DEADWOOD MANAGEMENT IN PRODUCTION FORESTS

Management guidelines for forest managers in Central European temperate forests

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Abstract

In spite of the great importance of deadwood for biodiversity, there are no simple suggestions helping forest managers incorporating deadwood management into day-to-day forest management. The aim of this guide is to help find an optimal way for deadwood management in production forests to enhance biodiversity. We propose temporal and spatial distribution of deadwood with regards to its quality and quantity. Operational challenges, risk and economic loss reduction were taken into account meanwhile focusing on the positive effects of biodiversity. Since species richness logarithmically increases with the dependence on the availability of suitable habitat, retention of a small proportion of potential natural volume of deadwood on a site facilitates the survival of many saproxylic species. It is important is to achieve qualitative diversity of the retained deadwood. The availability of sun-exposed thick logs is a crucial factor in the occurrence of numerous threatened saproxylic species. The most efficient measure to support the enhancement of biodiversity in production forests is to preserve large old trees and large snags on sun-exposed sites. The objective of this document is to provide forest owners and forest managers with a set of best practice guidelines. The use of deadwood management guidelines should involve the application of new knowledge on (1) the potential benefits of retaining deadwood which primarily promotes biodiversity as one of the most positive consequences, and (2) the effects causing certain limitations or losses to forestry operations.

The deadwood management guidelines were originally published in Czech language within the context of Czech forestry (i.e. Bače and Svoboda 2015). However, in general, they are considered to be suitable for the application in Central European temperate forests.

Key words: Deadwood management, saproxylic diversity, habitat trees, sun-exposed deadwood of large dimensions.

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1. The importance of deadwood

Almost all forests in Central Europe play multiple roles; while being a source of wood, multifunctional forests also have non-production ecosystem services such as recreation and water and soil protection. Recent research shows that forests with a more enhanced level of tree species diversity performs better in meeting most of the forest functions (Gamfeldt et al. 2013). While diversity of tree species is the foundation for the overall forest biodiversity, such biodiversity is essential for the support of forest ecosystem services provided by the forest ecosystem. Therefore, forest management accommodating for biodiversity protection is the foundation for a long-term survival of the multifunctional forest.

Forests are a keystone ecosystem for overall biodiversity as they host the majority of Earth's plant and animal species. The presence and creation of deadwood are essential parts of a functional ecosystem preserving biodiversity on a high level (Harmon et al. 1986). The concept of deadwood (commonly also called decaying or rotting wood) refers to the various forms of standing or lying deadwood that is produced through the process of a tree death. Deadwood includes standing dead trees (snags), stumps, entire fallen trees, lying thick/thin branches, lying pieces of fragmented wood but also dead parts of living trees such as dry branches (Zhou et al. 2007). The volume of deadwood in the given type of forest ecosystem depends on the site productivity, species composition, climatic conditions, natural disturbance regimes and the stage of forest stand development and, in production forests, mainly on forest management operations. In temperate deciduous forests, deadwood usually accounts for 5 % to 30 % of the entire forest stand volume, which equates to roughly 40 to 200 m^3h^{-1}. According to Dudley and Vallauri (2005), for example, the mean volume of deadwood in natural beech forests is 136 m^3h^{-1}. Shortly after a strong disturbance, however, the stock of deadwood can increase up to 700 m^3h^{-1} (Müller et al. 2010).

The form of deadwood and the way it decays over time is determined by the cause of tree death; e.g. breakage, uprooting, competition, infection by root rot or infestation by insects. Deadwood passes through a complex set of decomposition process that are influenced by a number of biological and physical factors such as biological respiration, leaching and fragmentation. Deadwood is gradually colonised by a wide range of organisms whereby wood-decaying (lignicolous) fungi are of particular importance. The deadwood disintegration process is influenced by temperature, humidity and the ambient O_2 to CO_2 ratio; qualitative characteristics such as deadwood size, tree species and deadwood dependant (saproxylic species) are also considered to be important factors (Zhou et al. 2007, Lonsdale et al. 2008).

It took tens of millions of years for forest ecosystems to develop into the current state. Therefore, many important links to deadwood have evolved in this complex ecosystem:

1.1. Deadwood as a substrate for tree seedlings

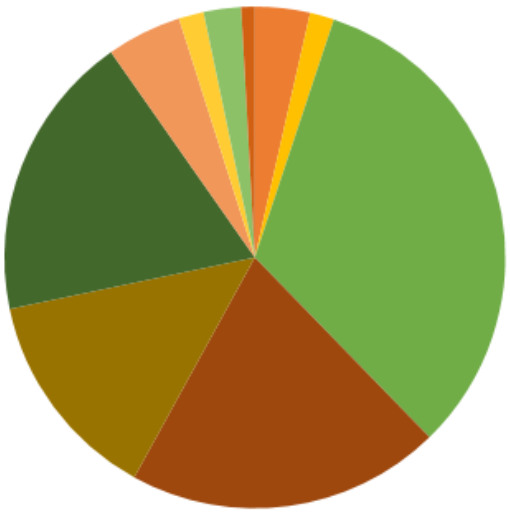
Deadwood provides a substrate where germination of seedlings of many tree species takes place; young trees produce microsites for their own species to regenerate to help maintain their dominance in the plant community (Christie and Armesto 2003, Bellingham and Richardson 2006, Lonsdale et al. 2008, Svoboda et al. 2010). In some forests, the natural regeneration of certain species is fully dependant on deadwood presence (Takahashi et al. 2000, Nakagawa et al. 2001, Narukawa and Yamamoto 2002, Narukawa et al. 2003). In some cases, seedlings only colonise fallen logs of their own species (Hofgaard 1993), while in others 'parasitically' colonise logs of other species (Harmon and Franklin 1989).

1.2. Deadwood as a habitat for a diverse range of organisms

Deadwood provides an important habitat for many species of fauna, bacteria, fungi and lichens, as well as for many species of lower and higher plants. Moreover, as demonstrated on scientific studies within the last 20 years, dead and dying trees are a keystone for a wide range of saproxylic organisms in phanerophyte-dominant ecosystems around the world (Grove 2002, Zhou et al. 2007, Davies et al. 2008, Lonsdale et al. 2008). The major saproxylic taxa include fungi (Pouska et al. 2010), bryophytes (Zielonka and Piatek 2004, Kushnevskaya et al. 2007), lichens (Kushnevskaya et al. 2007), beetles feeding on bark and wood (mainly in their larval stages; Davies et al. 2008), wood-decaying fungi (Jonsell and Nordlander 2002, Persiani et al. 2010) and birds (Bütler et al. 2004; Fig. 1). Other species dependent on deadwood and dying trees include amphibians (DeMaynadier and Hunter 1995), molluscs (Kappes et al. 2009), dipterans (Dziock 2006) as well as parasites and predators of deadwood dwelling beetles.

Corridors mined by saprotrophic insects serve as shelters for other insect species; i.e. wasps (Ehnstrom 2001). Deadwood also plays a role in foraging habits of large mammals as they are used as a look-out places for carnivores; e.g. European lynx (Bobiec et al. 2005). Additionally, deadwood is essential for biodiversity of aquatic ecosystems such as streams, rivers, lakes and even seas (Harmon et al. 1986). Thirty to fifty per cent of all forest organisms are estimated to be deadwood dependant at certain stage of their life cycle (Bobiec et al. 2005). In Great Britain and in Ireland, the number of invertebrate species was estimated to be 1800 and 600, respectively (Alexander 2002). In Central Europe, every fifth and sixth beetle species is bound to deadwood (Zach and Kulfan 2003). A large proportion of deadwood dependant species is threatened due to unsuitable forest management practices. For example, out of all forest-dwelling red-listed species in Sweden, 85 % of beetles, 75 % of dipterans, 81 % of hymenopterans and 78 % of hemipterans are saproxylic species (Jonsell et al. 1998). In Europe, while some saproxylic species became extinct in distant past due to human intervention since they were only identified by fossils, others vanished over the last two centuries. Nonetheless, the process of extinction of saproxylic species

continues at a rapid rate often due to an intensive forest management in certain areas (Grove 2002).



Taxon	No. of species	Proportion (%)
Lichens	220	3.5
Bryophytes	97	1.6
Fungi	2021	32.6
Beetles	1257	20.3
Diptera*	850	13.7
Hymenoptera*	1150	18.6
Mites	300	4.8
Nematoda*	100	1.6
Myxomycetes	150	2.4
Vertebrates	54	0.9
	6199	100.0

Fig. 1. *The numbers of saproxylic species by taxa; i.e. saproxylic species in Scandinavia (data are based on Stokland et al. 2004). The number with an asterisk is only an estimate.*

BOX 1: How is biodiversity enhanced by deadwood?

In theory, there are two main reasons why boosting the amount of deadwood in forests increases the number and density of species while diversifying the species structure (Müller and Bütler 2010). First, the greater the amount of deadwood, the larger the surface occupied by deadwood in the forest; consequently, this leads to a higher availability of resources. According to the theory of ecological islands (Cook et al. 2002), a greater number of species can be expected to occur within a studied unit on a larger island. Second, more surface means a greater potential for the differentiation of the surface (Müller and Bütler 2010). Therefore, it can be assumed that increased quantities of deadwood not only locally increase species diversity but also reduce the risk of the species to become extinct through an increased population of the species. Maintaining a larger population reduces the risk of extinction or undesirable loss of genes, which occurs during prolonged reduction of the population due to ecological and stochastic reasons (Okland et al. 1996).

Many studies confirmed the importance of diversity of deadwood; i.e. tree species, stage of decay, deadwood size, etc. (e.g. Okland et al. 1996, Jonsell et al. 1998, Similä et al. 2003, Buse et al. 2008, Brin et al. 2009, and Persiani et al. 2010). According to an

analysis of oak-beech forests in southern Germany, the diversity of deadwood and the number of critically endangered species increase with the amount of deadwood (Müller and Bütler 2010). Similar results were found in boreal and tropical forests (Müller and Bütler 2010). This correlation raises the question whether quantity or diversity of deadwood is more important for biodiversity. While some studies have indicated deadwood diversity and connectivity in time and space to be more important for saproxylic insects (Schiegg 2000, Similä et al. 2003) and wood-decaying fungi (Heilmann-Clausen and Christensen 2004) to survive than the total amount of deadwood, no experimental studies have been conducted to resolve this question (Müller and Bütler 2010). Despite the fact that deadwood amounts and diversity are correlated in scientific studies, in certain cases, some form of deadwood may go unnoticed, and thus it is not included in the total amount. This is the case of, for instance, hollow trees that are an important habitat for highly and critically endangered species (Ranius 2002, Müller and Bütler 2010).

1.3. Deadwood as a long-term natural fertilizer

Deadwood fundamentally influences nutrients and energy flow in the ecosystem as well as the local nutrient cycles. It is used in the ecosystem as a reservoir of water in periods of drought (Harmon and Sexton 1995). As it disintegrates, deadwood releases nutrients gradually, thus serving as a natural fertilizer with a long-term action (Holub et al. 2001, Hruška and Cienciala 2002). Nutrients become available through the degradation of wood and the related chemistry and action of micro-organisms; this involves not only the substances contained in the wood alone but also those found in the inorganic area of soil that would be of no use without the existence of relevant processes and interactions. Substances released as the wood decays enhance the soil adsorption complex (Male and Formánek 2007).

Although the relative concentration of nutrients is low in wood and bark, it is deadwood where the nutrient capital and carbon mostly accumulate due to the extent of biomass (Harmon et al 1986, Caza 1993). Bacteria found in wood residues and in soil wood fix 30 % to 60 % of nitrogen in forest soil (Harvey et al. 1987). Deadwood was also reported to contain up to 45 % of the above the ground stock of organic material (Harmon et al. 1986). In terrestrial ecosystems, deadwood is an important habitat for fungi as it often provides refuge for mycorrhizal fungi during ecosystem disturbances (Triska and Cromack 1980, Harmon et al. 1986, Caza 1993). Colonisation of deadwood by fungi and microbial organisms can be one of the most important stages in the nutrient cycle (Caza 1993). The flow of nutrients from deadwood is something in which mycelia

of both wood-decaying fungi (Zimmermann et al 1995) and ectomycorrhizal fungi (Lepšová 2001) are involved.

1.4. Deadwood as a means of protection from erosion

In a forest ecosystem, deadwood influences the surface run-off and the geomorphology of both forest soil and small watercourses. The deadwood matter found on the surface of the forest soil contributes to an increased stability of slopes as well as to the stability of the soil surface, while preventing soil erosion and influencing the nature of small watercourses in forest stands (Stevens et al. 1997).

2. The lack of deadwood in production forests: attempts to set it right

A low amount of deadwood in production forests (Kučera 2012) results in the disappearance of deadwood dependent species groups from the forests and subsequently in the loss of biological diversity. Low quantities of deadwood and old trees retained in production forests are an issue for all European countries with well-developed forestry. The need to tackle the lack of deadwood in production forests has attracted interest of many scientists. While the results of scientific studies indicated the ecological importance of deadwood as key habitats as a part of the efforts to monitor the changes in the diversity of saproxylic species, no 'one-size fits all' biodiversity indicators have been found so far (Bouget et al. 2014). Indicators based on national forest inventories seem to be ideal since the existing recommendations based on scientific literature primarily result from data collected specifically for the purpose of answering a scientific question.

Saproxylic beetles are the most frequently studied saproxylic group as there are multiple reasons for the interest in this species group. First, beetles are the largest group in terms of species numbers. A considerable proportion of beetle species is deadwood dependent in some of their developmental stages. As a group with the greatest diversity and dependence on deadwood, large numbers of them are also found on national Red Lists also including a large proportion of endemic species (Fig. 2). Secondly, saproxylic beetles are considered to be a good indicator group as they are able to reveal detailed information about habitat quality and thus about biodiversity in general. Unlike birds, for example, the ability to move at greater distances appears to be a limitation for this species group - beetles reveal the information regarding the site where they were trapped more readily. This means that the information on this species group's demands can be used as a determinant whether the intended deadwood management will be effective for biodiversity enhancement.

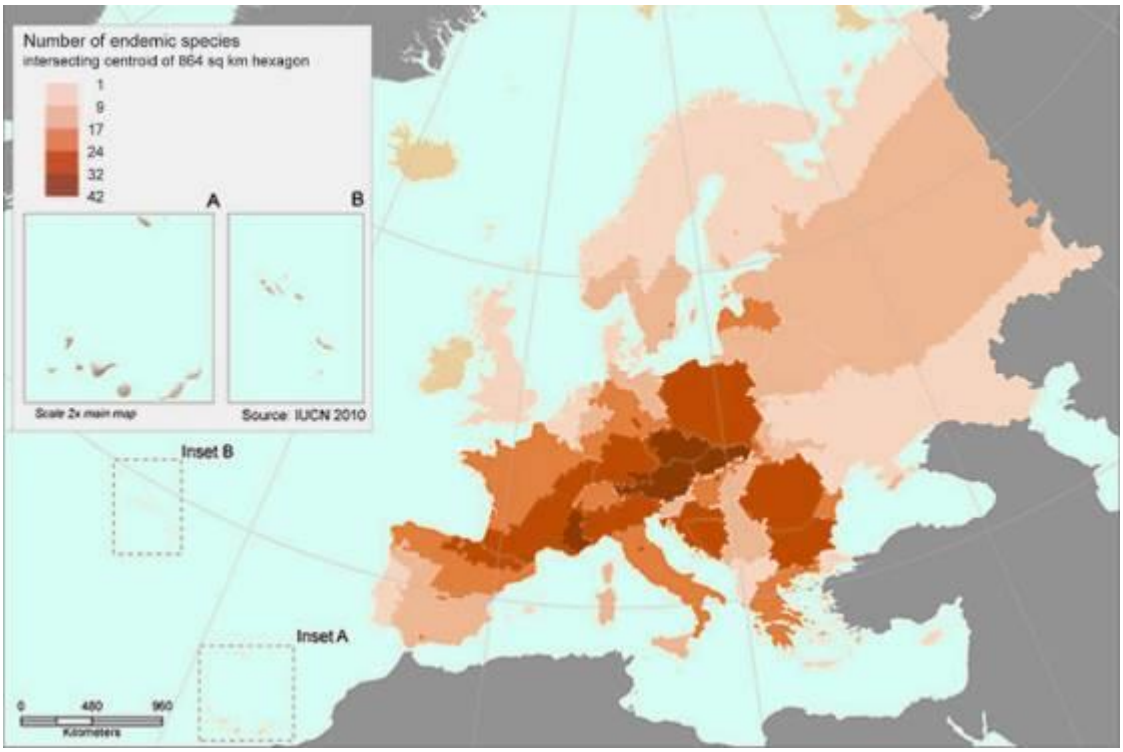


Fig. 2. *Distribution of endemic saproxylic beetles in Europe (according to Nieto and Alexander 2010). Along with Slovakia and Austria, the Czech Republic appears to be the stronghold of rare endemic species.*

Bače and Svoboda (2012) carried out a study including an analysis of a variety of factors associated with individual management measures that aim to increase the amount of deadwood. Their results showed that the best method is to retain live trees. However, the retention of standing snags was also shown to be a suitable method. Therefore, the adoption of these two approaches is recommended. These two options proved to be the most suitable in all types of forest management also reflecting the most recent research on functional effectiveness of measures promoting biodiversity (Fedrowitz et al. 2014, Hämäläinen et al. 2014). However, the use of the above-mentioned practices should not eliminate the practice of other methods such as retention of felled lying logs, windthrown trees, high tree stumps and targeted tree killing by e.g. ring-barking.

Opting for a different way of deadwood enhancement can increase the deadwood diversity, which is more essential for biodiversity than the actual amount of deadwood. Diversification of management methods and the revision of current forestry practices provide greater opportunity for differentiation of ecological conditions affecting deadwood. Promoting tree species diversity particularly by incorporating less-represented or absent tree species native to the habitat should be the essential aspect for the proposed deadwood management. The diversity of tree species is a

prerequisite for deadwood diversity – a cornerstone of biodiversity, forest stability and sustainable forest management (Gamfeldt et al. 2013).

BOX 2: The interaction between the changed light exposure and continued wood-decay process

This measure fully preserves all stages of spontaneous deadwood development that are specific for individual tree species:

- *progressing stage of wood decomposition*
- *continuous change in the location of the deadwood; i.e. from vertical to horizontal position*
- *gradually decreasing exposure of deadwood to sun*

Some saproxylic invertebrate species are found on sun-exposed dead logs of early decay stages; in contrast, other invertebrate species are bound to advanced decay stages in shaded locations (Jonsell et al. 1998). Deadwood is often created by natural disturbances in natural forests (mainly wind in the Czech Republic). Therefore, in such cases, deadwood is preserved in gaps as individual snags in early stages of decay exposed to intense solar radiation. However, the forest stand consequently develops and begins to shelter deadwood that has transformed into lying logs of advanced stages of decay at that point.

Overall, standing deadwood hosts more saproxylic species than lying deadwood. For example, Bouget et al. (2012) studied the influence of dead oak logs positions whereby the standing oak snags hosted more individuals of saproxylic species – thus more species – per unit of deadwood volume. At the same time, the snags hosted distinct taxocenoeses and iconic species in comparison to lying logs.

Retaining live trees also provides suitable conditions for mycorrhizal fungi to appear (Peter et al. 2013). This helps restore the mycorrhizal fungi networks while facilitating the forest stand development by means of increased root growth and natural regeneration.

2.1. Groups of trees left to reach the end of their life span

The most effective measure to increase the amount of deadwood is to allow a small group of trees to reach the end of their life span. Gradually, the retained groups of trees reach the stage of veteran trees. Such veteran trees consequently develop into snags that over time transform into decaying lying logs. As a matter of priority, the retained group of trees should be placed at a sun-exposed open site. Areas outside of forests should be also included; i.e. boundaries between forest stands

and meadows, fields, orchards, gardens, riparian zones, etc. In continuously forested landscapes, areas such as electricity pylon routes, forest tracks and rides, small bodies of water, forest pastures and fields used by game are also considered as suitable places where deadwood can be located. Priority should be given to the oldest and largest trees, preferably those already containing hollows or bearing some extent of deadwood.

Why should we leave small tree groups to reach the end of their life span?

- Decreases the negative effect on production and quality of future stands (in comparison to individual dead trees scattered across the area)
- Reduces the amount of obstacles to logging and transport operations
- Avoids the use of intensive operations such as ring-barking or high tree stumps creation

What tree groups shall we avoid retaining?

- Trees that may cause damage to a fenced area (e.g. a fall of a dead branch due to wind)
- Trees considered a serious obstacle to logging, transport or tending operations
- Tree species susceptible to insect outbreaks; e.g. do not leave Norway spruce on freshly sun-exposed spots in a close proximity to forest stands susceptible to bark beetle infestation
- Trees near busy routes (e.g. marked hiking or cycling trails) where the trees present an increased risk to the health and safety of forest of visitors

The key measure of allowing groups of trees to reach the end of their life span does not have to be strictly applied under all circumstances. This recommendation does not need to be strictly adhered to in the case it is possible to create deadwood elsewhere in the forest stand, especially if its retention creates a smaller economic loss. Priority should be therefore given to the deadwood retention option that minimises the losses. Even if one could define an ideal type of deadwood that is most lacking in our forests and whose retention would most promote biodiversity, retention of a different deadwood type may still support other species with different demands.

Which trees are suitable for deadwood retention creating minimum economic losses?

- Trees in areas with difficult access; i.e. steep slopes, extremely rugged terrain, land enclosed by other owners' properties, etc.
- If young stands of pioneer trees species are available, it is highly recommended to choose such species for deadwood retention
- Trees with poor stem quality
- Trees intended to perform the functions of forest outside the forested areas
- Trees on property with an unknown land owner
- Trees located on the fringes of farmland not utilised for farming
- Misshaped trees; e.g. trees struck by lightning or those with obvious cavities
- Already existing habitat trees

2.1.1. *Factors affecting specific management decision in deadwood management*

Deadwood size

A significantly positive effect of deadwood of large dimensions on biodiversity was confirmed in a number of diverse studies including older (Økland et al 1996) as well as more recent research (Gossner et al. 2013a, Svensson et al. 2014, Juutilainen et al. 2014, Seibold et al. 2014). Deadwood size is a more important factor than, for example, deadwood position (standing/lying) in explaining species diversity (Bouget et al. 2012). Prioritising the retention of deadwood of large dimenstions is thus based on scientific results. In recent years, research has also confirmed that a smaller number of large logs cannot be replaced with a large number of small logs in order to enhance biodiversity since many species cannot exist on deadwood whose size is smaller than certain threshold size (Kraus and Krumm 2013). A study from boreal forest also showed the importance of high stumps retention; i.e. 4 m tall tree stumps with a large diameter in comparison to retaining all brash only (Ranius et al. 2014). Retaining brash along with high tree stumps may be the best option in terms of both economy and functional effectiveness of biodiversity.

BOX 3: Habitat trees

When taking a decision on retaining a group of trees, we should specifically concentrate on the retention of habitat trees (Bouget et al. 2014, Müller et al. 2014a). Habitat trees bear a number of ecology niches (i.e. microsites); they can be found in a form of standing live trees or snags both bearing specific microsites; e.g. tree cavities, bark crevices, thick dead branches, epiphytic organisms (mainly bryophytes and lichens), cracks, scorched bark, stem rot, etc. Due to the various characteristics of such trees, subsequent terminology has evolved: veteran trees, ancient trees or monumental trees.

Key microsites of habitat trees (modified according to Bütler et al. 2013; photos L. Vítková)

- ***Cavities (according to their origin and morphology):***
  - *Created by birds for the purpose of nesting purposes. They play an important role for secondary cavities inhabitants (e.g. birds, bats, a range of smaller mammals, invertebrates; i.e. spiders, beetles, wasps).*
  - *Cavities created by decay that was initiated by injuries to the tree. Although such cavities serve as hideouts of small and large mammals, reptiles, amphibians, or birds, they are mainly used by bats for roosting.*
  - *Water pockets; i.e. the tree cavity is filled with water on a temporary or permanent basis commonly occupied by dipteran insects and plankton.*
  - *Cavities caused by root rot at the stem base.*

- ***Cracks and loosened bark:*** *abundant on snags and on dying trees; can be found even on live trees damaged by natural disturbances (e.g. lightning) or during timber harvesting. These microsites are particularly important for bats that often nest under the bark:*

- ***Fruiting bodies of saproxylic fungi:*** *provide an important niche and food source for other species; i.e. beetles, dipterans, moths, etc.:*

- ***Other microsites:*** *epiphytic plants (e.g. ivy, vines, lichens and bryophytes), cankers, witch's brooms, gummosis, etc.:*

The number of fully developed habitat trees is rather low in production forests (in comparison to primary forests) due to the application of intensive forest stand management, the use of negative selection and reduced rotation periods. When selecting trees for retention in production forests, the focus should be on trees with already developed microsites. However, trees with weakly developed habitat tree features shall be also selected for retention with the intention to ensure they develop microhabitats as quickly as possible. If tree age is known, retention priority should be given to the oldest trees as they often feature well developed microsites (e.g. thick or cracked bark, presence of lichens).

Tree species

Tree species is considered a key factor influencing the occurrence of certain saproxylic species among other qualitative characteristics of deadwood (Jonsell et al. 1998). Almost all tree genera

have monophagous saproxylic species of invertebrates associated with them (Jonsell et al. 1998) with wood decaying fungi also being bound to certain tree species (Heilmann-Clausen et al. 2005). In Scandinavian forests, deadwood of broadleaved species supports a greater diversity of saproxylic species as opposed to the deadwood of conifers (Stokland et al. 2004). In addition, the tree species ceases to be essential and organisms colonising the deadwood are no longer as highly specialised as the process of wood decay progresses (Jonsell et al. 1998).

Individual tree species differ in the number of species bound to them – including saproxylic organisms. The special importance of *Quercus* genus should be emphasized with pedunculate oak (*Quercus robur* L.) and sessile oak (*Quercus petrea* (Matt.) Liebl.) being significant tree species for biodiversity of saproxylic invertebrates in Europe (Vodka et al. 2009, Bouget et al. 2011). In Sweden, for example, 32 % (i.e. 174) saproxylic species stated in Sweden's Red List are known to be dependent on *Quercus* genus (Jonsell et al. 1998). Sycamore (*Acer pseudoplatanus* L.) is another key species in terms of biodiversity – mainly in the case of lichens, particularly at higher elevations; its bark provides a special habitat for lichens in the otherwise acidic environment of mountain forests. Hornbeam (*Carpinus betulus* L.) deadwood attracts a large number of saproxylic beetle species in the first years of decomposition even if left in a shade (Müller et al. 2015). In contrast to this, ash (*Fraxinus excelsior* L.) trees do not host many saproxylic species, which is linked to the phylogenetic isolation of the *Oleaceae* family and to the specific chemistry of its wood (Müller et al. 2015).

In Central Europe, native coniferous trees attract more saproxylic species; native Norway spruce (*Picea abies* (L.) H. Karst.) hosts significantly more saproxylic beetles compared to introduced Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco) or larch (*Larix* spp.) (Müller et al. 2015). It is important to retain tree species that are rare in a forest stand but they are still native to the given area (Økland et al. 1996). The aim should be to achieve a greater diversity of tree species while supporting rare species. Late successional species such as European beech (*Fagus sylvatica* L.) or pioneer species such as birch (*Betula* spp.), poplar (*Populus* spp.) or willow (*Salix* spp.) should not be excluded from the management.

Environmental conditions

Deadwood management should be adapted to the given environmental conditions since the effects of deadwood and habitat trees on biodiversity are dependent on meso- and micro-climatic characteristics of a habitat (Kraus and Krumm 2013). Meta analyses of scientific studies across Europe indicated important facts worth considering when planning deadwood management. Although the correlation between the amount of deadwood and saproxylic diversity is clear, it is only of a moderate strength ($r = 0.31$). Lying and standing logs or stages of decay also did not show differences with regard to species richness (Lassauce et al. 2011). However, the strength of an important relationship; i.e. species richness vs. deadwood amount, was found to be significantly different in two primary biomes of Europe; i.e. the relationship between the amount

of deadwood and species richness was found to be less correlated in temperate deciduous forests of Europe than is the case of boreal forests. There are many possible explanations to such difference and may also apply simultaneously. While the variations in forest management history and the length of time the given forest management has been applied may be essential factors, the differences the landscape structure may also play an important role.

BOX 4: Large deadwood and its significance for biodiversity

- *Trees of large diameter have thicker bark and therefore a higher occurrence of cracks and rugged texture on outer bark*
- *Smaller surface area/volume ratio of large trees leads to a greater stability of temperature and moisture*
- *Large trees take longer time to disintegrate; i.e. longer time for the suitable substrate to disappear*

Unlike deadwood of large dimensions, small sized deadwood is relatively abundant in production forests (Fridman and Walheim 2000, Bače and Svoboda 2012). Managing the diversity of deadwood sizes is necessary especially since a threshold size below which the saproxylic species no longer exist should be also considered (Brunet et al. 2010, Juutilainen et al. 2014).

Results relevant for the deadwood management were also published by Lachat et al. (2012). Using data from forests in several European countries a larger amount of deadwood was reported to be of particular importance, especially in colder environments (i.e. in mountain forest) in order to maintain a high level of biodiversity. Therefore, the importance of deadwood retention rises with increasing elevation. This recommendation is linked to the balance of nutrients and soil-forming processes, which is another important aspect of deadwood. Already acidic mountain forests experienced a strong acidification due to the air pollution in recent decades. Therefore, deadwood plays an important role in preventing the loss of alkaline nutrients in the areas damaged by acidification located in higher altitudes (Hruška and Cienciala 2002).

Recent scientific results show that the extent of canopy openness has a positive effect on saproxylic beetles in both broadleaved and coniferous forests, which is, however, particularly the case for lower elevations (Bouget et al. 2014, Della Rocca et al. 2014, Horák et al. 2014, Seibold et al. 2014). These results also demonstrate the presence of human activity in temperate forests of Europe in recent centuries as well as throughout the Holocene period. Since human settlement has been most extensive in lower elevations, associated activities generated open habitats meanwhile reducing the deadwood volume. Most of Europe's forests were deforested during the Middle Ages with the greatest pressure on forests and wood production peaking in 18th century (Lomborg

2001). Traditional forms of management (e.g. coppice practice, wood pasture, temporary farming on forest land, litter raking, twigs and shoots collection) that resulted in a considerable canopy opening - sometimes up to the park level - have been abandoned. Large amounts of sun-exposed deadwood at higher elevations (or in boreal forests) also results from the frequent occurrence of extensive and severe disturbances (i.e. insect outbreaks, wind and fire; Seidl et al. 2011). This has implications when proposing deadwood management, especially at lower altitudes since the deadwood quality is essential for biodiversity as opposed to deadwood quantity. There is also a number of factors positively correlating with each other; i.e. canopy openness (no obstacles in the form of leaves and branches) and light reaching the forest floor. It is advisable to retain the largest segments of deadwood, which enables normal development of a greater proportion of deadwood in more advanced decomposition stages (Gossner et al. 2013a).

The hypothesis of saproxylic diversity interacting with temperature is supported by an extensive study from the temperate zone of Europe (Müller et al. 2014b). Temperature and the amount of deadwood had a positive effect on overall diversity overall as well as on the diversity of endangered saproxylic beetles. The interaction of these factors was negative meaning that a small amount of deadwood may be compensated by a higher mean temperature of the given habitat. It is necessary to promote saproxylic diversity through an increased amount of deadwood especially in colder zones (north-facing slopes or higher elevations). These results contradict the general assumptions of the increasing negative effect of global warming (along with loss of natural habitats) on biodiversity. The global warming may thus offset the shortage of deadwood to some extent (Müller et al. 2014b).

2.1.2. Management level

An analysis of scientific studies on the influence of deadwood on saproxylic diversity on different temporal and spatial scales showed are large differences in the responses between different saproxylic taxa and individual species (Sverdrup-Thygeson et al. 2014). At the moment, the authors are of an opinion that it is not possible to firmly establish an exact recommendation on the spatial arrangement of deadwood in the landscape or in the stand.

Landscape level

At a national scale, it is recommended to focus the conservation efforts on landscapes with a high concentration of appropriate habitats (Franc 2007). According to the theories of island biogeography and meta-populations, biodiversity is enhanced with the size of the island and with the decreasing distance of the island from the main island. Species meta-populations can function well if species can migrate via biological corridors such as smaller islets and habitat trees operating as ‘stepping stones’.

When choosing sites for deadwood retention, areas with higher ecological value (Box 5) should be emphasized; i.e. locations where deadwood already exists and where the links between habitats with an increased amount of deadwood can be assumed. An even distribution of deadwood across forest units should be avoided. Instead, it should be ensured that, in the long-term, deadwood is concentrated in stands with a greater ecological value. For the remaining forest units, the amount of deadwood should be increased at least to some extent since even a small increase in deadwood volume may be a positive prerequisite for some saproxylic species to occur.

It is also possible to establish or expand a network of non-intervention natural reserves at a landscape scale where the amounts of deadwood is considerably greater in comparison to commercial production forests. Such sites may serve as refuges and offer resources for specialist saproxylic species with an increased demand on the amount of deadwood (Gossner et al. 2013a). It is also possible to use natural sites of no use to forestry for deadwood management; i.e. waterlogged depressions, rocky slopes and riparian zones. If there are already existing natural reserves around the area of interest, the priority should be given to deadwood retention in a close proximity of such sites in order to increase the population of saproxylic species and their potential to spread further.

BOX 5: Designation of territorial units with a greater ecological value

The five general factors listed below can be used to determine the forest unit quality in terms of saproxylic species habitats availability (Humphrey and Bailey 2012):

- *Existing value of deadwood volume*
- *Continuity and diversity of deadwood habitats over time*
- *Interests in the conservation of specific saproxylic species at the site of interest*
- *Ecological coherence of the given system*
- *The history of forest management*

Stand level

The implementation of deadwood management is based on spatial arrangement of deadwood and it should ensure that deadwood is not evenly distributed across the forest of interest and that the efforts to increase the deadwood amounts focus on the areas of greatest necessity. Groups of trees as well as individual trees can be used to create deadwood. Some authors recommend the retention of both scattered and aggregated deadwood in a form of e.g. lying trees and snags (Bütler et al. 2013). Aggregated habitat trees have been shown to provide a better habitat for birds than in the case of dispersed trees. Lichens also grow better on an aggregated group of trees as opposed to scattered individuals (Nascimbene et al. 2013). However, taking a decision should be case specific. If appropriate (habitat) trees for retention are only available in a dispersed spatial pattern, it is

suitable to use them.

Interests in a conservation of specific saproxylic species

Evaluating the occurrence of particular species in a forest and in its close proximity is not easy to conduct. However, the records of certain species occurrences of can be found in national databases such as the Czech Conservation Record Database in the case of the Czech Republic. The focus should be on indicator species demonstrating a high biological quality of the given habitat. For example, the family of stag beetles (*Lucanidae*) was evaluated to be a group including a high percentage of indicator species in European beech woodlands (Lachat et al. 2012) making it a suitable priority group for biodiversity monitoring. Indicator species are those that have been assessed as appropriate measurable substitutes for the entire biodiversity of the habitat. They are mostly species with very well explored ecology or those with well-known relationships to the conditions of the habitat. The importance of such species was attempted to be validated since the overall species richness throughout a community or geographical area is very difficult to describe since organisms exist in large quantities even in relatively simple ecosystems (Rich 2003). The presence of an indicator species at a particular site is therefore very important and gives valuable information because it tells us about a certain level of quality of the habitat for the entire community. It is subsequently assumed that the species diversity is reduced if any indicator species disappears from the community.

Continuity and diversity of deadwood over time

Saproxylic organisms can be seen as organisms colonising a melting iceberg. Once the iceberg has melted completely, they need to move to another one. Their habitat disappears and reappears all the time. It is then logical for scientists to come to a conclusion that biodiversity is greater in areas with an uninterrupted continuity of deadwood presence (Sverdrup-Thygeson et al. 2014). Accordingly, adequate spatial continuity needs to be ensured in relation to the needs of individual species in line with the theory of meta-populations along with the time continuity of species occurrence. This is why most studies stress the importance of factors associated with a great spatial scale in explaining the functional effectiveness of deadwood (Sverdrup-Thygeson et al. 2014).

Generally, the greater the diversity of different deadwood types, the higher the ecological value of the stand in terms of habitats availability. The continuity of deadwood over time can be identified by the presence of dead logs in various stages of decay – from completely unaffected trunks, through the stage of peeling bark to disintegrating sapwood and heartwood up to a total loss of the inner solid structure and incorporation into the soil. The process of deadwood decomposition is influenced by temperature, humidity, ambient O_2 to CO_2 ratio, and qualitative characteristics such as tree size, tree species and the cause of death. Taxonomical classification alone is a considerable factor for the speed of decay, oak species, for instance are typical European tree species with a slow decomposition rate. Species which disintegrate faster than oaks in European forests include spruces

(1.4 times), pines (1.6 times) and European beech (1.8 times) (Rock et al. 2008). The specific time of primary deadwood biomass decomposition varies based on habitat conditions, species composition, deadwood position and the cause of death. In the cold boreal zone, therefore, the average decomposition rate for 95 % of the primary biomass is 280 years in the case of Scots pine, 240 years for spruces and firs, and 110 years for aspens and birches (Shorohova and Kapitsa 2014). The presence of deadwood of large dimensions provides a good indicator of continuity since its decomposition is rather slow. The presence of veteran trees also indicates the continuity of deadwood occurrence.

Selecting, maintaining and highlighting (e.g. a blue triangle mark) appropriate habitat trees is a recommended prerequisite for the support of microsites; especially where habitat trees and snags are absent. Even if there is a sufficient number of habitat trees, choosing additional candidates that may replace the current habitat trees and thus prevent reducing the number habitat trees is a desirable activity.

Deadwood diversity is preferred over deadwood quantity

Based on the study on the occurrence of saproxylic beetles in temperate deciduous forests, it was recommended to diversify deadwood types mainly by combining their location and tree species in order to support creation of appropriate habitats (Bouget et al. 2013). The amount of deadwood was the main factor determining the diversity of wood-decaying fungi in forests (Blaser et al. 2013). However, the diversity of the substrate also plays a significant role (i.e. various stages of decay, tree species and deadwood dimensions) (Blaser et al. 2013).

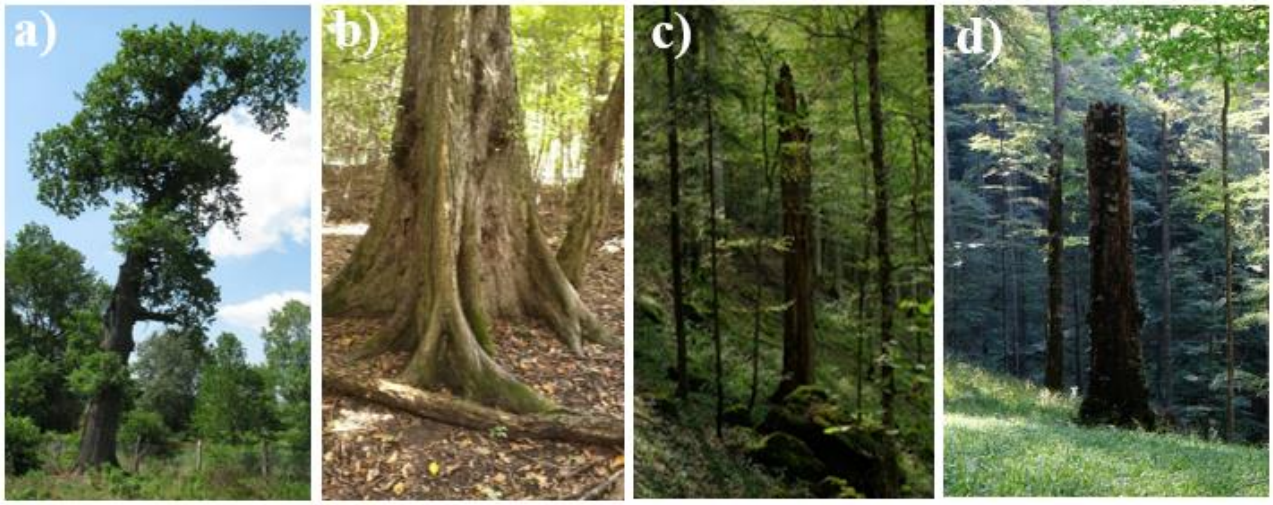


Fig. 3: *a) microhabitat-bearing tree retained on the edge of a forest stand; b) an example of a large elm tree with the presence of root buttress cavities and epicormic shoots; c) and d) examples of snags bearing numerous microhabitats (photo: R. Bače and L. Vítková).*

2.2. Retaining snags

If possible, all standing snags of large dimensions are to be kept with the exceptions including snags that:

- pose an imminent risk to the health and safety of forest workers (felling, marking, etc.)
- constitute an obstacle for skidding operations
- present, in addition to the above, a risk to forest protection
- threaten public safety (i.e. snags near publicly accessible roads and paths in places with an increased recreational intensity).

2.3. Retaining fallen deadwood

All existing lying logs should be retained as far as possible. Nonetheless, it is not necessary to follow this rule if the lying deadwood originates from natural disasters (i.e. uprooted trees and trees broken by wind/snow) as salvage logging may be applied in such case. However, should deadwood resulting from natural disturbances pose no risk in terms of further pest outbreaks, it can be used to increase deadwood volumes since it forms essential microsites such as uprooted trees, uprooted root plates and holes. These features are also important for soil formation processes (Šamonil et al. 2010, Šamonil et al. 2014). It is desirable to retain root plates with longer stems in order to prevent them from closing into the position prior to the disturbance.

Current forest stands lack deadwood in the later decomposition stages that are important habitat for endangered species. The negative impacts of logging damaging the existing large lying segments of deadwood, high stumps or uprooted trees should be reduced. If a snag needs to be cut, it is desirable to retain its remnants at the place where it was cut, if possible. When choosing logs to be retained the following points shall be considered:

- Cavities and other defects found on the first 2 m of the tree stem should be prioritised.
- Healthy logs and trees thinner than 30 cm should be used for retention only if there is no other option.
- Broadleaved trees that may contain more holes and cavities should be preferred for retention.
- Prioritise tree species with slow decomposition rate (the decay rate substantially varies among tree species; e.g. birch vs. oak).
- Do not retain Norway spruce logs with fresh/wilting phloem due to the risk of bark beetle outbreak.
- Retain thick crown branches after felling.

3. The effects of measures targeting biodiversity promotion

The vast majority of scientific papers focusing on deadwood are based on natural or semi-natural forests; such studies involve comparative studies describing natural forests and their biodiversity. However, it is also important to include production forests where old trees are removed, which reduces the amount of deadwood and forests' ecological stability and biodiversity. These studies tend to provide the basis for real-life forest management recommendations. Practical outputs; i.e. scientific studies evaluating the effectiveness deadwood management, are still lacking. This is due to the unavailability of the optimal type and amounts of old trees and decaying wood in most production forests. It is important to note that although the interests in deadwood management have been growing in the last 20 – 30 years, this period is too short in the overall time necessary for suitable deadwood types and amounts to form.

Many researchers focusing on saproxylic diversity assume the abundance and diversity of saproxylic insect species to be limited by the amount of deadwood in managed forests. However, the researchers fail to pay sufficient attention to the importance of other factors in the species composition of this indicator group (Gossner et al 2013A). While it is believed that forest management resulting in an increased amount of deadwood increases the number and diversity of saproxylic species, there is insufficient experimental evidence to support this assumption (Gossner et al. 2013b). Any extensive and long-term studies assessing the effects of measures promoting deadwood and therefore increasing biodiversity and the occurrence of endangered species have not yet been conducted (Davies et al. 2008, Müller and Bütler 2010). However, several local studies are available and provide relevant information on the influence of various forest management measures on saproxylic diversity in a short term (Davies et al. 2008); for details, see Box 6.

BOX 6: Studies focusing on the effects of forest management on saproxylic diversity

- *The effects of artificially formed high tree stumps on the presence of saproxylic insect species were studied in the boreal zone of Sweden (Jonsell et al. 2004, Lindhe et al. 2005, Wikars et al. 2005).*
- *Retention of branches at shaded sites in England was reported to host different saproxylic communities compared to branches left at a sun-exposed site (Alexander 1999). While man-made deadwood had a positive effect on biodiversity in most cases, it largely lagged behind deadwood in natural processes (Davies et al. 2008).*
- *While a five-year effort aiming to promote diversity in saproxylic fungi had positive effects, it has so far failed to support endangered species as showed by a study carried out in Finland (Pasanen et al. 2014).*
- *The total amount of deadwood in forest was concluded to play only a minor role in explaining the composition of saproxylic beetles populations compared to other factors such as the total*

precipitation, temperature, composition of woody plants and vertical stratification of the forest stand in an observational study based in German production forests (Gossner et al. 2013b). This study included experiment using artificially formed deadwood; wood was placed in the canopy and at the ground level. A high diversity and abundance of saproxylic beetle species with varying diets and habitat requirements were found on artificially formed young deadwood in comparisons to control sites without deadwood manipulation. It is therefore clear that deadwood retention in production forests is going to have an immediate positive effect on biodiversity. However, greater species richness and species abundance were noted in deadwood installed in the canopy layer, which is likely to be related to the given light conditions.

- *Based on a study in the Czech Republic, species diversity of saproxylic beetles was reported to increase with increasing height of deadwood above the ground level (Šebek 2011). However, the amount of deadwood at the ground level was stated to be an insufficient indicator for the local diversity of saproxylic beetles (Gossner et al. 2013b).*
- *The review of scientific results indicates that consequences of deadwood retention must be further examined, especially at a large landscape scale since there is a delay after the management measure implementation (Sverdrup-Thygeson et al. 2014).*

4. Practice innovation and guidelines application in the Czech Republic

Deadwood management has not yet been fully incorporated into the Czech forestry system. Although deadwood management has been applied in certain forests (particularly those with FSC certification), the scientific knowledge on the impacts of deadwood management on saproxylic biodiversity has only begun to grow in recent years. These guidelines form the first comprehensive overview and description of the factors relating to the potential of deadwood retaining in the Czech production forests. The proposed practice with the best economic balance; i.e. retention of tree group until the end of their life span, has so far only been applied marginally in the Czech Republic. It has been, for instance, practised in the conflux zone of Morava and Dyje Rivers where it evolved as a compromise between conservation efforts in the Special Area of Conservation (SAC) Soutok-Podluží and the interests of the production forests owners.

The guidelines shall be applied in forest estates with the FSC certification. They may also be applied in production forests located in the second and third zone of protected landscape areas (PLA) as well as those that are a part of SAC. The guidelines are expected to be used as a foundation, among other documents, for the PLA management planning as well as for the compilation of management measures that can be used for the management recommendations of

SACs. The guidelines are intended to guide the decision-making regarding the type and spatial distribution of deadwood that is aimed to be retained.

It is also possible to apply the basic principles of the guidelines in the forests with the 'special purpose' designation; i.e. conservation priority. In such case, however, the overall management should be more tailored to particular management plan that is specifically designed for the purpose of protection of the given area. The guidelines should not be implemented in forests with a high conservation status such as the National Nature Reserves or the cores zone of National Parks. In the Czech Republic, Svitavy Forest Estate (private forest ownership) and the Czech Ministry of Environment are the guidelines users.

5. Economic aspects

While the practice of deadwood management is a current topic, it is difficult to present the overall economic performance of this type of forest management. Presenting the economic outcomes of the deadwood management application shall be covered by forestry economists. Simplified quantification of economic aspects; i.e. positive/negative effects of deadwood management approaches, were considered in this document.

Financial compensation regarding financial losses can be assessed under the Decree No. 55 from 15th March 1999 by means of the method calculating the loss or damage to the given forests. If a part of the forest is taken out of production due to e.g. retaining a small group of mature trees and snags, the loss can be assessed according to the temporary withdrawal or temporary limitation of the production function. Retaining – albeit a small – proportion of trees and snags present a case where the key economic commodity of the forest is not used, which may cause an imminent economic loss. The retention of poorly-shaped, damaged trees, pioneer tree species or those located in places with difficult access that can be used as fuel may also create an economic deficit. Nonetheless, retaining deadwood may increase ecological stability of the forest, which is linked with increased biodiversity and consequently a positive ecosystem feedback.

Improving or at least slowing down the deterioration of nutrient balance of the forest ecosystem is another positive long-term effect necessary to consider when taking the economics into an account. In low-nutrient ecosystems, in particular, preventing the removal of nutrients could increase forest's production potential. Deadwood also prevents soil erosion while improving the balance of the water cycle in the forest ecosystem. Retaining at least some deadwood positively influences many non-production forest functions. Thus, retaining wood contributes to sustainable forest management. Maintaining biodiversity and a wide range of ecosystem services in forests is in the public interest and any immediate economic loss from wood retention should be an acceptable sacrifice.

An official acknowledgement of public interests of deadwood in forests will need a thorough legal analysis in the Czech Republic. Subsequently, the necessity of deadwood retention shall be incorporated into the forestry legislation, which is the case of e.g. proportion of wind resistant and meliorating tree species in the forests, the maximum size of clear cuts, etc. Although such factors to certain extent limit the forest owners, the society found them as necessary for sustainable forests management. As a part of the efforts to increase the amount and diversity of deadwood, the Czech Forestry Act on salvage cutting should be amended as its strict interpretation largely makes foresters and forest owners remove all snags and damaged trees to achieve the so-called 'clean forest', although no risk to forest protection or danger to forest visitors is posed.

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7. Glossary

Disturbance: a single event that disrupts the structure of an ecosystem, community or population and changes the sources, availability of substrates, or its environment.

Habitat/Site: a state of community components; i.e. the set of all factors forming the environment of local organisms.

Indicator species: a species whose presence, absence or abundance reflects the status of environmental conditions. Indicator species specifies the change in conditions in a particular ecosystem and it can be therefore used as a mean to diagnose the state of particular ecosystem.

FVZ (forest vegetation zone): a unit representing a vertical segmentation of vegetation in relationship to changes in the altitudinal meso-climate

Microhabitat: physical requirements of certain organism or population of specific environment at a small scale

Saproxylic diversity: a diversity of species directly or indirectly dependant on wood

Saproxylic species: a species dependent, in some stage of its life, on deadwood as well as on any other deadwood dependent organism, e.g. beetles developing in the fruiting bodies of wood-decaying fungi

High stump: the remaining part of a tree stem after felling at a height of 2 to 5 m above the ground

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DEADWOOD MANAGEMENT IN PRODUCTION FOREST

Summary

The aim of this guide is to help find an optimal way for deadwood management in production forests in order to enhance biodiversity. Temporal and spatial distribution of deadwood with regards to its quality is proposed. The convenient operational options, risk minimisation, economic loss reduction and the positive effects on biodiversity were all taken into an account. Since species richness logarithmically increases with dependence on the amount of suitable habitat, retaining the minimum of potential natural volume of deadwood facilitates the survival of many saproxylic species. Areas where deadwood retention is recommended are those with already existing ecological value such as those in a close proximity to protected areas. The key measure is to retain a group of trees located at the edge of a forest stand. The retained group shall be also located on an open site with a constant sun exposure. Priority for retention should be given to older and/or large trees, partially decayed individuals (i.e. trees with various types of microhabitats such as woodpecker cavities). It is recommended to preferably retain native tree species together with existing snags and fallen decomposing tree stems that pose no danger. The aim is to achieve a wide range of deadwood types and decay stages in different habitat types.