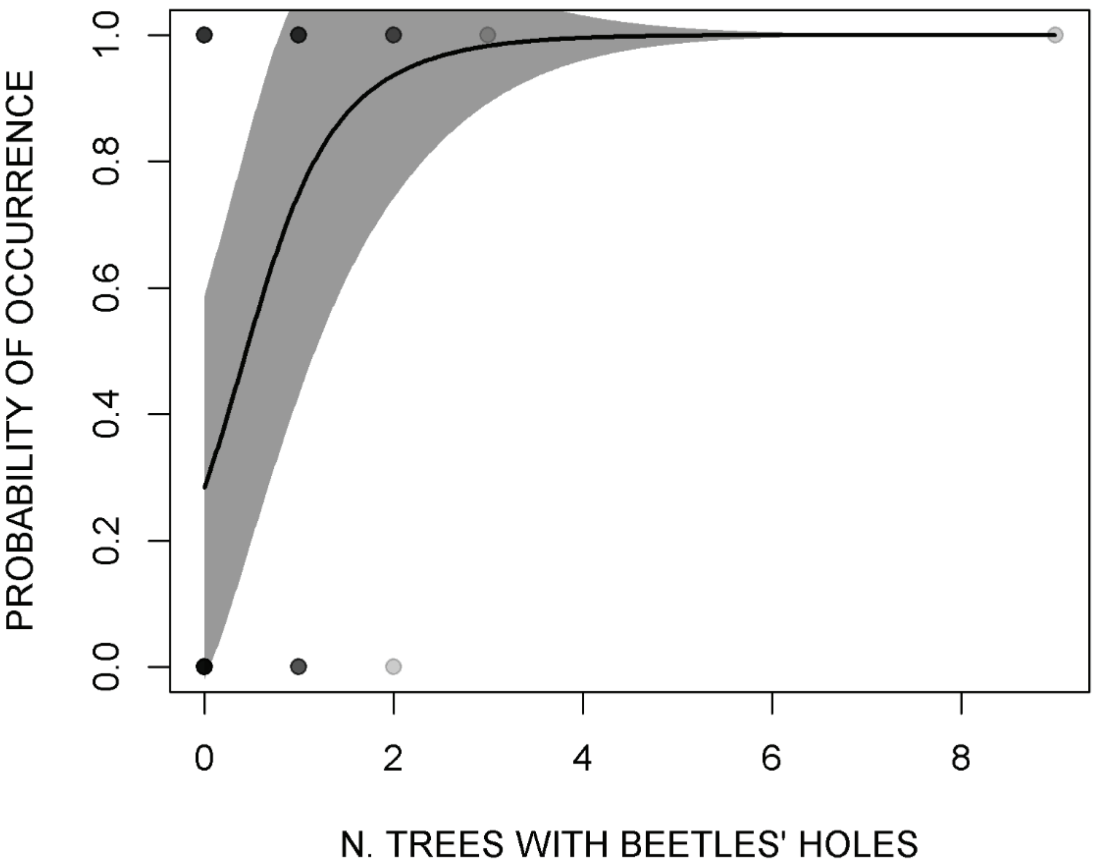

Figure 3. Estimates of the probability of occurrence as a function of increasing number of trees with saproxylic beetles' holes in the average binary logistic regression to investigate the nest-site selection of the Great Spotted Woodpecker in northern Italy.

Table 3. The average logistic regression explaining the nest site selection of the Great Spotted Woodpecker in northern Italy. For the dead wood, the reference level was "Absent or very rare". In bold are the most important variables ($\Sigma w_i > 0.90$).

Variable		β	SE	LCI	UCI	Σw$_i$	VIF
Intercept		12.947	19.98	-	-	-	-
Dead wood	*rare*	-18.768	23.99	-49.09	48.71	0.64	1.15
	abundant	-18.793	23.99	-49.09	48.71		
	very abundant	-22.116	23.99	-49.12	48.68		
Tree diversity		0.716	0.554	-0.414	1.845	0.24	1.22
N. whole trees		0.842	0.450	-0.071	1.755	0.17	1.18
N. trees with DBH > 18 cm		1.793	0.938	-0.095	3.681	0.83	1.46
N. trees with beetles' holes		**3.301**	**1.665**	**-0.048**	**6.650**	**1.00**	**1.31**

in May (March = 2.11, April = 1.93), with significant differences among months (χ^2 = 9.649; df = 3; P = 0.022).

The densities estimated with the multiple covariates distance sampling (MCDS) were equal to 7.61 ind./km^2 ± 1.13 (SE) (LCI 95% = 5.60, UCI 95% = 10.32, CV = 14.8%). The best model for calculating the detection probability function was the hazard-rate with simple polynomial adjustments (Tab. 4, Fig. 4). The goodness-of-fit of the model was adequate (χ^2 = 4.871, df = 3, P = 0.181). The ESW calculated from the model was 96 m and the average probability of detection was estimated to be 0.31 ± 0.02 (SE).

Breeding

During the breeding season 2021, 19 Great Spotted Woodpecker nests were found between the 7th of May and the 25th of June. The nests were dug mainly

Figure 4. Histogram of the detection function calculated to estimate the density of the Great Spotted Woodpecker in northern Italy. On the y-axis, the detection distance in meters, on the x-axis the detection probability (from 0 to 1).

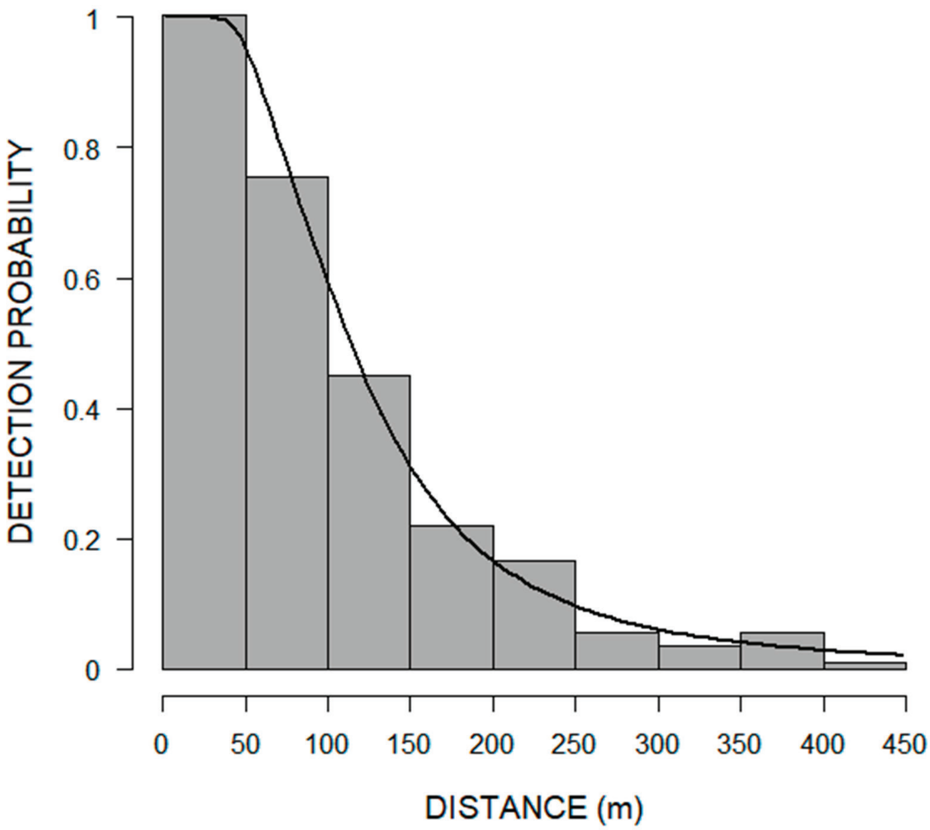

Table 4. Distance sampling models computed to estimate the density of Great Spotted Woodpecker in northern Italy. We showed the function (key + series adjustment), the model used, the AICc and its Δ, and the average estimated detection probability (P_a).

Function	D± SE	CV (%)	AICc	ΔAICc	P_a ± ES
Hazard-rate simple polynomial	7.61 ± 1.13	14.8	963.00	0.00	0.31 ± 0.02
Half-normal Hermite polynomial	7.18± 0.99	13.8	968.60	5.60	0.32 ± 0.01
Half-normal cosine	7.18± 0.99	13.8	968.60	5.60	0.32 ± 0.01

in white poplar (n = 11, 57.9%) and black locust (n = 4, 21.1%), but also in white willow (n = 3, 15.8%) and black poplar (n = 1, 5.3%) on trees with an average height of 17.2 m (± 6.1 SD). The mean diameter of the trees used was 47.3 cm (± 18.7 SD). The nests were at an average height of 9.3 m (± 4.7 SD) and were exposed on average to south, south-west (precisely 193°N ± 96.1 SD). The nest trees were mostly in a rotting state (n = 8, 42%), alive (n = 7, 37%) but also dead (n = 4, 21.1%). Five of the 19 trees were covered with ivy (26.3%). Due to too high nests and obstacles such as vegetation, only 7 out of 19 nests were inspected, in which a total of 21 juveniles were counted (SM Fig. S2). Of these seven nests, three contained 4 juveniles, two contained 3 juveniles, one contained 2 juveniles and one 1 juveniles (mean = 3.0 juv/nest, SD = 1.15).

DISCUSSION

Habitat selection

Habitat selection: macrohabitat

The results of this study allow to define the environmental characteristics that promote the presence of the Great Spotted Woodpecker in an area of the Ticino Valley Park. During the breeding season, the species has a rather homogeneous distribution and essentially inhabits both woodlands and tree plantations, as showed by our analyses and previous research done in this area (Chiatante et al. 2019b, Porro et al. 2021). These results agree with the ecology of this bird, indicated as the most generalist of the European woodpeckers, occurring anywhere where there is tree vegetation (Cramp 1985, Hannsson 1992, Rolstad et al. 1995, Tobalske & Tobalske 1999, Gorman 2004).

Our analyses show that increasing coverage of woodlands and tree plantations positively associated with the presence of the species in our study area. Among forest habitats, oak and black locust woodlands seem to be play an important role for the occurrence of the Great Spotted Woodpecker, whereas willow woodlands, although with a positive effect, only weakly correlated to the presence of the species. Generally, the selection of oak woodlands is found in many studies (Smith 1997, Hebda et al. 2017, Komlós et al. 2021), and can be attributed to a greater foraging activity, thanks to a high presence of seeds and insects as a consequence of the occurrence of large and senescent trees (Török 1990). The only study describing the selection of forest habitats of woodpeckers disagree with our result relating to black locust woodlands and suggest an underutilization of forests composed of non-native and invasive species compared to native oak and willow forests (Ónodi & Csörgö 2014). However, in our case, their positive effect could be linked to the fact that the black locust woodlands are mostly young woods with less crown coverage. It follows that in spring the undergrowth is more developed, leading to a higher density of insects foraged by the woodpecker than in mature woods with a thicker crown coverage (Hansson 1983, Blake & Hoppes 1986). In addition, black locust trees are very prone to the formation of dead wood (McComb & Muller 1983), which is fundamental for the presence of the woodpecker (Gorman 2004, Smith 2007).

Among tree plantations, poplar plantations and especially reforestations are positively associated with the presence of the species. This is likely related to the fact that poplar plantations are more managed than reforestations, which appear more natural. Indeed, poplar plantations are generally ploughed and sprayed to avoid attacks of wood-boring and bark beetles (such as, *Saperda carcharias*; Allegro 1991); in addition, snags and dead wood are generally removed. The link between dead wood and woodpeckers is well known, because most woodpecker species are indeed dependent on dead wood for either nesting, foraging, or both (Roberge et al. 2008, Gutzat & Dormann 2018). Thus, dead wood is often a limiting factor for woodpecker using managed forests, as snags and logs are usually scarce (Virkkala 2006). That is the case for poplar plantations as well, where woodpeckers appear to be positively associated with the presence of at least some standing decaying trees within the stand

(Porro et al. 2021). Nonetheless, the selection for tree plantations could be due to the presence of natural features inside them, such as big elder trees and vegetated edges that provide nesting and foraging sites (Barrientos 2010, Basile et al. 2020). However, tree plantations represent a complementary or supplementary habitats (Dunning et al. 1992, Ekroos et al. 2016), as the density in this environment is lower than that in woodlands (Chiatante et al., 2019a, Porro et al., 2021).

Habitat selection: nest site selection

Our results from the microhabitat selection of the Great Spotted Woodpecker indicated selection for some of the variables measured. Indeed, nesting plots, compared to random plots, have a greater number of trees, which are characterized by a greater presence of holes created by saproxylic beetles and with an average DBH greater than 18 cm. The explanation underlying the higher number of trees in the nesting sites may be related to the woodpecker feeding habits and requirements. In fact, in all seasons both wood-dwelling and surface-living insects are the main food sources of this species (Cramp 1985, Gorman 2004), that are searched mainly on the tree trunk (Török 1990, Gorman 2004). In the study area there are few large trees and the tree trunk diameter is generally low, especially in black locust woodlands (Motta et al. 2009, Tescari 2020), which were selected by the species. Therefore, due to the needs of environments rich in food to rear the offspring, the species may select areas with a greater number of trees where large quantities of food resources are possibly available. Furthermore, nesting in closed forests offers better shelter from aerial predators, as well as from some arboreal predators (Short 1979, Li & Martin 1991, Stenberg 1996); indeed, in the area occurred Eurasian Sparrowhawks *Accipiter nisus*, Northern Goshawk *Accipiter gentilis*, and Pine Martens *Martes martes* (Casale 2015, Balestrieri et al. 2015), which are some of the natural predators of the woodpecker. The high presence of trees with saproxylic beetle's holes is in line with the previous result and probably derives from the feeding habits of the species, based in summer on the larval and adult forms of forest arthropods (Cramp 1985, Osiejuk 1998, Gorman 2004). The selection for habitats rich in saproxylic insects has been observed for many woodpeckers (Török 1990, Nappi et al. 2003, Kosiński et al. 2006, Komlós et al. 2021), and in most of these studies, it appears that it was mainly a consequence of the selection for deadwood. The selection for areas with trees having an average DBH > 18 cm agrees with most of the previous research (Smith 1997, Kosiñski & Winiecki 2004, Pasinelli 2007, Komlós et al. 2021). Indeed, the species selects these trees because are suitable to dig a nest, whereas younger trees - with a DBH < 18 cm - are usually avoided (Kosiñski & Winiecki 2004, Pasinelli 2007, Barrientos 2010). In addition, the younger the trees the smaller the nests, leading to overcrowding which can reduce nest survival (Wiebe & Swift 2001). Furthermore, nests built in small and dead trees are colder during incubation and appear to be energetically more expensive for adults and chicks than warmer nests (Wiebe 2001).

The low number of differences found between nesting and control plots could have several explanations. First, they could be an artefact originating from the small sample size. In most of the microhabitat selection studies regarding this species the number of nesting plots used was bigger than 50 (Smith 1997, Kosiñski & Winiecki 2004, Hebda et al. 2017), while here we found only 19 nests. Another explanation could be that the microhabitats of the woodlands of the study area are structurally almost similar, at least at the spatial scale we worked at (20-50 m), and therefore it is not possible to show a selection. Finally, in other studies carried out in North America, it was found that the vegetation in the immediate proximity of the nesting tree minimally affects the nesting site selection of the woodpeckers (Gutzwiller & Anderson 1987, Adkins Giese & Cuthbert 2003). In fact, since the Great Spotted Woodpecker is a generalist species, it can live in various microhabitats depending on the architecture of the habitat, the distribution of prey and the spatial distribution of competitors.

Abundances and density

The Great Spotted Woodpecker was detected 299 times in the four months of investigation, with a decrease of the abundances over time. This result is explained by the fact that in February and March the woodpecker is very active in establishing nesting territories and in finding a partner and is therefore more detectable. In April and especially in May, however, the adults are engaged in the incubation of the eggs and rearing of the offspring (Gorman 2004, Brichetti & Fracasso 2020) and for this reason they are less detectable.

The estimated density is equal to 7.6 ind./km^2 for this area of the Ticino Valley Regional Park, indicating a good state of conservation of this species. Indeed, Gustin et al. (2016) indicated 5 pairs/km^2 as favourable reference value for Italian populations inhabiting in mature broadleaved and riparian woodlands. This result is comparable to that found by Casale (2015) in the whole Park: 500-700 pairs found in 20.000 hectares of forests, which correspond about 2.5-3.5 pairs/km^2. The density measure of this study seems slightly higher than that found by Porro (2014) for a fragmented area of Lombardy (6.8 ind/km^2) and Woodward et al. (2020) in the southern and coastal area of Great Britain in the period 2007-2009 (4.5-9 ind/km^2). The data is also comparable to the estimates of pairs and territories found by other authors in various European regions. Indeed, in natural forests, in Germany it was estimated a density of 4.5 pairs/km^2 (Scherzinger 1982), in western Poland, Wesołowski and Tomiałojć (1986) identified 6.6 territories/km^2, whereas in Southern Finland were estimated 3.78 pairs/km^2 (Virkkala et al. 1994). Conversely, in a Romanian managed forest were estimated 0.08 pairs/10 ha-1 (Domokos & Cristea 2014). Altogether, the density estimated in this study is higher than that found in other studies related to environments where the distribution of resources is less concentrated or fragmented and vital areas are necessarily larger (McCollin 1993).

Breeding

Despite the small sample of nests found not allowing for an in-depth analysis of the breeding biology of the Great Spotted Woodpecker in this study area, it is possible to make some considerations. The environmental characteristics found appear to be in line with many studies on the nest site selection of the Great Spotted Woodpecker in Europe in similar areas. For example, the average DBH of trees in which the woodpeckers dig nests was 47 cm, matching with results found in Swiss old oak-hornbeam forest managed for centuries as coppice (Pasinelli 2007), in continental forests of Croatia (Ćiković et al. 2014) and in oak woodlands of southern England (Smith 1997). Another example is the result related to a greater number of nests dig on living or rotting trees, which is in agreement with the general ecology of the species (Cramp 1985, Gorman 2004, Ónodi & Csörgö 2014). Furthermore, even the average height of the nests found, equal to 9.3 m, is in line with results found in Croatia (7.8 m; Ćiković et al. 2014) and in Poland (10.0 m; Kosiński et al. 2006).

Finally, we found 3 juveniles per nest, a value similar to that observed in Central Europe (Poland: 2.9-4.1; Mazgajski 2002) even though lower than that observed in other places, such as United Kingdom (3.78; Smith & Smith 2019) and Poland (3.92-4.48; Mazgajski & Rejt 2006, Kosiński & Ksit 2006).

Conclusion

In this study, we investigated which macro- and micro-habitat characteristics are selected by the Great Spotted Woodpecker across natural and man-made wooded environments. Our results indicate that both woodlands and tree plantations are selected. Specifically, oak and black locust woodlands positively associate with the occurrence of the species in our study area, as well as reforestations and traditional poplar plantations. However, despite the species also occurring in tree plantations, such areas possibly represent a complementary or supplementary habitat possibly exploited solely for foraging, as further suggested by the fact that all nests we found were in woodlands. Furthermore, for breeding, rather dense arboreal vegetation and fairly large trees are necessary, useful both for the presence of food resources, such as saproxylic beetles, and for digging the nests.

Finally, the density estimated for the species is similar to that found in other European areas and, considering the characteristics of this territory, indicates a good state of conservation. Nevertheless, this species faces local threats, such as the modification of the nesting and feeding habitat, the removal of dry or perishable trunks and the use of pesticides. To promote the presence of the species it is therefore advisable (i) to increase the surface of mature tree vegetation, keeping in mind the limited contribution of poplar plantations to the species occurrence, (ii) to promote the maintenance of mature trees and remaining natural vegetation in tree plantations, and (iii) avoid silvicultural practices during the breeding season, that is between late January and late July.

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