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Foraging activity of woodpeckers on various forms of artificially created deadwood

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Abstract. Many woodpecker species rely on different forms of deadwood for nesting and foraging. However, the knowledge of the effect of enrichment of their habitat with different types on deadwood of this species group is lacking. Complex conservation-oriented management, including deadwood enrichment, was applied in a 20 ha even-aged oak-dominated woodland in Hungary. The foraging activities of woodpecker species were documented on selected treated trees over one, two and three years since these measures were implemented. The 109 individual oak trees examined represented five deadwood types: damaged-, girdled-, felled trees, and low- and tall stumps. We analysed the relationships between three variables (depth of foraging work, type of deadwood, and year) and foraging activity. Our results illustrated the prompt responses of woodpeckers to the treated trees. The woodpeckers used the five deadwood types in very different ways, and foraging activity was found to vary greatly in terms of depth of foraging and between years. More activity was carried out on both low- and tall stumps than on any other type one year after the treatment, whilst work on girdled trees and tall stumps predominated two and three years after the treatment. The utilisation of felled- and damaged trees by woodpeckers proceeded at a markedly slower pace than that of girdled trees and stumps, but the utilisation increased gradually. Most of the foraging activity was found to be on the outer bark, however, work on the inner bark and in the sapwood increased between the three years. The measures to conserve the woodpecker species should include the permanent creation and maintenance of various forms of deadwood to provide diverse and continuous foraging sites for woodpeckers.

Key words: cavity excavators, stump, standing deadwood, foraging activity, feeding sign, deadwood enrichment

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INTRODUCTION

Different forms of deadwood are important habitats for forest bird species, as both breeding and foraging sites. Natural forest ecosystems host various forms of deadwood, such as dead limbs and branches on living trees, standing deadwood, broken stumps and fallen trees, and these are invariably in different stages of decay. They also differ in diameter, volume and tree species (Arnett et al. 2010, Czeszczewik et al. 2013). During decaying processes, various woodboring arthropods inhabit the various deadwood layers and serve as food resources for birds. Treecreepers *Certhia* spp., nuthatches *Sitta* spp., tits (Paridae) and other species, mostly collect food items directly from the bark surface, however, woodpeckers (Picidae) are able to strip the bark off and thus probe deeper into the inner tissue of wood. They can even excavate through the bark (Gorman 2004, 2011, 2015).

There are numerous studies that focus on woodpeckers utilising dead trees. Several studies based on actual observations of foraging birds (Imbeau & Desrochers 2002, Pechacek 2006, Czeszczewik 2010, Ónodi & Csörgő 2014, Lorenz et al. 2016, Duron et al. 2018). However, far fewer studies have been published on the signs of foraging that woodpeckers leave on dead trees. Some woodpecker species leave distinct signs of foraging, such as the large, deep foraging cavities that Black Woodpecker *Dryocopus martius* makes or the fine, horizontal lines of peck marks of White-backed Woodpecker *Dendrocopos leucotos*. The excavating marks of other 'pied' woodpecker species (*Dendrocopos* spp., *Leiopicus medius*, *Dryobates minor*) in Europe are not species-specific (Gorman 2004, 2011, 2015).

In natural conditions, the establishment of diverse forms of deadwood can take many years — sometimes decades or even centuries (Gibbons & Lindenmayer 2002). However, the natural processes involved can be accelerated for nature conservation purposes by the creation of artificial deadwood in order to enrich the habitat structure of intensively managed, homogenized forest habitats, such as even-aged or monoculture stands (Hane et al. 2012, Zarnoch et al. 2013, Barry et al. 2017, Weiss et al. 2018), where the amount and diversity of deadwood is markedly reduced. Conservationists use different methods to create diverse forest microhabitats, such as topping, girdling, bark-peeling of standing trees, felling to create fallen trees, supplementation with deadwood brought from elsewhere, and even prescribed burning (Halett et al. 2001, Sandström et al. 2018, Roth et al. 2019). This so-called "deadwood enrichment" has proved to be a successful tool for increasing the diversity and abundance of a wide range of taxa, such as fungal and saproxylic beetle communities (Doerfler et al. 2018, Roth et al. 2019). Research on the relationships between artificially created deadwood habitats and woodpeckers are scarce. Woodpecker activity on topped and girdled coniferous trees has been investigated (Arnett et al. 2010, Weiss et al. 2018) and various conifer snags, i.e. standing deadwood, have been compared (Hallett et al. 2001). Other authors have worked on home range, nest site utilisation and reproductive biology of a certain woodpecker species in a deadwood experiment, where treatments included snag removal, unmanipulated control, and experimentally created snags (Kilgo & Vukovich 2014). Studies to observe the foraging signs or foraging activities of woodpeckers on different artificially made deadwood forms, especially in deciduous forests, are fewer. Aulén (1991) studied the foraging activity of White-backed Woodpecker on two types of artificially created deadwood (girdled and notched) made from three deciduous tree species, such as birch (*Betula* spp.), Goat Willow *Salix caprea* and Common Alder *Alnus glutinosa*.

A conservation-oriented management action plan in an even-aged oak-dominated forest stand in Hungary was started in 2015 as a pilot study of an EU-funded LIFE4OakForests (LIFE16NAT/IT/000245) project. We applied different management techniques to enhance forest composition and structure, including the creation of various forms of deadwood. Besides the emulation of small-scale gap-dynamics, treatments aimed to provide nesting, breeding, and sheltering habitats for forest-dwelling species. One of the most important target groups, as primary cavity excavators and keystone species, was the woodpeckers. Uneven-aged, high-quality oak forests are important habitats for various woodpecker species (Weiss et al. 2018), such as Great Spotted Woodpecker *Dendrocopos major* and Middle Spotted Woodpecker *Leiopicus medius* (Pasinelli 2000, Walankiewicz et al. 2011).

Our three-year study (2017–2019) focused on annually surveying the treated trees for foraging signs of woodpeckers. The following species were observed in the study area: Black Woodpecker *Dryocopus martius*, Great-, Middle- and Lesser Spotted Woodpeckers *Dryobates minor*, and Grey-headed Woodpecker *Picus canus*. All five species use deadwood for foraging, but Grey-headed Woodpecker mostly forages on ground and mound-living ants. However, when foraging on trees the ant-eating Grey-headed Woodpeckers use only rotten trunks or stumps. Middle- and Lesser Spotted Woodpeckers mostly use limbs, Black Woodpecker more frequently excavates its food from the trunk, whilst Great Spotted Woodpecker utilises both sources, depending on the tree species composition (Török 1990, Stenberg & Hogstad 1992, Gorman 2004, Ónodi & Csörgő 2014). We were interested in the relationships between the appearance of the foraging signs of the four species other than the Grey-headed Woodpecker and the deadwood that we had artificially created in terms of: 1) the main influencing factor for foraging activity (depth of foraging work, type of deadwood, year), 2) the preferred types of deadwood, the depth of foraging activity, and 3) how preferences and feeding depth change over time. We predicted that the extent and the depth of foraging signs will significantly increase with time on all artificially created deadwood types. The asynchronous use of the different forms of deadwood was also postulated beforehand.

METHODS

Study site and management

We started our conservation-oriented management in 2015 in a 70-year-old, oak-dominated (*Quercetum petrae-cerris* and *Quercetum petrae-Carpinetum*), structurally and compositionally homogeneous forest stand in Garáb municipality (47°59′02″N; 19°39′02″E) in the Northern Hungarian Mountain Range. This 32 ha site is situated on west-facing, moderate slope (7.0–10.0°), at 400–540 m a.s.l. The average annual mean temperature is 8.5 °C, with a mean annual precipitation of 600 mm. Most frequent tree species are Sessile Oak *Quercus petraea*, Turkey Oak *Quercus cerris*, Hornbeam *Carpinus betulus*, Field Maple *Acer campestre*, and Manna Ash *Fraxinus ornus*. Their mixture ratios on the basis of basal area are (respectively): 80.4%, 10.2%, 6.4%, 1.2%, and 0.6%. The study site is surrounded by similar oak-dominated forests, their majority is managed by shelterwood system.

The primary aim of our conservation-oriented management was to maintain and enhance the forest structural and compositional heterogeneity. The active management work was carried out on 20 ha, in the winter of 2015–2016, and included the creation of standing deadwood by girdling (ring barking) of standing living trees; creation of damaged trees by bark stripping of individual trees; and felling to create fallen wood and both low stumps (height: 15–25 cm) and tall stumps (height: 1–2 m). Selected trees were girdled approximately at breast height. A complete band of bark around the trunk was removed with an axe in a 20–30 cm wide ring. In some cases, a band of bark as above was removed only half-way around the trunk. The bark was stripped by hand from the wounded part of the tree (damaged tree). Treatment of circa 550 individual trees, 15% of the living wood biomass in a 20 ha area was converted into deadwood consisting of approximately 150 standing dead trees, 350 downed trees with a low or tall stump, and 50 damaged trees. This action tripled the original amount of deadwood (12 m^3/ha) (Aszalós et al. 2017).

Sampling of woodpecker foraging activity

In 2016, we initiated a monitoring study to investigate the effects of conservation-oriented forest management on woodpecker foraging activity (FA). Visual surveys of feeding signs were carried out in February of three successive years (2017, 2018, and 2019) following active management on 150 randomly selected Sessile Oak, Turkey Oak, and Hornbeam trees. FA was described as a percentage interval expressing the percentage of the tree surface with feeding signs; 0%, 0.1–1%, > 1–5%, > 5–10%, > 10–25%, > 25–50%, > 50–75%, and > 75–100%. Binoculars were used to estimate the FA on the upper trunk parts and limbs. Only feeding signs that became visible after management work was carried out were surveyed. The earlier markings and signs were not recorded. These fresh, bright markings could be easily distinguished from the dark bark of the treated trees. However, to standardize the estimation as much as possible, the same team of surveyors carried out this task every year. The 2018 survey included signs from 2017, and the 2019 survey included those from the two previous years (cumulative data). The investigated trees represented five treatment (deadwood) types: damaged-, girdled-, felled tree, and low and tall stumps. The visual surveys defined the percentage of FA only for the trunk in the case of low and tall stumps, and separately for the trunk and for the limbs in the cases of damaged-, girdled-, and felled trees.

The survey differentiated and categorised the foraging depth of FA: outer bark, inner bark, and sapwood (Fig. 1). 'Outer bark' means that the bird searched for prey by only peeling off the outer bark layer, but did not penetrate through the bark, thus leaving the inner bark intact. 'Inner bark' means that the bird peeled off whole areas of bark, including the inner bark, and collected prey

Fig. 1. Feeding signs presenting foraging depth categories of foraging activity. A — outer bark; B — inner bark; C — sapwood.

from the layer between the bark and the sapwood, but did not penetrate the sapwood. When the FA penetrated deeper, work on the sapwood was recorded.

Data analyses

We analysed the relationship between deadwood type, foraging depth, temporal replicates (year) and the FA as a response variable. FA on the trunks and limbs was analysed separately in case of damaged-, girdled-, and felled trees. For the analysis, only the 109 Sessile Oaks were used out of 150 selected tree individuals, as the sample sizes of the other two tree species (Turkey Oak and Hornbeam) were inadequate.

We applied cumulative link mixed models with ordinal response distribution (Agresti 2003, Mangiafico 2016, Christensen 2019), as we had an ordinal scaled response variable (see our categories of FA percentages). First, we applied a broad model with the following explanatory variables: deadwood type, year, foraging depth, and the interactions between year and deadwood and between the year and foraging depth. We applied an AIC-based model selection to find the best model (Zuur et al. 2009). In this case, we were only interested in discovering the important explanatory variables. We analysed separately the data on marks on the limbs and trunks (as all the deadwood did not have limbs, the data for limbs and trunks are not comparable in a complex model). The random factor was the code of the measured trees.

Second, we compared the deadwood types in multiple paired comparisons. We applied cumulative link models where the response variable was the FA and the explanatory variable was the deadwood type. We subset two types of deadwood and compared these, and we repeated this for all paired comparisons. We analysed separately the data of FA on the limbs and trunks, and within these divisions separately for foraging depth, and for years. We adjusted the p-values using Bonferroni correction (Bonferroni 1936), and separately handled the years and foraging depth for adjustment. To facilitate a comparison of the groups containing only zero values with other groups, we added to all deadwood types (in all cases) a dummy tree with value 1 (Appendix 1).

Third, we analysed the effect of years with a similar multiple paired comparison, using cumulative link mixed models. The response variable was FA and the explanatory variable was the year. We distributed two consecutive years into subsets and compared these (2017–2018 and 2018–2019) and analysed the data on limbs and trunks and, within this, the foraging depth, and deadwood types. The random factor was the code of the measured trees. We adjusted the p-values using the Bonferroni method (Bonferroni 1936), and separately handled the foraging depth for these corrections (Appendix 2).

The statistical analyses were carried out using the R 3.4.4 statistical environment (R Core Team 2018), using the 'ordinal' package version 2019.3-9 for cumulative link mixed models (Christensen 2019).

RESULTS

Importance of deadwood type, foraging depth and year in foraging activity

The fitted broad model revealed that the model which included all the background variables and their used interactions — year, deadwood type, foraging depth, interaction of year and deadwood type, interaction of year and foraging depth — had the highest explanatory power for trunks (Table 1). The best model for explaining FA on

Table 1. Model-selection statistics of the effect of deadwood type, foraging depth, year and their interactions (indicated by ×) on foraging activity of woodpeckers on trunks. AIC values of all the cumulative link mixed models are given, ordered by delta AIC, first row show the best model.

explanatory variables	AIC	delta AIC	AIC weight	residual df
year + deadwood type + foraging depth + year × deadwood type + year × foraging depth	2415.7	0	1	960
year + deadwood type + foraging depth + year × deadwood type	2438.5	22.8	0	962
year + deadwood type + foraging depth + year × foraging depth	2457.1	41.4	0	964
year + deadwood type + foraging depth	2478.4	62.7	0	966
year + foraging depth + year × foraging depth	2512.4	96.7	0	968
year + foraging depth	2593.2	177.5	0	970
foraging depth	2733.9	318.2	0	971
year + deadwood type + year × deadwood type	3191.4	775.7	0	964
year + deadwood type	3203.1	787.4	0	968
year	3244.2	828.5	0	972
deadwood type	3257.2	841.5	0	969

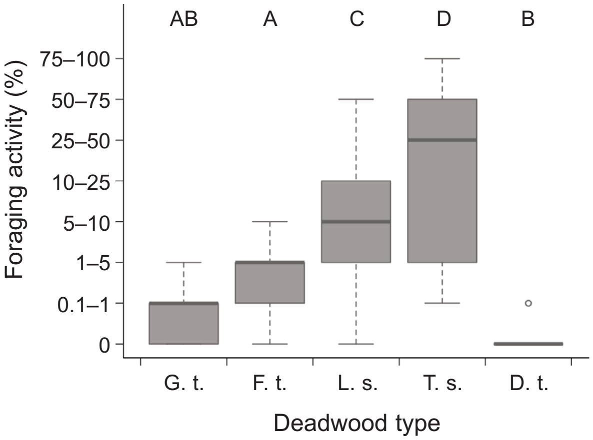

Fig. 2. Foraging activity (FA) on the outer bark of 5 deadwood type trunks in the first year. G. t. — Girdled tree, F. t. — Felled tree, L. s. — Low stump, T. s. — Tall stump, D. t. — Damaged tree. Box plots show medians (thick line), lower, and upper quartiles of FA (boxes), whiskers include the range of distribution without outliers. Different letters above the boxes illustrate significant differences between deadwood types. Subset of Fig. 3 for the first year after the treatment (2017).

limbs was that included all the background variables and the interaction of year and deadwood type (Table 2).

Foraging activity on different types of deadwood

Significant differences were found among deadwood types in FA on trunks (Fig. 2–4) by multiple paired comparisons (Appendix 1). The outer bark of low and tall stumps showed significantly higher FA in the first year after the treatment than the other three deadwood forms (Fig. 2). In the first year, tall stumps were visited most, with often 25–50% (median) for the outer bark peeled off, whilst only 0–5% of the outer bark of damaged-, girdled-, and felled trees was foraged upon in that year. Foraging activity on the outer bark changed in the second and third years. The trunks of girdled trees showed significantly higher FA than felled- and damaged trees (Fig. 3, Appendix 1). In the third year, in case of most of the girdled trees 50% of the outer bark was peeled off. Differences were not as pronounced in the utilisation of the inner bark layer of trees. In the first year, the trunks of felled trees and low stumps had the highest FA, usually remaining under 1% (medians, Fig. 4). In the third year, four deadwood types — felled- and girdled trees, low- and tall stumps — showed significantly higher FA of inner bark layer than on damaged trees (Fig. 4), reaching 5–10% (median) FA. Foraging activity in sapwood was generally very low on trunks, with significant differences between deadwood types recorded in the third year, where girdled trees, felled trees, and tall stumps had higher FA than damaged trees (Appendix 3).

Limbs of damaged-, girdled- and felled trees also had some significant differences in FA. Multiple paired comparisons revealed (Appendix 1) that the outer and inner bark of felled tree limbs had significantly higher FA in the first year than the other two forms of deadwood (Fig. 5, 6), however, activity was low (median: 1%). FA on inner and outer bark layers on both girdled trees and felled trees was significantly higher than that on the damaged trees in the second and third years (Fig. 5, 6). Neither the trunk nor the limbs of the damaged trees showed high woodpecker FA during the three years of investigation.

Effect of time on foraging activity

We found significant differences and changes in woodpecker FA over the years among the deadwood types (Appendix 2). FA on the outer and inner bark of girdled tree trunks (Fig. 3, 4) and

Table 2. Model-selection statistics of the effect of deadwood type, foraging depth, year and their interactions (indicated by ×) on foraging activity of woodpeckers on limbs. AIC values of all the cumulative link mixed models are given, ordered by delta AIC, first row shows the best model.

explanatory variables	AIC	delta AIC	AIC weight	residual df
year + deadwood type + foraging depth + year × deadwood type	851.2	0	0.7	472
year + deadwood type + foraging depth + year × deadwood type + year × foraging depth	853.3	2.1	0.3	470
year + deadwood type + foraging depth	880.5	29.3	0	474
year + deadwood type + foraging depth + year × foraging depth	883.4	32.2	0	472
year + foraging depth	944.9	93.7	0	476
year + deadwood type + year × deadwood type	963.1	111.9	0	474
year + deadwood type	989.0	137.8	0	476
year	1035.6	184.4	0	478
foraging depth	1154.7	303.5	0	477
year + tree depth + year × foraging depth	1159.8	308.6	0	474
deadwood type	1160.4	309.2	0	477

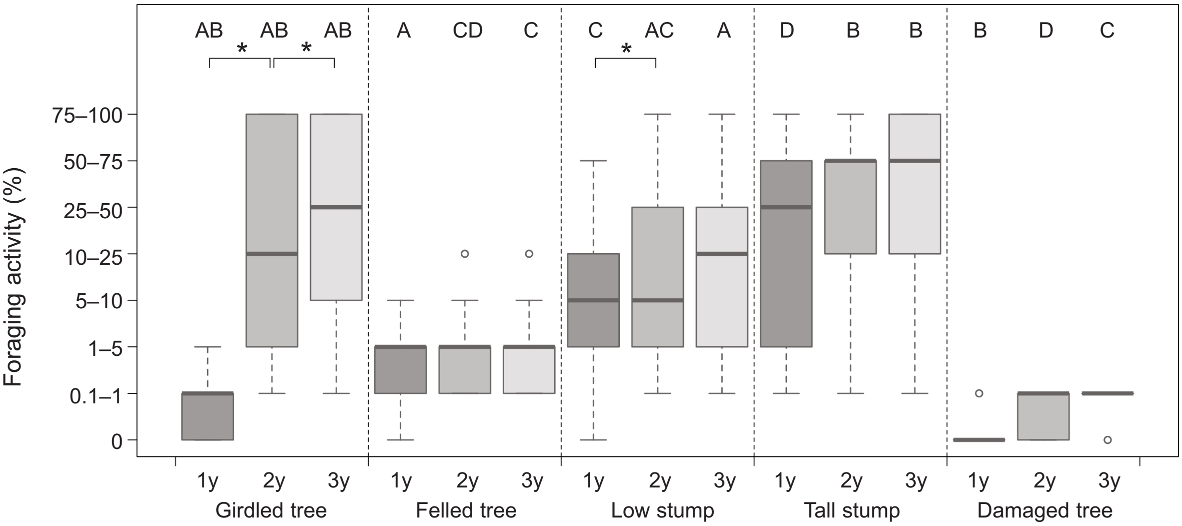

Fig. 3. Foraging activity (FA) on the outer bark of 5 deadwood type trunks, in relation to the time after treatment. Box plots show medians (thick line), lower, and upper quartiles of FA (boxes), whiskers include the range of distribution without outliers. 1y, 2y, 3y mean 1st, 2nd, 3rd year after the treatment, respectively. Different letters above the boxes show significant differences between deadwood types within years. Stars illustrate significant differences between two consecutive years within deadwood types (for p values see Appendices 1–2).

limbs (Fig. 5, 6), and in the sapwood part of limbs (Appendix 4) increased with the passage of time and the differences between subsequent years were significant. The outer bark of low stumps (Fig. 3), inner bark of tall stumps (Fig. 4), and outer bark of felled tree limbs (Fig. 5) also showed significantly higher FA in the second year than in the first. The inner bark of low stumps was utilised significantly more intensively in the third year than in the second. The activity on the inner bark of the limbs of the felled trees seemed to increase from year to year (Fig. 6), however, no significant differences were noticed.

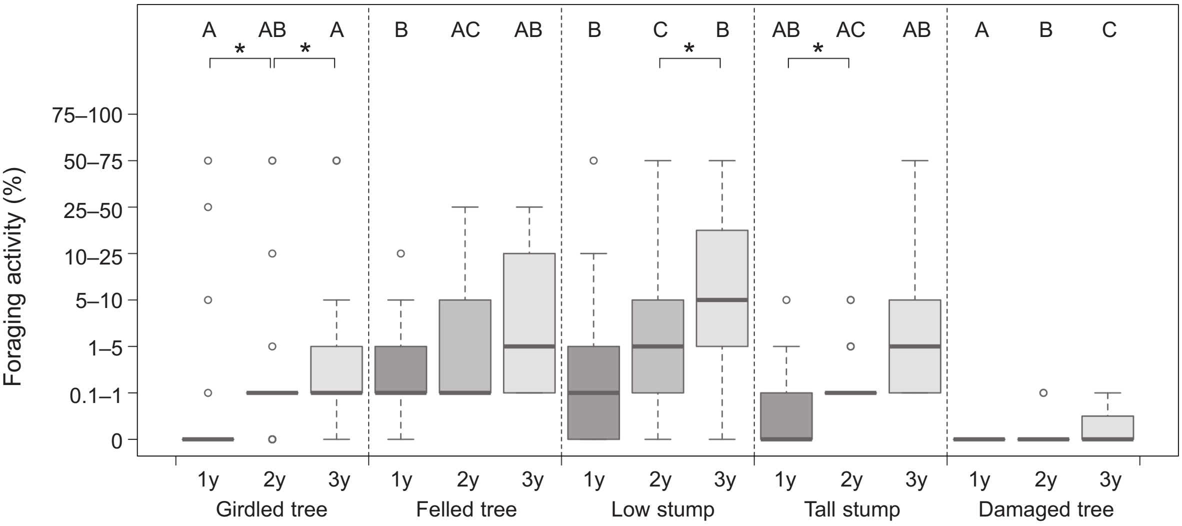

Fig. 4. Foraging activity (FA) on the inner bark of 5 deadwood type trunks, in relation to the time after treatment. Box plots show medians (thick line), lower, and upper quartiles of FA (boxes), whiskers include the range of distribution without outliers. 1y, 2y, 3y mean 1st, 2nd, 3rd year after the treatment, respectively. Different letters above the boxes show significant differences between deadwood types within years. Stars illustrate significant differences between two consecutive years within deadwood types (for p values see Appendices).

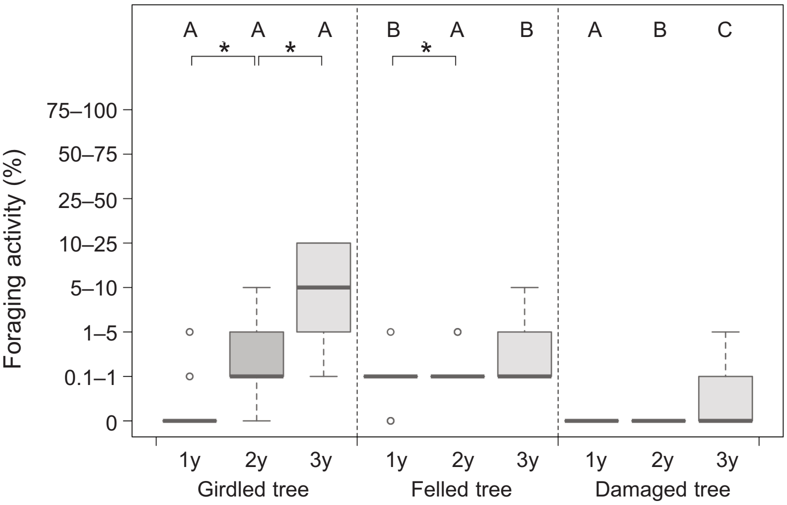

Fig. 5. Foraging activity (FA) on the outer bark of 3 deadwood type limbs, in relation to the time after treatment. Box plots show medians (thick line), lower, and upper quartiles of FA (boxes), whiskers include the range of distribution without outliers. 1y, 2y, 3y mean 1st, 2nd, 3rd year after the treatment, respectively. Different letters above the boxes show significant differences between deadwood types within years. Stars illustrate significant differences between two consecutive years within deadwood types (for p values see Appendices).

DISCUSSION

Our results showed that woodpeckers rapidly utilise artificially created deadwood. The foraging activity (FA) of woodpeckers was explained by all the variables investigated in our models — by the deadwood type, the year of the survey, and the foraging depth. The five deadwood types were used in very different ways by woodpeckers, and high variability in FA was noticed from year to year as also in the depths of foraging. In the first year after the treatment, mainly the bark of low- and tall stumps was foraged upon. Thus, these forms of deadwood were the first food resources exploited by woodpeckers after our initial active management. In the following year, girdled trees

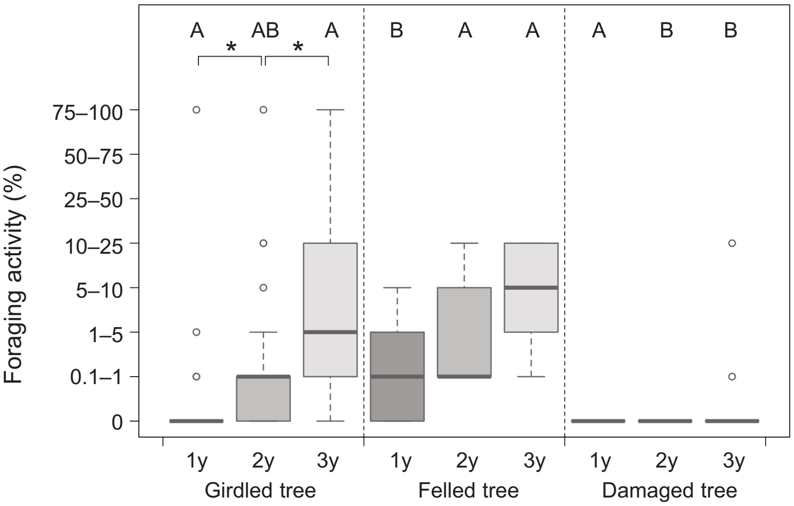

Fig. 6. Foraging activity (FA) on the inner bark of 3 deadwood type limbs, in relation to the time after treatment. Box plots show medians (thick line), lower, and upper quartiles of FA (boxes), whiskers include the range of distribution without outliers. 1y, 2y, 3y mean 1st, 2nd, 3rd year after the treatment, respectively. Different letters above the boxes show significant differences between deadwood types within years. Stars illustrate significant differences between two consecutive years within deadwood type (girdled tree; for p values see Appendices).

started to die out. Their trunks were then actively visited and, by the third year, in most cases, 50% of their outer bark was peeled off. This suggests that artificially created snags can be very important habitat features for tree-foraging bird species and provide a remarkable food resource for woodpeckers two and three years after their creation. It should be noted that other trees (beech, hornbeam) can survive significantly longer after girdling than the oaks we treated for this study. The exploitation of felled trees by woodpeckers was markedly slower than that of the girdled trees and stumps, and FA usually started with the peeling off of the whole bark. Damaged trees, due to their slow mortality, provided very limited food resources for the observed woodpecker species during the three years of the study. However, we discovered some work in the third year, which suggests that these trees will most probably provide food for woodpeckers in the longer term. FA usually started on the outer bark, then on the inner bark, and by the third year had penetrated to the sapwood. The most intense FA was found on the outer bark, but feeding on the inner bark and sapwood subsequently increased during the three years as the dead tree became softer with the passage of time and became inhabited by various insect species in ever deeper layers.

Similar results from North America were reported by Weiss et al. (2018). In mixed stands of Ponderosa Pine *Pinus ponderosae* topped trees had significantly more foraging excavations than girdled trees when foraging activity was monitored seven years after the last treatment. Brandeis et al. (2002) and Hallett et al (2001) arrived at the same conclusions in North American coniferous stands. We found that tall stumps had higher activity than girdled trees, however, girdled trees were also foraged upon very intensively during the second and the third years after management. We found increasing foraging activity of woodpeckers throughout the study years for all forms of created deadwood. From a study made in North American Douglas fir forests by Arnett et al. (2010), and another by Hallett et al. (2001) in mixed coniferous stands, the researchers drew conclusions that match the conclusions about increasing FA arrived at in this study.

As in this study, several other studies highlight the importance of snags as foraging resources for woodpeckers and other cavity-nesting birds (Farris et al. 2004, Czeszczewik 2009, Homyack et al. 2011, Barry et al. 2018). However, our results also suggest the importance of the creation and retention of other forms of deadwood. Various types of deadwood provide diverse arthropod communities and thus foraging resources for insectivorous bird species (Grove 2002, Roth et al. 2019). We demonstrated, that artificially created deadwood is a powerful tool for providing not merely a potential food resource for woodpecker species, but also for saproxylic beetle and wood-inhabiting fungal communities (Roth et al. 2019). Nevertheless, further investigation is needed, as we did not document the real effect on the woodpecker population (e.g. increasing population and breeding performance).

Usually only few naturally-formed cavities can be found in commercially managed forests. In such habitats, woodpecker activity is crucial by creating nesting sites and habitat for other cavity-nesting birds and for mammals, such as bats (Chiroptera) and rodents (Rodentia). By their foraging activities, woodpeckers can also inoculate fungi, and by that, initiate the decaying processes of wood. This process favours the creation of natural tree cavities or hollows, and woodpecker's excavation (Conner et al. 2001, Farris et al. 2004, Jackson & Jackson 2004, Jusino et al. 2015). Conservation-oriented management, by creating various forms of deadwood, will certainly increase the abundance of saproxylic insects. This will result in the improved foraging base for woodpeckers, which are key species for other birds. This can increase the overall biodiversity and natural value of the forest. In managed forests, trees with less valuable timber are suggested to be cut to leave high stumps or to be girdled and left in the forest stand as standing dead tree. To manage for diversity, we also encourage forest managers to retain at least 10–20 m^3 naturally or artificially generated standing deadwood and downed trees per hectare with various decay stages in the stand.

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STRESZCZENIE

[Żerowanie dzięciołów na różnych rodzajach martwego drewna powstałego w wyniku celowych zabiegów]

Wiele gatunków dzięciołów wykorzystuje różne postacie martwego drewna do gniazdowania i żerowania. Jednak w drzewostanach poddanych intensywnemu gospodarowaniu, zwykle homogennych pod względem wieku czy składu gatunkowego, ilość martwego drewna jest niewielka. W ramach działań związanych z ochroną bioróżnorodności podejmuje się takie, które mają na celu zwiększenie jego udziału w środowisku. Niewiele jest jednak informacji na temat wpływu na dzięcioły zabiegów sztucznego wzbogacania ich siedlisk różnymi rodzajami martwego drewna.

Badania prowadzono w 70-letnim drzewostanie dębowym w północnych Węgrzech. Na terenie tym występuje pięć gatunków dzięciołów: czarny, duży, średni, dzięciołek i zielonosiwy. Zimą 2015/2016 na powierzchni 20 ha przeprowadzono zabiegi, których celem było takie przekształcenie drzew, aby uzyskać martwe drewno. W wyniku przeprowadzonych zabiegów uzyskano pięć typów martwego drewna: 1) drzewa obrączkowane, u których wokół całego pnia został usunięty pas kory o szerokości 20–30 cm; 2) drzewa uszkodzone, z których zdarta została kora, 3) drzewa ścięte i pozostawione na ziemi, 4) niskie pniaki po ściętych drzewach, o wysokości 15–25 cm i 5) wysokie pniaki, o wysokości 1–2 m. W sumie przekształceniami objęto ok. 550 drzew, czyli 15% biomasy drzew.

Ślady żerowania dzięciołów monitorowano przez trzy kolejne sezony (2017–2019), co pozwoliło na analizę zmian czasowych w wykorzystaniu stworzonego martwego drewna. Ślady żerowania wyszukiwano w lutym, w sumie na 150 losowo wybranych drzewach (dąb bezszypułkowy, dąb burgundzki i grab pospolity) poddanych zabiegom. Oceniano powierzchnię, na której znajdowano ślady żerowania, przyporządkowując ją następnie do jednej z 8 klas. W przypadku pniaków ślady żerowania oceniano na pniu, a w przypadku drzew obrączkowanych, uszkodzonych i ściętych — osobno na pniu oraz osobno na konarach i gałęziach. Określano także głębokość żerowania, przypisując ją do jednej z trzech klas: 1) korowina, gdy ptak usuwał tylko zewnętrzną warstwę kory, ale ślady żerowania nie wchodziły głębiej w korę, pozostawiając warstwę wewnętrzną nienaruszoną; 2) kora wewnętrzna, gdy ptaki usuwały duże połacie kory, w tym jej warstwę wewnętrzną, żerując na zdobyczy znajdującej się między korą a bielem 3) biel, gdy ślady żerowania znajdowały się w bielu martwego drzewa (Fig. 1). Ze względu na zbyt małą wielkość próby w przypadku dębu burgundzkiego oraz graba pospolitego, w analizach wykorzystano wyłącznie dane dla dębu bezszypułkowego (109 drzew).

Zaobserwowano szybką reakcję ptaków na zwiększoną dostępność martwego drewna i stworzony w ten sposób zasób pokarmowy. Dzięcioły wykorzystywały pięć rodzajów martwego drewna w bardzo różny sposób, a ich aktywność żerowania — zarówno na pniach, jak i na konarach, zależała od rodzaju martwego drewna, głębokości żerowania oraz roku (Tab. 1, 2).

W pierwszym roku po zabiegu dzięcioły najchętniej żerowały na obu typach pniaków (Fig. 2, Appendix 1), zaś w drugim i trzecim roku po zabiegu — na drzewach obrączkowanych oraz wysokich pniakach (Fig. 3, Apendyks 1). Wykorzystanie drzew ściętych i pozostawionych na ziemi oraz uszkodzonych drzew stojących również rosło z czasem, chociaż znacznie wolniej niż w przypadku pozostałych trzech grup martwego drewna (Fig. 3–6, Apendyks 2–4). Większość śladów żerowania stwierdzono w korowinie, jednak ich częstość w wewnętrznej warstwie kory oraz bielu rosła z upływem czasu (Fig. 4–6, Apendyks 2–4).

Badania prowadzono przez stosunkowo krótki czas, szczególnie biorąc pod uwagę powolny czas zamierania drzew po przeprowadzeniu zabiegów. Prawdopodobnie z tego powodu pewne rodzaje martwego drewna, jak drzewa uszkodzone, mogą zyskiwać na znaczeniu dla dzięciołów dopiero w dłuższej perspektywie czasowej. Autorzy konkludują, że działania mające na celu ochronę dzięciołów powinny obejmować stałe tworzenie i utrzymywanie różnych rodzajów martwego drewna w celu zapewnienia zróżnicowanych i stałych miejsc żerowania. Dalsze badania wpływu zwiększenia zasobów martwego drewna na dzięcioły powinny obejmować także aspekty związane z liczebnością ich populacji oraz biologii rozrodu.

Appendix 1. Original and adjusted p-values of multiple paired comparison of foraging activity among deadwood types. Subsets of two types of deadwood were compared by cumulative link mixed models for all paired comparisons, separately for limbs and trunks, and within this separately foraging depths, and also years.

Trunk — outer bark

		original p-values				
		Girdled tree	Felled tree	Low stump	Tall stump	Damaged tree
adjusted p-values	2017					
	Girdled tree		0.1242	< 0.0001	< 0.0001	0.4556
	Felled tree	0.1790		0.0266	< 0.0001	0.0115
	Low stump	< 0.0001	0.0321		0.0023	< 0.0001
	Tall stump	< 0.0001	< 0.0001	0.0025		< 0.0001
	Damaged tree	0.9586	0.0132	< 0.0001	< 0.0001	
adjusted p-values	2018					
	Girdled tree		0.0057	0.7884	0.5060	< 0.0001
	Felled tree	0.0063		0.0467	< 0.0001	0.1616
	Low stump	1.0000	0.0591		0.0284	0.0001
	Tall stump	1.0000	< 0.0001	0.0344		< 0.0001
	Damaged tree	< 0.0001	0.2446	0.0001	< 0.0001	
adjusted p-values	2019					
	Girdled tree		< 0.0001	0.0889	0.8712	< 0.0001
	Felled tree	< 0.0001		0.0248	< 0.0001	0.3758
	Low stump	0.1216	0.0298		0.0057	0.0001
	Tall stump	1.0000	< 0.0001	0.0064		< 0.0001
	Damaged tree	< 0.0001	0.7249	0.0002	< 0.0001	

Trunk — inner bark

		original p-values				
		Girdled tree	Felled tree	Low stump	Tall stump	Damaged tree
adjusted p-values	2017					
	Girdled tree		0.0121	0.0034	0.6469	0.8787
	Felled tree	0.0139		0.9998	0.2108	0.0396
	Low stump	0.0037	1.0000		0.0913	0.0264
	Tall stump	1.0000	0.3388	0.1254		0.3944
	Damaged tree	1.0000	0.0493	0.0318	0.7762	
adjusted p-values	2018					
	Girdled tree		0.4308	0.0307	0.9000	0.0829
	Felled tree	0.8821		0.8579	0.8749	0.0032
	Low stump	0.0374	1.0000		0.1931	0.0001
	Tall stump	1.0000	1.0000	0.3039		0.0152
	Damaged tree	0.1123	0.003	0.0001	0.0176	
adjusted p-values	2019					
	Girdled tree		0.8593	0.0185	0.9429	0.0073
	Felled tree	1.0000		0.3316	0.9982	0.0011
	Low stump	0.0218	0.6098		0.1241	< 0.0001
	Tall stump	1.0000	1.0000	0.1788		0.0012
	Damaged tree	0.0082	0.0011	< 0.0001	0.0013	

Trunk — sapwood

		original p-values				
		Girdled tree	Felled tree	Low stump	Tall stump	Damaged tree
adjusted p-values	2017					
	Girdled tree		0.9968	0.9357	0.9783	1.0000
	Felled tree	1.0000		0.9959	0.9997	0.9974
	Low stump	1.0000	1.0000		0.9998	0.9555
	Tall stump	1.0000	1.0000	1.0000		0.9844
	Damaged tree	1.0000	1.0000	1.0000	1.0000	
adjusted p-values	2018					
	Girdled tree		0.5840	0.1124	0.8974	0.5985
	Felled tree	1.0000		0.0119	0.1665	0.1727
	Low stump	0.1593	0.0136		0.3594	0.9555
	Tall stump	1.0000	0.2536	0.6811		0.8977
	Damaged tree	1.0000	0.2650	1.0000	1.0000	
adjusted p-values	2019					
	Girdled tree		0.9999	0.1175	1.0000	0.0409
	Felled tree	1.0000		0.1224	1.0000	0.0379
	Low stump	0.1678	0.1759		0.1057	0.4583
	Tall stump	1.0000	1.0000	0.1483		0.0375
	Damaged tree	0.0511	0.0470	0.9669	0.0466	

Limb — outer bark

		original p-values		
		Girdled tree	Felled tree	Damaged tree
adjusted p-values	2017			
	Girdled tree		0.0009	0.6345
	Felled tree	0.0009		0.0051
	Damaged tree	1.0000	0.0054	
adjusted p-values	2018			
	Girdled tree		0.6479	0.0003
	Felled tree	1.0000		0.0015
	Damaged tree	0.0004	0.0016	
adjusted p-values	2019			
	Girdled tree		0.0004	< 0.0001
	Felled tree	0.0004		0.0159
	Damaged tree	< 0.0001	0.0173	

Limb — inner bark

		original p-values		
		Girdled tree	Felled tree	Damaged tree
adjusted p-values	2017			
	Girdled tree		0.0025	0.6470
	Felled tree	0.0026		0.0115
	Damaged tree	1.0000	0.0124	
adjusted p-values	2018			
	Girdled tree		0.0480	0.0460
	Felled tree	0.0548		0.0014
	Damaged tree	0.0524	0.0015	
adjusted p-values	2019			
	Girdled tree		0.4565	0.0002
	Felled tree	0.6969		< 0.0001
	Damaged tree	0.0002	< 0.0001	

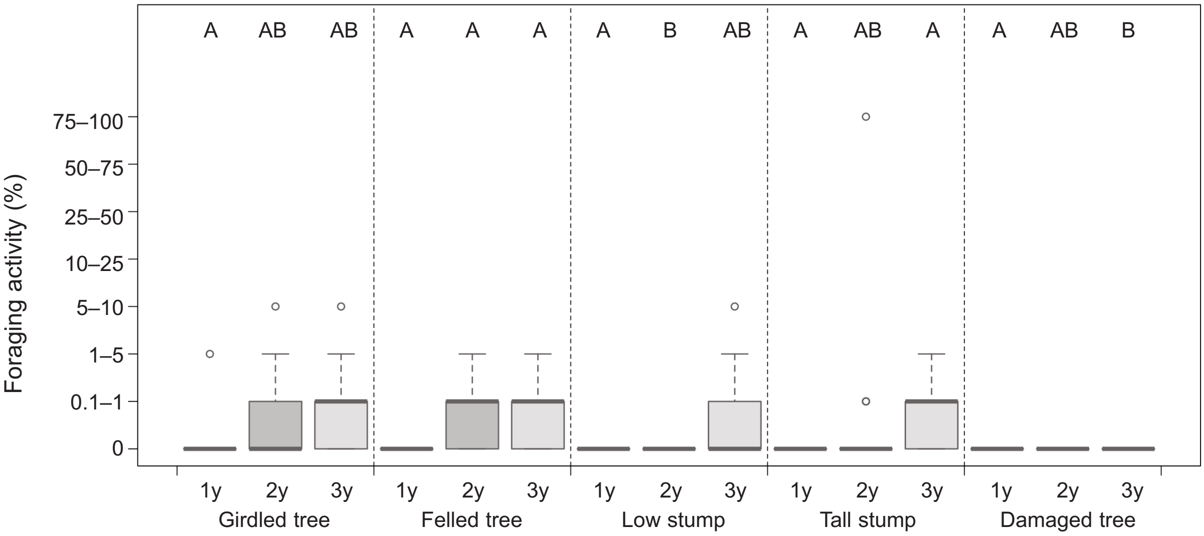
Limb — sapwood

		original p-values		
		Girdled tree	Felled tree	Damaged tree
adjusted p-values	2017			
	Girdled tree		1.0000	1.0000
	Felled tree	1.0000		1.0000
	Damaged tree	1.0000	1.0000	
adjusted p-values	2018			
	Girdled tree		1.0000	1.0000
	Felled tree	1.0000		1.0000
	Damaged tree	1.0000	1.0000	
adjusted p-values	2019			
	Girdled tree		0.3068	0.0150
	Felled tree	0.4270		0.0010
	Damaged tree	0.0163	0.0010	

Appendix 2. Original and adjusted p-values of multiple paired comparison of foraging activity among years, by cumulative link mixed models. Data on limbs and trunks was analysed separately, and within this the foraging depth, and deadwood types.

	compared pairs of years			
	original p-values		adjusted p-values	
	2017–2018	2018–2019	2017–2018	2018–2019
Trunk — outer bark				
Girdled tree	< 0.001	< 0.001	< 0.001	< 0.001
Felled tree	0.122	0.142	1.000	1.000
Low stump	0.003	0.319	0.027	1.000
Tall stump	0.083	0.114	0.829	1.000
Damaged tree	0.498	0.436	1.000	1.000
Trunk — inner bark				
Girdled tree	< 0.001	0.002	0.006	0.019
Felled tree	0.038	0.074	0.381	0.739
Low stump	0.016	< 0.001	0.162	< 0.001
Tall stump	0.003	0.013	0.029	0.134
Damaged tree	1.000	0.406	1.000	1.000
Trunk — sapwood				
Girdled tree	0.057	0.322	0.569	1.000
Felled tree	0.992	0.194	1.000	1.000
Low stump	1.000	0.98	1.000	1.000
Tall stump	0.985	0.011	1.000	0.106
Damaged tree	1.000	1.000	1.000	1.000
Limb — outer bark				
Girdled tree	0.0021	< 0.001	0.013	< 0.001
Felled tree	< 0.001	0.111	< 0.001	0.664
Damaged tree	1.000	0.984	1.000	1.000
Limb — inner bark				
Girdled tree	0.005	< 0.001	0.032	< 0.001
Felled tree	0.022	0.042	0.132	0.251
Damaged tree	1.000	0.989	1.000	1.000
Limb — sapwood				
Girdled tree	0.002	0.008	0.013	0.050
Felled tree	0.979	0.981	1.000	1.000
Damaged tree	1.000	0.992	1.000	1.000

Appendix 3. Foraging activity (FA) on the sapwood of 5 deadwood type trunks, in relation to the time after treatment. Box plots show medians (thick line), lower, and upper quartiles of FA (boxes), whiskers include the range of distribution without outliers. 1y, 2y, 3y mean 1st, 2nd, 3rd year after the treatment, respectively. Different letters above the boxes show significant differences between deadwood types within years (for p values see Appendices).



Appendix 4. Foraging activity (FA) on the sapwood of 3 deadwood type limbs, in relation to the time after treatment. Box plots show medians (thick line), lower, and upper quartiles of FA (boxes), whiskers include the range of distribution without outliers. 1y, 2y, 3y mean 1st, 2nd, 3rd year after the treatment, respectively. Different letters above the boxes show significant differences between deadwood types within years. The star illustrates significant difference between two consecutive years within deadwood type (Girdled tree; for p values see Appendices).