Izvirni znanstveni članek / Original scientific paper

PATTERNS OF TREE MICROHABITATS ACROSS A GRADIENT OF MANAGED TO OLD-GROWTH CONDITIONS: A CASE STUDY FROM BEECH DOMINATED FORESTS OF SOUTH-EASTERN SLOVENIA

DREVESNI MIKROHABITATI V BUKOVIH GOZDOVIH JUGOVZHODNE SLOVENIJE: PRIMER GOZDNIH REZERVATOV KOBILE IN RAVNA GORA TER BLIŽNJEGA GOSPODARSKEGA GOZDA

Kristina SEVER[1], Thomas A. NAGEL[2]

(1) Slovenian Forestry Institute, kristina.sever@gozdis.si

(2) University of Ljubljana, Biotechnical Faculty, Department of Forestry and Renewable Forest Resources, tom.nagel@bf.uni-lj.si

ABSTRACT

An inventory of tree microhabitats was done in two unmanaged forests (Kobile and Ravna gora forest reserves) and one managed beech forest in SE Slovenia. The purpose of this study was to determine the influence of forest management, natural disturbances, and tree characteristics on microhabitat patterns. Forest structure and microhabitats were recorded in systematically placed plots (500 m^2 in size) across each area. In total, we inventoried 849 trees on 54 plots and 1833 tree microhabitats. The results showed that forest management had no significant influence on the abundance of microhabitats per tree, but there were differences regarding microhabitat type between managed and unmanaged sites. There were substantially more microhabitats related to standing dead and live habitat trees in unmanaged forest (e.g. woodpecker cavities, insect galleries and bore holes, branch holes, dead branches and fruiting bodies of fungi), whereas in managed forests there were more tree microhabitats related to management (e.g. exposed heartwood, coarse bark, and epiphytic plants). The results also indicate that disturbance, tree diameter, vitality, and species influence the density, diversity, and occurrence of tree microhabitats.

Key words: forest management, biodiversity, tree microhabitats, beech forests, old-growth, veteran tree, natural disturbance, dead wood

IZVLEČEK

V bukovih gozdovih na območju Gorjancev (JV Slovenija) je bil jeseni 2014 opravljen popis drevesnih mikrohabitatov (DM). Skupno 54 ploskev velikosti 500 m^2 je bilo sistematično postavljenih na treh raziskovalnih območjih (v pragozdnem rezervatu Ravna gora in gozdnem rezervatu Kobile ter v bližnjem gospodarskem gozdu). Zabeležili smo 1833 drevesnih mikrohabitatov na 849 drevesih. Namen študije je bil ugotoviti, kako gospodarjenje, naravne motnje ter sestojne značilnosti vplivajo na pojav DM. Podatke smo analizirali s programoma Excel in SPSS z neparametričnimi metodami. Ugotovili smo, da način gospodarjenja ne vpliva značilno na številčnost DM na drevo, vpliva pa na vrsto DM. V obeh rezervatih je bilo zabeleženih več DM, povezanih z odmrlimi in starimi drevesi (dupla ptic, izletne odprtine in rovi podlubnikov ter žuželk, vejne votline, večje odmrle veje in trosnjaki gliv), v gospodarskem gozdu pa več DM, povezanih z gospodarjenjem (izpostavljena beljava, razbrazdana skorja in epifiti). Prav tako smo ugotovili, da na gostoto, raznolikost in pojav DM vplivajo tudi naravne motnje, premer in stanje drevesa ter drevesna vrsta.

Ključne besede: gospodarjenje z gozdovi, drevesni mikrohabitati, bukovi gozdovi, gospodarski gozd, negospodarski gozd, Kobile, Ravna gora, naravne motnje

GDK 22:53+180(497.4Kobile)(497.4Ravna gora(045)=111 Prispelo / Received: 12. 3. 2019

DOI 10.20315/ASetL.118.3 Sprejeto / Accepted: 26. 4. 2019

1 INTRODUCTION

1 UVOD

Maintaining forest biodiversity is a key challenge to managing the world's forests. Most countries tend to rely on a segregated approach to preserve forest biodiversity, whereby large regions are set aside in strict forest reserves to maintain native biodiversity and wood production is carried out in intensively managed-short rotation plantations (Paquette and Messier, 2010). Across Europe, and particularly in Slovenia, maintenance of forest biodiversity is often integrated with wood production goals. Under an integrated approach, it is necessary to balance wood production with key habitat structures for forest biodiversity. For example, silvicultural systems that create continuous cover, uneven-aged forest stands using native tree species may be sufficient for maintaining a broad range of generalist species, but a large component of forest biodiversity also requires habitat features that develop when forests are left unmanaged (Brunet et al., 2010). These features include large amounts of standing and lying woody debris and old veteran trees (Nagel et al., 2017a). Biodiversity experts suggest that more than 25 % of forest biodiversity is dependent on such features, including many saproxylic species of fungi, lichens, bryophytes, insects, birds, and bats (Siitonen, 2001; Bütler et al., 2013). Determining the amount (e.g. volume of deadwood or density of habitat trees) of these key habitat structures to maintain in managed forests is a challenge. In general, the more of these features that are left and maintained in a forest (i.e. moving toward old-growth conditions), the less profitable the forest will be.

A recent study of deadwood and habitat trees across managed forests and forest reserves in Slovenia clearly indicates that continuous cover management is not sufficient for maintaining species that require old-growth type habitat (large amounts of decaying deadwood and habitat trees) (Nagel et al., 2017a). However, that study only focused on the density of large trees (i.e. > 50 cm dbh) as a measure of habitat trees. A key feature of old decaying habitat or veteran trees is that they contain a high density and diversity of tree microhabitats. These are defined as distinct structures occurring on living or standing dead trees that represent essential substrates for species or communities to develop, feed, shelter, or breed during a part of their life cycle. They include a diverse array of structures, such as cavities, cracks, conks of fungi, and broken branches, many of which expose sap and heartwood and facilitate wood decay in the canopy (Larrieu et al., 2018).

Most studies that have examined the influence of forest management on biodiversity habitat have overlooked microhabitats (Paillet et al., 2017; Larrieu et al., 2012), yet there are an increasing number of studies that quantify them, mainly in managed forests or formerly managed forest reserves (e.g. Paillet et al., 2017; Vuidot et al., 2011; Winter et al., 2015; Winter and Möller, 2008; Regnery et al.; 2013, Larrieu and Cabanetes, 2012; Larrieu et al., 2012; and 2018; Caurbaud et al., 2017; Bütler et al., 2013) and, to a lesser extent, in well preserved old-growth forests (Kozak et al., 2018; Larrieu et al., 2014; Michel and Winter, 2009). Taken together, these studies generally show a different profile of microhabitats between managed and unmanaged stands. This is mainly because rotation cycles (e.g. < 100–150 years in managed forests) typically do not allow veteran trees to develop, and management activities tend to both remove damaged trees with little economic value or create particular types of microhabitats during harvesting and thinning operations (e.g. bark loss) (Larrieu et al., 2012; Vuidot et al., 2011). In contrast, old-growth forests have a high density of large old trees, which support a unique set of structures, including cavities, large broken branches from natural disturbance, and substantial accumulation of canopy deadwood (Kozak et al., 2018; Brunet et al., 2010).

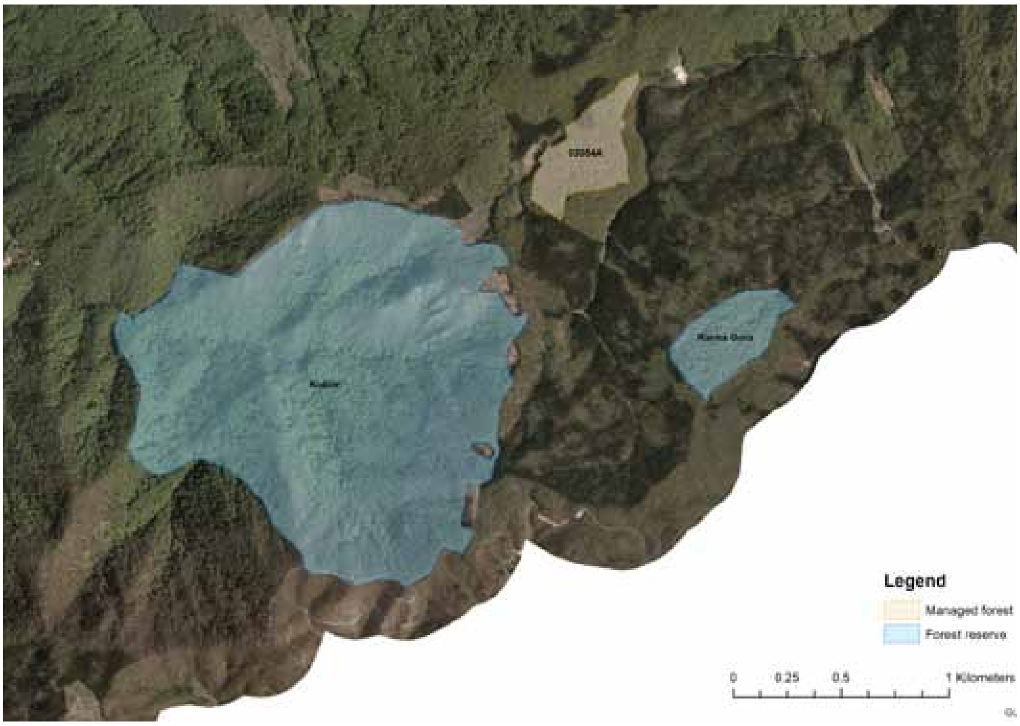

Fig. 1: Study area showing the locations and sizes of the three sampling areas (source: GURS, 2019 and ZGS, 2019a).

Slika 1: Območje raziskave (vir: GURS, 2019 in ZGS, 2019a).

In Slovenia, many authors have highlighted the importance of habitat and dead trees for biodiversity. Jurc (2004) described the importance of old trees as habitat for saproxylic insect species. Perušek (2004) emphasized their importance for certain bird species. Golob (2006) suggested that habitat and dead trees are two of the most important indicators for monitoring the conservation of forest habitat types and species. Finally, Diaci and Perušek (2004) and Papež (2005) gave guidelines and recommendations for maintaining and increasing the number of old and dead trees in managed forests. However, there have been no studies explicitly on tree microhabitats in Slovenia thus far.

In this case study, we take advantage of a gradient of forest conditions, from a managed stand, to a mature forest reserve, to a well-preserved old-growth remnant, in a region of south-eastern Slovenia dominated by beech forests. The overall goal was to quantify the density and diversity of tree microhabitats across these three levels of naturalness. Because this is the first study on microhabitats in Slovenia, the primary justification for this research was to provide baseline conditions on microhabitats in beech forests, the most common forest type in Slovenia. This information is necessary to help develop management recommendations concerning microhabitats and habitat trees, such as defining target values for the density and types of microhabitats in managed forests (Paillet et al., 2017). A secondary goal was to examine how natural disturbances influence microhabitat patterns. Both the forest reserve and old-growth forest studied here were damaged by former windthrow events, providing an opportunity to examine microhabitats in disturbed and undisturbed stands, something that has received little attention in the international literature on tree microhabitats. We emphasize that our research is a case study without replication of stand types, such that we hope this work will encourage future studies across Slovenia to provide more robust baseline conditions on tree microhabitats across various forest and management types.

2 MATERIALS AND METHODS

2 MATERIALI IN METODE

2.1 Study area

2.1 Območje raziskave

The inventory of tree microhabitats was performed at three different locations: The Ravna gora old-growth forest reserve, the Kobile forest reserve, and a nearby managed forest. All three sites are located in close proximity in the Gorjanci region in South East Slovenia (Figure 1), where beech forests dominate. Ravna gora is a small remnant of old-growth (15.5 ha), with typical old-growth features, including large amounts of coarse woody debris and large canopy trees (some exceeding 100 cm dbh). The reserve was damaged by a strong thunderstorm in 1983 that caused a distinct damage patch in part of the reserve, mainly uprooting most of the canopy within the patch. The Kobile forest reserve (231 ha) is one of the largest forest reserves in Slovenia; it is located 750 m from Ravna Gora. The reserve is characterized by mature beech dominated stands, which have been unmanaged for about 90 years; natural mortality of old canopy trees indicate that some stands are reaching the beginning of the old-growth stage of development. Part of Kobile was also damaged by a windstorm about 15 years ago. Both the Kobile and Ravna Gora reserves are included in the Natura 2000 network. They provide habitat to many rare and protected plant and animal species that are linked to dead trees or veteran habitat trees, such as the white backed woodpecker (*Dendrocopos leucotos* Bechstein, 1802) and longhorn beetles (*Morimus funereus* Mulsant, 1863

Table 1: Basic characteristics of the three study locations (source: ZGS, 2019b).

Preglednica 1: Predstavitev osnovnih značilnosti objektov raziskave (vir: ZGS, 2019b).

Location *Lokacija*	Size *Površina* (ha)	Forest type *Gozdne združbe*	Growing stock *Lesna zaloga* (m^3/ha)	Altitude *Nadmorska višina* (m)	Bedrock *Vrsta kamnine*	Average slope *Povprečni naklon* (°)	Exposition *Lega*	Tree species *Drevesne vrste*
KOBILE FOREST RESERVE SECTION 05128 B	23,2	*Arunco - Fagetum* 80 % *Ostryo - Fagetum* 20 %	349,0	570 - 960	Dolomite	30.0	West	*Fagus sylvatica* 90 % *Acer pseudoplatanus* 6 % Other 4 %
RAVNA GORA OLD-GROWTH FOREST RESERVE SECTION 03060	15.51	*Savensi - Fagetum* 100 %	832.0	860 - 965	Dolomite	9.0	South-West	*Fagus sylvatica* 85 % *Acer pseudoplatanus* 15 %
MANAGED FOREST SECTION 03054A	17.59	*Savensi - Fagetum* 100 %	396.0	865 - 930	Dolomite	7.0	North	*Fagus sylvatica* 64 % *Acer pseudoplatanus* 28 % *Picea abies* 3 % Other 4 %

and *Rosalia alpina* Linnaeus, 1758). The managed forest (section 03045 a) has a relatively homogeneous structure and is about 80 years old, with an average growing stock of 396 m^3/ha, and the larger area is managed with an irregular shelterwood system (Smolič, 2014). The managed forest is located in the vicinity of both forest reserves – 290 m from Kobile and 850 m from Ravna gora). All study areas are described in Table 1.

2.2 Field measurements
2.2 Postavitev ploskev in meritve

Field work was conducted in autumn 2014. It is recommended to inventory microhabitats when trees are without leaves (Larrieu et al., 2018), as visibility of tree crowns is improved. Together, we established 54 square plots, each 500 m^2 in size. Plots were spaced systematically along line transects every 20 m. We placed two parallel transects in each study area; transects were approximately 300–400 m long to accommodate 8 to 10 plots per transect. At Ravna gora and Kobile, some line transects crossed areas that had been damaged by a windthrow. We placed 18 plots at Ravna gora (2 of which had fallen in the windthrow area), 18 plots at Kobile (8 in the windthrow area), and 18 plots in the managed forest.

On each plot, we recorded the diameter (DBH), species, and status (live or dead) of all trees with DBH above 10 cm. The 10 cm DBH threshold was used because there are fewer microhabitats in small or young trees (Vuidot et al., 2011; Larrieu et al., 2012) and we were mainly interested in mature canopy trees. Each tree was carefully examined from the roots to the top of the crown, and all microhabitats were counted and recorded. To help with visual assessments of the crown, we used 8 power binoculars. The different types of microhabitats were based on a standardized catalogue of tree microhabitats (Kraus et al., 2016). In total, 11 different microhabitat types were distinguished in the field, of which 8 were saproxylic and 3 epixylic. These microhabitat types (categories) were further divided into sub-categories according to the size or height at which they were located:

Saproxylic microhabitats that mainly occur on dead or rotten wood:

- woodpecker cavities,
- trunk and mould cavities,
- branch holes,
- water-filled cavities (dendrotelms)
- insect galleries and bore holes,
- bark loss / exposed sapwood,
- bark pockets and bark structure (coarse bark),
- dead branches and limbs / crown deadwood / trunk and crown breakage.

Epixylic microhabitats that mainly appear on trees:

- root buttress cavities,
- fruiting bodies of fungi,
- epiphytic bryophytes and lichens.

Some additional categories were originally included in the survey, including vertebrate and invertebrate nests and sap and resin runs, but were later excluded because they were not present at the sites. Altogether, we recorded 1,833 microhabitats on 849 trees across the three sites.

2.3 Analyses
2.3 Izračuni in statistična obdelava

Although there is no replication among the three different forest classes, we nevertheless carried out basic statistical tests to examine and compare various microhabitat patterns. It should therefore be noted that caution is needed when generalizing these data beyond the study area. The data were not normally distributed, such that nonparametric Mann-Whitney U and Kruskal-Wallis tests were used to test for differences in the quantity and diversity of microhabitats among management type (managed versus unmanaged), living and dead trees, control and windthrow areas, and differences among species and tree diameter classes. In some cases, we used the Chi-Square test of independence to determine if there were significant relationships between categorical variables, such as between management type and tree species and tree status. For tree species, we examined the two most abundant species, beech (*Fagus sylvatica*) and sycamore maple (*Acer pseudoplatanus*), and grouped all other species into a separate class; these species included *Acer platanoides, Carpinus betulus, Picea abies, Salix caprea, Abies alba, Tilia platyphyllos, Ulmus glabra* and *Prunus avium*. We used Pearson's correlation coefficient to examine the relationship between microhabitats and tree diameter. All tests were performed with SPSS.

3 RESULTS
3 REZULTATI

3.1 Basic stand structure patterns
3.1 Osnovni podatki po območjih raziskave

There were clear differences in stand structure among and within the study areas (Table 2), characterized by a higher density of smaller trees in the managed forest, and a lower tree density and larger diameter trees in the unmanaged areas.

Fig. 2: Examples of different tree microhabitat types: (a) Woodpecker cavities – feeding holes; (b) Trunk cavities with mould; (c) Water-filled cavities (dendrotelms); and (d) Bark loss / exposed sapwood.

Slika 2: Različne kategorije drevesnih mikrohabitatov: (a) Votline ptic (prehranjevalne) iz reda plezalcev (Piciformes); (b) Debelne votline z razkrajajočim lesom; (c) Votline, napolnjene z vodo; (d) Izpostavljena beljava in deli debla brez skorje

Table 2: Basic characteristics of the different sampling areas.

Preglednica 2: Osnovne značilnosti sestojev po objektih raziskave.

Location *Lokacija*	N. of plots *Št. ploskev*	N. of measured trees *Št. izmerjenih dreves*	Average n. of trees per plot *Povprečno št. dreves na ploskev*	Average n. of snags per plot *Povprečno št. odmrlih stoječih dreves na ploskev*	% of snags *% odmrlih stoječih dreves*	Average dbh [cm] *Povprečni prsni premer*	% of *Fagus sylvatica* *% bukve*	N. of recorded tree microhabitats *Št. zabeleženih drevesnih mikrohabitatov*
KOBILE	10.0	133	13.6	1.8	13.5	40.4	82.0	346
KOBILE WINDTHROW	8.0	43	5.4	1.3	23.3	44.7	95.3	209
RAVNA GORA	16.0	271	16.9	0.4	2.6	35.2	91.1	492
RAVNA GORA WINDTHROW	2.0	74	37.0	2.5	6.8	20.2	43.2	150
MANAGED FOREST	18.0	328	18.2	0.3	1.5	32.2	77.7	636

All the areas were dominated by beech, although other more light demanding species, such as maple and cherry, were relatively abundant in the managed stand. The windthrow patch at Kobile is approximately 15 years old (the disturbance date is not known) and is dominated by a dense layer of beech and maple saplings, as well as scattered remnant canopy trees that survived the windthrow. There is also a high density of standing dead beech snags in the windthrow area, trees which presumably died sometime after the windthrow event due to crown damage or exposure. The windthrow patch at Ravna gora, which dates back to 1983, is dominated by a dense layer of pole-sized maple and beech, with very few surviving canopy trees. These differences in development stage following windthrow are clearly seen in the data, and also have implications for microhabitats, which is described further below.

3.2 Microhabitats patterns
3.2 Drevesni mikrohabitati glede na način gospodarjenja

A comparison of microhabitats per tree (abundance and diversity) showed no significant difference ($p > 0.05$, Z value for abundance = –0.437 and diversity = –0.273) between managed (i.e. the managed forest stand) and unmanaged forest classes (i.e. Kobile and Ravna gora forest reserves together, including windthrow areas) (Figure 3). The average number of microhabitats per tree in unmanaged and managed forest was 2.4 and 1.8, respectively. Likewise, there was no significant difference with respect to diversity (different microhabitat categories per tree) between management classes. In both management classes, the average diversity per tree was 1.1. The most abundant types of tree microhabitats were branch holes, exposed sapwood, and root buttress cavities across both management classes. However, there were some important differences in specific types between management classes

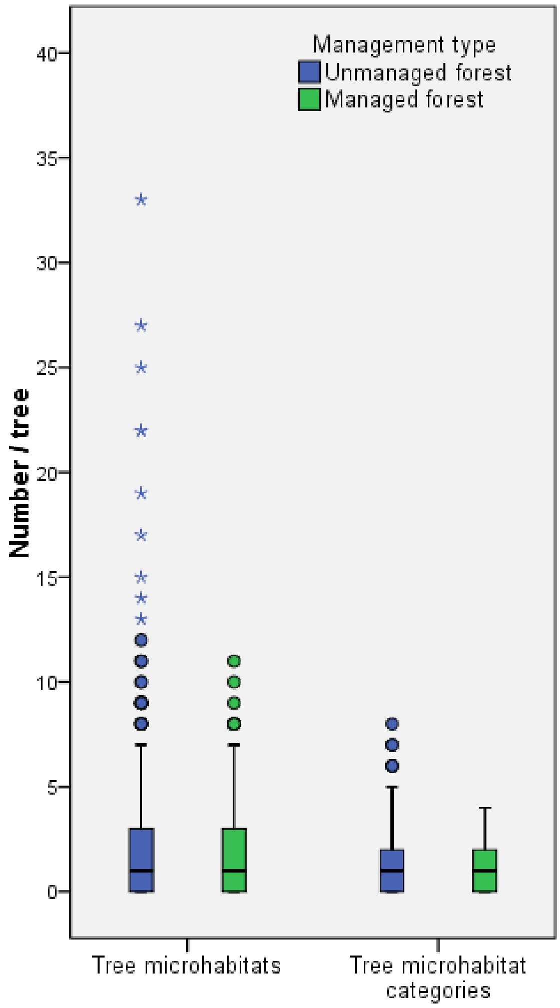

Fig. 3: Number of tree microhabitats and number of different categories of tree microhabitats per tree with respect to management class. Unmanaged forest includes Kobile and Ravna gora forest reserves together, including windthrow areas; managed forest represents the managed forest stand.

Slika 3: Število drevesnih mikrohabitatov na drevo in število različnih kategorij drevesnih mikrohabitatov na drevo v sestojih gospodarskega (odsek 03054 a) in negospodarskega gozda (gozdna rezervata Kobile in Ravna gora skupaj s poškodovanimi površinami).

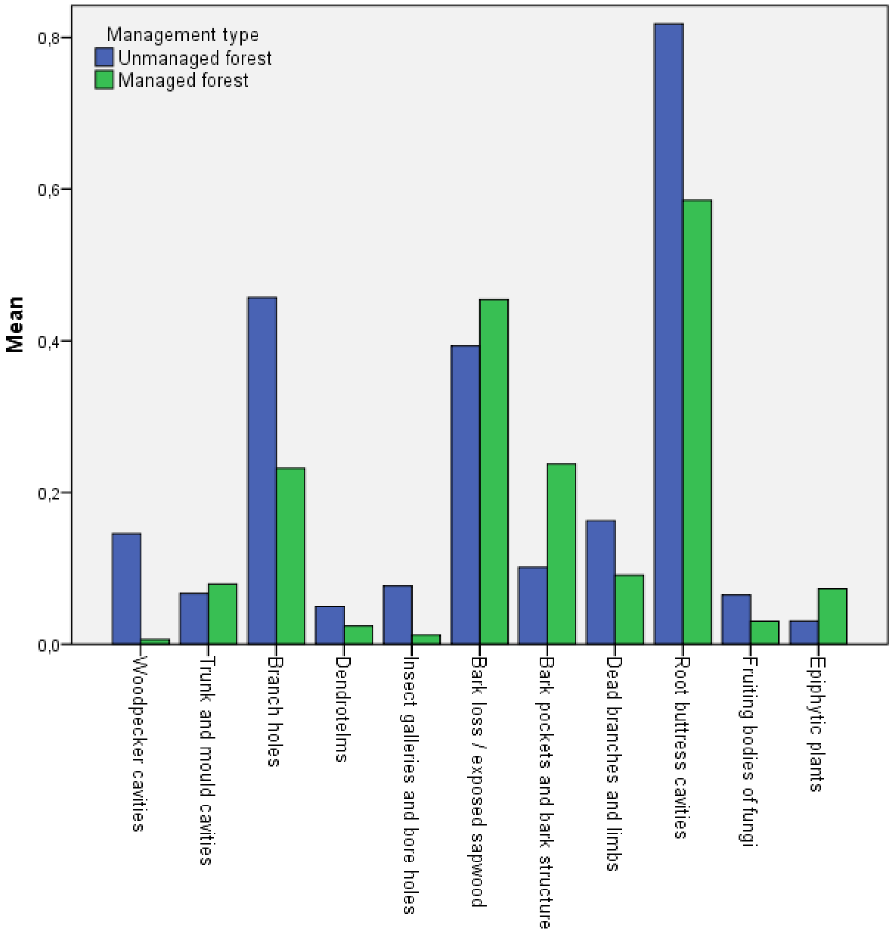

Fig. 4: Mean values of different tree microhabitat categories per tree with respect to management class. Unmanaged forest includes Kobile and Ravna gora forest reserves together, including windthrow areas; managed forest represents the managed forest stand.

Slika 4: Srednja vrednost števila drevesnih mikrohabitatov na drevo po različnih kategorijah DM v sestojih gospodarskega (odsek 03054 a) in negospodarskega gozda (gozdna rezervata Kobile in Ravna gora skupaj s poškodovanimi površinami).

that are worth pointing out. In unmanaged forest, for example, there were more woodpecker cavities ($p < 0.05$, $Z = -2.174$), insect galleries and bore holes ($p < 0.01$, Pearson Chi-Square = 11.379, df = 1), branch holes ($p < 0.01$, $Z = -3.341$) and *Fomes fomentarius,* which was found only in unmanaged forest. In managed forest there were more exposed sapwood ($p < 0.05$, $Z = -1.957$) and coarse bark ($p < 0.05$, $Z = -2.389$) microhabitats and, consequently, epiphytes ($p < 0.05$, Pearson Chi-Square = 8.083, df = 1). The higher frequency of coarse bark in managed forest was linked to the larger proportion of maple in managed forest. However, the managed forest lacked microhabitats related to dead wood, such as woodpecker cavities, insect galleries and bore holes, and *Fomes fomentarius*. The mean values of different tree microhabitat categories per tree with respect to management type are presented in Figure 4.

Another important difference between managed and unmanaged forest classes was the higher frequency of veteran habitat trees in unmanaged forest, which is well illustrated by the skewed distribution and large number of outliers regarding the number and diversity of microhabitats per tree (Figure 3). For example, the maximum number of microhabitats per tree was 33 in unmanaged forest, and 11 in the managed forest. Moreover, we identified up to 8 different microhabitat categories per tree in unmanaged forest compared to 4 categories per tree in the managed forest.

Differences among and within the different research areas were tested. The results showed significant differences regarding the abundance ($p < 0.01$, df = 4, Chi-square = 49.153) and diversity ($p < 0.01$, df = 4, Chi-square = 48.042) of microhabitats per tree (Table 3 – average values).

The highest density and diversity were found within the windthrow patch in the Kobile forest reserve (Table 3). A comparison between the control and windthrow area at Kobile indicated that some microhabitats were significantly ($p < 0.05$) more abundant in the windthrow area, including woodpecker cavities ($Z = -3.766$), branch holes ($Z = -2.692$), bark loss/exposed sapwood ($Z = -2.290$) and fruiting bodies of fun-

Table 3: Average values of the abundance and diversity of microhabitats per tree by research area, tree status, and tree species.

Preglednica 2: Povprečne vrednosti drevesnih mikrohabitatov na drevo po območjih raziskave, stanju in drevesni vrsti.

Category *Kategorija*	Average n. of tree microhabitats per tree *Povprečno št. drevesnih mikrohabitatov na drevo*	Average n. of categories of tree microhabitats per tree *Povprečno št. kategorij drevesnih mikrohabitatov na drevo*
MANAGEMENT TYPE:		
Unmanaged forest (Kobile and Ravna gora together with windthrow patches)	2.4	1.1
Managed forest	1.8	1.1
LOCATION:		
Kobile	2.6	1.6
Kobile windthrow	4.9	2.0
Ravna gora	2.3	1.1
Ravna gora windthrow	0.8	0.5
TREE STATUS:		
Dead	8.1	3.3
Alive	1.8	1.0
TREE SPECIES:		
Beech	2.2	1.1
Sycamore maple	1.8	1.0
Other	2.3	1.5

gi ($Z = -2.211$). In contrast, the Ravna gora windthrow site had the lowest values, but is due to the fact that plots were located within a young pole phase forest recovering from the windthrow. Outside the windthrow patches, both unmanaged areas exhibited higher densities of microhabitats than the managed forest.

Across the study sites, standing dead trees had a significantly higher ($p < 0.01$) density ($Z = -8.261$) and diversity ($Z = -9.077$) of microhabitats than live trees (Table 3). Microhabitats that were more frequent on snags ($p < 0.05$) included woodpecker cavities ($Z = -13.450$), insect galleries and bore holes ($Z = -21.513$), bark loss/exposed sapwood ($Z = -18.262$), bark pockets ($Z = -9.618$), dead branches and limbs ($Z = -2.158$) and fruiting bodies of fungi ($Z = -11.867$).

Beech had significantly more microhabitats per tree than maple ($p < 0.05$), including woodpecker cavities (only on beech), branch holes ($Z = -3.782$), and root buttress cavities ($Z = -5.166$). Maple had a higher frequency ($p < 0.05$) of coarse bark and bark pockets ($Z = -8.390$) and, consequently, epiphytes ($Z = -5.271$). All other tree species combined had the highest density and diversity, which is likely because these were mostly low-quality trees.

There was a moderate but significant positive correlation between tree dbh and abundance of tree microhabitats per tree (Pearson correlation coefficient: 0.447, $p < 0.01$) as well as dbh and diversity of microhabitats per tree (Pearson correlation coefficient: 0.424, $p < 0.01$).

4 DISCUSSION

4 RAZPRAVA

This study demonstrated a number of key differences between tree microhabitat patterns in managed and unmanaged beech dominated forests. Unmanaged forests had a larger number of old habitat trees and snags, which supported a larger number and diversity of microhabitats (Figure 5). The unmanaged area also hosted a higher frequency of microhabitat types associated with old-growth conditions, such as cavities, large dead branches, woodpecker cavities, and fruiting bodies of fungi. These microhabitats were largely lacking in the managed forest, which hosted a higher frequency of other microhabitats, such as exposed sapwood and coarse bark (Figure 4) associated with the higher abundance of maple, which are likely a result of management activities. Many of the microhabitats found in the managed forest could potentially develop into larger cavities or canopy dead wood as trees mature, although the harvest rotation period may prevent this from happening.

Our results are similar to those documented across similar temperate forests in Europe (Larrieu et al., 2012; Larrieu and Cabanettes, 2012; Paillet et al., 2017; Vuidot et al., 2011; Winter and Möller, 2008; Winter et al., 2015). Studies that have compared managed and unmanaged forests generally show that the density of microhabitats is often similar between the two management regimes, but there are key differences in microhabitat types. For example, Vuidot et al. (2011) and Larrieu et al. (2012) found that tree species

Fig. 5: Research areas: (a) homogenous structure of managed forest; (b) windthrow area at Kobile, (c) habitat tree snag in Ravna gora old growth forest.

Slika 5: Objekti raziskave: (a) homogena struktura gospodarskega gozda; (b) območje, poškodovano po vetrolomu v rezervatu Kobile; (c) odmrlo habitatno drevo v pragozdu Ravna gora.

and tree vitality had greater influence on the number of microhabitats per tree than the management type. A key finding of many studies (and this study) is that standing dead trees (snags) host a large number and diversity of microhabitats (Vuidot et al., 2011; Larrieu and Cabanettes, 2012; Kozak et al., 2018; Bull et al., 1997; Larrieu et al., 2012). Given that large standing dead trees rarely develop or are routinely removed in managed forests, they lack a number of key microhabitats compared to unmanaged forest.

In addition to the importance of snags, we also found that tree diameter and tree species were positively related to tree microhabitat density and diversity. These findings are also consistent with the literature. Larger trees and more diverse species mixtures generally tend to support more abundant and diverse microhabitats (Larrieu and Cabanettes, 2012, Larrieu et al., 2014; Vuidot et al., 2011; Kozak et al., 2018). For example, maple has characteristically coarser bark than beech and substantially contributed to the microhabitat profile in the managed forest in our study. It is important to note that our study included only broadleaf trees, which tend to differ in some types of microhabitats compared to conifers (Kozak et al., 2018), such that care should be taken when comparing our results with those from mixed conifer-broadleaf types.

Another key finding in this study was the importance of disturbance in influencing microhabitat patterns, which has not received much attention in the literature. The windthrow patches at Kobile and Ravna gora illustrate this well. The windthrow at Ravna gora was severe (very few large windfirm trees were left standing in the patch), and the current stand is dominated by a dense stand of young pole sized trees. While such disturbances are key for creating habitat for biodiversity, specifically large amounts of sun exposed deadwood (Seibold et al., 2016), the Ravna gora windthrow supported a low density of microhabitats. In contrast, the windthrow at Kobile was intermediate severity, leaving a number of windfirm canopy trees with broken crowns, stripped bark, and sun-exposed trunks (Figure 5b). Some of the trees survived and now host many microhabitats and have large amounts of canopy deadwood. Many of the damaged trees eventually died, leading to the development of snags. Together, these processes led to the high density and diversity of microhabitats found in the study.

Windstorms and other types of disturbance agents (ice storms, heavy snow) that cause intermediate severity damage are relatively common in the temperate zone of Europe, particularly in the Dinaric Mountain range (Nagel et al., 2017b). Such disturbances play a key role in the formation of deadwood and, based on this study, tree microhabitats. As such, management practices that remove such structures (deadwood and badly damaged but living trees) should be limited in areas where biodiversity habitat is a management goal (e.g. Natura 2000 forests), especially in forest regions that rely on close-to-nature forest management rather than large areas of unmanaged forest reserves to preserve native biodiversity (Nagel et al., 2017a). The 2014 ice storm that caused widespread damage to forests in Slovenia is a good example. Although many trees were salvaged, badly damaged but living trees were left to recover in the forest; these trees will likely develop a variety of microhabitats due to severe crown damage and could be beneficial for biodiversity that requires such structures.

Finally, we emphasize that this research is a case study without replication of managed and unmanaged forest classes, such that caution is needed when generalizing any of the results. We therefore hope that this study will encourage others to quantify microhabitat patterns in different regions and forest types in Slovenia to provide more robust baseline estimates of microhabitat density and diversity.

5 SUMMARY

5 POVZETEK

V bukovih gozdovih na območju Gorjancev v JV Sloveniji smo ugotavljali, kako gospodarjenje in naravne motnje vplivajo na drevesne mikrohabitate (DM), na njihovo številčnost in raznolikost. Drevesni mikrohabitati so definirani kot strukture na živih in odmrlih stoječih drevesih, ki dajejo življenjski prostor ali zavetje različnim rastlinskim in živalskim vrstam. Za številne vrste imajo velik pomen, saj so le te vezane nanje vsaj del svojega življenja – v njih se razvijajo, prehranjujejo, gnezdijo ali vedrijo (Larrieu in sod., 2018). Poleg tega so lahko DM dober kazalec biotske pestrosti gozdov (Larrieu in sod., 2014; Winter in Möller, 2008), saj neposredno spremljanje le te ni enostavno.

Popis drevesnih mikrohabitatov smo opravili na treh lokacijah: v gozdnih rezervatih Ravna gora in Kobile ter v bližnjem gospodarskem gozdu (slika 1). Gozdna rezervata sta zavarovana in izvzeta iz gospodarjenja, zato se tam gozd razvija brez človekovega vpliva. V obeh rezervatih najdemo območja s posledicami vetroloma, ki so bila prav tako zajeta v raziskavo. Gospodarski gozd (odsek 03054 a) je enomeren bukov sestoj, v katerem se redno gospodari. Star je približno 80 let, lesna zaloga je ocenjena na 396 m^3/ha.

Popis smo opravili jeseni 2014. Ploskve velikosti 500 m^2 smo postavili sistematično vsakih 20 metrov. Na vsakem območju smo jih postavili po 18 in na njih popisali vsa drevesa, debelejša od 10 cm v prsni višini, ter zabeležili na njih obstoječe drevesne mikrohabitate.

Mikrohabitate smo povzeli po Katalogu drevesnih mikrohabitatov (Kraus in sod., 2016). Skupaj smo zabeležili 8 vrst saproksilnih in 3 vrste epiksilnih DM, te pa razdelili v podvrste glede na velikost ali lokacijo na drevesu (slika 2).

Saproksilni mikrohabitati, ki smo jih zabeležili in so običajno povezani z odmirajočim lesom, so:

- dupline žoln in detlov,
- debelne in razkrajajoče se votline,
- vejne votline,
- vlažne in z vodo napolnjene votline,
- rovi žuželk ter vhodne / izhodne odprtine,
- izguba skorje / izpostavljena beljava,
- odstopajoča skorja in skorjini žepi, ter
- odmrle veje in deli dreves / odmrli les krošnje / prelomljeno deblo in krošnja.

Epiksilni mikrohabitati, ki smo jih zabeležili in se pojavljajo na drevesu oz. deblu, so:

- koreninske oporne votline,
- trosnjaki in trosišča gliv ter
- epifitski kripto- in fanerogami (mahovi, lišaji, ovijalke, praproti).

Skupno smo popisali 849 dreves in zabeležili 1833 drevesnih mikrohabitatov.

Obdelavo podatkov in analize smo napravili s programoma Excel in SPSS. Ker so bili podatki nenormalno porazdeljeni, smo uporabili neparametrične metode (Mann-Whitneyev U in Kruskal-Wallisov test) za testiranje razlik med območji, Hi kvadrat test za ugotavljanje odvisnosti med spremenljivkami in Pearsonov korelacijski koeficient za ugotavljanje odvisnosti med DM in prsnim premerom dreves.

Že osnovne značilnosti sestojev kažejo, da se raziskovalna območja med seboj razlikujejo (tabela 2). V gospodarskem gozdu smo zabeležili večjo gostoto dreves, ki pa so imela manjši povprečni prsni premer kot drevesa v obeh rezervatih. Prav tako smo v gospodarskem gozdu zabeležili več drugih drevesnih vrst in manj odmrlih dreves. Na poškodovanem območju v Kobilah smo zabeležili več odmrlih dreves v primerjavi z drugimi območji. Sestoj na poškodovanem območju v Ravni gori pa je bil v fazi drogovnjaka, saj se je po vetrolomu leta 1983 pomladil. Vse te značilnosti so vplivale na številčnost in raznolikost drevesnih mikrohabitatov.

Razlike v številu in raznolikosti DM na drevo med gospodarskim gozdom in obema rezervatoma (skupaj s poškodovanima površinama) niso bile statistično značilne ($p > 0,05$; Z vrednost za število = –0,437, Z vrednost za raznolikost = –0,273), kar pomeni, da smo pri obeh načinih gospodarjenja našli približno enako število DM ter različnih kategorij na drevo. Vseeno pa so povprečne vrednosti števila DM na drevo v negospodarskih gozdovih nekoliko višje (2,4) kot v gospodarskih (1,8) (preglednica 3). Pri obeh načinih gospodarjenja so bili najpogostejši DM vejne votline, izpostavljena beljava in koreninske oporne votline. Kljub temu da nismo zaznali razlik v številu in raznolikosti, pa smo zaznali razlike v vrsti DM. Tako smo v obeh rezervatih zabeležili več saproksilnih DM, kot so votline ptic ($p < 0,05$; Z = –2,174), rovi žuželk ter vhodne in izhodne odprtine ($p < 0,01$; Pearsonov hi-kvadrat = 11,379, df = 1), vejne votline ($p < 0,01$; Z = –3,341) in bukova kresilka, ki je bila zabeležena samo v negospodarskem gozdu (slika 4). Prav tako smo v omenjenih gozdovih zaznali več habitatnih dreves z velikim številom DM (do 33) (slika 3). V gospodarskem gozdu pa so bili pogostejši: izpostavljena beljava ($p < 0,05$; Z = –1,957), razbrazdana skorja in skorjini žepi ($p < 0,05$; Z = –2,389) ter epifiti ($p < 0,05$; Pearsonov hi-kvadrat = 8.083, df = 1), manj pa je bilo DM, povezanih z odmrlim lesom (slika 4).

Razlike med posameznimi raziskovalnimi območji so bile statistično značilne ($p < 0,01$; df = 4,), kar nakazujejo tudi povprečne vrednosti v preglednici 3. Največjo gostoto in raznolikost DM na drevo smo zabeležili na poškodovani površini v Kobilah (4,9 in 2,0), kjer je bilo tudi največ odmrlih dreves in DM, povezanih z odmrlim lesom. Najmanjšo gostoto in raznolikost pa smo zabeležili na poškodovani površini v Ravni gori (0,8 in 0,5 DM na drevo), saj tam prevladuje sestoj v fazi drogovnjaka, drevesa so tanjša in posledično je manj DM. Oba rezervata brez poškodovanih površin sta imela večjo gostoto drevesnih mikrohabitatov v primerjavi z gospodarskim gozdom.

Status dreves je močno vplival na gostoto in raznolikost drevesnih mikrohabitatov na drevo ($p < 0,01$; Z vrednost za gostoto = –8,261, Z vrednost za raznolikost = –9,077). Odmrla drevesa so imela več mikrohabitatov kot živa (povprečno 8,1 in 1,8 DM na drevo) (preglednica 3). Saproksilni mikrohabitati, kot so votline ptic ($p < 0,05$; Z = –13, 450), rovi podlubnikov ter vhodne in izhodne odprtine ($p < 0,05$; Z = –21,513), izpostavljena beljava ($p < 0,05$; Z = –18,262), skorjini žepi ($p < 0,05$; Z = –9,618), odmrle veje in deli dreves ($p < 0,05$; Z = –2,158) ter trosnjaki in trosišča gliv ($p < 0,05$; Z = –11,867), so bili pogostejši na odmrlih drevesih.

Prav tako smo zaznali razliko v številu in vrsti DM na drevo med drevesnima vrstama bukev in javor ($p < 0,05$). Na bukvi smo našli več DM na drevo kot na javorju (povprečno 2,2 DM na drevo na bukvi in 1,8 na javorju) (preglednica 3). Poleg tega so bili na bukvi pogostejši naslednji DM ($p < 0,05$): vejne votline (Z = –3,782), koreninske oporne votline (Z = –5,166) ter votline ptic, ki smo jih našli samo na bukvi. Na javorju pa so bili pogostejši ($p < 0,05$): razbrazdana skorja in skorjini žepi (Z = –8,390) ter epifiti (Z = –5,271), saj ti potrebujejo oporo za vzpenjanje, ki jo zagotavlja razbrazdana skorja.

Med prsnim premerom dreves in številom ter raznolikostjo drevesnih mikrohabitatov smo zaznali zmerno pozitivno korelacijo. Pearsonov korelacijski koeficient za gostoto DM je znašal 0,447 ($p < 0,01$), za raznolikost pa 0,424 ($p < 0,01$).

Nekateri avtorji (Larrieu in sod., 2012; Larrieu in Cabanettes, 2012; Paillet in sod., 2017; Vuidot in sod., 2011; Winter in Möller, 2008; Winter in sod., 2015), ki so raziskovali tematiko drevesnih mikrohabitatov v gozdovih zmernega pasu v Evropi, so prišli do podobnih rezultatov. Gostota drevesnih mikrohabitatov je bila pogosto podobna med različnimi stopnjami intenzivnosti gospodarjenja, razlika je bila predvsem v kategoriji drevesnih mikrohabitatov. Drevesna vrsta in vitalnost drevesa sta imela večji vpliv na številčnost DM v primerjavi z načinom gospodarjenja.

V raziskavo smo vključili tudi površine v rezervatih, ki so bile poškodovane po vetrolomu. Poškodbe, ki jih povzročijo naravne motnje, kot je vetrolom, so pomembne z vidika nastanka odmrlega lesa in drevesnih mikrohabitatov. V rezervatu Kobile je veter srednje jakosti podrl in poškodoval večino dreves. Na odmrlih in poškodovanih drevesih, ki so še ostala, smo zabeležili največjo gostoto drevesnih mikrohabitatov. Nasprotno pa je v rezervatu Ravna gora zelo močan veter podrl večino dreves, nastala je vrzel, kjer se je sestoj pomladil, in na tem mestu smo zabeležili najnižjo gostoto DM na drevo. V gospodarskih gozdovih smo zabeležili visoko gostoto DM, tudi potencialnih, ki nastanejo zaradi poškodb pri sečnji in spravilu, vendar pa zaradi gospodarjenja ne dobijo možnosti, da bi se razvili, saj poškodovano drevje iz sestoja prej odstranimo.

Iz rezultatov raziskave je razvidno, da so odmrla in poškodovana drevesa pomemben dejavnik za nastanek drevesnih mikrohabitatov, zato bi bilo treba del takšnih dreves v sestoju ohraniti, še posebej na območjih, kjer sta poudarjeni biotska pestrost in ohranjanje vrst (npr. območja Natura 2000).

6 REFERENCES
6 VIRI

Brunet J., Fritz Ö., Richnau G. 2010. Biodiversity in European beech forests – a review with recommendations for sustainable forest management. Ecological Bulletinns, 53: 77–94.

Bull E.L., Parks C.G., Torgersen T.R. 1997. Trees and logs important to wildlife in the interior Columbia river basin. Portland, U. S. Department of agriculture, Forest service, Pacific northwest research station: 55 str.

Bütler R., Lachat T., Larrieu L., Paillet Y. 2013. Habitat trees: key elements for forest biodiversity. V: Integrative Approaches as an opportunity for the conservation of forest biodiversity. Kraus D., Krumm F. (ur.). European forest institute: 84–91.

Courbaud B., Pupin C., Letort A., Cabanettes A., Larrieu L. 2017. Modelling the probability of microhabitat formation on trees using cross-sectional data. Methods Ecol. Evol. 8 (10), 1347–1359.

Diaci J., Perušek M. 2004. Možnosti ohranjanja starega in odmrlega drevja pri gospodarjenju z gozdovi. V: Staro in debelo drevje v gozdu: zbornik referatov XXII. gozdarskih študijskih dni. Ljubljana, 25.–26. marec 2004. Brus R. (ur.). Ljubljana, Biotehniška fakulteta, oddelek za gozdarstvo in obnovljive gozdne vire: 227–240.

Golob A. 2006. Izhodišča za monitoring ohranjenosti gozdnih habitatnih tipov in habitatov vrst na območjih Natura 2000 v Sloveniji. V: Monitoring gospodarjenja z gozdom in gozdnato krajino. Hladnik D. (ur.) Strokovna in znanstvena dela, št. 27. 2006. Ljubljana, Biotehniška fakulteta, Oddelek za gozdarstvo in obnovljive gozdne vire: 223–245.

GURS. 2019. Ortofoto posnetki. Geodetska uprava republike Slovenije.

Jurc M. 2004. Pomen saproksilnih hroščev ter njihovo ohranjanje v Sloveniji. V: Staro in debelo drevje v gozdu: zbornik referatov XXII. gozdarskih študijskih dni. Ljubljana, 25.–26. marec 2004. Brus R. (ur.). Ljubljana, Biotehniška fakulteta, oddelek za gozdarstvo in obnovljive gozdne vire: 57–74.

Kraus D., Bütler R., Krumm F., Lachat T., Larrieu L., Mergner U., Paillet Y., Rydkvist T., Schuck A., Winter S. 2016. Catalogue of tree microhabitats – Reference field list. Integrate+ Technical paper, 16 p.

https://informar.eu/sites/default/files/pdf/Catalogue_Tree-Microhabitats_Reference-Field-List_EN.pdf

Kozak D, Mikolaš M., Svitok M., Bače R., Paillet Y., Larrieu L., Nagel T.A., Begovič K., Čada V., Diku A., Frankovič M., Janda P., Kameniar O., Keren S., Kjučukov P., Labusova J., Langbehn T., Malek J., Mikac S., Morrissey R.C., Novakova M.H., Schurman J.S., Svobodova K., Synek M., Teodosiu M., Toromani E., Trotsiuk V., Vitkova L., Svoboda M. 2018. Profile of tree-related microhabitats in European Primary beech-dominated forests. Forest Ecology and Management, 429: 363–374.

Larrieu L., Cabanettes A., Delarue A. 2012. Impact of silviculture on dead wood and on the distribution and frequency of tree microhabitats in montane beech-fir forests of the Pyrenees. European journal of forest research, 131: 773–786.

Larrieu L., Cabanettes A. 2012. Species, live status and diameter are important tree feature for diversity and abundance of tree microhabitats in subnatural montane beech-fir forests. Canadian Journal of Forest Research, 42: 1433–1445.

Larrieu L., Cabanettes A., Brin A., Bouget C., Deconchat M. 2014. Tree microhabitats at the stand scale in montane beech-fir forests: practical information for taxa conservation in forestry. Eur J Forest Res, 133: 355–367.

Larrieu L., Paillet Y., Winter S., Bütler R., Kraus D., Krumm F., Lachat T., Michel A.K., Regnery B., Vandekerkhove K. 2018. Tree related microhabitats in temperate and Mediterranean European forests: A hierarchical typology for inventory standardization. Ecologial Indicators, 84 (2018): 194–207.

Michel A.K., Winter S. 2009. Tree microhabitat structures as indicators of biodiversity in Douglas-fir forests of different stand ages and management histories in the Pacific Northwest, U.S.A. Forest Ecology and Management, 257; 1453–1464.

Nagel T.A., Firm D., Pisek R., Mihelic T., Hladnik D., de Groot M., Rozenbergar D. 2017a. Evaluating the influence of integrative forest management on old-growth habitat structures in a temperate forest region. Biological Conservation, 216: 101–107.

Nagel T.A., Mikac S., Dolinar M., Klopčič M., Keren S., Svodoba M., Diaci J., Bončina A., Paulić V. 2017b. The natural disturbance regime in forests of the Dinaric Mountains: A Syntesis of evidence. Forest Ecology and Management, 388: 29–42.

Papež J. 2005. Načrtno gospodarjenje z odmrlo lesno biomaso. Gozdarski vestnik, 63, 4: 197–221.

Paquette A., Messier C. 2010. The role of plantations in managing the world's forests in the Anthropocene. Frontiers in Ecology and the Environment, 8, 1: 27–34.

Paillet Y., Archaux F., Boulanger V., Debaive N., Fuhr M., Gilg O., Gosselin F., Guilbert E. 2017. Snags and large trees drive higher tree microhabitat densities in strict forest reserves. Forest Ecology and Management, 389: 176–186.

Perušek M. 2004. Prilagoditve nekaterih vrst ptic na staro, debelo in odmrlo drevje. V: Staro in debelo drevje v gozdu: zbornik referatov XXII. gozdarskih študijskih dni. Ljubljana, 25.–26. marec 2004. Brus R. (ur.). Ljubljana, Biotehniška fakulteta, oddelek za gozdarstvo in obnovljive gozdne vire: 75–85.

Regnery B., Couvet D., Kubarek L., Julien J-F, Kerbirou C. 2013. Tree microhabitats as indicators of bird and bat communities in Mediterranean forests. Ecological indicators, 34: 221–230.

Seibold S., Bässler C., Brandl R., Büche B., Szallies A., Thorn S., Ulyshen M.D., Müller J. 2016. Microclimate and habitat heterogeneity as the major drivers of beetle diversity in dead wood. Journal of Applied Ecology, 53: 934–943.

Siitoneen J. 2001. Forest management, coarse woody debris and saproxylic organisms: fennoscandian boreal forests as an example. Ecological bulletins, 49: 11–41.

Smolič J. 2014. »Pragozd Ravna gora in okoliški gozdovi«. Šentjernej, Zavod za gozdove Slovenije (osebni vir, oktober 2014).

Vuidot A., Paillet Y., Archaux F., Gosselin F. 2011. Influence of tree characteristics and forest management on tree microhabitats. Biological conservation, 144: 441–450.

Winter S., G.C. Möller. 2008. Microhabitats in lowland beech forests as monitoring tool for nature conservation. Science Direct, Forest ecology and management, 255: 1251–1261.

Winter S., Höfler J., Michel A.K., Böck A., Ankerst D.P. 2015. Association of tree and plot characteristics with microhabitat formation in European beech and Douglas-fir forests. Eur. J. Forerst Res, 134: 335–347.

ZGS. 2019a. Gozdni rezervati. Zavod za gozdove Slovenije.

ZGS. 2019b. Pregledovalnik podatkov o gozdovih. Zavod za gozdove Slovenije. http://prostor.zgs.gov.si/pregledovalnik/ (23.4.2019).