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The Potential of Artificial Snags to Promote Endangered Saproxylic Beetle Species in Bavarian Forests

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Abstract: The creation of artificial snags, so-called high stumps, within forest management operations is a recently established tool to enrich standing deadwood as a habitat for saproxylic species. In this study, we analysed the impact of active high stump management on saproxylic beetle species. We selected 63 high stumps in six Bavarian forest districts (Germany), which were felled and subjected to close examination, focusing on beetle (Coleoptera) colonization. We identified 63 emerged coleopteran species belonging to 29 families; a further 10 taxa were identified only at the genus or family level, respectively. Moreover, 17% of the obtained taxa are listed in the German Red List of Coleoptera. Furthermore, 32% of the examined high stump trunks, predominantly broad-leaved tree species, harboured Red List beetle taxa. In particular, trembling aspen (*Populus tremula*) showed a disproportionately high number of Red List beetle species. The total species richness of beetles was independent of the height, diameter and decay stage of the snags. High stumps (snags) containing Red List beetle species tended to have higher amounts of deadwood in their surroundings, but the difference was not significant. According to the results of our study, actively creating high stumps proved to be a suitable method for creating habitats and serve as stepping-stones for endangered saproxylic species. Proactive high stump management during harvest can be a valuable component of deadwood management and biodiversity protection in forests.

Keywords: high stump; saproxylic Coleoptera; forest biodiversity; forest management; deadwood

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1. Introduction

Deadwood is widely known to be a key element for biodiversity in forest ecosystems as it provides various habitats for numerous saproxylic species [1–5]. In central European forests, around 25% of the beetle and fungus species depend on deadwood [6]. The accumulation of deadwood is therefore an important aspect of ecologically sustainable forestry, not only promoting deadwood-dependent but also non-saproxylic species [7]. Deadwood is thus one of the fifteen main indicators of biodiversity proposed by the European Environmental Agency [8].

The most species-rich groups of organisms inhabiting deadwood are fungi, followed by insects [9]. Among insects, saproxylic beetles (Coleoptera) are important indicators regarding the degree of preservation of the forest ecosystem. Few beetle taxa, mostly pioneers such as bark beetles, specialize in just one tree species [10]. The vast majority of xylobionts, on the other hand, are bound to either hardwood or softwood [4]. With progressive decomposition, the importance of the tree species is lost, and the substrate becomes more important. Some of the beetle species feed on the wood itself, but many depend on various fungi that feed on the wood or the fine wood mould that accumulates in the rot cavities of standing trees [9]. Still, more are hunters, feeding on the species depending on the wood and fungi [7].

However, many saproxylic species are threatened since most European forests are intensively managed. The receding mass of deadwood in the forests results in a substantial loss of biodiversity. Many species of saproxylic insects have thus become endangered or extinct [11,12]. Zumr and Remeš [10] state that in commercial forests with a full stand canopy and lack of deadwood, the environment is almost uninhabitable for saproxylic beetle species. In Germany's Red List of Endangered Species, 28% of the saproxylic beetle species are listed as endangered or regionally extinct [11,13]. The management of deadwood is therefore an important aspect of ecologically sustainable forestry to preserve saproxylic species.

Deadwood management and research hitherto mostly focused on accumulating lying deadwood (e.g., [14]), while studies on standing deadwood are less common (e.g., [7,15]). Zumr and Remeš [10] concluded that high stumps and standing large living and dead trees are the most important hosts of microhabitats. According to Rothacher et al. [7], who performed a study on different types of standing and lying deadwood in homogeneous production beech forests, snags provide longer-lasting deadwood resources, underlining the sustainability of snag enrichment for forest biodiversity. The creation of high stumps is intended to improve the natural habitats of xylobiont insects, as well as bats and birds [16]. With this measure, the harvester at the approximate height of 3–5 m removes the tree crown and the remaining trunk (high stump) is left standing. In Scandinavia, this form of proactive nature conservation has been practiced for around two decades since the 2000s (e.g., [17]). According to the Forest Stewardship Council (FSC) in Sweden, at least three high stumps or ringed trees per hectare are required for felling measures to significantly improve biodiversity.

In southern Germany, some forest departments started to create deadwood artificially about 20 years ago (starting from 2002). A special nature conservation program was implemented by the Bavarian State Forests (BaySF) in 2019 to enrich standing deadwood proactively. Approximately six thousand high stumps were actively created in forests throughout the federal state Bavaria since 2002; however, the benefit of this measure for the conservation of saproxylic beetles has not yet been assessed. Here, we evaluated the potential of these artificially created high stumps as a management tool for increasing habitats for saproxylic beetle species in forests, with a special focus on Red List species. Previous studies from Northern and Eastern Europe already demonstrated the value of high stumps as an important habitat component for saproxylic beetles, including rare and threatened species (e.g., [18–20]). Our study draws a more detailed picture of the spectrum of beetles and their ecology found in the artificial snags of forests in southern German forests and assesses whether specific characteristics of high stumps (height, diameter, decay stage) or the amount of deadwood in the vicinity affected beetle diversity and the occurrence of Red List species.

Our study focuses on the following questions:

1. Do artificially created high stumps harbour saproxylic beetle species of the Red List?
2. How do beetle species richness and the occurrence of Red List beetle species differ among high stump characteristics as well as the amount of deadwood in the vicinity of the high stumps?

2. Material and Methods

2.1. Study Area and Site Selection

Our study was conducted in six forest areas in Bavaria, southern Germany (Figure 1). The forest areas were chosen according to their differences in tree species composition. Forest areas Ebrach (latitude 49.9223°, longitude 10.5055°) and Forchheim (latitude 49.7183°, longitude 11.0202°) are dominated by deciduous tree species like beech (*Fagus sylvatica*) and oak (*Quercus robur/petraea*), whereas forest areas Flossenbürg (latitude 49.6673°, longitude 12.3723°) and Waldsassen (latitude 49.9016°, longitude 12.0158°) are dominated by coniferous tree species like spruce (*Picea abies*). In the forest areas Freising (latitude 48.4224°, longitude 11.6903°) and Nuremberg (latitude 49.4875°, longitude 11.2543°), we predominately find mixed forest stands. In these six forest areas, we selected stands where high stumps have been created regularly since 2002 to be able to assess age differences. The forest stands are part of the Bavarian state forests and regularly managed through processes including harvesting and thinning.

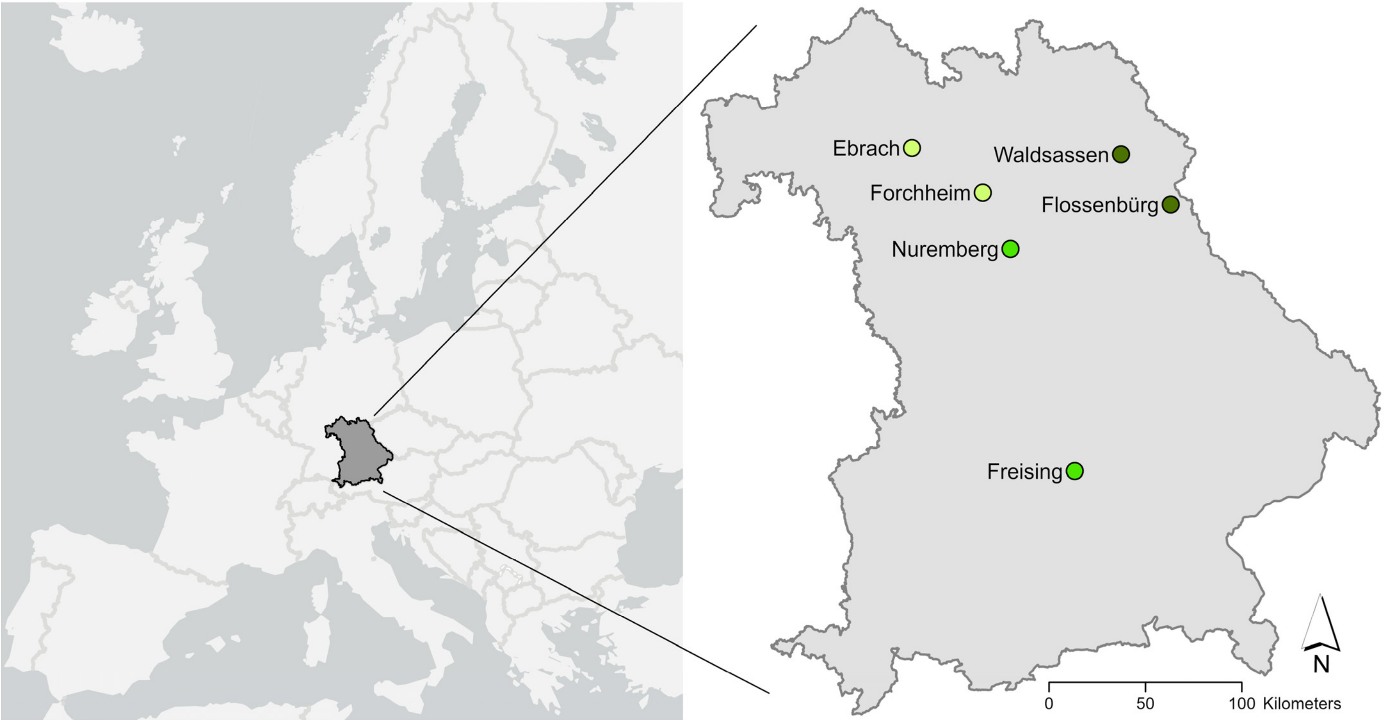

Figure 1. High stumps examined in six forest areas Ebrach, Flossenbürg, Forchheim, Freising, Nuremberg and Waldsassen. Light green = deciduous tree species dominated, darker green = mixed stands dominated, dark green = coniferous tree species dominated.

2.2. High Stumps Sampling

Within the six forest areas, we monitored a total of 635 snags and selected a total of 63 of them (height > 1.70 m; Figure 2) for our survey, i.e., 10 within each forest area except for the forest area of Nuremberg, where 13 high stumps were sampled. For each high stump, we determined the following characteristics that were expected to influence the diversity of the saproxylic insect species [21]: tree species, diameter at breast height (DBH at 1.3 m), high stumps height, degree of decomposition (Table 1; [6]) and deadwood mass in the vicinity of the high stumps.

Table 1. Degree of decomposition in five decay stages (DS) modified after Lachat et al. [6].

DS	Decay Stage	Description
1	No decomposition	Recently artificially created high stumps (<2 years). Outer bark still well attached.
2	Slight decomposition	Outer bark loosely attached to sap wood. Wood mostly intact.
3	Mesic decomposition	Outer bark partially absent; wood showing signs of decomposition.
4	Mid decomposition	Outer bark absent; wood largely decomposed with some remaining hardy parts.
5	Strong decomposition	Most parts of the wood decayed into humus.

To analyse the influence of deadwood in the immediate vicinity of the 63 high stumps on the diversity of saproxylic beetle species, standing deadwood (tall high stumps: height $\geq$ 1.3 m, diameter at breast height $\geq$ 20 cm; shorter stumps: height < 1.3 m, diameter $\geq$ 20 cm) and lying deadwood (length $\geq$ 1.3 m, diameter at 1.3 m from the thicker end ≥20 cm) was mapped within a radius of 18 m (=1000 m^2) with the following parameters: diameter at breast height or diameter (cm) and height or length (m). Using these parameters, we derived the deadwood volume around the high stumps.

Figure 2. A typical beech (*Fagus sylvatica*) high stump as observed in Waldsassen, Bavaria, Germany. The high stump is marked with a wavy line that identifies it as a biotope tree.

2.3. Insect Sampling and Identification

After the sampling of the 63 artificially created high stumps in the field, we logged them at a height of 1 m above ground and cut a 50 cm long piece subsequently from the fallen log. The severed piece was then placed inside a translucent plastic bag (size 120 cm × 60 cm) and kept there for approximately three months at room temperature. The challenge here was to achieve the highest possible hatching rate, which required a balance in the microclimate between drying out and detrimental fungal growth. All samples were checked regularly three times a week for moisture conditions and beetle hatch. The condensed water was removed with tissue paper to prevent the wood being infested by fungus. The bags were then left open for two hours to allow them to be rid of the condensed water. Once every 14 days, the wood was sprayed with water to simulate rainfall occurring naturally. The emerging beetles were collected either by hand (individual collecting) or by an aspirator and conserved in 98% ethanol. Species of the coleopteran families were identified under stereoscopic microscope using standard and reference work of coleopterology in science and research [22]; some large and conspicuous species (e.g., *Anaglyptus mysticus* (L., 1758)) were identified by the naked eye. After approximately three months, the experiment was terminated due to time and financial restrictions.

2.4. Data Analyses

The statistical analyses were performed in R version 4.0.3 [23]. Species richness was calculated based on the number of different beetle species found in each sample, only including adult individuals. Differences in the amount of deadwood surrounding high stumps with and without Red List species were tested using a permutation t-test (package RVAideMemoire; [24]). Differences in species richness among tree species, decay stages, diameter and height classes were assessed using permutation-based pairwise t-tests from the same package.

The preferences of Red List beetle species for high stump characteristics were calculated using the Ivlev's electivity index [25]. This index indicates the preference of a resource in terms of the ratio of availability of the resource in the environment to its usage. The formula for calculating the Ivlev's electivity index (E) is as follows:

$$E = \frac{r_i - p_i}{r_i + p_i}$$

where r is the proportion of the number of high stumps used by the beetle species within the high stump characteristic i to the total number of high stumps used by the beetle species, and p is the proportion of the number of high stumps within the high stump characteristic i to the total number of high stumps potentially available. The index values range between −1 and +1, where a value of −1 corresponds to complete avoidance, 0 to no selection and +1 indicates a strong preference.

3. Results

3.1. High Stump Characteristics

The 63 sampled high stumps were divided into 21 coniferous trees containing three tree species and 42 deciduous trees containing seven different tree species (Table 2). The most common tree species were spruce (*Picea abies*), oak (*Quercus robur/petrea*), beech (*Fagus sylvatica*) with 12 high stumps and poplar (*Populus tremula*).

Table 2. Sixty-three high stumps and their characteristics regarding tree species, number of high stumps (n), diameter at breast height (DBH), height, degree of decomposition (for decay stage, see Table 1) and deadwood volume in the vicinity of the high stumps.

		DBH [cm]		Height [m]		Decay Stage					Deadwood Volume [m^3/0.1 ha]	
Tree Species	**n**	**Mean**	**Min–Max**	**Mean**	**Min–Max**	**1**	**2**	**3**	**4**	**5**	**Mean**	**Min–Max**
Coniferous trees	21	41	25–57	2.85	1.70–4.60	5	5	4	5	2	2.2	0.7–4.7
Picea abies	17	41	25–57	2.50	1.70–4.78	5	3	4	3	2	2.3	0.7–4.7
Pinus sylvestris	3	32	24–40	4.33	3.90–4.60	0	1	0	2	0	1.9	1.1–3.4
Larix decidua	1	36	36	4.30	4.30	0	1	0	0	0	3.1	3.1
Deciduous trees	42	40.5	21–60	4.33	2.17–6.35	10	8	7	14	3	3.9	0.1–18.3
Acer pseudoplatanus	1	21	21	2.97	2.97	0	0	0	1	0	13.4	13.4
Alnus glutinosa	2	42.25	41.5–43	3.98	3.58–4.37	0	0	0	2	0	7.9	3.4–12.4
Betula pendula	3	30.5	29–52	4.33	3.78–5.30	1	1	0	1	0	2.4	0.5–6.0
Carpinus betulus	1	35	35	2.17	2.17	0	1	0	0	0	4.6	4.6
Fagus sylvatica	12	40.5	21–60	3.83	2.79–5.74	2	4	4	1	1	4.8	0.9–18.3
Populus tremula	7	42	27–57	4.83	3.90–5.80	5	1	0	1	0	5.6	1.1–15.4
Quercus robur/petraea	16	35	25–45	4.75	3.30–6.35	2	1	3	8	2	1.7	0.1–11.4

The average diameter at breast height for all 63 high stumps was 41 cm, ranging from 21 to 60 cm (Table 2).

The average high stump height was 3.7 m (ranging from 1.7 m to almost 8 m; Table 2). Our average high stump height was a little more than one meter below the heights recorded in the Semenic primeval forest (Romania) for naturally formed stumps (5 m) and is justified for safety reasons [26].

Deadwood volume differed between coniferous trees with a range from 0.7 to 4.7 $m^3/0.1$ ha and deciduous trees with a wider range from 0.1 to 18.3 $m^3/0.1$ ha (Table 2).

3.2. Beetle Species and Their Ecologies

A total of 73 beetle (Coleoptera) morphospecies was sampled from the 63 high stumps incubated in the laboratory. Of these, 63 specimens could be identified at the species level; in the case of ten taxa (14% of all taxa), the identification was only possible at the genus or family level. The obtained Coleoptera belonged to 29 families, demonstrating a high level of beetle diversity (Table 3). With ten species, weevils (Curculionidae) were the most species-rich family, followed by long-horned beetles (Cerambycidae; seven species) and soft-winged flower (Melyridae) and click beetles (Elateridae), respectively (four species, each family). Fungivorous taxa accounted for 27%, while saprophagus taxa were most numerous, accounting for 31%. A smaller number of taxa belonged to predaceous (21%) and phytophagous (21%) feeding ecologies (Table 3; Figure 3).

Table 3. Coleopteran families obtained in our study and their main feeding ecologies, indicated by x. Fungivorous: customarily feeding on fungi; Predaceous: living by preying on other animals; Saprophagous: feeding on decaying matter; Phytophagous: feeding on plants.

Family	Fungivorous	Predaceous	Saprophagous	Phytophagous
Anthribidae	x			
Buprestidae				x
Cantharidae		x		
Cerambycidae				x
Chrysomelidae				x
Ciidae	x			
Cleridae		x		
Coccinellidae		x		
Cryptophagidae			x	
Curculionidae				x
Dermestidae			x	
Elateridae				x
Eucnemidae			x	
Histeridae		x		
Latridiidae			x	
Lucanidae			x	
Lymexylidae	x			
Melandryidae	x			
Melyridae		x		
Monotomidae			x	
Mordellidae				x
Mycetophagidae	x			
Ptinidae			x	
Scraptidae			x	
Silvanidae	x			
Staphylinidae		x		
Tenebrionidae	x			
Tetratomidae	x			
Zopheridae			x	

Regarding the number of collected specimens, we counted 1222 individuals belonging to the order Coleoptera (Figure 4). Among them, 459 or 37.6% of the emerged individuals belonged to the family of deathwatch beetles (Coleoptera: Ptinidae). Their entire biomass, however, consisted merely of two species. This saproxylic beetle family is typical for dry standing deadwood, a prominent representative of this group being, e.g., *Ptilinus pectinicornis* (L., 1758). However, there are also species that colonize tree fungi, such as the *Dorcatoma* (*Pilosodorcatoma*) *substriata* (Hummel, 1829). With 305 specimens (or 25%), the bark beetles (Coleoptera: Curculionidae: Scolytinae) were the second most numerous, belonging albeit also only to two species, not considered being relevant for the forest protection. The checkered beetles (Coleoptera: Cleridae) with 87 recorded specimens (or 7.12%) were the third most common group. Both the larvae and the adults are mostly predatory and prey upon the wood-inhabiting larvae of other insect species. *Thanasimus formicarius* (L., 1758) is particularly well known as the predator of *Tomicus piniperda* (L., 1758) and *Ips typographus* (L., 1758). False click beetles (Eucnemidae) follow clerids very closely, with 84 obtained individuals (or 6.87%). The fifth most common group of beetles were the longhorn beetles (Coleoptera: Cerambycidae), constituting 37 individuals or 3.2% of the total. Typical for longhorn beetles is the change in habitat between the saproxylic ways of life in the wood body as larva and as adult that often visits flowers where they mate. The longhorn beetle larvae are often large and are an important food resource for woodpeckers.

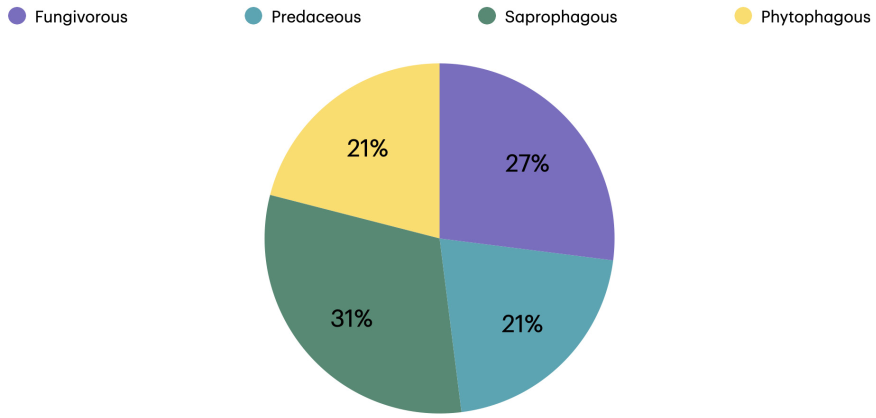

Figure 3. Distribution of feeding ecologies of coleopteran families found in the samples (for feeding ecologies, see Table 3).

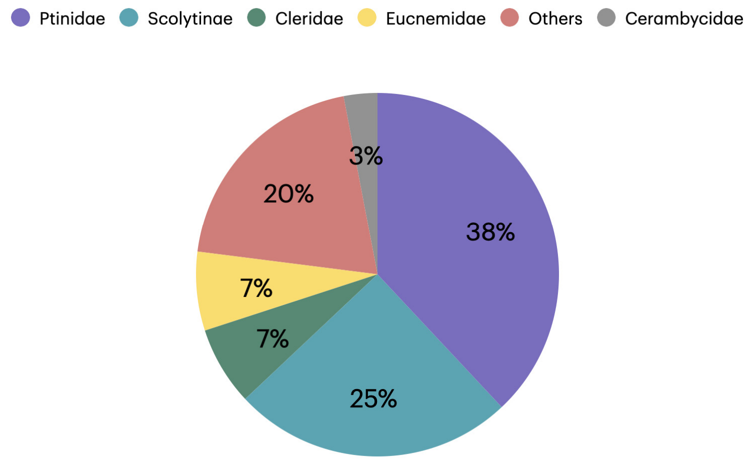

Figure 4. Number of coleopteran individuals of the obtained beetles per family.

Red List beetle species were present in one-third (19 out of 63) of the high stumps. A total of eleven Red List beetle species were found (Table 4).

The spotted poplar jewel beetle (*Agrilus ater* (Linnaeus, 1767); Coleoptera: Buprestidae: Agrilinae; Figure 5), considered to be extinct in Bavaria and strongly endangered in Germany emerged from one of the observed poplar trunks. This beetle, which specializes in poplar and willow tree species, targets weakened, dying trees. Aspen trunks cut off by harvesters are severely weakened, which enhances colonization by this jewel beetle. This explains why this species emerged from a trunk belonging to the decomposition degree 1 group (“not decomposed”).

Table 4. Red list beetle species found in our study. RLD: Red List Germany, RLB: Red List Bavaria. 0—extinct or missing data; 1—threatened with extinction; 2—strongly endangered; 3—endangered; V—on the warning list of possibly becoming endangered. Taxa marked with asterisk (*) are indicators of near-natural beech forest sensu, Lachat et al. [27].

Species	Family	RLD	RLB
Acanthocinus griseus (F., 1792)	*Cerambycidae*	3	3
Agrilus ater (L., 1767)	*Buprestidae*	2	0
Bolitophagus reticulatus * (L., 1767)	*Tenebrionidae*	3	3
Colydium elongatum (F., 1787)	*Zopheridae*	3	2
Megatoma undata (L., 1758)	*Dermestidae*	3	3
Hylis olexai (Palm, 1955)	*Eucnemidae*	3	3
Hypoganus inunctus (Lacordaire, 1835)	*Elateridae*	3	V
Lymexylon navale (L., 1758)	*Lymexylidae*	3	3
Saperda perforata (Pallas, 1773)	*Cerambycidae*	2	2
Sinodendron cylindricum (L., 1758) *	*Lucanidae*	3	3
Tillus elongatus (L., 1758)	*Cleridae*	3	

Figure 5. *Agrilus ater* (L., 1767) (Coleoptera: Buprestidae) considered regionally extinct in Bavaria and strongly endangered in Germany.

Another beetle species found in the same tree host is the cerambycid *Saperda perforata* (Pallas, 1773). Ranked as strongly endangered in Germany and Bavaria, it targets poplar trees, especially *Populus tremula*. For its development, it requires a moist substrate and is crepuscular/nocturnal as an adult. The predaceous colydid *Colydium elongatum* (F., 1787) is strongly endangered in Bavaria and endangered in Germany. This widely distributed but local and rather uncommon taxon is nocturnal and may often be overlooked due to its hidden way of life.

3.3. Preferences of Beetle Species Regarding High Stump Characteristics

Of the 42 high stumps of deciduous trees, 38% (n = 16) harboured Red List beetle species, while of the 21 conifer high stumps, just 14% (n = 3) contained Red List beetle species (Table 4). The investigated poplar high stumps (mainly aspen) tended to have a higher mean species richness (Figure 6A) and were colonized by Red List beetle species with an Ivlev's electivity index of 0.17 disproportionately more often than beech (0.05), oak (0.02) or spruce high stumps (−0.44) (Figure 6B). The mean beetle species richness of spruce high stumps was lower than the mean species richness of beech, oak and poplar high stumps, although not significantly (Figure 6A).

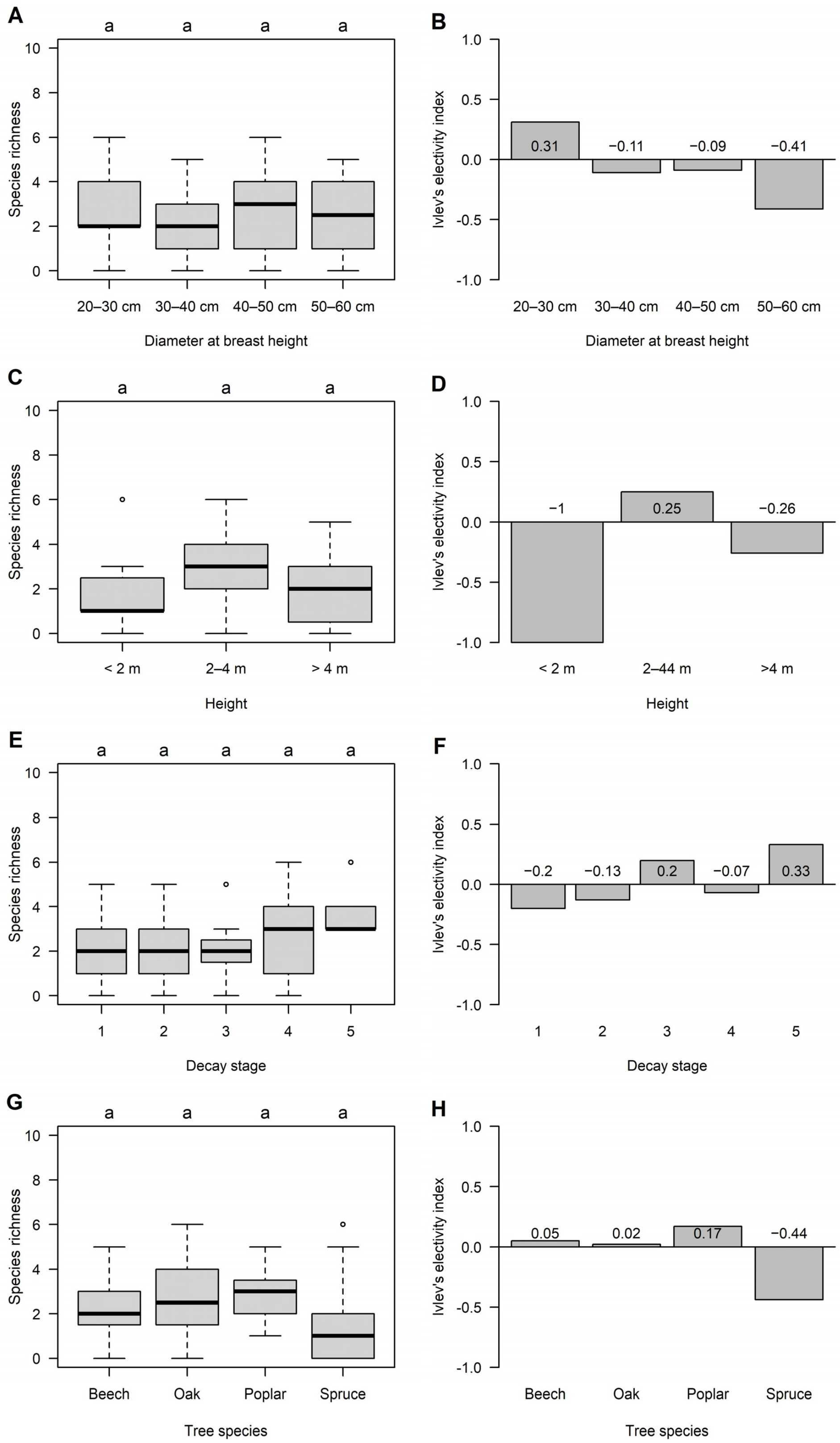

Figure 6. Total beetle species richness (left) and Ivlev's electivety index of the Red List beetle species (right) grouped by diameter at breast height (**A**,**B**), height of the high stumps (**C**,**D**), decay stages ((**E**,**F**); see Table 1) and tree species (**G**,**H**). Identical letters above the boxes on the left indicate non-significant differences ($p > 0.05$) between factor levels, as obtained by pairwise permutation t-tests. Bars on the right indicate the values of Ivlev's electivity index that Red List species displayed for the different factor levels.

Species richness showed no significant differences between the DHB classes (Figure 6C). However, Red List beetle species seemed to prefer lower diameter classes (Figure 6D). Beetle species richness was highest for high stumps between 2 and 4 m (Figure 6E), although the difference was not significant. Red List beetle species preferred high stumps of medium heights with an Ivlev's electivity index of 0.25 (Figure 6F).

High stumps with decay stages of mid and strong decomposition (decay stage 4 and 5) were slightly richer in beetle species than high stumps of lower decomposition (Figure 6G). Red List beetle species, however, prefer, in addition to the strongly decomposed high stumps (Ivlev's electivity index of 0.33), also high stumps of intermediate decomposition (Ivlev's electivity index of 0.2) disproportionately more often (Figure 6H).

High stumps containing Red List beetle species tended to have higher amounts of deadwood in their surroundings (18 m buffer) than high stumps without Red List species (Figure 7). However, the difference was not significant (t = −0.34; p = 0.73). Total beetle species richness showed no correlation to deadwood amounts either.

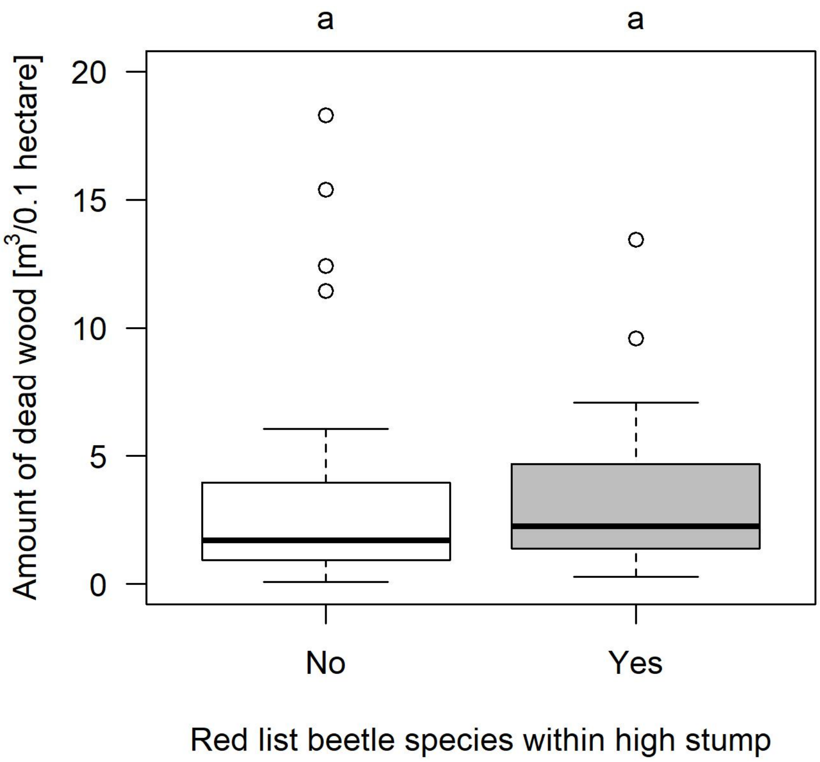

Figure 7. Deadwood amounts within 18 m radius (0.1 hectare) around high stumps with and without Red List species. Identical letters above the boxes indicate a non-significant difference ($p > 0.05$) in the deadwood volume between high stumps with and without Red List species, as obtained by a permutation t-test.

4. Discussion

In this study, we investigated beetles emerging from artificially created snags and assessed which snag characteristics promoted species richness and the occurrence of Red List species. We obtained a broad range of beetle species representing various functional groups, including eleven different Red List species (17% of all species) found in one-third of the sampled snags. Our results are comparable with those of Henneberg et al. [28], who, during a two-year study aimed at tree hollows, reported that 22% of the obtained species were threatened. One of our emerged beetles, *Agrilus ater*, was considered regionally extinct and two other species (*Saperda perforata* and *Colydium elongatum*) are strongly endangered in Bavaria. Likewise, we found two species that serve as indicators of near-natural beech forests [27]. Given that this spectrum of conservation-relevant species was found in a rather small sample of high stumps, our study underlines the high potential of artificially created snags as a suitable habitat for rare saproxylic beetles.

Overall, beetle species richness tended to be higher in deciduous trees, while conifers such as spruce were less species-rich and were no preferred habitat of Red List species. Investigating logging residues in Sweden, Jonsell et al. [29] also reported low species richness and numbers of Red List species in spruce compared to deciduous trees. Concordant with our study, they also found high numbers of Red List species in aspen. Other studies confirmed the high value of this tree species for the conservation of saproxylic beetles [20,30]. In contrast, Vogel et al. [31] observed that Red List species were ubiquitously distributed in both deciduous and coniferous deadwood, based on an experiment exposing freshly cut branch bundles from 42 different tree species in forest stands of Southern Germany. Although communities in coniferous deadwood might be less diverse, their composition clearly differs from those in broadleaved deadwood [31] and may thus complement species pools to enhance overall beetle diversity [20,32].

Snag characteristics such as diameter, height or decay stage had no significant effects on beetle richness, while Red List species seemed to avoid snags with low diameters and prefer snags with intermediate to high decay stages. Previous studies showed positive correlations between snag diameter and total as well as Red List species numbers [20,33,34], although in other analyses, diameter was a less important determinant [18,35]. However, the lacking effects may also be due to a limited range of diameters investigated in these studies, suggesting that size effects might be more pronounced when including higher diameters [18], which were less frequent in our study. Positive associations between the stage of decay and the number of (Red List) beetle species have also been observed in logging residues [29] and high stumps [18] in Sweden. Importantly, standing deadwood such as snags may persist longer in forest stands than lying logs, which are subjected to faster decomposition processes [36]. Rare and threatened beetle species that prefer late decay stages can therefore be supported by high stumps as they provide longer-lasting habitats and resources for these species [7].

Beetle species richness was independent of the amount of deadwood surrounding the snags. Deadwood amounts were slightly higher around snags containing Red List species but not significantly. Local deadwood amounts generally have a positive influence on the richness of saproxylic beetles [5], but this effect may vary depending on other factors such as the surrounding tree species composition [28], temperature [37] and sun exposure [38]. Although we were not able to control for these effects in our study design, our results suggest that the creation of high stumps may benefit saproxylic beetle diversity independent of the habitat amount in the local surroundings. Still, as canopy openness is known as a key driver of deadwood biodiversity (e.g., [7,38]), the positive effects of artificial snags on deadwood biodiversity may be enhanced by choosing trees in open areas or canopy opening as an accompanying measure.

Our results emphasize the potential of artificial snags to enhance the beetle species richness of various functional groups in commercial forests. The high conservation value of artificial snags for forest biodiversity has been demonstrated in several studies. Comparing natural and human-made snags in Sweden, Jonsell et al. [18] showed that although the beetle fauna in artificial snags differed in species composition and showed lower species richness, they still were inhabited by a similar number of Red List beetles compared to natural ones. In an experiment actively creating deadwood structures under open and closed canopy conditions, Rothacher et al. [7] showed that in treatments with artificial snags, the species richness and abundances of both saproxylic and non-saproxylic beetles increased over time. In a recent study comparing the saproxylic beetle diversity of standing and lying deadwood, Zumr et al. [19] found that Red List saproxylic beetles were more abundant and species-rich in snags compared to logs. In line with these results, our study confirms that artificially created snags provide important habitat components enhancing the diversity of saproxylic and non-saproxylic beetles, including rare and threatened species.

5. Conclusions

By capping the crown as part of the Bavarian "The forest in bloom" program, the phase of proactively creating deadwood has shifted significantly forward. In addition, rare habitat structures such as weakened, ailing trees are produced—harbouring their own communities. Snags are used by woodpeckers and other birds that create hollows—one of the rarest habitats in today's Central European managed forests that are considered key structures for high biodiversity in forests [28]. The goal of retaining high stumps to provide a habitat for wildlife is essential for sustainable forest management and should be continued. In conclusion, high stumps provide a proactive tool to enhance standing deadwood and thus promote the biodiversity of saproxylic and non-saproxylic beetle communities. They serve as an important habitat component for rare and endangered beetle species but also for animals of higher trophic groups such as birds or bats. In particular, broad-leaved trees contained many endangered beetle species, with particularly aspen exhibiting a high conservation value. Therefore, deciduous trees should be prioritized when creating high stumps, although coniferous snags may provide additional resources to support diverse forest communities. Ideally, snags should be created in gap situations or in combination with canopy opening. Creating high stumps with a harvester can easily be integrated in the normal harvest of wood and should become a part of sustainable deadwood management in productive forests.

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