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The importance of standing deadwood in white-backed woodpecker (*Dendrocopos leucotos*) habitat from deciduous forests in central Romania

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Abstract The white-backed woodpecker (*Dendrocopos leucotos*) is one of the bird species which depends on dead and dying trees as their most important habitat resource. Because of this, it is affected by forest management that removes deadwood and changes the structure of old stands. In Romania, its relations with the structures of forests with and without management, including standing deadwood, are not known. The main objectives of this study were the analysis of the most representative elements of snags in its specific habitat – mainly beech forest in low mountains from central Romania. Based on the presence-absence of species, by applying the standard woodpeckers monitoring protocol using a total of 25 fixed points we compared deadwood variables (snag density, volume, basal area) for the entire study area, regardless of forest structure and management, and for stands over 70 years old, as potentially suitable or optimum habitat for the species. The comparison between plots with and without analysed species shows several significant differences especially regarding the number of snags, volume and basal area mainly for stands older than 70 years. The PCA of the variables for the trees with a DBH > 10 cm explained 74.4% of the variance, but for the very large trees (DBH > 40 cm) this percent is the highest one (89.9%). At the same time, the values of several variables (e.g. snag volume, basal area) are similar or higher than those in various areas of Europe. As a main conclusion, these forests are suitable or optimal for white-backed woodpecker and the Romanian forest management can be considered "closer-to-nature" at least for beech stands but for maintaining and improving the species typical habitat structure a few conservation measures should be applied in addition.

Keywords: white-backed woodpecker, standing deadwood, deciduous stands, forest management.

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Introduction

Europe's forests, including those in Romania, have historically suffered area losses, but also structural changes. In Romania, it is estimated that without anthropic influences, forest ecosystems occupied between 70-80% of the national territory in the Neolithic period (Biriș 2017), and currently, they only occupy approximately 28% (https://insse.ro/cms/ro/content/statistica-activitatilor-din-silvicultura-in-anul-2022). Structurally, the current forests in Europe and Romania are different from the ancestral ones, where man did not intervene significantly. Thus, these changes can be found in the forest types, their composition, age, etc. Another impact of forest management is the removal of deadwood (Roberge et al. 2008a, 2008b), an essential element for many species, as a critical resource for forest biodiversity (Jonsson et al. 2005). In Romania deadwood is partially removed by different cuttings, such as: sanitary, salvage loggings, all other main cuttings (OM 2534/2022) with some rules and exceptions in protected areas.

One of the species with narrower habitat requirements, which needs large amounts of deadwood, is white-backed woodpecker (*Dendrocopos leucotos*) - WBW (Keller et al. 2020). Some studies have shown that dead and dying trees are the most important resource for the WBW (Wesołowski 1995, Walankiewicz et al. 2002). For this reason, this species is considered an indicator of forest biodiversity (Mikusiński et al. 2001) or has been proposed as an umbrella species in habitats represented by mature or old deciduous forests with significant amounts of deadwood (Roberge et al. 2008b, Angeleri et al. 2024). Modern forestry has affected the species, especially by extracting deadwood from the forest (Hagemeijer & Blair 1997). Clear cutting, removal of deadwood from the forest and intensive forest management in general are the most important threats to the species and the fragmentation of the habitat together with the applied forest management, can even cause the extinction of some local populations (Carlson 2000).

In this context, over time, the species has had population declines at the European level, such as those in Poland, Norway, Lithuania, Latvia, Ukraine, etc. (Hagemeijer & Blair 1997). Moreover, historically the species probably occupied large areas of western Europe, being later affected by the clearance of the forest and the cutting of lowland deciduous forests (Hagemeijer & Blair 1997). However, the species has had some recent expansions of its breeding territory, as is the case in Germany, the Czech Republic and Switzerland and at the European level its trend is considered stable (Keller et al. 2020).

If in Europe there are several discontinuities in the breeding distribution area (Keller et al. 2020), in Romania, at least in the Carpathian Mountains, the species has a continuous distribution, being the characteristic of deciduous or mixed forests in the hill and mountain areas. The only totally isolated populations are in the south-eastern part of Romania (Dobruja) (Atlas II 2022).

The European breeding population of the WBW represents 35% of the world population of the species, with a significant population in central Europe. The actual Romanian breeding population of WBW was estimated at 16,633-55,564 pairs. This is by far the largest population in an EU member state (Atlas II 2022). Comparing the last two monitoring cycles at the national level, an apparent increase in the number of pairs is observed, from 8,500-35,000 for the 2001-2013 interval to 16,633-55,564 pairs in the 2013-2018 interval (Hagemeijer & Blair 1997, Atlas II 2022). Most probably, this increase is due to better field observation coverage and an improved monitoring protocol. In our study area there were estimated 20-61 pairs which represent 1-3 pairs/100 ha (Ionescu et al. 2023). Thus, the species density is similar with those found in its favorable or optimal habitats at the European level (Ionescu et al. 2023).

The purpose of the current study is to assess the importance of standing deadwood for WBW in the conditions of a Romanian deciduous forest habitat. This habitat corresponds to the requirements of the species in relation to the composition of the forest (almost exclusively deciduous, dominated by beech *Fagus sylvatica*) and the altitude (approx. 600-1300 m) (Hagemeijer & Blair 1997, Atlas II 2022).

Our main objectives were the analysis of the most representative variables and elements of standing deadwood in the habitat of the species. Based on the presence and absence of the WBW, we compared dead wood variables in two situations: forest habitats where the species has been identified and not, regardless of the stand structure (e.g., the age of the stand) and management, considering the entire study area, and forest stands over 70 years old, as potentially suitable or optimum habitat for the species where WBW has been identified and not. We compare our results with previous findings in different European countries and we propose measures to preserve the habitat of the species related to forest management.

Materials and Methods

Study area

The study area is part of central Romania, Perșani Mountains (Eastern Carpathians), (45°43'N 25°22'E - Figure 1). Concerning the altitude, this area belongs to the group of low mountains in Romania (the minimum altitude is 560 m and the highest peak is 1292 m). This is called Măgura Codlei (MC) and it amounts to approx. 2000 ha covered by forest as part of a Natura 2000 Site – ROSPA0037 Dumbrăvița-Rotbav-Măgura Codlei (Ionescu et al. 2023, https://natura2000.eea.europa.eu/Natura2000/SDF.aspx?site=ROSPA0037).

Deciduous forests cover the whole forested area except some coniferous plantation stands (mainly represented by Scots pine *Pinus sylvatica* and Black pine *Pinus nigra*). The primary forest type within the MC area is beech forest (beech is the dominant tree species), then mixed sessile oak – beech stands and pure sessile oak stands (*Quercus petraea* is the dominant tree species) partially with hornbeam (*Carpinus betulus*). Other deciduous tree species as components of the forest are Norway maple (*Acer platanoides*), European ash (*Fraxinus excelsior*), etc. Concerning the forest age (Forest management plan, 2014), there are both even-aged and uneven-aged stands. Thus, the area is covered mainly by mature stands (forests over 80 years) which represent about 60 % of MC's total forested area (Ionescu et al. 2023). Almost 300 ha on the steep of MC have been studied from the point of view of the stand's naturalness, being identified as old-growth quasi-virgin stands (IRISILVA 2022).

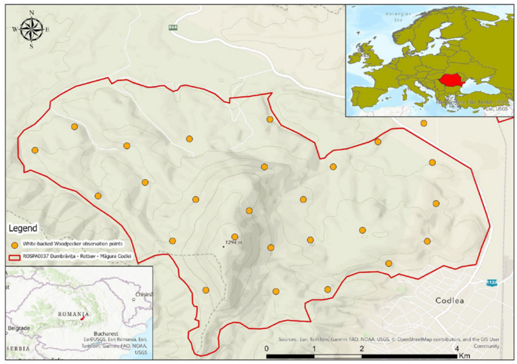


Figure 1 Study area and the observation points for white-backed woodpecker monitoring in ROSPA0037 Dumbrăvița - Rotbav - Măgura Codlei.

Concerning the forest management within the study area, it is applied to most of the forest area but with different cutting types and intensities (Forest management plan, 2014). The most used forest treatment (cutting) in mature/old stands is that of shelterwood cutting based on regeneration gaps within stands. Conservation cuts were made on steep slopes and on other stands with protection aims, similar in technique and purpose to shelterwood. Some of the mature stands are not subject to main cuttings, but sanitation harvestings (sanitary cuttings) and salvage loggings are used to them. In this case, especially dead-standing and downed trees are cut down and removed. The management plan of the Natura 2000 Site provides some restrictions on such cuts to keep some of the essential trees for biodiversity (e.g., trees/ha of the categories such as snags, hollow trees, etc.; OM 999/2016). For the young stands which have yet to reach the age of harvesting, repeated thinning is applied. There will be other changes regarding forest management within Natura 2000 Site, such as changing the types of cuttings in several forest units such as only sanitary cuttings instead of some shelterwood (Ionescu et al. 2023).

WBW surveys

WBW survey follows the national woodpecker monitoring scheme (Standard guide for monitoring bird species of community interest, 2020) to build the data collection protocol (Ionescu et al. 2023). The method is based on point monitoring (vantage point), with a minimum distance between observation points of 500 m. This is the point count method usually used in woodpecker surveys (Roberge et al. 2008a, Baumgardt et al. 2014, Ettwein et al. 2020). The observation points were randomly selected within the study area based on stratified random sampling (5 squares of 2 x 2 km², each of them with 5 points). According to the size of the study site, 25 points resulted (Figure 1). All points are found in the potential habitat of the species, including the altitude for the territory of Romania (550-1230 m in our stands; over 400 m nationally, according to Atlas II 2022). Considering the randomized stratification of the points, all points overlap proportionally with forest habitats, on all forest types in terms of composition and age. Thus, the WBW habitat was uniformly covered by points, 70% of points are in mature stands (over 70 years) and 30% in younger (under 70 years) which corresponds to the distribution of stands by age within the study area.

In case of difficult conditions for accessing the points, they were relocated in a stand with similar characteristics to a maximum of 400 m from the initial point and a minimum of 500 m from any other point.

For each point, one visit was performed per breeding season and the method was applied in two consecutive years, 2021 and 2022 (Ionescu et al. 2023). The species was considered present in a point if it was identified in at least one of the two field visits. These rules are used in specific woodpeckers' surveys using the point count method with one field session/year (Roberge et al. 2008a). All observations were made during March-April. Only in the case of 2022, due to the weather conditions, for those points above 1100 m the observations were made at the beginning of May (Ionescu et al. 2023). However, the usual survey period of this species is March-April (May) (Czeszczewik & Walankiewicz 2006, Roberge et al. 2008a, Ettwein et al. 2020).

The observations were conducted by at least two observers during morning hours, between 6 and 12 o'clock and only in favorable weather conditions, using playback. For playback were used standard recorded calls and/or drumming of the target species, within the official monitoring of woodpeckers at the national level (Ionescu et al. 2023).

The recording of calls and drumming included woodpecker species specific to forests in Romania. The WBW sequence follows three other species (*Dryobates minor*, *Dendrocoptes medius* and *Dendrocopos major*). In all cases, WBW responded exclusively to the sounds of the species, not being influenced by the calls or drumming of other species.

For our study, the total recording time for WBW is 2 minutes and it has the following structure: 2 repeated sequences, each 1 minute of playback (drumming and calls), 1 minute of listening. One minute of playback is also used in WBW monitoring / studies (Ettwein et al. 2020). We used the same loudspeaker as in the national monitoring scheme for woodpeckers: a JBL type (model FLIP5) which produces 360-degree sound. Thus, it was in a fix position during the playback producing sounds spread all around. Considering the relatively large territory of the species and the fact that it reacts generally from maximum distances of 200-250 m from the source in the forest condition (our pers. obs.), the sound amplitude was selected in this sense. Thus, as in the case of the national monitoring protocol for woodpeckers, we used the maximum sound amplitude of the mobile phone and also for loudspeaker otherwise there would have been the possibility that certain birds would not hear the sounds and thus not react. The amplitude of the broadcast signals was perceived by us and by the experts who designed the entire national woodpecker protocol comparative to the natural calling and drumming events (Standard guide for monitoring bird species of community interest 2020, Ionescu et al. 2023). It was tried to match by ear the amplitude of the playback with that of natural events.

Regarding the date and time of the observation, in addition to the basic rules of the national protocol, we took into account the fact that the probability of detection decreases with the time of the day and from March to May (Ettwein et al. 2020).

During the observations, all woodpeckers were recorded. For each individual heard or seen, we recorded the observation time, the initial position and estimated distance from the observer, the subsequent direction of movement and behavior. All the observations were integrated into an ArcGIS database, using the marked location for each woodpecker (Ionescu et al. 2023).

The rigorous application of the described method, with the stated rules, eliminates the possibility of not detecting individuals and a false unoccupied territory, as well as double counting. Thus, we assume that we have actually detected all occupied territories in our sample based on presence/absence.

Standing dead wood measurements

We measured the standing deadwood (snags as standing deadwood with a height >1.30 m and stumps as standing dead wood with a height ≤1.30) in all observation points as a circular plot with a 30 m radius (area of 0.2827 ha) during 2022-2023 season (winter-spring). In all these plots, there were no interventions / cuttings between the period of the woodpecker's inventory and the time of measuring the deadwood.

We measured the diameter at breast height (DBH) of all dead trees with a DBH ≥10 cm and also the height. There were considered three classes of diameters (≥10 cm, ≥20 cm and ≥40 cm) for which several variables were measured or calculated, such as: dead trees density (number of pieces/ha), DBH of dead trees/ha, height of dead trees/ha, standing deadwood volume/ha (m^3/ha) (Giurgiu & Draghiciu 2004), basal area of deadwood (m^2/ha). These diameter classes are used in different studies on woodpecker's habitat structure (Roberge et al. 2008a, Urkijo-Letona et al. 2020).

Statistical analysis

For the whole population including the 23 sampled plots (two points were excluded due to non-representative conditions and inaccessibility), descriptive statistics (mean, median, minimum, maximum, range, standard deviation, standard error of mean) were calculated for all considered variables: elevation, number of snags per hectare (for trees having a DBH larger than 10, 20 and 40 cm), mean height (for all stands), but also separated by stand age (>70, <70 years), mean DBH (for trees having a DBH larger than 10, 20 and 40 cm), at population level but also separated by stand age (>70, <70 years), deadwood volume and basal area (for trees having a DBH larger than 10, 20 and 40 cm), at population level but also separated by stand age (>70, <70 years).

To check if there are statistically significant differences between the group of plots with presence of white-backed woodpecker (WBW, n=8) and the group of plots without white-backed woodpecker (No WBW, n=15), we applied the non-parametric Kruskal-Wallis H test instead of one-way ANOVA due to not fulfilling of assumptions necessary to a parametric test (lacking of data normality, tested by Shapiro-Wilk test and not validity of homoscedasticity of variances, proofed by Levene's test, $p < 0.05$).

To determine the key factors influencing the presence of WBW in the sampled plots, a principal component analysis (PCA) was performed for each of the tree size categories (DBH >10 cm, >20 cm, >40 cm) using the following variables: mean height, mean DBH, basal area, volume and number of snags, but also the presence of WBW. A univariate logistic regression was run to detect the thresholds values of number of snags per hectare, deadwood basal area per hectare and deadwood volume per hectare in determining the WBW presence. For the logistic regression model, a logit model was built by applying the GLM function in R and using the logit-link-function, by specifying family = 'binomial'.

All statistical analyses were performed using Statistica 8.0 (Statsoft 2007) and R 4.1.2 (R Core Team 2024) softwares.

Results

From the total of 25 points, two were excluded from the evaluation of dead wood. Thus, one point overlapped a small isolated stand of 6 ha which is not representative for this assessment, and the other was inaccessible for measurements.

For both years out of the total of 23 points considered, WBW was identified in 8 points (35%). From the total of 17 points with forests over 70 years old, in 8 points the species was identified (47%). There were no major differences between the two years (2021 and 2022) regarding presence-absence of the WBW / point. Thus, in 2021 WBW was detected in 6 points and in 2022 in 8 points. Of these, 5 points were common to the two years.

The comparison between WBW and non-WBW plots showed significant differences for the number of snags having a DBH larger than 20 cm and for the number of snags having a DBH larger than 40 cm, while if we consider only the old stands (> 70 years), all three DBH classes populations (>10 cm, >20 cm, and >40 cm) showed significant differences for the number of snags (Figure 2a, Table 1).

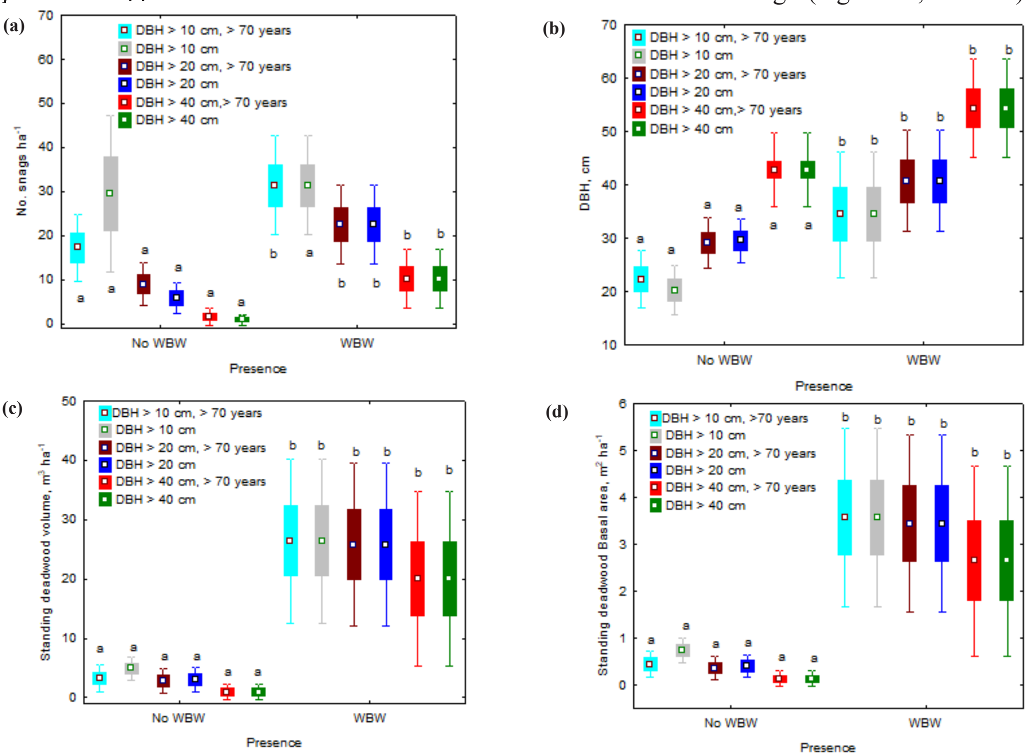


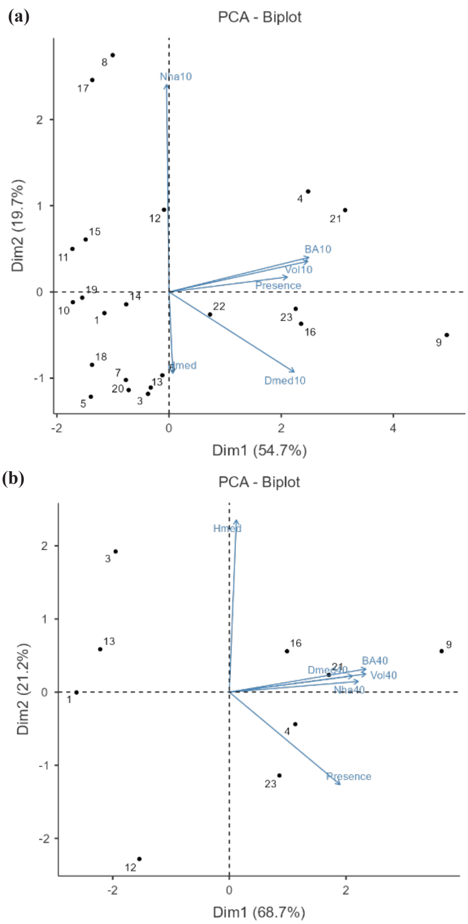
Figure 2 Number of snags (a), mean DBH (b), standing deadwood basal area (c) and standing deadwood volume (d) for trees having DBH > 10 cm, > 20 cm, > 40 cm (all stands and >70 years old stand). Middle point: mean value, box: mean ± standard error; whisker: mean ± 95% confidence interval. Different letters denote significant difference between plots with WBW and plots without WBW ($p < 0.05$, KH-W test)

Table 1 Relationship between deadwood and presence of WBW: results of univariate logistic regression model.

Deadwood variable	Coefficients		Std. error	Z value	Pr (>|z|)
Number of snags (>10 cm DBH), no ha-1	Intercept	-0.7119	0.667	-1.066	0.286
	Variable	0.0027	0.016	0.167	0.868
Number of snags (>20 cm DBH), no ha-1	Intercept	-3.8744	1.534	-2.524	0.012*
	Variable	0.2498	0.101	2.451	0.014*
Number of snags (>40 cm DBH), no ha-1	Intercept	-1.9288	0.728	-2.647	0.008**
	Variable	0.3247	0.144	2.245	0.025*
Deadwood basal area (>10 cm DBH), m^2 ha-1	Intercept	-4.2450	1.898	-2.236	0.025*
	Variable	2.5860	1.481	1.746	0.081
Deadwood basal area (>20 cm DBH), m^2 ha-1	Intercept	-4.2620	1.956	-2.179	0.029*
	Variable	3.3750	1.910	1.767	0.077
Deadwood basal area (>40 cm DBH), m^2 ha-1	Intercept	-1.8938	0.709	-2.669	0.007**
	Variable	1.7173	0.972	1.767	0.067
Deadwood volume (>10 cm DBH), m^3 ha-1	Intercept	-3.6589	1.545	-2.368	0.018*
	Variable	0.2998	0.168	1.780	0.075
Deadwood volume (>20 cm DBH), m^3 ha-1	Intercept	-3.4551	1.443	-2.394	0.017*
	Variable	0.3286	0.177	1.855	0.064
Deadwood volume (>40 cm DBH), m^3 ha-1	Intercept	-1.8421	0.696	-2.646	0.008**
	Variable	0.2118	0.116	1.817	0.061

No significant difference was found between the two plot groups regarding the mean height. However, significant differences in mean DBH were tested for plots older than 70 years irrespective of DBH size (>10 cm, >20 cm, and >40 cm) (Figure 2b, Supplementary Table S1, p< 0.05). This significant difference between WBW and non-WBW plots remains valid also for volume and basal area for older than 70 years stands (p values < 0.05, KW-H test, Table S1, Figure 2d, Figure 2c). Although around 150 m higher elevation characterizes the plots where WBW was recorded, no significant difference in elevation was found between plots with WBW and plots without WBW (Table S1).

The PCA of the variables for the trees with a DBH > 10 cm explained 74.4% of the variance (Figure 3a), for the trees having a DBH > 20 cm the explained variance increased to 79.9% (Figure 3b), while for the very large trees (DBH > 40 cm) the proportion of the variance explained by the considered variables is the highest one (89.9%) (Figure 3c). In the first case of including all found snags (DBH> 10 cm) in PCA, the main explanatory variables were deadwood basal area and volume, and the presence of WBW showed the highest correlation with both these variables. The same pattern was found also for the trees



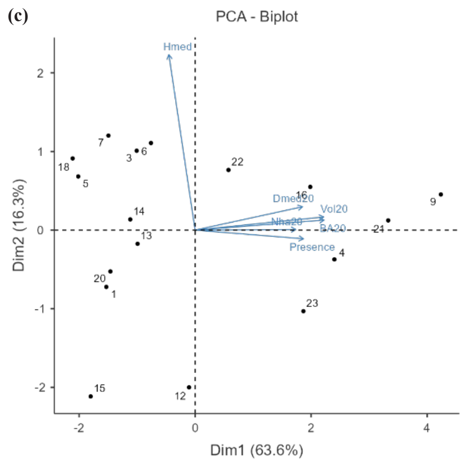


Figure 3. Principal component analysis (PCA) for trees having a DBH > 10 cm (a), DBH > 20 cm (b) and DBH > 40 cm (c).

having a DBH larger than 20 cm, where the presence of WBW was strongly correlated also with number of snags per hectare and mean DBH. In the case of largest trees (DBH > 40 cm), again, the main explanatory variables were basal area, volume, number of snags and mean DBH, but the correlation of these variables with the presence of WBW was lower. In all three cases, mean height of snags and presence of species were independent (Figure 3a, 3b, 3c).

The probability of WBW occurrence reached 100% when the number of snags having a DBH > 20 cm was >35 snags per hectare (Figure 4b, Table 1, $p = 0.014$), or the number of snags larger than 40 cm was > 20 snags per hectare (Figure 4c, Table 1, $p = 0.008$), while the occurrence of WBW was not related to the number of snags per hectare when all trees were considered (DBH > 10 cm) (Figure 4a, Table 1, $p > 0.05$).

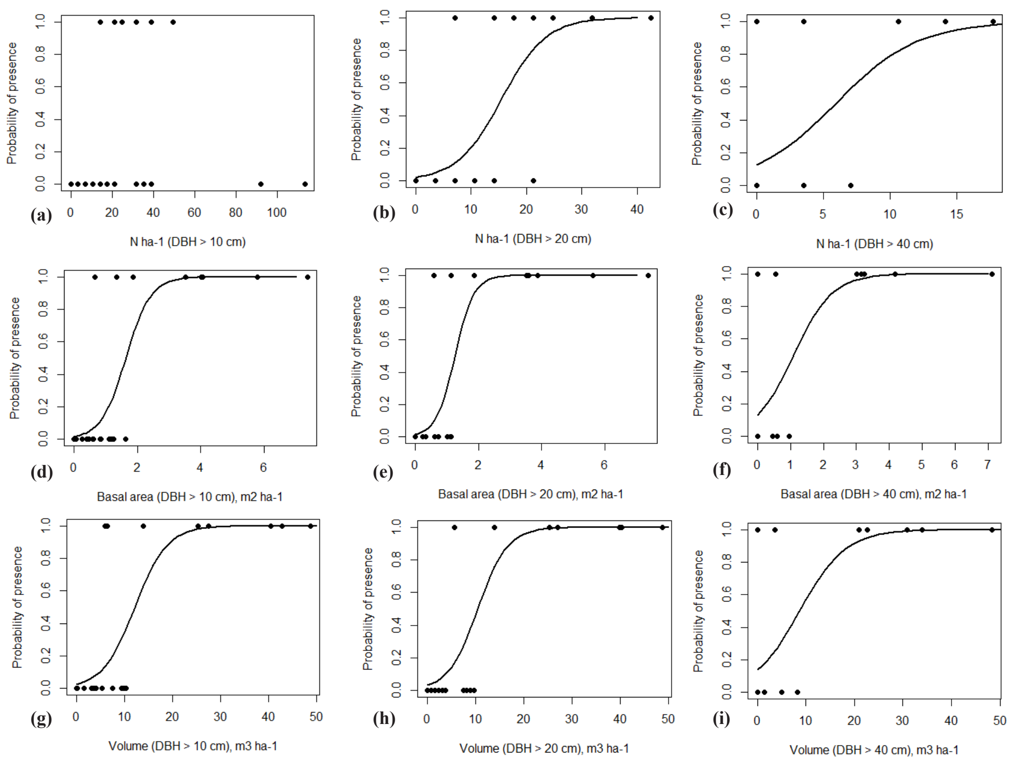


Figure 4. Relationship between the presence of WBW and different deadwood indicators (number of snags per hectare – a, b, c; deadwood basal area per hectare – d, e, f; deadwood volume per hectare – g, h, i) modeled by univariate logistic regression model.

A probability of 100% of WBW presence corresponds to a basal area of snags of 3 $m^2 ha^{-1}$ for all trees (DBH > 10cm) (Figure 4d), 2.5 $m^2 ha^{-1}$ for trees having a DBH > 20 cm (Figure 4e) and 3.5 $m^2 ha^{-1}$ for the largest ones (DBH > 40 cm) (Figure 4f). The volume of standing deadwood trees yielding a probability of presence of 100% for WBW would be approximately 25 $m^3 ha^{-1}$ for trees with DBH > 10 cm and for those with a DBH > 20 cm and 30 $m^3 ha^{-1}$ for the largest trees (DBH > 40 cm). However, the significance of logistic model coefficients corresponding to the independent variable is marginally proofed (very close to 0.05) both for basal area ($p = 0.08$, 0.07, 0.06 respectively, Table 1) and for volume ($p = 0.07$, 0.06 and 0.06 respectively, Table 1), although the significance for the model intercept is found statistically significant for all cases ($p < 0.05$, Table 1).

Discussion

The white-backed woodpecker thrives in old-growth forests rich in deadwood. These habitats provide essential resources for feeding, nesting and shelter (Roberge et al. 2008a). The present study analyzed white-backed woodpecker (WBW) presence across 23 points (two points were excluded due to non-representative conditions and inaccessibility). Our results suggest that the species has a relatively uniform distribution in the study area, occupying almost 50% of the mature stands (over 70 years) as potential suitable or optimum habitats. This situation is found in the conditions where about 85% of the forest are managed stands with different cutting types applied over time. Only about 250 ha have not been affected by forest management, being stands on steep and rocky slopes, proposed for inclusion in the National Catalog of Virgin and Quasi-Virgin Forests in Romania (IRISILVA 2022). In addition, the estimated density of WBW breeding population in the study area (1-3 breeding pairs/100 ha) is comparable to those found in its favorable and optimal habitats at the European level (Ionescu et al. 2023).

Regarding deadwood, the study found significant differences in the number of snags between WBW and non-WBW plots, specifically in snags larger than 20 cm and 40 cm DBH. While there was no significant difference in mean height, significant differences were noted in mean DBH, volume and basal area for stands older than 70 years. The significant difference in the number of snags larger than 10 cm and 40 cm DBH between WBW and non-WBW plots aligns with the existing literature on the species' habitat preferences. Studies consistently highlight the importance of larger diameter snags for WBW, which require substantial trees for nesting and foraging. For instance, Mikusiński et al. (2001) demonstrated that woodpecker density, including WBW, correlates positively with the volume of larger diameter deadwood. Similarly, Roberge et al. (2008a) found that larger diameter snags are more likely to host woodpecker nests due to their increased structural integrity and higher likelihood of containing suitable cavities for nesting.

Regarding other woodpecker species, studies on the three-toed woodpecker (*Picoides tridactylus*) have demonstrated a preference for larger diameter snags for foraging and nesting (Imbeau & Desrochers 2002). This preference is attributed to the greater abundance of insect prey within larger snags, which provide a more reliable food source (Gjerde & Saetersdal 1997).

The number of snags with DBH > 40 cm in our study area for plots with WBW (10 snags/ha) was double the number of snags with DBH > 30 cm in managed forests (4,6 snags/ha) in western Austria, eastern Switzerland and Liechtenstein where this species was found (Ettwein et al 2020). At the same time, the number of snags with DBH >20 cm in our study area for plots with WBW (22 snags/ha) is greater than found in Białowiża Forest (Poland) for DBH >20 cm for plots with WBW – 17 snags/ha (Czeszczewik & Walankiewicz 2006). The primary diet of the white-backed woodpecker consists of insects that inhabit decaying wood, such as beetle larvae. Research by Mikusiński et al. (2001) highlights that the availability of deadwood directly influences the food resources available to the species. Snags are rich in insect life, particularly beetle larvae, which form a significant part of the white-backed woodpecker's diet (Mikusiński et al. 2001).

The significant differences in mean DBH, volume, and basal area for stands older than 70 years underline the importance of mature forests for WBW. Mature forests typically have higher volumes of deadwood and larger snags, which are critical for the species. Older forests with abundant deadwood provide ideal conditions for WBW and other woodpecker species (Aulén 1991, Gjerde & Saetersdal 1997).

Woodpecker density, including that of the white-backed woodpecker, is positively correlated with the volume of standing deadwood (Mikusiński et al. 2001). High volumes of deadwood are crucial as they provide abundant foraging opportunities and nesting sites, which are critical for woodpecker survival and reproduction. Black Woodpecker (*Dryocopus martius*) and the Great Spotted Woodpecker (*Dendrocopos major*), have also shown similar dependencies on deadwood volume and snag density. For instance, the Black Woodpecker is known to prefer forests with a high volume of large deadwood for both nesting and foraging (Aulén 1991).

The Great Spotted Woodpecker's abundance is similarly linked to the availability of deadwood, particularly larger diameter snags that offer rich foraging grounds (Smith 1997). Deadwood snags volume (DBH > 10 cm) with WBW in our study totals 26 m^3/ha. This amount is similar with that found in Białowiża Forest (Poland) – 27 m^3/ha (Czeszczewik & Walankiewicz 2006) but much higher than the one in Spain – 6 m^3/ha (Urkijo-Letona et al. 2020) and higher than other European areas: 16-19 m^3/ha in western Austria, eastern Switzerland and Liechtenstein (Ettwein et al 2020). It is important to emphasize that the amount of standing deadwood found in current study falls into the sustainable category for WBW (>20 m^3/ha) established as a reference in Białowiża Forest (Angelstam et al. 2003). A much smaller amount of snags (8 m^3/ha) is considered as a threshold to indicate a good forest for WGW, this amount being a target for the restoration of degraded forest habitats in central Sweden (Trogen 2015). Although we found a high volume of dead wood, as an average of plots with WBW, this amount was not evenly distributed between plots. Thus, the largest amounts of deadwood (snag) were assessed in quasi-virgin and virgin stands.

In these stands, over 150-200 m^3/ha of total deadwood (snags and downed logs) were evaluated at certain points, in a study carried out as part of a project within the Natura 2000 Site – ROSPA0037 (SC New Way SRL 2023). An average total volume of deadwood was estimated at almost 17 m^3/ha, which falls within the recommended values of 15-20 m^3/ha of dead wood volume in managed forests at the national level (SC New Way SRL 2023). Standing deadwood totals on average just over 5 m^3/ha (26% of the total deadwood assessed in the area), but this value refers to the entire surface of the forest, including young stands and those where there have been recent main cuts usually without deadwood or with very small amounts (SC New Way SRL 2023). At the same time, for all European forests, a study shows that a minimum of 20–50 m^3/ha of dead wood is necessary to preserve existing biodiversity including managed forests (Müller & Bütler 2010).

The significance of the logistic model coefficients for basal area and volume of snags is marginally proven (p values close to 0.05), with basal area p-values of 0.08, 0.07, and 0.06, and volume p-values of 0.07, 0.06, and 0.06, respectively. Despite this marginal significance, the model intercept is statistically significant for all cases ($p<0.05$). This marginal significance suggests that while there is a trend indicating the importance of larger snags, more robust data (on a longer period) or a larger sample size may be needed to confirm these findings conclusively. The basal area in our study site is more than 3 m^2/ha for DBH >10 cm and 2.6 m^2/ha for DBH >40 cm. In comparison with these values, the basal area was evaluated at 0.92 m^2/ha in south-central Lithuania and 2.13 m^2/ha in northeastern Poland (Roberge et al. 2008a) which suggests high values of snags basal area for the Romanian sample. Furthermore, for WBW a basal area ≥1.4 m^2/ha of deciduous snags with DBH ≥10 cm is associated with a high probability of occurrence (≥0.9) (Roberge et al. 2008a). Our value of 3 m^2/ha for DBH >10 cm is double compared to this, emphasizing the existence of optimal forest habitats for the species at least related to the basal area.

Traditional forestry practices in the Balkans often involve the removal of deadwood to reduce fire hazards, for sanitary purposes or to improve forest aesthetics. This practice negatively impacts the white-backed woodpecker's habitat by reducing feeding and nesting sites. Deadwood removal in managed forests leads to a decline in woodpecker populations (Gjerde et al. 2005). However, there is no evidence of WBW decreasing in Romania (Atlas II 2022). At the same time, there is no study regarding its habitat structure and the importance of dead wood for this species at the Romanian level until now.

Across Europe, the white-backed woodpecker faces similar challenges related to deadwood availability, with regional variations in the extent and impact. Ongoing conservation efforts aim to preserve old-growth forests and increase deadwood quantities. Protected areas and national parks in the region play a crucial role in maintaining suitable habitats. These conservation measures are effective in supporting woodpecker populations (Hällfors et al. 2020, Pakkala et al. 2024). The quantities of deadwood (snag) evaluated in plots with WBW in the study area, regardless of whether we are talking about average diameters, densities, volumes or basal, are showing that at least the beech or mixed mature or old forests of Romania in which most stands are managed, can be considered as suitable or optimal habitats for WBW. Probably, these habitat structures also benefit other species for which WBW is considered an umbrella species.

Regarding the limitations of current study, it should be mentioned the most important three directions: number of sampled plots, habitat features and forest management practices.

While the logistic regression offers snag density, basal area, and volume thresholds, the significance levels for model coefficients are marginally above the standard p-value threshold (0.05). The marginal significance of some logistic model coefficients suggests that a larger sample size or longer study period may be necessary to confirm certain trends with greater confidence. The exclusion of two points due to inaccessibility may have also limited the representativeness of the data. Therefore, further research with larger sample sizes might strengthen these results.

Related to the habitat quality, it is evident that the study focuses on standing deadwood, but other habitat elements might also influence WBW presence (e.g., large lying deadwood pieces, various decomposition stage, tree species composition large deciduous trees etc.) (Czeszczewik & Walankiewicz 2006, Roberge et al. 2008a, Domokos & Cristea 2014). Future work could explore the combined effects of various habitat features.

Furthermore, the study suggests that current forest management practices in the area might be "closer-to-nature" for WBW due to the presence of large snags. However, it's important to consider long-term effects of management on deadwood availability and implement conservation measures if necessary (Czeszczewik & Walankiewicz 2006, Roberge et al. 2008a).

Implications for forest management: how

could we maintain or improve WBW suitable or optimum habitats?

The new management plan for the studied forest was designed in the period 2023-2024 and will be applied starting from 2025. Some provisions of the new plan refer to the conservation of several stands (more than 200 ha) with higher densities of some bird species, such as the collared flycatcher (*Ficedula albicollis*) and the red-breasted flycatcher (*Ficedula parva*) by abandoning shelterwoods with gaps for less intensive cuttings (e.g. sanitary cuttings). Both species of flycatcher need large trees, possibly also dead wood, such as snags. Probably such provisions can also benefit woodpeckers, including WBW as an umbrella species (Roberge et al. 2008b).

Another provision of the plan is the total protection of quasi-virgin and virgin forests and their inclusion in the Catalog of Virgin Forests in Romania. Even if in these stands cuttings were made only at the base of the slope on a certain width of the forest (e.g. 100-200 m), through the new restriction these stands will be completely protected without cuttings (IRISILVA 2022). In this regard, more restrictive forest management in certain stands can lead to the stabilization of the woodpecker populations including WBW and to maintaining a favorable conservation status in the future (Ionescu et al. 2023). However, we consider that other conservation measures are necessary, some more general and with an effect on the entire forest as WBW national home range, others more specific and technical could be applied at the local level (Ionescu et al. 2023).

At the forest unit landscape level (e.g. a few thousand hectares) first of all is the maintenance of as much as possible a percentage of mature/old stands (80-100 years old) from the total forest area, depending on the current situation and without reducing this area over time (Ionescu et al. 2023). Within these mature and old managed stands there should be a permanent amount of standing deadwood (mainly of large-diameter snags, e.g. 30-40 cm DBH), of over 15-20 m^3/ha (Ettwein et al. 2024a), taking into account the particular situations of stands, as the sustainable category for WBW (>20 m^3/ha) (Angelstam et al. 2003). The amount and distribution of dead wood in the forest will have to take into account the current and especially the future situation regarding forest fires and their propagation under the conditions of climate change (Parente et al. 2024, Poduška & Stajić 2024).

One of the most important is maintaining the current national forest management for beech and mixed stands, with the basic principles used in Romania, which should especially take into account: the continuity of the forest in space and time, the promotion of natural stands, natural regeneration, the age of exploitation over 100-120 years, regardless of the owner of the forest (Gerdzhikov et al. 2018, OM 2536/2022). The combination of protected areas and forests with varying silvicultural systems seem to be optimum for maintaining the ecological diversity (including habitat for the white-backed woodpecker) while fulfilling economic interests (Nolet et al. 2018, Ettwein et al. 2024b).

Conclusions

The results of this study suggest that standing deadwood is an important element and source of the forest as habitat for WBW. The various average values found in stands with WBW from the studied area, such as snag density, standing dead wood volume or snag basal area, are close to or higher than those at the European level with which we compared them. These results place the studied forests in the category of valuable or sustainable for this species of woodpeckers. Significant differences between areas with and without WBW, over 70 years old, also resulted for certain parameters.

All this underlines, on the one hand, that these forests can be considered suitable or optimal for WBW, but also that forest management in Romania can be considered "closer-to-nature" at least in the species' typical habitats - beech stands. Thus, in a forest unit (several thousand hectares) with beech, a diversity of cutting types can be promoted, including the less intensive ones (e.g. sanitary cuttings with restrictions) but also old-growth stands without cuttings. At the same time, maintaining or improving the structure of the habitat, especially in terms of standing deadwood, can be done through specific measures that complement the forestry techniques of management. To understand even better the relationship between species, habitat and forest management it is necessary to continue studies on WBW and other species of woodpeckers' habitat structure and requirements in various types of forests with different cuttings or with no interventions on a larger scale such as the national level.

Conflict of interest

The authors declare that they have no conflict of interest.

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