Determining structure and volume of the European beech (*Fagus sylvatica* L.) deadwood in managed stands in the Rodopi Mountain Range National Park, Greece

Stavros Kechagioglou[1*], Dimitra Papadopoulou[2], Thekla Tsitsoni[3]

[1]Forest Service of Drama – Management Body of Rodopi Mountain Range National Park, Agiou Konstantinou 1, Drama, 66133, Greece
[2]Department of Forest and Natural Environment Sciences, International Hellenic University, Drama, 66100, Greece
[3]School of Forestry and Natural Environment, Aristotle University of Thessaloniki, P.O. Box 262, Thessaloniki, 54124, Greece

Abstract

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The multifaceted role of deadwood in forest ecosystems has been widely recognized while it is regarded as an indicator of sustainable forest management. Nevertheless, there are hardly any data on deadwood volume and structure in managed forests in Greece. The study took place in beech forests of the Western and Central part of the Rodopi Mountain Range. The objective was to determine the amount, variability and quality of deadwood and to compare it with data from managed as well as natural forests. Data were collected on 30 randomly distributed circular plots of 0.1 ha. The results showed that the average deadwood amount (13.46 m^3 ha^{-1}) was much lower compared to that recorded in other European forests and they highlighted the absence of large dead standing trees due to the management regime. The deadwood quality showed great variation in stages of decay.

Keywords

coarse woody debris, decay stages, downed wood, logs, snags, stumps

Introduction

Deadwood is a key component in forest ecosystems both in terms of structure and function. It plays a significant role in maintaining biodiversity (Bradshaw et al., 2009; Brassard and Chen, 2008; Bobiec et al., 2005) by providing habitat and food for numerous species (Mason, 2003). Several saproxylic species are associated with deadwood, i.e. bacteria, fungi (Renvall, 2003; Siitonen, 2001; Stokland et al., 2004), lichens and bryophytes (Crites and Dale, 1998), invertebrates (Vanderwel et al., 2006; Parisi et al., 2018) and vertebrates (Vaillancourt et al., 2008; Ecke et al., 2001). Among vertebrates associated with deadwood many species of mammals and birds are known to utilize this specific substrate as a source of food or shelter (Hagan and Grove, 1999; Siitonen, 2001; Altamirano et al., 2017).

Fallen deadwood and stumps can ensure natural regeneration as they provide nurse logs facilitating the germination of seedlings (Hofgaard, 2000; Vallauri et al., 2003; Ježek, 2004). Deadwood is also an important component for conserving and regulating carbon stock (Harmon, 2001; Cornwell et al., 2009) as well as a key factor in nutrient cycling (Krankina and Harmon, 1995; Laiho and Prescott, 2004) and water-storing during dry periods thereby influencing the forest microclimate (Harmon et al., 1986). It is crucial for improving slope and soil surface stability thus preventing erosion, rock falls and avalanches (Stevens, 1997; Yan et al., 2006).

In natural forest ecosystems deadwood input originates apart from age-based tree mortality and canopy competition, from natural disturbances that ensure a constant supply of

*Corresponding author:
e-mail: skehagio@gmail.com

deadwood to the ecosystem (Vološčuk et al., 2013). However, in managed ecosystems deadwood amounts are usually much lower than in unmanaged old-growth forests because of the extraction of the large-sized harvestable timber (Green and Peterken, 1997; Kirby et al., 1998; Ódor and Standovár, 2001; Winter and Nowak, 2001; Atici et al., 2008). According to Fridman and Walheim (2000) the quantity of deadwood in managed forests is between 2% and 30% of the quantity in unmanaged forests. Christensen et al. (2005) concluded that the amount of deadwood was 10–20 times higher in unmanaged than in intensively managed production forests. Additionally, the structure of deadwood in managed stands differs as it mainly consists of small twigs and branches and short stumps with snags and large logs are usually absent (Kruys et al., 1999; Atici et al., 2008).

Over the last years forestry has been oriented towards a more close-to-nature approach to forest management aiming at emulating the natural processes in forests in terms of forest structure and composition (O'Hara, 2016). This has been intensively supported by the European federation of foresters (Pro Silva) which promotes forest management strategies that ensure both the conservation and utilization of forest ecosystems while maintaining ecological and socio-economic functions sustainable and profitable (Pro Silva, 2012). For this purpose it is recommended to maintain deadwood both in terms of ecosystem function but also of preservation and development of biodiversity (Pro Silva, 2012). Moreover, the forest management policy within Europe regards deadwood as indicator of sustainable forest management as the volume of standing and fallen deadwood is considered one of the nine pan-European indicators for sustainable forest management (criterion 4: maintenance, conservation and appropriate enhancement of biological diversity in forest ecosystems) (MCPFE, 2003; Christensen et al., 2005).

In this framework a growing interest on deadwood has been established as well as efforts in order to increase the volumes of deadwood in managed forests (Hodge and Peterken, 1998; Harmon, 2001; Christensen et al., 2005; Marage and Lemperiere, 2005) by modifying silvicultural practices in a way that they ensure the creation and maintenance of an adequate stock of deadwood as well as a similar structure to that found in unmanaged forests (Siitonen et al., 2000; Nordén et al., 2004; Ranius and Kindvall, 2004).

Vítková et al. (2018) provide a thorough compilation of key aspects of deadwood management aiming to promote biodiversity without compromising or negatively affecting operational and commercial aspects of forest management.

Extended research on deadwood assessment has been carried out during the last decades in forests of North America (Spies et al., 1988; McCarthy and Bailey, 1994; Sturtevant et al., 1997) and Northern Europe (Guby and Dobbertin, 1996; Sippola et al., 1998; Jonsson, 2000; Siitonen et al., 2000; Krankina et al., 2002) which was followed by studies in Central and Southern Europe (Marage and Lemperiere, 2005; Motta et al., 2006; Lombardi et al., 2008).

Numerous studies have been focusing on pure or mixed beech stands as they comprise the potential natural vegetation of lowland areas of North-western (NW) and North-central (NC) Europe and of mountainous areas of the Central, Southern, and Eastern Europe (Christensen et al., 2005). In Greece there has been hardly any research on deadwood carried out and there are no estimates on managed stands showing the effect of the applied silvicultural management practices.

The aim of this study was to assess the volume, variability and quality of deadwood in managed beech forests in northern Greece. This information can provide a basis for forest managers and policy-makers in order to formulate and adopt proper management practices in the study area and in the broader region where beech forests are present.

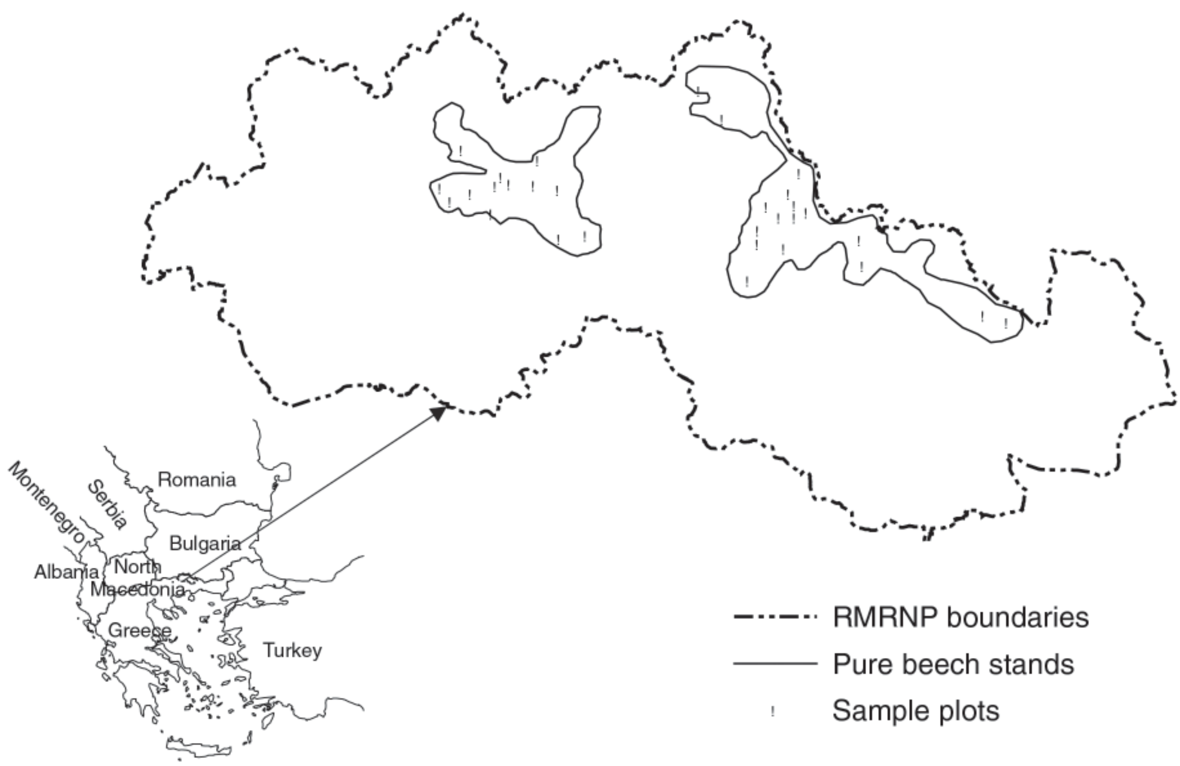

Fig. 1. Location of the study area and sample plots in the Rodopi Mountain – Range National Park in Greece.

Materials and methods

Study area

The study area is located in the Rodopi Mountain-Range National Park (RMRNP) covering the southern part of the Rodopi Mountain Range in Northern Greece (Fig. 1). It covers an area of 173,115 ha, thus being one of the largest National Parks in mainland Greece. The altitude ranges from 68 and 2,232 m showing an uneven terrain. The mainly mountainous character with steep slopes, high altitudes and a complex hydrographic network prevails in the area. The site is characterized by crystalline rocks belonging to the Rhodope metamorphic core complex. West-Thracian gneiss complex, which consists of quartzofeldspathic and pelitic gneisses and schists, migmatites, amphibolites, and ultramafic bodies, as well as Elatia-Skaloti granites, Paranesti andesites and Phalakron marble series are observed (Papazisimou et al., 2002). The climate is classified as transitional from sub-Mediterranean to central European, with a wet continental character, characterized by severe winters, short warm summers and a relatively uniform distribution of rainfall throughout the year. The mean annual precipitation is calculated around 875 mm, while the mean annual temperature is 10.3 °C (Gatzogiannis, 1999).

The area constitutes a mosaic of different land uses including forests, pastures and agricultural land while the forest vegetation is organized in several vegetation zones. The Submediterranean zone (Quercetalia pubescentis) is observed up to an altitude of 1,100 m represented by *Quercus coccifera* L., *Carpinus orientalis* Mill., *Ostrya carpinifolia* Scop. at lower altitudes and *Quercus pubescens* Willd., *Quercus frainetto* Ten., *Quercus dalechampii* Ten., *Quercus petraea* (Matt.) Liebl., *Castanea sativa* (Mill.) and other deciduous trees in higher altitudes. This zone is followed by a well-developed Fagetalia zone, up to 1,500–1,800 m, where *Fagus sylvatica* L. forms extended forests. In the lower parts of beech occurrence it forms mixed forests with *Quercus frainetto* Ten. and *Quercus dalechampii* Ten., while in higher altitudes one can find acidic as well as calcareous beech forests depending on the substrate. In higher altitudes (above 1,400 m) there can be found either pure beech forests or mixed forests with Norway spruce (*Picea abies* (L.) H. Karst.) and Bulgarian fir (*Abies borisii-regis* Mattf.). This vegetation type is considered to be representative of the so-called climax community. The formation of *Betula pendula* Roth stands appears also in the area while *Pinus nigra* J.F. Arnold may also be present depending on the local and soil conditions. Vaccinio-Picetalia zone extends in the higher altitudes of the RMRNP and is represented mainly by *Pinus sylvestris* L. and *Picea abies* (L.) H. Karst., while the alpine and subalpine zone is characterized by low vegetation, mainly shrubs and herbs. In the streams of the area, the riparian vegetation is composed by *Alnus glutinosa* (L.) Gaertn. in altitudes below 1,000 m, and *Alnus incana* (L.) Moench accompanied i.e. by *Salix alba* L., *Salix appendiculata* Vill. and *Platanus orientalis* L. in the altitudes above 1,200 m.

Thus, the area hosts a variety of habitats including some of the least disturbed natural forests of Europe with a high ecological value which led to its designation as a National Park in 2009. In fact, the Park encompasses several protected sites designated at different times during the past decades including seven sites of the European Ecological Network NATURA 2000 and two sites designated as "Preserved Natural Monuments" under national Law. The RMRNP hosts some of the most productive forests in Greece (Kazana et al., 2020). As a result, depending on the ecological significance and the degree of protection of the individual ecosystems, the RMRNP is divided into zones determining the intensity of protection and the human activities allowed.

Data collection

For the purpose of the study 30 randomly selected circular sample plots of 0.1 ha were established (Fig. 1). The plots were randomly distributed within the area covered by pure beech stands in the RMRNP using the "create random points" command in a Geographic Information Systems environment (ArcGIS 10.2) (Kershaw et al., 2016). Further, the distinction of the different site qualities in the selected forest stands was conducted using the site quality maps of the management plans of the Forest Service. Site quality expresses an estimation of present and future forest productivity with site class I being the highest site in terms of productivity and site class V or VI being the lowest (Deyoung, 2016). The Strict Nature Reserves of the area were excluded as there is no forest exploitation taking place.

Deadwood was classified on the basis of tree species, structural characteristics and decay stage (class) and categorized as standing deadwood or snags (≥5 cm diameter at breast height (DBH) and ≥1.3 m height), stumps (short, vertical remains from cutting or windthrow, top diameter ≥ 5 cm and height < 1.30 m) and lying deadwood or logs (fallen stems or branches ≥ 10 cm mid diameter). The separation of snags from logs was established at a 45° angle. Deadwood constituting snags, stumps and logs was referred to as coarse woody debris (CWD).

The volume ($m^3\ ha^{-1}$) of standing dead trees was estimated from the DBH and heights by means of volumetric tables in the same way as in living trees. The volume of standing trees with broken stems was calculated similarly if the broken part was identified on the ground (Saniga and Schütz, 2001). In case this was not possible, the calculation of volume of broken snags was estimated as a frustum of a cone (Motta et al., 2006, Castagneri et al., 2010).

The volume of logs was calculated according to the Huber's formula (Saniga and Schütz, 2001; Rahman et al., 2008; Merganičová and Merganič, 2010):

$$V = (\pi/4) \times d_{1/2}{}^{2} \times l,$$

where
V = volume (m^3),
l = length of the log (m),
$d_{1/2}$ = tree diameter at the half of its length (m),
π = constant (3.14159).

The volume of the stumps was calculated as the volume of the cylinder at the height of 0.3 m (Merganičová and Merganič, 2010). The volumes were subsequently converted to ($m^3\ ha^{-1}$).

Decay stages (classes) of logs were defined according to a five class system (Motta et al., 2006; Castagneri et al., 2010): (1) bark intact, small branches present, shape round, wood texture intact, log elevated on support point; (2) bark intact, no twigs, shape round, log elevated but sagging slightly; (3) trace of bark, no twigs, shape round, wood hard, texture with large pieces, log sagging near the ground; (4) no bark, no twigs, shape round to oval, wood hard, texture with blocky pieces, all of log on the ground; (5) no bark, no twigs, shape oval, wood soft and powdery structure, all of the log on the ground.

Table 1. Distribution of volume of coarse woody debris (CWD) among site quality classes

Site quality classes	Snag volume (m^3 ha^{-1})	Log volume (m^3 ha^{-1})	Stump volume (m^3 ha^{-1})	Total CWD (m^3 ha^{-1})	Ratio CWD and living tree volume (%)	Proportion of snag volume (%)	Proportion of log volume (%)	Proportion of stump volume (%)
II	1.21	8.40	3.85	13.46	3.39	8.99	62.41	28.60
III	1.23	8.61	3.82	13.66	4.81	9.00	63.03	27.96
IV	1.47	8.41	3.38	13.26	5.40	11.09	63.42	25.49
Overall	1.30	8.47	3.68	13.46	4.53	9.68	62.25	27.37

Table 2. Statistical analysis (One-Way ANOVA) of difference in deadwood volume between the areas of the 3 site quality classes (II, III, IV)

	Sum of squares	df	Mean Square	F	P- value
Between groups	2.819	2	1.409	1.793	0.186
Within groups	21.221	27	0.786		
Total	24.040	29			

The decay stage of snags was classified according to a five class system (Sollins, 1982; Motta et al., 2006; Castagneri et al., 2010): (1) standing dead tree with bark and most of the branches intact, wood hard; (2) dead tree with few branches left and loose bark, wood hard; (3) no bark, no twigs, wood hard; (4) no bark, no twigs, wood hard to soft (soft sapwood < 70%); (5) no bark, no twigs, wood hard to soft (soft sapwood > 70%).

The decay stage of stumps was classified according to a five class system (cf. Robin and Brang, 2008).

Statistical evaluation was carried out by applying One-Way Variance Analysis (ANOVA) in order to determine whether there are statistically significant differences in the deadwood volumes between the different site quality classes. The SPSS26.0 statistical software was used for analyzing the collected data (IBM Corp., 2019).

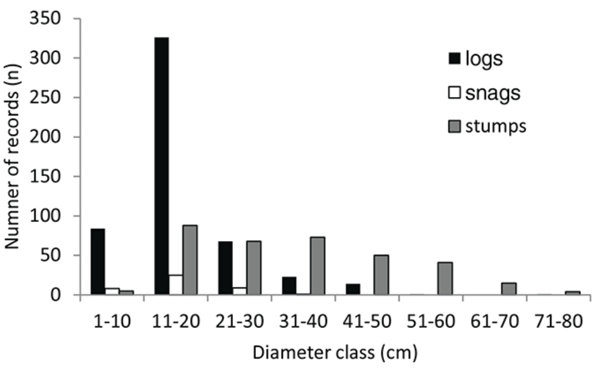

Fig. 2. Frequency size distribution of logs, snags and stumps within the diameter classes.

Results

The mean volume of CWD (snags, logs and stumps) was 13.46 m^3 ha^{-1}, of which 1.3 m^3 ha^{-1} (9.68%) were snags, 8.47 m^3 ha^{-1} (62.25%) were logs and 3.68 m^3 ha^{-1} (27.37%) stumps, hence the highest amount of CWD was found in the form of logs and the lowest amount in the form of snags (Table 1). According to the forest management plan of the investigated beech forest district, no area with the site quality I was available. On the site quality II, III and IV plots the mean volume of deadwood was 13.47, 13.66 and 13.26 m^3 ha^{-1} respectively. There were no statistically significant differences in the deadwood volumes between the site quality classes II, III, and IV (One-Way ANOVA, $p < 0.05$, Table 2).

Within all quality site classes the snags accounted for the lowest amount of CWD with the values ranging from 1.21 to 1.47 m^3 ha^{-1} while the logs accounted for the highest amount ranged from 8.40 to 8.61 m^3 ha^{-1}. The proportion of the total CWD in relation to the living tree volume was 4.53% with no significant differences between the three forest quality classes.

The diameter distribution of snags (Fig. 2) indicates that small trees were most abundant as the mean diameter corresponds to 16.60 cm while the minimum value is 5 cm and the maximum 34 cm. Stems within the diameters 11–20 cm accounted for 60% of the total number of stems. This shows that there are no dead old trees as a consequence of forest exploitation. Logs showed a unimodal distribution with a modal (mode) value of 16.99 cm. The density of logs showed greater concentration in the diameter class of 11–20 cm and decreased with larger diameter classes. Stumps, almost exclusively of man-made origin, were 8–78 cm thick, with a modal (mode) value of 33.57 cm.

Regarding the proportion of decay stages of the total deadwood volume all decay stages were represented (Table 3), with the prevailing decay stage 3 – proportion 26.6%, followed by the decay stages 4, 5 and 2 sharing with 24.4%, 23.1% and 17.7% respectively. The decay stage 1 accounted

Table 3. Coarse woody debris (CWD) type and decay class distribution (%) within different site quality classes

Decay stages	Snags	Logs	Stumps	Overall
1	5.1	10.8	8.8	8.2
2	36.9	4.4	11.7	17.7
3	39.2	22.9	17.5	26.6
4	16.7	29.5	27.2	24.4
5	2.1	32.4	34.8	23.1

only for 8.2% of the total deadwood volume.

The volume of logs was concentrated within the decay stage 5–32.4% of the total volume of lying deadwood, followed by the decay stage 4 (29.5%) and the decay stage 3 (22.9%). The decay class 1 and 2 accounted for 10.8% and 4.4% of the total volume of the lying deadwood. The snags were mostly concentrated in the decay stages 2 and 3 and with 39.2% and 36.9% respectively. The most frequent decay class for stumps was the class 5 (34.8%) followed by the class 4 (27.2%).

Lying deadwood was on average more decayed than the standing deadwood, 84.8% of the logs belonged to the decay stages 3, 4 and 5. The decay of stumps was also pronounced, 79.5% of the deadwood volume corresponded to the decay stages 3, 4, and 5.

Discussion

The levels of deadwood in managed beech stands in the RMRNP are discussed in comparison with other European beech forests as there has been a great amount of research on that topic but there have been hardly any studies on deadwood in managed beech forests in Greece. According to Puletti et al. (2019) the amount of deadwood at country level based on data from 19 European countries ranges from 5.6 m^3 ha^{-1} to 33.1 m^3 ha^{-1} with an average value of 15.8 m^3 ha^{-1} with deadwood being mostly present in Central Europe. According to the same research mountainous beech forests hold an average value of 25.4 m^3 ha^{-1} while Travaglini and Chirici (2006) reported for mountainous mixed beech forests a similar value of 22 m^3 ha^{-1} with the value of 13.46 m^3 ha^{-}1 of the present study being much lower.

An extended research on deadwood volumes in European beech forest reserves provided by Christensen et al. (2005) showed an average of 130 m^3 ha^{-1} ranging from nearly absence of deadwood to 550 m^3 ha^{-1}. The study also clearly indicated that the amount of deadwood is in the order of 10–20 times higher in unmanaged than in intensively managed production forests. Substantial differences between managed and unmanaged stands arose also in the study of Lombardi et al. (2008) where in the Apennine-Corsican montane beech forests the deadwood volumes in unmanaged stands (27 m^3 ha^{-1}) were significantly higher than in managed stands (5 m^3 ha^{-1}) while research in several European countries in production forests showed an average deadwood volume less than 10 m^3 ha^{-1} (Christensen et al., 2005). The results of the present study can also be compared to the deadwood levels of the Frakto virgin forest within the RMRNP, where large amounts of deadwood, reaching 175.70 m^3 ha^{-1}, were recorded (Papadopoulou, 2017). The proportion of the deadwood volume in the present study was 4.53% of the total living wood volume which lies also much lower compared to that of Frakto forest (31%) (Papadopoulou, 2017) and that of 86 European beech forest reserves where it ranged between 37% (for long established montane reserves) and 13% (for recently-established lowland/submontane reserves) (Christensen, 2005). It is similar though with the dead to live wood ratio in managed oriental beech forests in Turkey (4.8%) (Atici, 2008).

Reasons explaining the small amount of deadwood in managed forests has been discussed in relation to the management status by Debeljak (2006) and Lombardi et al. (2008) stating that forest management can result in reduced occurrence of deadwood. The main differences in deadwood between managed and natural forests can be attributed to management measures such as forest thinning that reduces the quantity, distribution and size of deadwood (Debeljak, 2006). This applies also to the study area where in the framework of the applied thinning practice (selective thinning) suppressed trees are removed thereby reducing competition intensity and consequently the natural mortality of trees.

This explains also apart from the quantity, the variability of deadwood as it occurs mainly as logging waste and stumps, with large logs being rare in managed stands (Kruys and Jonsson, 1999; Christensen et al., 2005; Lombardi et al., 2008). According to Harmon et al. (1986) logs in managed stands account for about 50% of the total deadwood volume in the form of logging residue left on site. The number of old big trees is also usually lower in managed than unmanaged forests, because classical forest management is based on rotations shorter than species longevity (Hahn and Christensen, 2004) which interrupt natural stage development thereby preventing forest ageing and deadwood accumulation (Vandekerkhove et al., 2009). Results showed that in the study area lying deadwood is the most abundant component followed by stumps while the snag volume has a small share which confirms the above statement.

As far as the decay stage is concerned more than half of the total deadwood volume corresponded to decay stage 3 and 4 while a significant proportion of 23.1% to decay stage 5 which is attributed to the proportion of logs and stumps in decay stage 5 rather than snags. Logs and stumps showed an increased share in the most decayed stages (62% each) while snags are concentrated mostly in the third (39.2%) and second (36.9%) decay stages with only a minor presence in decay class 5 (2.1%). This pattern can be attributed either to the fact that logs might have reached the ground after a first stage as a snag as stated by Motta et al. (2006) or as parts of snags while log dimensions are also discussed in this context thoroughly (Zhou et al., 2007). In particular small diameters of deadwood might be correlated to elevated decomposition rates (Abbott and Crossley, 1982). According to Herrmann et al. (2015) decomposition rates of beech logs decreased significantly with increasing diameter class.

According to the review of Müller and Bütler (2010) of threshold deadwood data from European forests values for mixed-montane forests lie between 30–40 m^3 ha^{-1} while according to Ammer (1991) also the deadwood structure has to be taken into account as it was concluded that at least half of the deadwood volume in the form of snags was of benefit to birds and insects. Therefore it can be stated that management measures have to be adapted in order to enhance deadwood volumes and balance the proportions of logs and snags in the area so as to ensure long-term preservation of biodiversity.

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