

Article

Key Elements of the White-Backed Woodpecker's (*Dendrocopos leucotos lilfordi*) Habitat in Its European South-Western Limits

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Abstract: In the last decade, the population of the white-backed woodpecker (*Dendrocopos leucotos lilfordi*) (WBW) in Navarre has been reduced mainly due to the loss of suitable habitat for this species from intensive forest management, leading almost to its extinction. This study aimed to identify the key structural elements of breeding habitats of the WBW and analyze their effect on the composition of the saproxylic fungi community within the habitats. In the Special Area of Conservation, namely Quinto Real in Navarre, 20 circular plots (500 m²) and 10 transects (150–300 m) were located inside and outside WBW territories. Within each sample plot, forest structure, deadwood, microhabitats, regeneration, and saproxylic fungi community were studied. The results showed that the key elements in the WBW territories were high trees, high diversity of deadwood (with a high presence of big and late-decay deadwood), high snag volume, and high microhabitat diversity. Although the past management is also evident in the variability of some of those characteristics, this species is well adapted to different structural and compositional conditions of the territory. The saproxylic fungi community was richer among the WBW territories, and in those areas, the presence of *Fomes fomentarius* was high, compared to non-WBW territories where it was not present. In conclusion, to maintain and protect the studied population, it is necessary to implement sustainable management that guarantees the conservation of the key elements for the WBW territories (structural heterogeneity and high deadwood diversity) in order to increase the suitability of the habitat for WBWs.

Keywords: deadwood; diversity; management; microhabitats; saproxylic fungi; structure

1. Introduction

The white-backed woodpecker (WBW), *Dendrocopos leucotos*, a species in the Picidae family, has a wide distribution as it extends from Asia to Europe. However, data show that its populations are declining mainly due to habitat degradation and loss [1]. The WBW has between 9 and 12 subspecies in its whole distribution-area [2]. In general, the “*leucotos* complex” shows a strong relationship with broadleaf forests for inhabiting, even though each subspecies can use different tree species for nesting. For example, those in northern Europe breed in forests with alder, oak, birch, or aspen, while in the south, they usually breed in beech forests [3].

The population found in the Pyrenees belongs to the subspecies *Dendrocopos leucotos lilfordi* Sharpe and Dresser (1871), which forms the south-western limit of its global distribution along with those of the Balkans, Corsica, Abruzzo, and the Caucasus [3,4], although it is the only population in the Iberian

Peninsula [5]. This population has around 330 pairs between the north and south [4]. Those found in the south live in a forest matrix that extends from Ansó (Aragón) to Quinto Real (Navarre). After the 1990s, some pairs were found living outside their main nucleus of the population, the Pyrenees with around 100 pairs being counted [6], in a more western area, in the surroundings of Belate and Bertiz (Navarre). In 2015, 20–24 new pairs were observed in those sites. It is believed that this subspecies has never bred with other subspecies [4], as its distribution is limited to the mountainside, showing an island-like distribution and, thus, increasing its isolation [3]. This subspecies in this southern limit lives in old beech forests with a high amount of deadwood [3], and it feeds mainly on the larvae of saproxylic beetles [7]. Within the woodpeckers, this species is the most site-specific, and it is very sensitive to forest management [5].

The forests where the WBW breeds are currently very threatened in Europe, and more specifically, in Navarre [8], on the one hand due to the high volume of wood that industry demands and on the other hand due to changes in land use. Even though the reduction of forested areas may be a threat in itself, its combination with the species' high territoriality and fidelity leads the WBW's status to dangerous levels because the couples will remain in the same area even if the habitat has been exploited or altered, while the population decreases until it disappears [3]. In fact, the WBW has been included in the Catalogue of Threatened Species of Navarre, in the category of endangered, and it is also mentioned in Annex II of the Habitats Directive (1992), defining the breeding sites as places of special interest. The main characteristics of WBW breeding territories are the presence of old large trees and a high amount of deadwood [5,9,10], characteristics that are usually scarce in exploited forests. In Navarre, beech forests were intensively managed and exploited in the past to obtain wood, and although at present their management is more focused on conservation, those uses have left their mark. Nevertheless, some experts have highlighted the importance of microhabitats for the WBW, like dead branches [11] and holes [10], due to its boring-beetle-larvae based diet. However, woodpeckers are also considered keystone species, creating cavities for other species to inhabit but also taking an active part in fungal dispersal [12], transporting spores on their body from tree to tree, and helping them get inside the deadwood [13]. There is also evidence of the dependence of woodpeckers on different species of endophytic fungi that soften the wood and facilitate nest excavation [14,15]. Thus, some relationships between woodpecker species and endophytic-fungi species have been observed [14–16]. However, in the case of the saproxylic fungi community, although some authors have determined a relationship between this community and deadwood size and decomposition state [17–19], there is a gap in terms of how the composition of the saproxylic fungi community is influenced by the WBW presence and which species are more influenced by it. Moreover, Roberge et al. [20] concluded that the WBW could be considered as an umbrella species, often linked to the presence of high-conservation-interest species in its habitat. For example, in a Finnish investigation, 16 threatened beetle species and 23 rare species were found in the territory of the WBW [21]. However, in Navarre, there are few studies on this topic. Therefore, there is a need to know the key elements of the WBW breeding territories in Navarre to improve forest management and avoid the degradation or destruction of those sites so that this species can be conserved. Thus, the main objectives of this study were: (i) to identify the key structural elements of the territories of WBW "*lilfordi*" and (ii) to analyze the effect of the WBW on the composition of the saproxylic fungi community within the territories.

2. Materials and Methods

2.1. Study Area

The sampling was carried out in Navarre's pre-Pyrenees, in the western side of the Quinto Real forests, which is defined as a Special Area of Conservation, near Eugi village (30N; X:621,417; Y:4,759,529) (Figure 1). This area has a temperate oceanic climate and in Eugi, specifically, the average annual temperature is 10 °C, and the average annual precipitation is 1450 mm [22]. This part of the Special Area of Conservation is mainly constituted by acidophilic pure beech forests (*Fagus sylvatica* L.)

with different characteristics along its extension due to the traditionally intensive management that took place, mainly between 1950 and 1970. The traditionally intensive management has created a mosaic of different patches as a result of uniform continuous harvests and thinning [23]. In the surroundings, mining is an important economic activity for the nearby villages, pigeon and deer hunting is often permitted, and livestock is regulated (and even prohibited in some places).



Figure 1. Map of Europe and Navarre, Eugi village is marked with a bullet-point in red. Images taken from Google Earth [24].

2.2. Sampling Methodology

In the area close to the mine, the WBW population had been monitored by Bioma Forestal experts, who noticed that in some forest patches apparently lacking the typical characteristics of the WBW territories, this species actually nests and vice versa. In those areas where WBW nests were observed and in close areas with key characteristics of the WBW territories where nests were not observed, 20 sample sites were located, 10 in WBW territories and 10 in non-WBW territories. Moreover, different forest structures in terms of appearance were taken into account when selecting the sample sites in order to capture the heterogeneity of both WBW and non-WBW territories (Appendix A, Table A1). The minimum distance between sample sites was 100 m. In each sample site, a circular plot of 500 m² was randomly located, in order to sample the structure of the forest, deadwood, and saproxylic fungi [25]. Moreover, as these circular plots had been previously shown to underestimate deadwood presence in this study area (according to Bioma Forestal experts), 10 large transects of 150–300 m length were located randomly, five in WBW territories and five in non-WBW territories (Figure 2b). In total, 1.43 ha were sampled inside WBW territories and 1.23 ha outside of them.

In each circular plot, slope, altitude, and orientation (north, south, east, and west) were recorded. Subsequently, tree cover and tree class (dominant, codominant, intermediate, dominated, and standing deadwood (snag)) was determined using a visual method, and the diameter of all trees bigger than 6 cm (diameter at the breast-height of 1.3 m, DBH) and the height of the four trees located on the cardinal points (nearest to the limit of the sample plot) was measured. Moreover, all microhabitat-bearing trees and microhabitat types were counted: dead branches (1), broken branches (2), snags (3), carpophores on the stem (4), debarking (5), cracks (6), picid cavities (7), basal holes with deadwood (8), hollow trees (9), and natural cavities (10) [25]. To measure deadwood, three transects of 15 m were located starting on the center of the plot in a direction of 30°, 180°, and 270°. In these, the diameter and decomposition state (with bark (C), without bark (SC), in a state to be cut with a knife (N), in a state to be broken with the fingers (D) and nearly disintegrated (Des)) of every piece of deadwood wider than 10 cm were recorded [25] (Figure 2). Then, tree regeneration was measured in three concentric circular sub-plots as follows: number of individuals of 10–40 cm height in a circumference of 5 m² (type 1 “Reg 1”), number of individuals of 40–130 cm height in 10 m² (type 2 “Reg 2”), and number of individuals of >130 height

and >5.6 cm diameter in 20 m² (type 3 “Reg 3”) [25] (Figure 2). Finally, all the macroscopic saproxylic fungi observed on every piece of deadwood of the circular plot were identified.

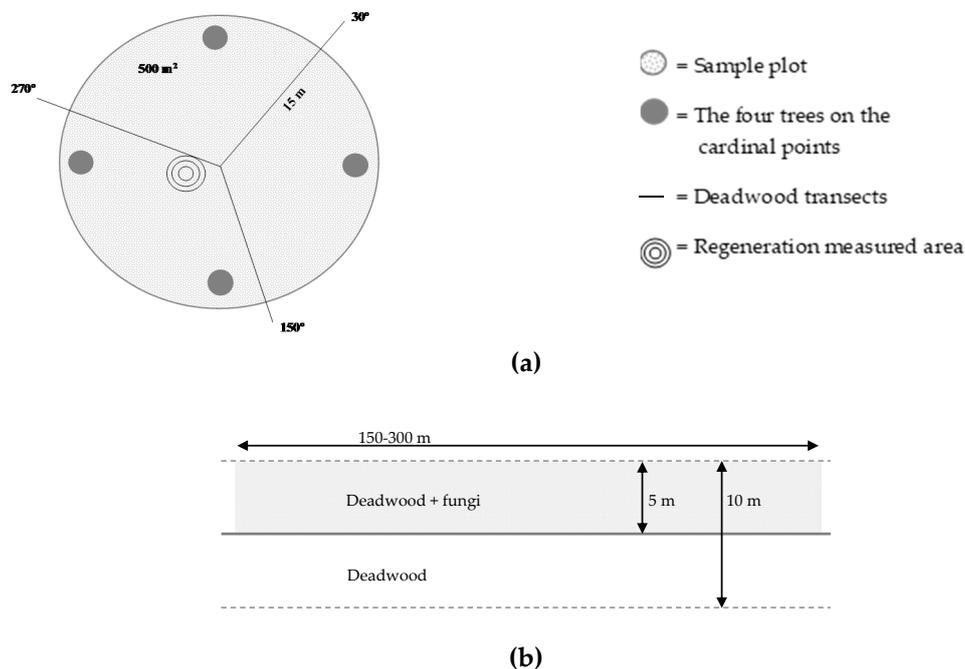


Figure 2. (a) Circular plots of 500 m² (the light grey), trees on the cardinal points (small dark grey circles), transects of 15 m oriented in 30°, 150°, and 270° (black line), concentric circular sub-plots of 5 m² (regeneration type 1), 10 m² (regeneration type 2), and 20 m² (regeneration type 3). Methodology based on Commarmot et al. [25] survey. (b) Transects of 150–300 m length and 5 m width to sample the saproxylic community and 10 m width to sample deadwood.

In each 150–300 m long and 10 m wide transect, the diameter and the class of all pieces of deadwood wider than 10 cm were recorded (using the method explained above), along with the position of the pieces (L = lying on the ground, Z = standing (snags), T = stump). This deadwood sampling was carried out to complement the data recorded in the circular plots’ transects, as previously discussed. Moreover, within the 150–300 m long transect and within a 5 m width, all the macroscopic saproxylic fungi observed on every piece of deadwood were identified. The sampling was carried out between April and May, in the WBW breeding season.

2.3. Data Analysis

To analyze the habitat structure, the following variables were calculated: tree basal area (m²/ha); tree density (tree/ha); density for each tree class (tree class/ha); tree-class diversity (CLdiv); density of regeneration depending on the type (individuals/ha); microhabitat diversity (MHdiv) and density (MHDtot) (microhabitat/ha); and density for each microhabitat type (MHD1-10) (microhabitat type/ha). Subsequently, to characterize deadwood, the following data were calculated: deadwood volume (m³/ha) and diversity (DW diversity); density for each deadwood class (number of pieces/ha); snag basal area (m²/ha), volume (m³/ha) and density (snag/ha); and number of saproxylic fungi taxa (Fungi taxa).

The diversity of tree class, deadwood classes, and microhabitats were calculated using the Shannon and Simpson diversity indices [26]. Deadwood classes were previously defined depending on their diameter (10 (5–15); 20 (15–25); and 30 (>25) cm) and decomposition state (as mentioned above). However, in the large transects of 150–300 m length, the positions of the pieces were also taken into account (as mentioned before).

The statistical analysis of the calculated variables was carried out with the R program 3.4.2 [27]. Firstly, the data of the WBW and non-WBW territories were compared by means of the Wilcoxon–Mann–Whitney U-test and t-test depending on the normality of the data. Afterwards, the distributions of tree DBH, tree classes, and deadwood classes were compared by the Kolmogorov–Smirnov test. Moreover, Spearman’s and Pearson’s correlations were carried out between all the variables. Subsequently, two principal component analyses (PCAs) were performed, one of them using the data obtained in the circular plots and the second one with the data obtained in the 150–300 m long transects, using R’s “factoextra” package. The variables that showed a significant correlation were represented by a single variable, which had the highest effect on the PCA axis. Finally, a rarefaction species richness curve as a function of deadwood volume was carried out ($q = 0$ according to the Hill numbers [28]) in order to compare this community between WBW territories and non-WBW territories.

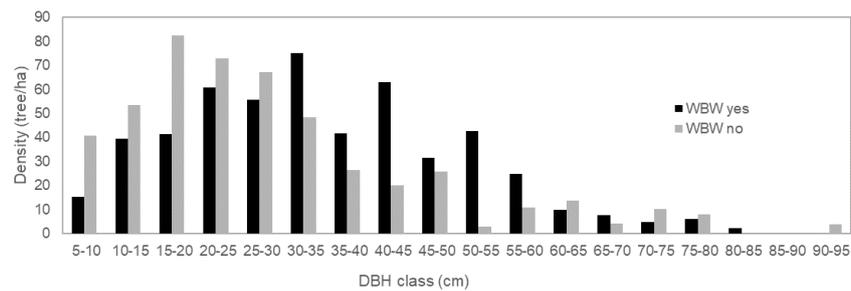
3. Results

All the WBW territories were oriented north or northeast, unlike the non-WBW territories, which were oriented both north and south. The comparison between WBW and non-WBW territories showed significant differences for altitude, tree height, tree basal area, snag basal area, Simpson diversity of tree classes, Shannon diversity of deadwood classes, snag volume, and Z20N-class deadwood (Table 1). The WBW territories were located in higher altitudes, in more heterogeneous (lower Simpson diversity index) and thicker forests (higher tree basal area) with taller trees (higher tree height) and a higher amount of standing deadwood (higher snag basal area). Moreover, the WBW territories showed a higher diversity of deadwood as well as bigger snags (Appendix A, Table 1). The rest of the assessed variables did not differ significantly between WBW and non-WBW territories (Appendix B, Table A2).

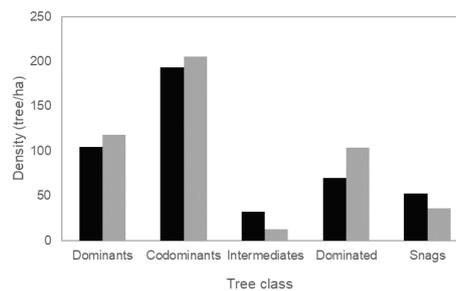
Table 1. Mean \pm standard error, and p -value of the variables measured and calculated that showed significant differences in white-backed woodpecker (WBW) territories and non-WBW territories in (a) the circular plots and, (b) the transects of 150–300 m length. “W” refers to the statistical value for the Wilcoxon–Mann–Whitney U-test and “t” for the t-test. Z20N = density of 20 cm diameter standing deadwood and in a state to be cut with a knife. * almost significant p -value.

Variable	WBW	Non-WBW	Statistic	p -Value
(a) Altitude (m)	897.5 \pm 21.87	769 \pm 15.65	W = 94	0.0009
Tree height (m)	20.27 \pm 0.97	14.54 \pm 1.04	t = 4.034	0.0008
Tree basal area (m ² /ha)	58.12 \pm 5.34	42.96 \pm 10.59	W = 82	0.0147
Snag basal area (m ² /ha)	3.48 \pm 0.97	1.25 \pm 0.91	W = 77	0.0423
Tree-class diversity (Simpson)	0.26 \pm 0.04	0.36 \pm 0.03	t = -2.067	0.0553 *
(b) Deadwood diversity (Shannon)	2.59 \pm 0.06	2.32 \pm 0.08	t = 2.618	0.0320
Snag volume (m ³ /ha)	6.16 \pm 0.64	1.19 \pm 0.34	t = 6.878	0.0004
Z20N (piece/ha)	8.46 \pm 2.74	0 \pm 0	W = 22.5	0.0254

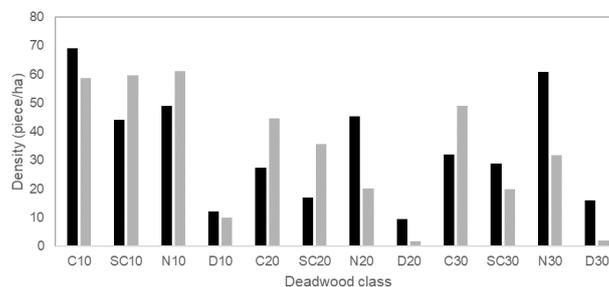
DBH class distribution showed higher values in WBW territories than in non-WBW territories ($p = 0.05$) (Figure 3a). The WBW territories showed a median of 33.25 cm and a mode of 30–35 cm, while the non-WBW territories showed a median of 24.05 cm and a mode of 15–20 cm. Regarding the giant tree category (DBH >80 cm), their density in WBW territories was 2.26 trees/ha, while in the non-territories it was higher, with 4 trees/ha. Moreover, in non-WBW territories the main tree classes were dominant and codominant (Figure 3b). In WBW territories, intermediate classes and snags were more relevant than in non-WBW territories (Figure 3b). Although deadwood-class distribution was not significantly different between the two territories, late-decomposition states (N and D) of thicker trees (20–30 cm diameter) showed higher densities in WBW territories (Figure 3c).



(a)



(b)



(c)

Figure 3. Bar chart of the distribution of diameter at breast-height (DBH) classes (a), tree classes (b), and deadwood classes (c) in WBW territories (“WBW yes”, black) and non-WBW territories (“WBW no”, grey). Deadwood classes are defined by letters indicating the decomposition state (C = with bark, SC = without bark, N = in a state to be cut with a knife, D = in a state to be broken with the fingers) and the diameter (10, 20, or 30 cm).

Moreover, 30 cm diameter deadwood density showed a positive significant correlation with number of saproxylic fungi taxa ($r = 0.698$; $p = 0.025$), Shannon diversity of deadwood with L30N-class deadwood ($r = 0.718$; $p = 0.019$), and deadwood diversity with deadwood volume ($r = 0.647$; $p = 0.002$). In addition, microhabitat diversity had a significant positive correlation with snag density ($r = 0.678$; $p = 0.001$) and snag basal area ($r = 0.736$; $p = 0.0002$).

The PCA of the circular plot variables explained 49.1% of the variance (Figure 4a), while the one for the transect variables explained 65.4% (Figure 4b). In both cases, the overlapping of the ellipses showed that the differences between the two territories did not differ strongly. For WBW territories, the main explanatory variables in circular plots were density and volume of snags, microhabitat density, tree height, and DBH, while those for transects outside of the circles were Shannon diversity of

deadwood and 20 cm diameter deadwood. Nevertheless, 10 cm diameter deadwood better explained the results for the non-WBW territories.

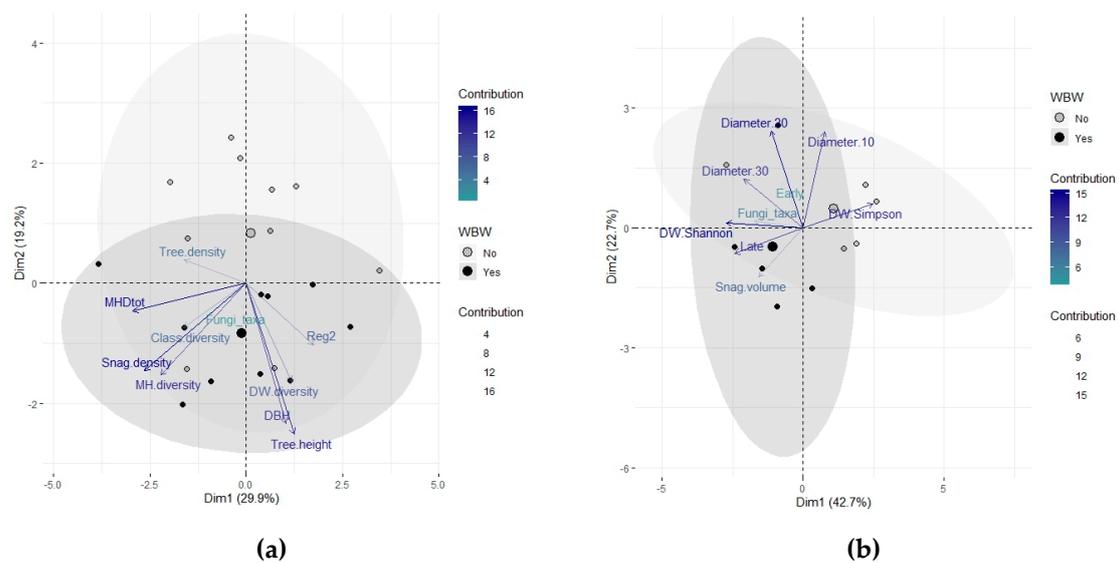


Figure 4. Principal component analysis (PCA) for circular plots (a) and transects (b). WBW territories (black; “yes”) and non-WBW territories (grey; “no”). The small dots represent each circular plot (a) and transect (b), the big dots represent the center of the ellipse. The longer the arrows, the higher the tendency of the variable towards a group. Dark arrows represent a high contribution of the variable when forming the graphics. MHDtot = total microhabitat density; MH = microhabitat; DW = deadwood; Fungi_taxa = number of fungi taxa; Reg2 = type 2 regeneration; Diameter 10, 20, 30 = density of 10, 20, or 30 cm diameter deadwood; Early decomposition = C and SC classes, Late decomposition = N and D classes. The drawn ellipses had a confidence level of 90%.

The rarefaction curves of the number of saproxylic fungi taxa as a function of deadwood volume showed that WBW territories had a higher richness for the same amount of deadwood (Figure 5). The species *F. fomentarius* appeared at a high frequency in WBW territories, while in non-WBW territories, it was absent (Appendix C, Table A3).

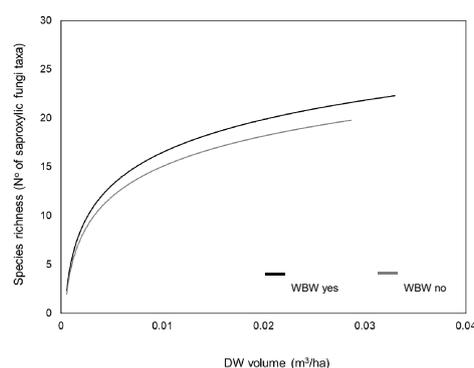


Figure 5. Rarefaction species richness curve (N° of saproxylic fungi taxa) as a function of deadwood (“DW”) volume (m³/ha) in WBW (black, “WBW yes”) and non-WBW territories (grey, “WBW no”).

4. Discussion

4.1. Key Elements of the WBW Nesting Habitat

The key elements of the territories of the population of “*lilfordi*” WBWs in Quinto Real in Navarre were high altitudes; structural heterogeneity, i.e., high diversity of tree class, high density of microhabitats, and large trees; as well as high diversity of deadwood, all of which are characteristics

of the mature forests. These results coincide with Grange et al. [3], Garmendia et al. [5], Barnard [9], and Fernández and Azkona [29], as far as Iberian populations of WBWs are concerned, and with Shurulinkov et al. [10] and Gerdzhikov et al. [30] in European populations. Although some studies have showed the importance of the higher amount of deadwood in WBW territories [5,9], there is not much information in relation to the impact of deadwood diversity or microhabitat density on the WBW's nesting-habitat preference.

Tree height was also relevant in the selection of the territories, as it has been observed that this bird makes its nests at heights of 11–14 m on beeches 19–20 m tall [3,31]. Moreover, the means for DBH in the studied forests were similar to the ones in the primary forests of Central Bohemia [32] and to others close to the Special Area of Conservation of Quinto Real [5]. In primary forests that have never been modified, DBH distribution shows an inverted “J” form and a peak around 70 to 80 cm [32,33]; however, in the studied area, the tree DBH distribution was normal, typical of managed forests [32], and its peak was between 30 and 40 cm, indicating that at some point this area had been managed, although not for a long time as some areas kept characteristics that allow the WBW to nest. Each area has been managed with a different intensity grade and at different moments. Therefore, although this area may not be the optimal habitat for this species, the WBW has adapted to the characteristics of the territory.

Another key element of WBW territories is the high amount of snags, although their volume has reflected the past management of the forests. In these WBW territories, snag volume was 3–6 times higher than the values found in the managed forests of Central Bohemia [32], but these values can reach up to 5 times lower than the values found in a primary forest of south-western Ukraine [25]. Some authors have observed that WBW distribution coincided with the number of big snags [5], as they are a source of food [31] and can be secure structures for the WBW to forage. Microhabitat density and diversity have also been shown to be relevant for the selection of WBW territories. In this study, snags and microhabitats were correlated, as snags can supply a wider variety and density of microhabitats as well. Although no deep research has been done on WBW dependence or preference for different microhabitats like dead branches [11] or holes [10], Domokos and Cristea [11] stated that this species is one of the most specialized in foraging microhabitats among European Picidae. However, it is not clear whether microhabitats are more abundant in old-growth forests due to the presence of snags [34] or in not so mature forests due to the presence of big trees that have not died yet [35]. Nevertheless, old trees offer a constant diversity and abundance of microhabitats for a long period of time, which may favor the presence of WBWs.

The diversity of deadwood size and decomposition states is also a key element of the WBW territories, which again reflects the higher complexity of these sites. In this study, diversity of deadwood diameters and decomposition states was higher in WBW territories than in non-WBW territories. In WBW territories, deadwood was thicker and more decayed than in non-WBW territories, which coincides with the comparisons made between non-managed and managed forests by Abrego and Salcedo [18] and Keren and Diaci [36]. This suggests that WBW territories might be more similar to non-managed forests than to the managed ones. In fact, deadwood diversity is very important as the insect supply of the forest changes during the seasons, and the WBW changes its feeding behavior according to its metabolic needs [37]. During the breeding season, when the WBW needs a high amount of energy, there is usually a high diversity and density of insects in the forest, so it can choose the most energy-rich food, which is usually the insects on the surface of deadwood [38]. In winter, the WBW still needs a high amount of energy to survive the cold temperatures [39]. Thus, it needs to exploit a supply that will have insects even in the least favorable seasons, like big logs and snags with boring-beetle-larvae. The large sizes of these pieces of deadwood allows the WBW to spend more time working on just one item, instead of having to search for more and wasting energy [37]. All this considered and combined with the fact that the WBW is very territorial, which makes it more difficult for it to change forest patch when deadwood supplies are not optimum, makes the high diversity of deadwood in the forest a key element for the WBW nesting. In contrast, deadwood volume has not

been shown to be as relevant as its diversity in WBW territories, even if different studies have proved that in WBW territories deadwood volume can be 1.38 times [40] or 3.5 times [9] higher than in sites where WBWs are not present. Nevertheless, Garmendia et al. [5] concluded that deadwood volume might only be a limiting factor when there are too many patches in the landscape with an insufficient deadwood volume.

4.2. Saproxylic Fungi Community

In this context, the higher number of saproxylic fungi taxa found in WBW territories might be related to the higher diversity of deadwood in those territories, as observed in other studies [17,41], and a higher amount of late-decay thick deadwood. In fact, deadwood supplies a high diversity of habitats for a high diversity of animals and fungi, especially those in late-decay, for example, for rare arthropod species that live inside them [42], for some specialized polyporoids that grow on them [17,41], and for saproxylic fungi taxa [18,42]. Moreover, the WBW might also facilitate saproxylic fungi dispersal, as Jusino et al. [12] and Jankowiak et al. [13] observed, since more saproxylic fungi taxa were found in WBW territories for the same deadwood volume. In this study, it was observed that WBWs may have a certain relationship with the fungi *Fomes fomentarius*, as it was recorded in all WBW territories, while it was absent in all non-WBW territories. These fungi usually grow on snags and thick logs [17], and they are widely dispersed across the landscape [43]. Therefore, the presence of a high density of snags and thick deadwood in WBW territories may have favored the presence of *F. fomentarius* in those territories. Nevertheless, this species is considered to be endophytic [44], living inside the stem inactively and being activated by the entry of oxygen (when a branch breaks, for instance) [45]. This way, the WBW could activate its growth, as it is a large bird and can dig larger cavities and get nearer to the stem core than other birds. Moreover, O'Daniels et al. [46] found that some hyphae reflect the light as eggs and feathers do, which may function as a signal for the woodpeckers. Thus, *F. fomentarius* could be one of the fungi taking part in the rotting of the nest trees of the WBWs or the WBWs could help the growth of these fungi when making the nest, although molecular analysis of the fungi in WBW nest trees would be necessary to make such assumptions. Thus, it would be interesting to make a more exhaustive analysis of this community by measuring the density of each species and identifying the species present in the stems of nesting trees, not only by sight but also at a molecular level, and analyze the possible interaction between *F. fomentarius* and the WBW.

5. Conclusions

In general, WBW territories resemble old-growth forests as they are structurally heterogeneous, with trees of different sizes and heights and prevailing the big and tall trees; a high diversity of deadwood, mainly big and late-decay deadwood; a high volume of snags; and a high microhabitat diversity, all of which is related to a high number of saproxylic fungi taxa. Though their past management has also been evident in the variability of some of those characteristics, this fact might show the plasticity of this species to adapt to different structural and compositional conditions of the territory. Moreover, the WBW might facilitate the colonization of some saproxylic fungi taxa on deadwood and its territories showed a special relationship with the fungi *F. fomentarius* which only appeared in these and at a high frequency.

The lack of high trees, large snags, and deadwood due to forest management in the territory has led to the lack of a suitable habitat for the WBW and its threatened state. Thus, to maintain and protect their populations, it would be necessary to guarantee the naturalness of their potential territories as well as to implement sustainable management that would guarantee a high structural, microhabitat, and deadwood diversity in the forest. This would lead to a more suitable forest for the WBWs to find habitats to nest and breed in, and at the same time, it would help conserve the biodiversity linked to them.

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Conflicts of Interest: There is no conflict of interest.

Appendix A

Table A1. The a priori quality of the circular plots (1–20P) and transects (1–10T) categorized as “High”, “Medium”, or “Low” based on their appearance and Bioma Forestal experts’ criteria. It is also shown whether the circular plots and transects were located in WBW territories (“WBW yes”) or no (“WBW no”).

Quality	Territory	
	WBW Yes	WBW No
High	3P, 4P, 9P, 19P, 2T, 3T, 4T	15P, 16P, 9T
Medium	1P, 2P, 7P, 10P, 20P, 1T, 5T	5P, 6P, 6T
Low	8P	11P, 12P, 13P, 14P, 17P, 18P, 7T, 8T, 10T

Appendix B

Table A2. Mean \pm standard error of the variables from the circular plots (a) and transects (b) in the WBW territories (WBW yes) and the non-WBW territories (WBW no). DW = deadwood; MH = microhabitat; MHD 1–10 = density of the microhabitat specified by the number; C, SC, N, D = density of DW in a state with bark (C), without bark (SC), to be cut with a knife (N), to be broken with the fingers (D); E10, E20, E30 = density of DW with a diameter of 10, 20, or 30 cm.

Variables	WBW Yes	WBW No
(a) Slope (m)	28 \pm 3.19	32 \pm 3.71
Tree cover (%)	87 \pm 5.44	90.5 \pm 4.59
DBH (cm)	35.25 \pm 1.84	31.7 \pm 4.27
DW diversity (Shannon)	0.77 \pm 0.16	0.37 \pm 0.13
DW volume (m ³ /ha)	0.0033 \pm 0.0006	0.0029 \pm 0.0008
Regeneration type 1 (ind./ha)	6387.24 \pm 5028	2411.06 \pm 1268.14
Regeneration type 2 (ind./ha)	2007.1 \pm 1189.38	623.7 \pm 623.7
Regeneration type 3 (ind./ha)	957.18 \pm 592.46	333.82 \pm 261.32
MH diversity (Shannon)	1.69 \pm 0.17	1.52 \pm 0.17
MHD1 (tree/ha)	52.98 \pm 20.37	31.15 \pm 12.15
MHD2 (tree/ha)	142.43 \pm 38.66	133.66 \pm 16.3
MHD3 (tree/ha)	64.03 \pm 15.7	45.57 \pm 16.07
MHD4 (tree/ha)	13.58 \pm 4.79	9.38 \pm 6.53
MHD5 (tree/ha)	139.9 \pm 25.21	123.65 \pm 18.01
MHD6 (tree/ha)	16.51 \pm 8.36	15.01 \pm 9.2
MHD7 (tree/ha)	13.58 \pm 4.79	9.38 \pm 6.53
MHD8 (tree/ha)	22.21 \pm 8.88	24.2 \pm 11.92
MHD9 (tree/ha)	11.44 \pm 6.29	0 \pm 0
MHD10 (tree/ha)	119.03 \pm 40.16	74.85 \pm 18.28
MHDtot (tree/ha)	59.56 \pm 11.29	46.29 \pm 6.75

Table A2. Cont.

Variables	WBW Yes	WBW No
Dominant (tree/ha)	104.6 ± 30.35	117.7 ± 24.23
Codominant (tree/ha)	193.01 ± 63.8	205.71 ± 20.55
Intermediate (tree/ha)	32.23 ± 17.59	12.45 ± 6.51
Dominated (tree/ha)	69.98 ± 16.77	103.51 ± 43.49
Snag (tree/ha)	52.15 ± 13.06	35.81 ± 15.12
Tree-class diversity (Shannon)	1.21 ± 0.07	1.06 ± 0.07
Tree density (tree/ha)	468.45 ± 66.38	383.98 ± 33.36
Fungi taxa number in sample plots	6 ± 0.89	5.7 ± 0.78
(b) Snag basal area (m ² /ha)	3.48 ± 0.97	1.25 ± 0.91
Snag density (snag/ha)	43.52 ± 10.37	19.05 ± 5.6
DW diversity (Simpson)	0.09 ± 0.01	0.11 ± 0.01
Fungi taxa number in transects	9 ± 0.35	7.4 ± 0.87
L10C deadwood-class density (piece/ha)	66.69 ± 18.47	51.87 ± 10.98
L10SC deadwood-class density (piece/ha)	39.88 ± 7.85	52.33 ± 9.95
L10N deadwood-class density (piece/ha)	44.08 ± 14.93	59.86 ± 11.09
L10D deadwood-class density (piece/ha)	10.69 ± 2.23	8.58 ± 5.1
L20C deadwood-class density (piece/ha)	23.32 ± 6.34	37.49 ± 9.44
L20SC deadwood-class density (piece/ha)	13.08 ± 4.69	14.76 ± 4.84
L20N deadwood-class density (piece/ha)	35.8 ± 5.39	17.39 ± 7.71
L20D deadwood-class density (piece/ha)	3.31 ± 1.63	1.6 ± 1.6
L30C deadwood-class density (piece/ha)	19.74 ± 4.95	30.74 ± 11.49
L30SC deadwood-class density (piece/ha)	7.72 ± 4.75	10.67 ± 9.09
L30N deadwood-class density (piece/ha)	48.49 ± 10.36	21.33 ± 19.71
L30D deadwood-class density (piece/ha)	13.23 ± 5.71	0.67 ± 0.67
Z10C deadwood-class density (piece/ha)	0 ± 0	4.8 ± 4.8
Z10SC deadwood-class density (piece/ha)	0.89 ± 0.89	0.67 ± 0.67
Z10N deadwood-class density (piece/ha)	2.87 ± 1.76	1.33 ± 1.33
Z10D deadwood-class density (piece/ha)	0 ± 0	0 ± 0
Z20C deadwood-class density (piece/ha)	2.81 ± 1.73	5.78 ± 2.93
Z20SC deadwood-class density (piece/ha)	2.96 ± 2.96	0.67 ± 0.67
Z20D deadwood-class density (piece/ha)	2.96 ± 2.96	0 ± 0
Z30C deadwood-class density (piece/ha)	7.82 ± 0.92	3.17 ± 2.42
Z30SC deadwood-class density (piece/ha)	4.7 ± 2.67	0.67 ± 0.67
Z30N deadwood-class density (piece/ha)	9.78 ± 3.59	2.67 ± 2.67
Z30D deadwood-class density (piece/ha)	0 ± 0	0 ± 0
T10C deadwood-class density (piece/ha)	2.5 ± 1.55	1.96 ± 1.3
T10SC deadwood-class density (piece/ha)	3.33 ± 3.33	6.76 ± 5.01
T10N deadwood-class density (piece/ha)	2.06 ± 1.56	0 ± 0
T10D deadwood-class density (piece/ha)	1.48 ± 1.48	1.33 ± 1.33
T20C deadwood-class density (piece/ha)	1.39 ± 1.39	1.25 ± 1.25
T20SC deadwood-class density (piece/ha)	0.89 ± 0.89	20.28 ± 12.1
T20N deadwood-class density (piece/ha)	1.11 ± 1.11	2.62 ± 1.61
T20D deadwood-class density (piece/ha)	3.11 ± 2.18	0 ± 0
T30C deadwood-class density (piece/ha)	4.43 ± 1.43	15.21 ± 10.34
T30SC deadwood-class density (piece/ha)	16.48 ± 6.16	8.45 ± 4.11
T30N deadwood-class density (piece/ha)	2.67 ± 2.15	7.87 ± 4.91
T30D deadwood-class density (piece/ha)	2.72 ± 1.71	1.33 ± 1.33
C decomposition-state density (piece/ha)	128.7 ± 21.02	152.27 ± 27.18
SC decomposition-state density (piece/ha)	89.94 ± 17.77	115.25 ± 22.42
N decomposition-state density (piece/ha)	155.32 ± 19.26	113.08 ± 34.21
D decomposition-state density (piece/ha)	37.51 ± 9.13	13.51 ± 6.93
E10 diameter deadwood density (piece/ha)	33.11 ± 9.51	37.08 ± 5.28
E20 diameter deadwood density (piece/ha)	18.01 ± 4.11	18.43 ± 3.13
E30 diameter deadwood density (piece/ha)	25.17 ± 5.5	19.35 ± 8.31

Appendix C

Table A3. Observed fungi species in WBW territories (WBW yes) and non-WBW territories (WBW no). Presence of a species is marked based on the number of transects and circular plots in which it appeared: – (0 times), + (1–5 times), ++ (6–10 times), and +++ (11–15 times).

Fungi Species	WBW Yes	WBW No
<i>Hypoxylon fragiforme</i>	+++	+++
<i>Hypoxylon cohaerens</i>	+++	+++
<i>Stereum hirsuta</i>	+	+
<i>Stereum gausapatum</i>	+	+
<i>Stereum insignitum</i>	+	+
<i>Stereum</i> sp.	+	-
<i>Trametes versicolor</i>	+	+
<i>Trametes gibbosa</i>	+	+
<i>Trametes ochracea</i>	+	-
<i>Exidia glandulosa</i>	+	+
<i>Myxarium nucleatum</i>	+	+
<i>Eutypella quaternata</i>	+	++
<i>Bertia moriformis</i>	++	++
<i>Chlorociboria aeruginascens</i>	+++	++
<i>Biscogniauxia nummularia</i>	++	++
<i>Diatrype disciformis</i>	++	+
<i>Nemania serpens</i>	+	-
<i>Nemania carbonacea</i>	+	+
<i>Ganoderma applanatum</i>	-	+
<i>Fomes fomentarius</i>	++	-
<i>Fomitopsis pinicola</i>	+	+
<i>Phellinus igniarius</i>	+	+
<i>Loweomyces fractipes</i>	+	+
<i>Pleurotus ostreatus</i>	+	+
<i>Henningsomyces candidus</i>	+	-
<i>Polyporus tuberaster</i>	+	-
<i>Pholiota</i> sp.	+	-
<i>Entoloma hebes</i>	-	+
<i>Polyporus</i> sp.	+	+
<i>Phlebia radiata</i>	+	+
<i>Nectria cinnabarina</i>	-	+
<i>Schizophyllum commune</i>	-	+
<i>Lenzites betulina</i>	-	+
<i>Dacrymyces stillatus</i>	+	-
<i>Crustomyces subabruptus</i>	+	-
<i>Junghuhnia lacera</i>	-	+
<i>Dentipellis fragilis</i>	+	-
Non-identified	-	+

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