

Original Articles

The White-backed Woodpecker (*Dendrocopos leucotos*) as an umbrella species for threatened saproxylic beetle communities in Central European beech forests

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ABSTRACT

The umbrella species concept is a popular conservation planning tool which postulates that conservation schemes targeting a specific species will indirectly benefit many other sympatric species. In Scandinavia and Central Europe, the White-backed Woodpecker (*Dendrocopos leucotos*) is considered an umbrella species for woodland birds and cryptogam species of conservation concern. Whether this also applies to saproxylic beetles, a group of high conservation concern, remains open. Therefore, we tested that umbrella function in Central European beech forests that are currently recolonized by this woodpecker. Relying on radiotracking data, we compared saproxylic beetle communities within the breeding home ranges of White-backed Woodpeckers (high and low activity of the bird) against forests with ascertained absence of the bird (control). Bayesian inference for linear regressions identified that species richness of threatened saproxylic beetles was 1.51 (lower and upper 5 % PPCrI=[1.09; 2.01]) times higher in sites with high White-backed Woodpecker activity compared to the control. Community composition analyses on threatened saproxylic beetles showed a reduced β -diversity at low and high White-backed Woodpecker sites compared to the control. Finally, an indicator species analysis showed that 17 saproxylic beetle species, including 4 threatened species, were positively associated with White-backed Woodpecker's breeding home ranges, while only 3 species, but no threatened species, were associated with the control sites. Overall, our results suggest that the White-backed Woodpecker plays the role of an umbrella species for threatened saproxylic beetle communities, opening new opportunities for conservation planning in European beech forests.

1. Introduction

Umbrella species are defined as organisms that need large expanses of habitat or habitat of high quality so that they can serve as surrogates for the overall biodiversity value of an ecosystem. In effect, their presence de facto encapsulates an array of other organisms that have similar but less stringent ecological requirements (Roberge and Angelstam, 2004; Suter et al., 2002). Umbrella species are therefore often selected for making conservation-related decisions and suggesting management measures that, if successful, are presumed to guarantee the persistence of a rich and diverse ecological community beyond the persistence of

that very species (Favreau et al., 2006; Wilcox, 1984). Umbrella species roles have been evidenced among birds (Suter et al., 2002), fish (Branton and Richardson, 2014), mammals (Mortelliti et al., 2022) and arthropods (Kašák et al., 2019). In addition to their umbrella function, these species may also sometimes play the role of a keystone species that make them superior indicators of ecological integrity (Carignan and Villard, 2002). Finally, some of these species can even play the additional role of flagship species that are helpful to raise public awareness and conservation support (Grega et al., 2020). For conservation practitioners, the reliance on umbrella species is often key to developing effective action plans for a suite of other species that are more difficult to monitor. This

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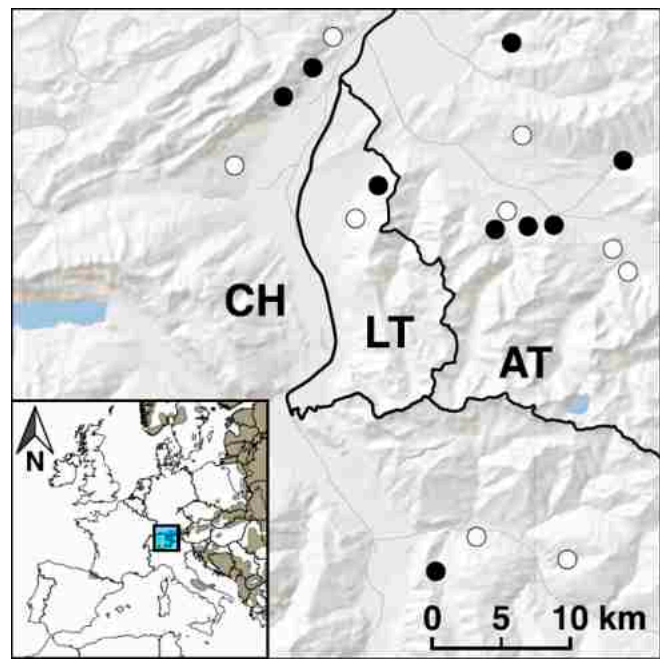


Fig. 1. Overview of the White-backed Woodpecker distribution in Western European (khaki area), the study region (blue square) and the study sites (dots). Black dots represent the White-backed Woodpecker breeding home range sites whereas white dots represent sites with a controlled absence of the target bird species. CH=Switzerland, LT=Liechtenstein, AT=Austria. Accessed on 09 March 2022. Source: Handbook of the Birds of the World and BirdLife International (2020); IUCN (2021), *The IUCN Red List of Threatened Species*. Version 2021-3. <https://www.iucnredlist.org> (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 1
Specimen abundance and species richness of the studied saproxylic beetle suites per White-backed Woodpecker activity treatment (Control: absence site, Low and High: presence sites). Values represent samples pooled per White-backed Woodpecker activity levels.

Saproxylic beetles set	Observation	White-backed Woodpecker activity level			Total
		Control	Low	High	
Overall	Specimen abundance	6'285	8'563	6'704	21'552
Threatened	Species richness	291	301	305	400
	Specimen abundance	136	229	214	579
Primeval forest relict species	Species richness	28	34	37	49
	Specimen abundance	12	17	13	42
	Species richness	4	6	6	8

approach is now widely employed as conservation efforts chronically suffer from restricted funding (Buxton et al., 2020) and because even basic ecological knowledge on numerous taxa is still lacking (Heywood and Watson, 1996; Nieto and Alexander, 2010; Ulyshen and Šobotník, 2018). However, the caveat remains that a species' umbrella role should be clearly demonstrated beforehand (Suter et al., 2002), which needs in-depth research.

The White-backed Woodpecker (*Dendrocopos leucotos*) is a saproxylic predator, mainly feeding on beetle larvae (Aulen, 1988; Hogstad and Stenberg, 1997). The bird species heavily rely on the dead wood for its foraging strategy (Ettwein et al., 2020; Urkijo-Letona et al., 2020). This resource has thus been promoted in specific conservation action plans, ultimately improving the quality of managed forest stands (Virkkala

et al., 1993; Stighäll, 2015; Mild and Stighäll, 2005). More generally, the species is referenced as an old-growth and mature forest specialist (Carlson, 2000) and previous research in Scandinavia has demonstrated its umbrella function for other forest birds and cryptogam species of conservation concern (Roberge et al., 2008a). Additionally, the species has been suggested to play a similar role for threatened saproxylic beetle communities (Bell et al., 2015; Martikainen et al., 1998) although firm evidence is still lacking. Consequently, it may be an ideal candidate as an umbrella species for saproxylic communities in beech-dominated forests of Central Europe. White-backed Woodpecker populations have declined strongly in Northern (Carlson, 2000; Virkkala et al., 1993) and Eastern Europe (Czeszczewik and Walankiewicz, 2006), but the species is currently expanding across Central Europe from the East, with its expansion front lying in the Eastern Swiss Alps (Mollet et al., 2009). There, the species occurs mainly in managed forests as old-growth forests are absent. Yet its presence is still positively correlated with a structure that typically characterizes old-growth forest stands (e.g., mean diameter at breast height of live trees and standing dead wood, see Ettwein et al. (2020) for details). Additionally, Ettwein et al. (2020) demonstrated that the density of emergence holes of saproxylic insects on both standing and lying dead wood was positively correlated to the occupancy probability of the White-backed Woodpecker. Given the relationship between this old-growth forest specialist and insects that inhabit dead-wood, we examine the potential of this woodpecker as an umbrella species for saproxylic beetle communities in Central Europe, with an emphasis on species of conservation concern.

Saproxylic beetles are defined as those that are “dependent, during some part of their life cycle, upon the dead or dying wood of moribund or dead trees (standing or fallen), or upon wood-inhabiting fungi, or upon the presence of other saproxylics” (Speight, 1989). They are a key component of forest ecosystems through their contribution to dead wood decay, spore dissemination and trophic interactions (Grove, 2002; Seibold et al., 2021; Ulyshen and Šobotník, 2018). Saproxylic beetle species are negatively affected by intensive forest management, a widespread practice in Central European forests (Ekström et al., 2021; Lindenmayer et al., 2006). According to the European Red-List for saproxylic beetles (Nieto and Alexander, 2010), 17.9 % of the evaluated species are categorized as threatened and 12.9 % of the population is thought to be declining, which is why saproxylic beetles are considered a conservation focus in European forests. Due to their ecological requirements for dead wood, saproxylic beetles are highly sensitive to habitat changes and are therefore widely used as indicators for undisturbed forest (Bouget et al., 2014; Brunet and Isacson, 2009; Eckelt et al., 2018; Lachat et al., 2014; Schmidl and Bussler, 2004). Yet, saproxylic beetles – and especially rare species – are inherently hard to monitor because they often occur at low densities, are represented by numerous species, their identification to the species level is challenging and skilled taxonomic specialists are rare. In contrast, birds are well suited for monitoring programs because they can be quickly and easily identified by sight and sound (Carignan and Villard, 2002; Williams and Gaston, 1994). Additionally, birds show promise as indicators for a wide range of taxa, including arthropods (Bell et al., 2015; Roth and Weber, 2008; Vallino et al., 2020), demonstrating their potential role as umbrella species.

Here, we examine the potential of the White-backed Woodpecker as a useful umbrella species for the saproxylic beetle community in beech-dominated forests of Central Europe. First, we hypothesize that specimen abundance and species richness of saproxylic beetles are positively correlated with White-backed Woodpecker habitat use, and with habitat characteristics preferred by the White-backed Woodpecker (i.e., type and volume of dead wood, live tree diameter).

Second, we expect predictable co-occurrence patterns between target woodpecker species and saproxylic species, resulting in pronounced changes in the saproxylic beetle community along the gradient of woodpecker habitat use.

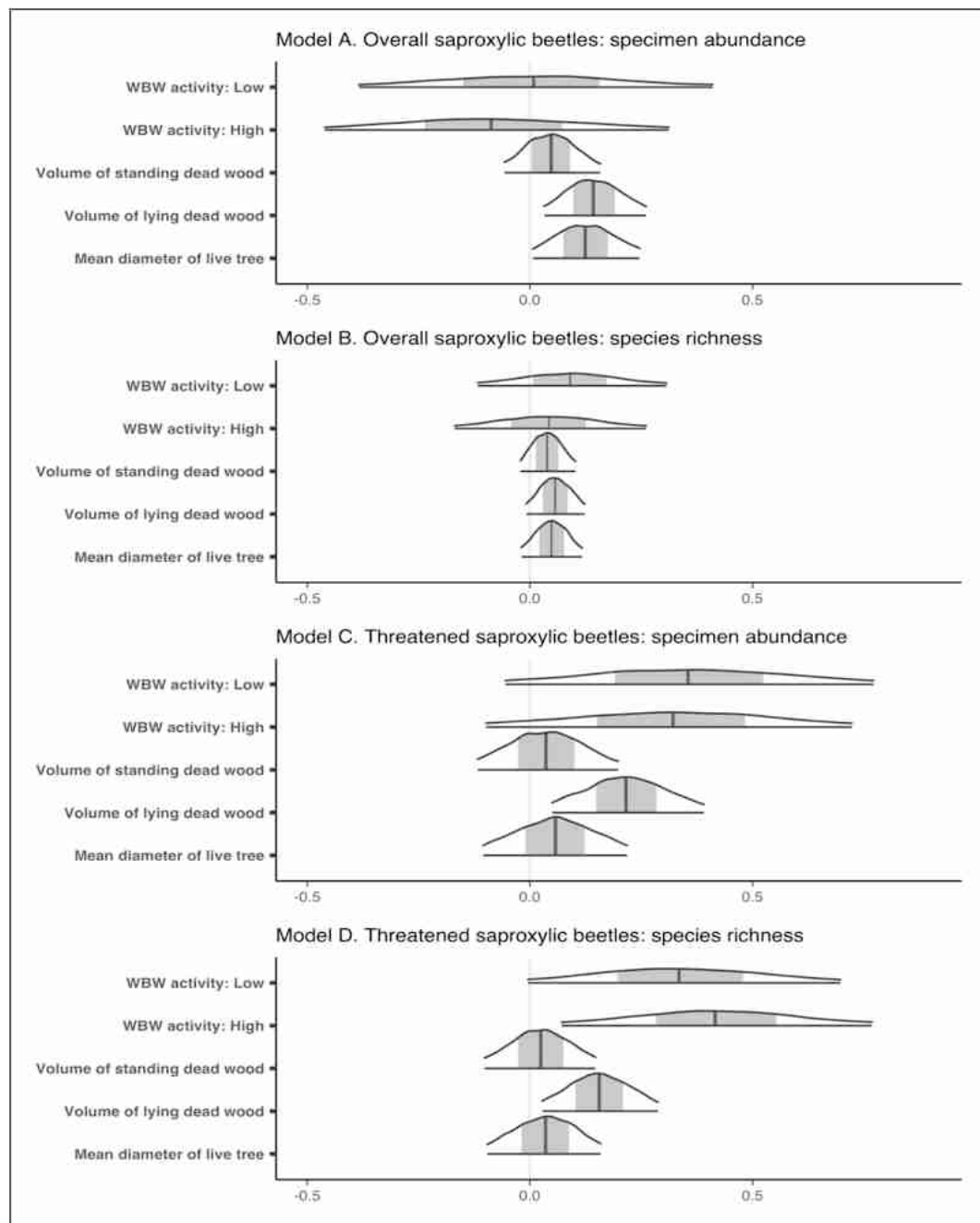


Fig. 2. Summary of parameter estimates for the effects of White-backed Woodpecker activity levels (WBW activity, “Control” as reference level), volume of standing dead wood, volume of lying dead wood and mean diameter of live trees on a) Overall saproxylic beetles: specimen abundance; b) Overall saproxylic beetles: species richness; c) Threatened saproxylic beetles: specimen abundance and d) Threatened saproxylic beetles: species richness. Vertical lines represent the parameter estimates. The grey area under curve, the total area under curve and the border of the area under curve represent the 50%, the 90% and the distribution of the HDI posterior probability, respectively.

2. Material and method

2.1. Study area

The study took place in Eastern Switzerland (cantons Grisons and St. Gallen), Western Austria (province Vorarlberg) and the Principality of Liechtenstein, in an area of approximately 40 km² (46.8–47.4°N, 9.2–10.2°E; Fig. 1). All sampling sites were in beech-dominated forest stands between 630 and 1230 m above sea level. The climate of the region is representative of the Central European Alps and described as ranging from a temperate climate, without dry seasons and with hot

summers, to a cold climate, without dry seasons and with cold summers (Beck et al., 2018).

2.2. Sites selection

The site selection was designed to represent 3 levels of White-backed Woodpecker activity: high (i.e., sites within a White-backed Woodpecker breeding home range and with high White-backed Woodpecker activity), low (i.e., sites within a White-backed Woodpecker breeding home range but with little White-backed Woodpecker activity) and control (i.e., sites where White-backed Woodpeckers did not occur). To

Table 2

Summary table of the Bayesian generalized linear mixed models. Explanatory variables with a non-null predicted effect (90% of the HDI posterior probability excluding 0) are displayed in bold.

Model	Saproxyllic beetles set	Response variable	Explanatory variable	Model output CrI 90 % HDI posterior probability: median (min; max)	Effect size exponential(CrI 90 % HDI posterior probability): median (min; max)
A	Overall	Specimen abundance	WBW activity: Low	0.009 (−0.391; 0.401)	1.009 (0.676; 1.493)
			WBW activity: High	−0.087 (−0.462; 0.312)	0.917 (0.63; 1.366)
			Volume of standing dead wood	0.048 (−0.057; 0.158)	1.049 (0.945; 1.171)
			Volume of lying dead wood	0.143 (0.03; 0.258)	1.154 (1.03; 1.294)
			Mean diameter of live tree	0.124 (0.009; 0.249)	1.132 (1.009; 1.283)
B	Overall	Species richness	WBW activity: Low	0.09 (−0.117; 0.307)	1.094 (0.89; 1.359)
			WBW activity: High	0.043 (−0.171; 0.257)	1.044 (0.843; 1.293)
			Volume of standing dead wood	0.039 (−0.022; 0.101)	1.04 (0.978; 1.106)
			Volume of lying dead wood	0.057 (−0.007; 0.125)	1.059 (0.993; 1.133)
			Mean diameter of live tree	0.048 (−0.023; 0.113)	1.049 (0.977; 1.12)
C	Threatened	Specimen abundance	WBW activity: Low	0.355 (−0.059; 0.764)	1.426 (0.943; 2.147)
			WBW activity: High	0.322 (−0.108; 0.714)	1.38 (0.898; 2.042)
			Volume of standing dead wood	0.036 (−0.116; 0.199)	1.037 (0.89; 1.22)
			Volume of lying dead wood	0.216 (0.048; 0.387)	1.241 (1.049; 1.473)
			Mean diameter of live tree	0.058 (−0.1; 0.223)	1.06 (0.905; 1.25)
D	Threatened	Species richness	WBW activity: Low	0.335 (−0.012; 0.681)	1.398 (0.988; 1.976)
			WBW activity: High	0.416 (0.092; 0.786)	1.516 (1.096; 2.195)
			Volume of standing dead wood	0.024 (−0.097; 0.152)	1.024 (0.908; 1.164)
			Volume of lying dead wood	0.156 (0.024; 0.282)	1.169 (1.024; 1.326)
			Mean diameter of live tree	0.035 (−0.097; 0.158)	1.036 (0.908; 1.171)

identify these sites, we applied a two-step approach.

First, we used White-backed Woodpecker telemetry data collected in 2016 and 2017 (Ettwein et al. – under revision) to identify forest surfaces with high and low White-backed Woodpecker activity within 9 monitored breeding home ranges. We identified high and low White-backed Woodpecker activity by creating a heatmap-type layer based on the number of telemetry locations using a hexagon approach of 500 m² in Quantum GIS (v.2.18) with the plugin QMarxan Toolbox (v.0.3.4). Second, out of these hexagons, we selected four sampling plots each with the highest and lowest woodpecker activity per territory, respectively, called “High” and “Low”. We then selected 9 forests without known White-backed Woodpecker observations as absence sites following the procedure described in (Ettwein et al., 2020). The absence sites had a size of 550 * 550 m (=30.25 ha), which approximately corresponds to the average breeding home range size of the tracked White-backed Woodpeckers (Ettwein et al. – under revision). From February to March 2018, we confirmed the absence of the White-backed Woodpecker by using playbacks every 200 m. In each of the 9 absence sites, four sampling plots were selected, as much as possible in the center of the absence sites. Plots were selected to have forest characteristics similar to the nearest White-backed Woodpecker breeding home range. In both breeding home ranges and control sites, sampling plots with overlapping rock cliffs and river streams were not selected for accessibility reasons, and the next sampling plot with high (or low) White-backed Woodpecker activity was selected from the created heatmaps in breeding home ranges. Within the breeding home ranges, sampling plots were installed at least 150 m away from the currently active breeding cavity of the tagged White-backed Woodpecker. This avoided the potentially confounding effect of visits to the nest on bird activity. We then distributed 4 sampling plots around the center of every control site, called “Control”. To avoid spatial autocorrelation, sampling plots were installed 50 m apart within each site. Slope aspect, slope gradient and cardinal orientation of all sampling plots were equally distributed across White-backed Woodpecker activity levels (i.e., High, Low, Control).

2.3. Beetle sampling

To quantify the saproxyllic beetle community, flying insects were collected using non-baited flight interception traps (PolytrapTM), a widely used and standardized method to study saproxyllic beetles. A trap was made from two transparent acrylic glass sheets above a funnel

leading into a collecting bottle filled with water and antifungal agent (ROCIMATM GT Biocid; 0.5 %). We installed one trap per sampling plot, for a total of 108 traps equally distributed among the three activity levels (Control, Low, High = 36 traps each). A trap was hung between two European beech trees at approximately 1.5 m from the ground. Traps were emptied monthly from mid-April 2018 to mid-August 2018.

2.4. Beetle identification

Beetle specimens were identified to species level by specialized taxonomists. Species were classified as saproxyllic following an enhanced list of (Schmidl and Bussler, 2004). Conservation status such as primeval forest relict species (Eckelt et al., 2018) and threatened species (i.e., Vulnerable, Endangered and Critically Endangered) were attributed to every saproxyllic species. Due to the lack of completeness of the Swiss red list for saproxyllic beetles (Monnerat et al., 2016), we considered the more comprehensive list for red-listed saproxyllic beetles developed for the Baden-Württemberg region, a neighboring German federal state (Bense, 2001). Samples were pooled across all months and non-saproxyllic species were excluded from further analyses.

2.5. Habitat characterization

We inventoried habitat characteristics in summer 2018 on plots of 500 m² centered on every trap. We recorded the species and diameter at breast height (DBH hereafter) of all living trees (DBH ≥ 7 cm). For all dead wood items (snag = height > 130 cm & DBH ≥ 7 cm; stump = height ≤ 130 cm & diameter at mid height ≥ 7 cm; logs = diameter at mid length ≥ 7 cm), we recorded their diameter with a slide caliper, decay stage (Keller, 2011) and when possible- originating species. Snag height was measured with a Haglöf Sweden® Vertex IV. Stump height and log length were measured with a logging tape. The volume of standing dead wood was estimated using either the formula of a cone for non-broken snags or the formula of a truncated cone for the broken ones. The volume of logs and stumps was estimated using the formula of a cylinder.

2.6. Statistical analysis

2.6.1. Forest characteristics, saproxyllic beetles and White-backed Woodpecker

Using four Bayesian generalized linear models with group-specific

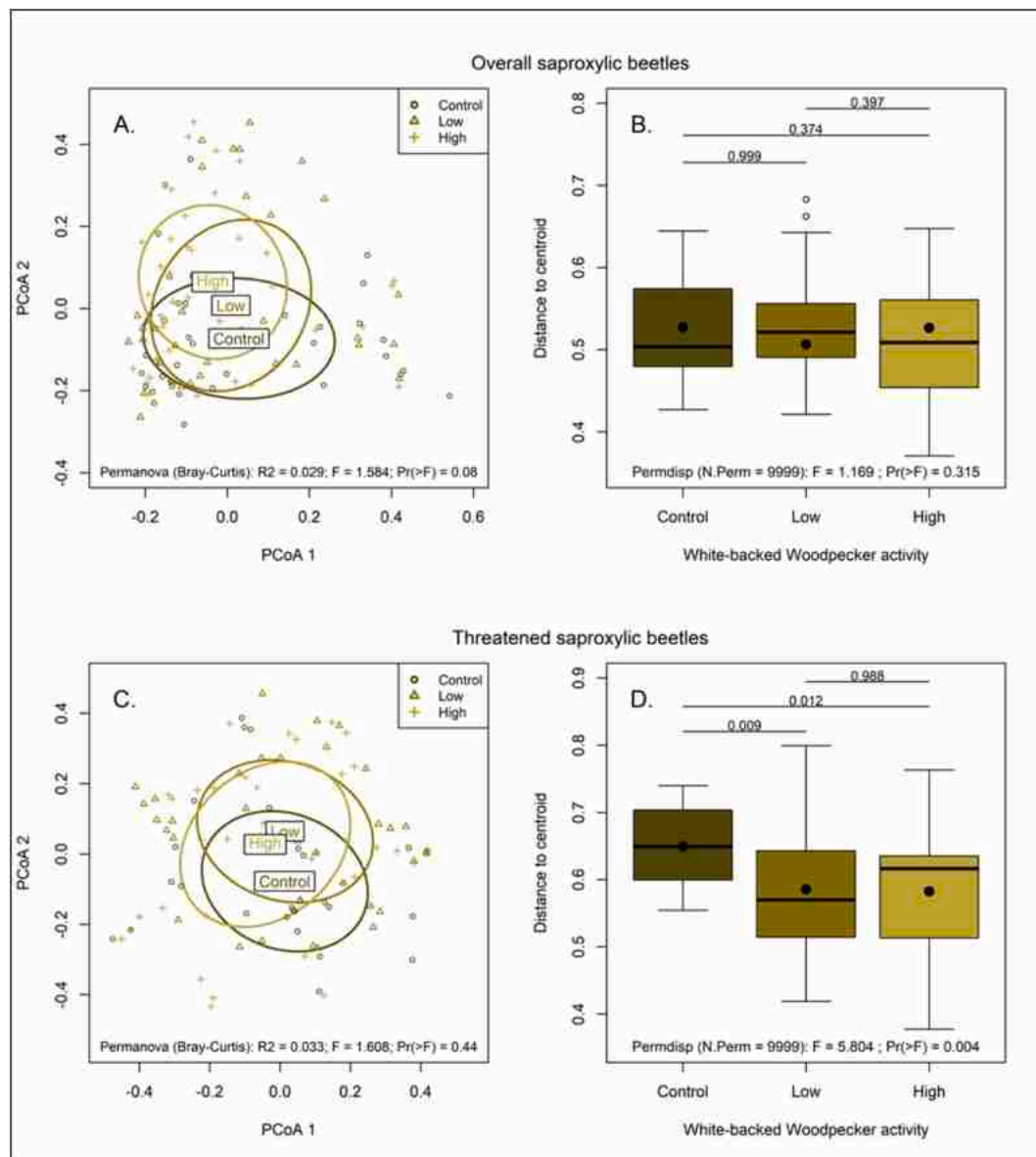


Fig. 3. Summary of the community composition analyses for the overall saproxylic beetle suite (A; B) and threatened saproxylic beetle suite (C; D). Group centroid position was tested with a permutational multivariate analysis of variance (A; C) and average distance to group centroid was tested with a permutational test for homogeneity of multivariate dispersions (B; D). Numbers above boxplots are p. values resulting of a pairwise Tukey Honest Significant Difference test comparing the means of the groups. Group mean is represented by the black dot and group median by the horizontal black line (B & D).

terms (i.e., random factor) via Stan (`stan_glm.nb` {`rstanarm`}) (Goodrich et al., 2020) we analyzed how specimen abundance and species richness of overall and threatened saproxylic beetles, respectively, varied as a function of the White-backed Woodpecker activity levels (Control, Low, High), amount and type of dead wood available in the surrounding (volume of standing dead wood, volume of lying dead wood), and forest characteristic (mean diameter at breast height of live tree) as a proxy for forest naturalness. All four models were run under a negative binomial distribution (`fitdist` {`fitdistrplus`}) (Delignette-Muller and Dutang, 2015), implementing 4 chains with 2000 iterations each (`warmup` = 1000; `sampling` = 1000) and default prior for 108 observations (i.e., sampling unit) and 18 groups (i.e., sites as random intercepts to account for the hierarchical design of the study). Estimates of the models were retrieved using the `bayestestR` (Makowski et al., 2019) and `effectsize` (Ben-Shachar et al., 2020) packages. All explanatory variables were a-priori controlled for collinearity with an exclusion threshold set at 0.8 (`tab_corr` {`sjPlot`}) (Lüdtke, 2021; Supplementary materials S9) and were then normalized ($\mu = 0$; $sd = 1$).

2.6.2. Community composition

Two complementary multivariate analyses were done to investigate compositional differences of the saproxylic beetle communities (overall or threatened) among the three White-backed Woodpecker activity levels using (1) a Bray-Curtis similarity based permutational test for homogeneity of multivariate dispersion followed with Tukey Honest Significant Differences test corrected for multiple comparisons and (2) a. First, we tested whether the three groups (i.e., activity levels) differed in species composition, using a permutational multivariate analysis of variance (`betadisper` {`vegan`}) (Oksanen et al., 2020; Anderson, 2014) followed by a permutational multivariate analysis of variance (`adonis2` {`vegan`}) (Oksanen et al., 2020). This method tests whether the group centroids (i.e., the average identity of saproxylic beetle species composing the community of a given activity level) in multivariate species space differed between groups, where overlapping group centroids indicates a degree of community similarity across the groups. Second, we tested whether or not groups differed in their compositional variance (i.e., β -diversity), that is, the degree of variation in species

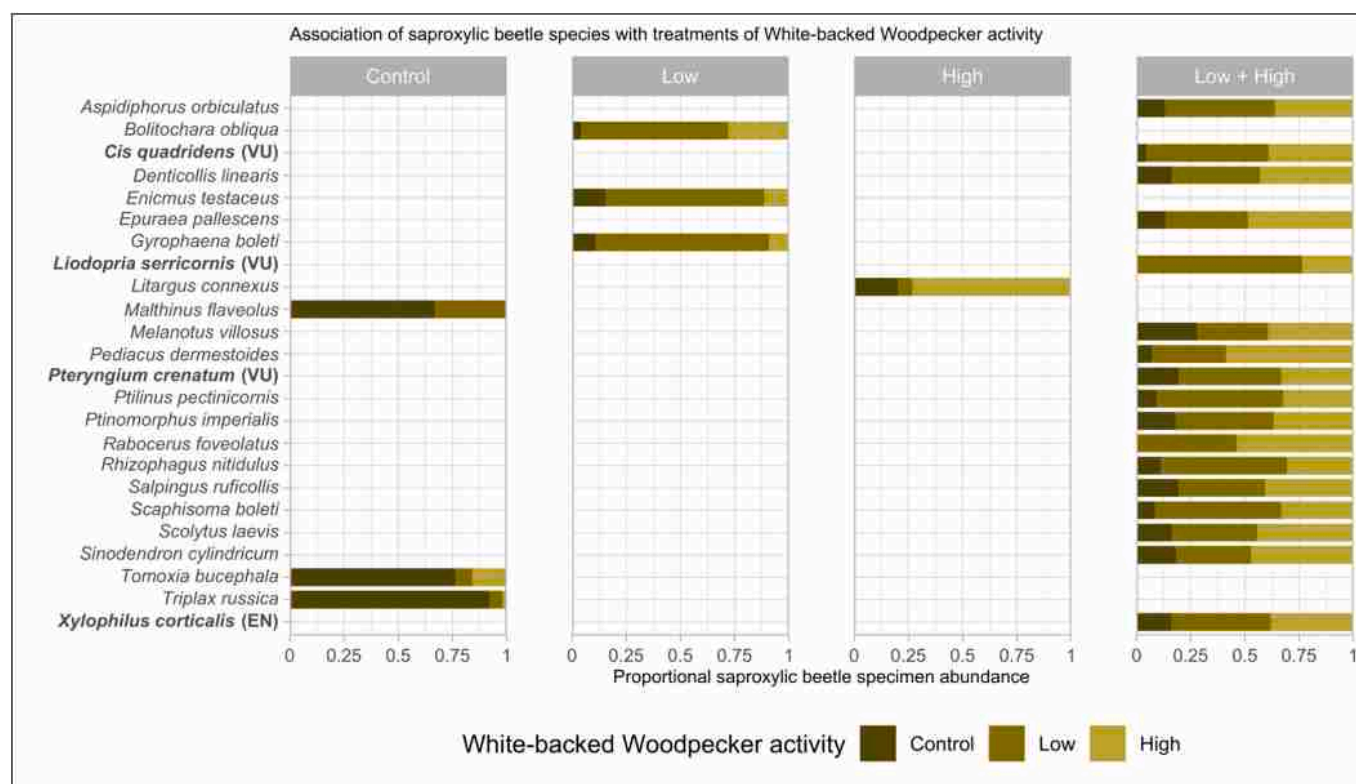


Fig. 4. Summary of the multi-level pattern analysis per species-sites group association (Control, Low, High, Low + High). Species' proportional specimen abundance per White-backed Woodpecker activity levels (Control, Low, High) is displayed within the corresponding site group association. Threatened species are displayed in bold.

identities among groups, using permutational test for homogeneity of multivariate dispersion with 9999 permutations (Anderson et al., 2006, 2011). This method statistically assesses the degree of biotic homogenization among treatments, where large treatment-wise dispersion indicates a large variation in species identities within a group and thus a low species overlap between sampling plots representing a group (i.e., high β -diversity); as opposed to small group-wise dispersion (i.e., low β -diversity). Differences in β -diversity among groups were assessed using a pairwise Tukey Honest Significant Differences test corrected for multiple comparisons (TukeyHSD {stats}). For both analyses, sampling site was used as the blocking factor to account for the hierarchical design of the study.

2.6.3. Multi-level pattern analysis

To test if some saproxylic beetle species were exclusively associated with a given White-backed Woodpecker activity level (hereafter site group), we performed a multi-level pattern analysis (multipatt {indic-species}) with 9999 permutations (De Cáceres et al., 2010, 2012; De Cáceres and Legendre, 2009; Dufrêne and Legendre, 1997). This method provides two outputs: the specificity index (the conditional probability of a positive predictive value of a given species as an indicator of the target site group) and the fidelity index (the conditional probability that a given species will be found in a newly surveyed site belonging to the same site group (Sattler et al., 2014). A good indicator species should therefore be both ecologically restricted to the target site group (specificity index = 1) and frequent within it (fidelity index = 1).

To better account for low abundance of rare species and therefore their true potential contribution as indicator species of the White-backed Woodpecker habitat, the species-sites group association (i.e., saproxylic beetle species-White-backed Woodpecker activity treatments) followed an abundance-based matrix (as opposed to presence-absence data) represented by equal site group size. These analyses were conducted for the three activity groups (Control, Low, High) independently and for the

Low and High activity groups pooled together, representing the breeding home range of the White-backed Woodpecker as a site. A total of four site groups (i.e., [Control] OR [Low] OR [High] OR [Low AND High]) were screened during this analysis.

All statistical analyses were performed using R Version 4.1.1 (R Core Team 2021) and figures were created using the {bayesplot} (Gabry and Mahr, 2022), {ggstatsplot} (Patil, 2021), {gridExtra} (Auguie, 2017), {patchwork} (Pedersen, 2020) and {tidyverse} (Wickham et al., 2019) packages.

3. Results

3.1. Specimen abundance and species richness of overall, threatened and primeval saproxylic beetles

In total, the sampling effort yielded 21'552 (579 threatened) saproxylic beetle specimens, represented by 400 (49 threatened) saproxylic beetle species. The Control sites yielded 6'285 (136) specimens for 291 (28) species, the Low White-backed Woodpecker activity level yielded 8'563 (229) specimens for 301 (34) species and the High White-backed Woodpecker activity level yielded 6'704 (214) specimens for 305 (37) species (Table 1). Additionally, 8 primeval relict saproxylic beetle species (Eckelt et al., 2018) were sampled: *Ceruchus chrysomelinus* (Control = 6 specimens; Low = 0 specimen; High = 1 specimen), *Cryptophagus confusus* (1; 5; 2), *Cryptophagus quercinus* (0; 1; 0), *Grynocharis oblonga* (1; 4; 4), *Ischnodes sanguinicollis* (4; 4; 4), *Pryonichus melanarius* (0; 0; 1), *Prostomis mandibularis* (0; 1; 1), *Triplax elongata* (0; 2; 0). Due to their low incidence, the statistical analysis of primeval forest relict species was not possible.

3.2. Drivers of saproxylic beetle species richness and specimen abundance

First, we did not detect differences between sites representing a Low

Table 3

Summary table of the multi-level pattern analysis per species-sites group association. Threatened species are displayed in bold.

Habitat association	Species	Family	Red List Status	IndVal stat	IndVal P-Value	Specificity	Fidelity	Control: Specimen abundance (Species incidence)	Low: Specimen abundance (Species incidence)	High: Specimen abundance (Species incidence)	Low + High: Average specimen abundance (combined species incidence)
Control	<i>Malthinus flaveolus</i>	Cantharidae	NE	0.451	0.005	0.667	0.306	12 (31 %)	6 (14 %)	0 (0 %)	3 (7 %)
	<i>Tomoxia bucephala</i>	Mordellidae	LC	0.46	0.014	0.763	0.278	29 (28 %)	3 (8 %)	6 (14 %)	4 (11 %)
	<i>Triplax russica</i>	Erotylidae	LC	0.479	0.003	0.918	0.25	45 (25 %)	3 (8 %)	1 (3 %)	2 (6 %)
Low	<i>Bolitochara obliqua</i>	Staphylinidae	LC	0.389	0.031	0.68	0.222	1 (3 %)	17 (22 %)	7 (8 %)	12 (15 %)
	<i>Enicmus testaceus</i>	Latridiidae	NE	0.473	0.002	0.731	0.306	4 (6 %)	19 (31 %)	3 (6 %)	11 (18 %)
	<i>Gyrophana boleti</i>	Staphylinidae	LC	0.615	0.014	0.8	0.472	22 (22 %)	164 (47 %)	19 (31 %)	92 (39 %)
High	<i>Litargus connexus</i>	Mycetophagidae	LC	0.378	0.038	0.733	0.194	3 (8 %)	1 (3 %)	11 (19 %)	6 (11 %)
Low + High	<i>Aspidiphorus orbiculatus</i>	Sphindidae	NE	0.631	0.003	0.87	0.458	9 (19 %)	35 (47 %)	25 (44 %)	30 (46 %)
	<i>Cis quadriens</i>	Ciidae	VU	0.446	0.012	0.957	0.208	1 (3 %)	13 (22 %)	9 (19 %)	11 (21 %)
	<i>Denticollis linearis</i>	Elateridae	LC	0.771	0.002	0.84	0.708	36 (50 %)	92 (61 %)	97 (81 %)	94 (71 %)
	<i>Epuraea pallescens</i>	Nitidulidae	LC	0.64	0.002	0.867	0.472	15 (19 %)	43 (47 %)	55 (47 %)	49 (47 %)
	<i>Liodopria serricornis</i>	Leiodidae	VU	0.441	0.006	1	0.194	0 (0 %)	16 (25 %)	5 (14 %)	10 (19 %)
	<i>Melanotus villosus</i>	Elateridae	NE	0.832	0.003	0.722	0.958	105 (69 %)	124 (94 %)	149 (97 %)	136 (96 %)
	<i>Pediacus dermestoides</i>	Cucujidae	NE	0.601	0.004	0.929	0.389	6 (17 %)	29 (39 %)	50 (39 %)	40 (39 %)
	<i>Pteryngium crenatum</i>	Cryptophagidae	VU	0.599	0.009	0.807	0.444	11 (19 %)	27 (44 %)	19 (44 %)	23 (44 %)
	<i>Ptilinus pectinicornis</i>	Ptinidae	LC	0.907	0.001	0.91	0.903	360 (81 %)	2349 (92 %)	1302 (89 %)	1826 (90 %)
	<i>Ptinomorphus imperialis</i>	Ptinidae	NE	0.684	0.011	0.821	0.569	19 (39 %)	48 (58 %)	39 (56 %)	44 (57 %)
	<i>Rabocerus foveolatus</i>	Salpingidae	LC	0.354	0.044	1	0.125	0 (0 %)	6 (8 %)	7 (17 %)	6 (12 %)
	<i>Rhizophagus nitidulus</i>	Monotomidae	LC	0.555	0.018	0.887	0.347	7 (19 %)	36 (44 %)	19 (25 %)	28 (35 %)
	<i>Salpingus ruficollis</i>	Salpingidae	LC	0.778	0.004	0.807	0.75	47 (56 %)	97 (72 %)	99 (78 %)	98 (75 %)
	<i>Scaphisoma boleti</i>	Staphylinidae	LC	0.422	0.04	0.917	0.194	2 (6 %)	14 (25 %)	8 (14 %)	11 (19 %)
	<i>Scolytus laevis</i>	Curculionidae	DD	0.629	0.041	0.838	0.472	32 (31 %)	78 (53 %)	88 (42 %)	83 (47 %)
	<i>Sinodendron cylindricum</i>	Lucanidae	LC	0.594	0.02	0.819	0.431	13 (25 %)	25 (42 %)	34 (44 %)	30 (43 %)
	<i>Xylophilus corticalis</i>	Eucnemidae	EN	0.611	0.002	0.841	0.444	10 (17 %)	29 (44 %)	24 (44 %)	26 (44 %)

and a High White-backed Woodpecker activity for the abundance and species richness of saproxylic beetles, regardless of their conservation status (overall or threatened) (see [Supplementary materials S5](#)).

Second, whereas no difference in species richness of threatened saproxylic beetles was demonstrated between the sites representing a Low White-backed Woodpecker activity and the Control sites, sites representing a High White-backed Woodpecker activity had 1.5 times more threatened saproxylic beetle species compared to the Control sites (Posterior Probability Credible Interval median [lower and upper 5 %] = 0.416 [0.092, 0.786]; [Fig. 2](#), Model D; [Table 2](#), Model D).

Third, the volume of lying dead wood had a positive effect on abundance of overall saproxylic beetles (0.143 [0.03, 0.258]; [Fig. 2](#), Model A; [Table 2](#), Model A), as well as on the abundance (0.216 [0.048, 0.387]; [Fig. 2](#), Model C; [Table 2](#), Model C) and species richness (0.156 [0.024, 0.282]; [Fig. 2](#), Model D; [Table 2](#), Model D) of threatened saproxylic beetles (see [supplementary material](#) for the effect of the total dead wood volume on the saproxylic beetle communities; S11, S12, S13, S14). Finally, the mean diameter of live trees also had a positive effect on the overall specimen abundance (0.124 [0.009, 0.249]; [Fig. 2](#), Model A; [Table 2](#), Model A).

3.3. Community composition

Neither community composition ([Fig. 3.A](#)) nor β -diversity ([Fig. 3.B](#)) of the overall saproxylic beetle community differed across the three White-backed Woodpecker activity levels. Additionally, community composition of the threatened saproxylic beetle community did not differ across the three White-backed Woodpecker activity levels ([Fig. 3.C](#)). However, White-backed Woodpecker activity levels significantly differed in β -diversity of threatened saproxylic beetles ($Df = 2$, Sum sq = 0.088, Mean sq = 0.044, $F = 5.804$, $N.Perm = 9999$, $Pr(>F) = 0.004$; [Fig. 3.D](#)). Specifically, post-hoc pairwise testing revealed that communities found in High and Low White-backed Woodpecker activity sites had a reduced β -diversity compared to control sites ($Pr(>F) < 0.05$ for both cases).

3.4. Multi-level pattern analysis

Out of the 400 identified species, 24 were identified as indicator of at least one of the White-backed Woodpecker activity level (i.e., site group). First, 3 saproxylic beetle species were significantly associated with sites representing the control level. Their specificity index ranged from 0.667 to 0.918 and their fidelity index ranged from 0.250 to 0.306. Second, 3 saproxylic beetle species were significantly associated with sites representing the Low White-backed Woodpecker activity level. Their specificity index ranged from 0.680 to 0.800 and their fidelity index ranged from 0.222 to 0.472. Third, 1 saproxylic beetle species was significantly associated with sites representing the High White-backed Woodpecker activity level. It had a specificity index of 0.733 and a fidelity index of 0.194. Finally, 17 saproxylic beetle species – including 4 threatened taxa (*Cis quadriens*, *Liodopria serricornis*, *Pteryngium crenatum*, *Xylophilus corticalis*) – were significantly associated with the complete breeding home range of the White-backed Woodpecker, which is represented by the combination of the Low and High White-backed Woodpecker activity levels. The specificity and fidelity index of these 17 exclusive indicator species ranged from 0.722 to 1 and from 0.125 to 0.958, respectively ([Fig. 4](#), [Table 3](#)).

4. Discussion

4.1. Umbrella species for threatened saproxylic beetles

Based on three main results, we provide evidence that the White-backed Woodpecker is an effective umbrella species for threatened saproxylic beetles in Central Europe. First, sites with a high White-backed Woodpecker activity were represented on average by a 1.5 times higher threatened saproxylic beetle species richness compared to the control sites. Second, threatened saproxylic beetle communities of the High and Low activity levels had reduced β -diversity compared to the control. Third, at the species level, 5.7 times as many species were associated with White-backed Woodpecker's breeding home ranges than with absence sites, of which 4 species were red-listed. A limitation of this

study is that very rare beetle species may have a comparatively low detection rate using the passive and non-attractive trapping method used here. More targeted sampling methods may demonstrate further associations of red listed saproxylic beetle species with the White-backed Woodpecker. Nonetheless, our findings suggest that the protection of White-backed Woodpecker breeding sites, presenting old-growth forest characteristics (high dead wood volume and live trees of large diameter) can contribute to achieving an important conservation goal in European forests, namely the protection of red-listed dead-wood dependent beetles.

Generally, our findings are in line with previous studies that proposed the White-backed Woodpecker as an umbrella species for forest species. Bell et al. (2015) demonstrated that a higher number of red listed –including near threatened (NT)– saproxylic beetle species were associated with forest patches restored to meet White-backed Woodpecker's habitat requirements compared to managed forest stands. Prior to it, peers already proposed the White-backed Woodpecker as an umbrella species for saproxylic beetles but yielded uncertain results. (Martikainen et al., 1998), identified threatened saproxylic beetle species within White-backed Woodpecker territories, but lacked control sites to validate the umbrella species hypothesis. Similarly, Roberge et al. (2008b) tried to answer the question addressed by Martikainen et al. (1998), without significant results in favor of saproxylic beetles. Yet, they did observe an umbrella effect of the White-backed Woodpecker for forest birds of conservation concern and red-listed cryptogam species. Nonetheless, it is important to stress that the present validation of the White-backed Woodpecker as an umbrella species for threatened saproxylic beetles was made possible by using the comprehensive red-list for saproxylic beetles of the geographically close Baden-Württemberg region (Bense, 2001). Preliminary analyses performed with the Swiss red-list for saproxylic beetles (Monnerat et al., 2016) did not show any relation between White-backed Woodpecker occurrence and threatened saproxylic beetles. From our understanding, this disparity in analysis outputs of both prior and present research could be explained by the different levels of completeness of the two red lists, where the first focus only on the *Buprestidae*, *Cerambycidae*, *Cetoniidae* and *Lucanidae* families, while the latter encompasses 60 beetle taxonomic families. Additionally, as demonstrated in the European red list of saproxylic beetles (Nieto and Alexander, 2010), most of the assessed taxa suffer from data deficiency regarding their conservation statuses and population trends, pointing out the fundamental need for enhanced red lists for saproxylic beetles, at both local and continental scale.

4.2. Importance of the habitat

Our results also highlight the importance of forest structure for the conservation of saproxylic beetles. The entire saproxylic beetle community and the threatened species both profited from the volume of lying dead wood and the presence of trees of large diameter. Sampling plots representing White-backed Woodpecker's breeding home range were characterized by a higher volume of lying dead wood and by larger live trees compared to control sites (32.25 cm DBH compared to 26.44 cm DBH, [Supplementary materials S4](#); 3.61 m³/500 m² compared to 1.94 m³/500 m²; [Supplementary materials S3](#)) and being representative of the study area (average live tree diameter at breast height = c.a. 31 cm; lying dead wood volume = c.a. 55 m³/ha⁻¹; see [Ettwein et al., 2020](#)).

As White-backed Woodpecker's breeding activity (i.e., cavity in dead standing trees and dead branches) foraging strategy heavily relying on the dead wood resource to find the many saproxylic beetles composing its diet, the quality of a forest stand, represented by its live tree of large diameter and its large amount of dead wood, seems therefore to be forest attributes of prime importance to support the bird and its associated saproxylic biodiversity.

Backing up those observations, previous studies delivered similar results in mature and old-growth forests characterized by a high

structural complexity, an increasing density and diversity of tree-related microhabitats ([Paillet et al., 2017](#)) as well as an increasing proportion of dead branches in the tree crown, having in turn a positive effect on dead wood availability in the surroundings ([Keren and Diaci, 2018](#); [Lachat and Müller, 2018](#)). Additionally, our results are in line with general findings of European studies reporting positive effects of mean live tree diameter and volume of lying dead wood on White-backed Woodpecker occurrence ([Czeszczewik, 2009](#); [Czeszczewik et al., 2013](#); [Czeszczewik and Walankiewicz, 2006](#); [Gerdzhikov et al., 2018](#); [Mollet et al., 2009](#); [Roberge et al., 2008a](#); [Urkijo-Letona et al., 2020](#)) and on saproxylic beetle communities, including species of conservation concern ([Gossner et al., 2013](#); [Haeler et al., 2021](#); [Jonsell et al., 1998](#); [Lachat et al., 2014](#); [Parisi et al., 2019](#); [Roth et al., 2019](#)). Finally, one should not overlook the importance of forest structures for both saproxylic beetles and White-backed Woodpeckers, as wood-living insect larvae represent the majority of invertebrates brought to the nestlings ([Hogstad and Stenberg, 1997](#)).

5. Conclusions

The presented results support the idea that the White-backed Woodpecker is a suitable umbrella species for threatened saproxylic beetles in beech-dominated forests of Central Europe, underlining the importance of protecting sites where our selected surrogate species occurs. Biodiversity conservation programs aiming at protecting and promoting this woodpecker species and its associated biodiversity should first protect sites with known White-backed Woodpecker occurrence ([Campion et al., 2020](#)). By doing this, conservation programs would also promote saproxylic beetles' persistence through habitat quality improvement enabling forests to reach late successional stages. Secondly, conservation programs should identify forest sites adjacent to existing White-backed Woodpecker territories to implement conservation actions such as limiting logging activity ([Czeszczewik and Walankiewicz, 2006](#)) and implementing dead wood enrichment protocols ([Doerfler et al., 2017](#); [Roth et al., 2019](#)) to match White-backed Woodpecker habitat requirements in this geographical context ([Ettwein et al., 2020](#)). Such conservation measures are expected to benefit not only our surrogate species but also its associated fauna such as saproxylic beetles. Additionally, combining the role of this umbrella species with the status of a flagship species could facilitate the acceptance for conservation measures that can sometimes be restrictive for forest users, and free up financial resources for protection ([Floyd and Martin, 2016](#); [Stighäll, 2015](#)). Finally, testing the umbrella function of the White-backed Woodpecker and other highly specialized surrogate species on a broader spectrum of organisms and their response to habitat parameters could help in building more comprehensive and integrative biodiversity protection programs.

Credit authorship contribution statement

Romain Angeleri: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Urs G. Kormann:** Conceptualization, Investigation, Software, Validation, Writing – review & editing, Supervision. **Nicolas Roth:** Investigation, Software, Writing – review & editing. **Antonia Ettwein:** Conceptualization, Data curation, Writing – review & editing. **Gilberto Pasinelli:** Conceptualization, Funding acquisition, Project administration, Writing – review & editing. **Raphaël Arlettaz:** Conceptualization, Writing – review & editing. **Thibault Lachat:** Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Writing – review & editing.

Declaration of competing interest

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

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

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