The Effect of Forest Management Practices on the Deadwood Resources and Structure in Protected and Managed Montane Forests During Tree-stand Reconstruction after a Dieback of Norway Spruce

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Staniaszek-Kik, M., Żarnowiec, J. and Chmura, D. 2019. The Effect of Forest Management Practices on the Deadwood Resources and Structure in Protected and Managed Montane Forests During Tree-stand Reconstruction after a Dieback of Norway Spruce. *Baltic Forestry* 25(2): 249–256.

Abstract

Forest management practices can not only influence the amount of deadwood but also the proportions of particular elements. In addition, deadwood resources can depend on the forest community and the dominant tree species. The goal of the present paper was to compare the number of logs, stumps and snags and their volume between the protected and managed forests and among the forest communities in the Karkonosze Mts. after a huge dieback of *Picea abies.* A massive decline of Norway spruce has been observed since the 1980s. The protected forests belong to the Karkonosze National Park and the managed forests are situated in its buffer zone. A total of 1366 elements of coarse woody debris (CWD) were included in the study. They were distributed on 180 study plots (10 m × 10 m) that were randomly selected. Among the deadwood elements, spruce *Picea abies* dominated (80.3%) tree species followed by beech *Fagus sylvatica* (14.3%). More logs were found in the protected forest (57.3%) than in the managed forests (42.7%). More of the snags and stumps were found in the managed forests, 56.9% and 52.8%, respectively, then in the protected forests, 43.1% and 47.2%, respectively. The mean volume of CWD was ca. 114 m^3 ha^{-1} in the protected forests, whereas it was ca. 70 m^3 ha^{-1} in the managed forests. The differences in the number of particular elements of CWD between the forests of different statuses were biased by differences among the types of forest community. The mean number of stumps per study plot was the highest in the planted spruce forest and in the natural spruce-fir forest. The mean volume of logs and snags was the highest in specific forest communities (beech forest and subalpine spruce forest, respectively) in the protected part, whereas the mean volume of stumps was higher in the managed beech forests. Regardless of how the deadwood was deposited, this was a positive phenomenon that contributed to maintaining biodiversity.

Keywords: dead trees, coarse woody debris, decay stage, fallen trees, stumps, snags

Introduction

The importance of deadwood for the proper functioning of forest ecosystems has been emphasized by numerous authors for many years. Because deadwood is an ecological niche for many groups of organisms (Harmon et al. 1986, Gutowski et al. 2004, Faliński and Mułenko 1995, Stockland et al. 2012, Kacprzyk et al. 2014), studies on deadwood resources have become common (Cornelissen et al. 2012, Venier et al. 2015, Puletti et al. 2017, Doerfler et al. 2017). There have been many postulates regarding the minimum volume of deadwood in protected and commercially managed forests. In Poland, on the territory of the State Forests, the average values are 5.3 m^3 ha^{-1} excluding stumps (Bujoczek et al. 2016). The amount of deadwood that is left on the forest floor varies regionally. The highest resources of standing dead trees (snags) in managed forests ranged from 1.4 m^3 ha^{-1} to 6.8 m^3 ha^{-1} and the mean volume of lying deadwood (logs) was estimated at 2.4 m^3 ha^{-1}, which is in the range of 0.5 m^3 ha^{-1} to 7.7 m^3

ha^{-1} . In turn, under national park management, there are 17.7 $m^3 ha^{-1}$ of standing dead trees and 19.7 $m^3 ha^{-1}$ of lying deadwood (Ministerstwo Środowiska 2015).

Suggestions about the required amount of deadwood in forests depend on many factors. First of all, whether a forest is a mountainous or lowland forest, a protected forest (e.g. covered by the NATURA 2000 programme) or a managed forest are important factors (Holeksa et al. 2014, Banaś et al. 2014). It is also believed that the forest habitat conditions, which are expressed in the classification of the forest habitat type, have an impact on the rate and amount of deadwood production. The structure of CWD in a forest in terms of the fertility gradient (Bujoczek et al. 2016) or in terms of the type of community, i.e. species composition (Yuan et al. 2017), is rarely analysed. In natural forests whose tree stands are not artificial or that have not been too disturbed by forest management, the conditions for the development of natural plant communities is good. In both the tree layer and the herb layer, species composition is a result of the habitat conditions and succession. Therefore, such forests can be described using the phytosociological approach. The division into forest communities is more distinct in montane forests, where altitude is an important factor. Obviously, forest management that primarily takes social and economic factors into account has a significant impact on the amount of deadwood in forests, which causes the number of snags and downed dead trees to be lower (Banaś et al. 2014). Dead wood is often removed during forest management practices. Among others, the amount of deadwood depends on the rate of decomposition. Over time, the volume of deadwood that is left decreases (Vrška et al. 2015). On average, nearly 90 years after the death of a tree, its coarse woody debris (CWD) disappears (Holeksa et al. 2014). For the purposes of comparison, although the average volume of deadwood per hectare is typically given, the total amount of deadwood is not estimated in a given unit of area. Much work is still necessary in order to clarify the definitions so that estimates can be directly compared or aggregated for international reporting about deadwood resources (Rondeux et al. 2012). In Poland, study plots with an area of a few hundreds of square metres are established and then the deadwood resources are estimated. Although the type of deadwood is rarely given, there have been exceptions (Bujoczek and Bujoczek 2016). Several categories of deadwood can be distinguished as follows: fine woody debris (FWD) and CWD viz. standing dead trees (snags), stumps and logs (Crecente-Campo et al. 2016). These can be further divided by taking into account diameter, size, etc. The structure of deadwood, i.e. the type (log, stump or snag), is important for the possible colonisation by plants, fungi and saproxylobiotic animals. Logs offer more area to be covered by plants and, moreover, adhere to the ground, thus facilitating their penetration. In turn, snags are often inhabited by birds such as the White-backed Woodpecker *Dendrocopos leucotos*, which needs a minimum of 23 m^3 of FWD and 17 pieces of deadwood with a diameter of at least 20 cm (Czeszczewik and Walankiewicz 2006). Hence, it is important not only the total volume but also the number of individual elements. In this study, we intended to compare the number of selected structural elements of CWD and their volume per unit area between managed and protected forests as well as among different types of forest communities. Therefore, we studied the forests that are located in a national park and the managed forests that are situated in the buffer zone established around the park. Moreover, we consider the forest communities because this also can affect the resources and compositional structure of deadwood. As was mentioned above, because forest management practices influence the number of deadwoods, we selected a region, in which intensive tree-stand recovery had occurred and species in the tree stands had been replaced, which resulted in an exceptionally large amount of deadwood being temporarily available. Because deadwood removal can be done selectively, we hypothesized that forest management practices not only influence the resources but also the proportions of particular elements of CWD.

The specific aims of the study were the following: 1) to compare the amount of deadwood between protected and managed forests as well as among three natural forest communities and one anthropogenic planted spruce forest, and 2) to compare the compositional diversity of deadwood among the distinguished categories of forests.

Material and Methods

The study area

The fieldwork research was carried out in the Karkonosze Mts., which are the highest part of the Sudeten Mts., where forests with a total area of 13,505 ha were studied. Both forested areas that belong to the Karkonosze National Park (KNP) in an active protection zone and in its buffer zone, where there is less restrictive protection, were taken into account (Figure 1). In the KNP, the average age of a stand is 90, and in the buffer zone it is 63 (Danielewicz et al. 2013), both of which naturally accumulate more deadwood than managed forests. The Karkonosze Mts. are an area that is characterised by low average temperatures and high annual precipitation (Sobik et al. 2013). The growing season lasts from about 130 to 220 days depending on the altitude. The tree stands include the following species of trees: Norway spruce *Picea abies*) making nearly 90%, beech *Fagus sylvatica* with its 3%, Scots pine *Pinus sylvestris* with its 3%, silver birch *Betula pendula* with its 2% and other trees comprising ca. 2% of the forest area. The spruce occurs in an anthropogenic spruce

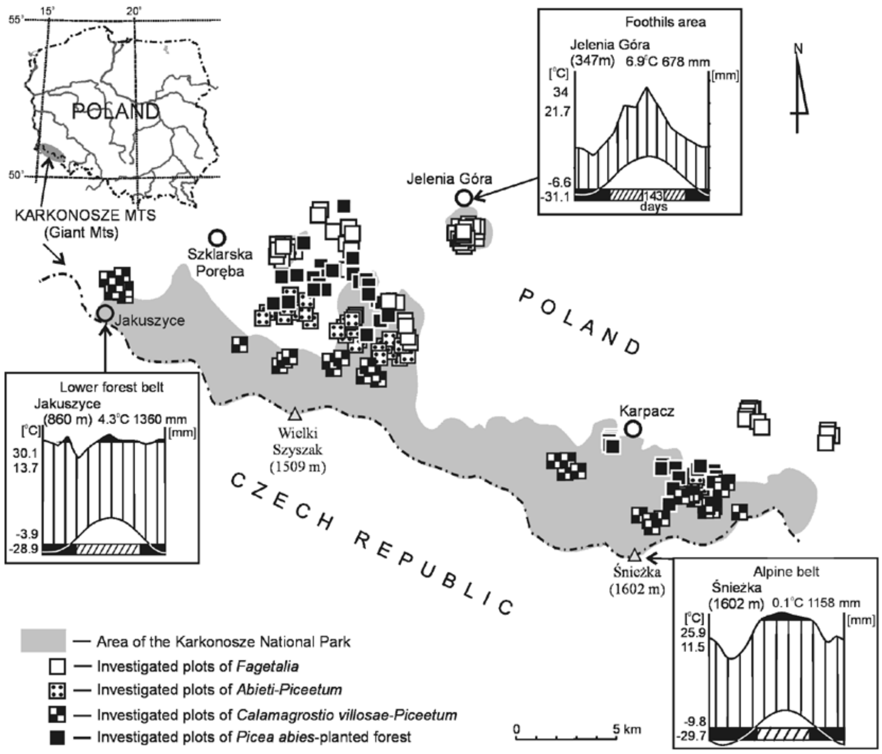

Figure 1. Study area with the locations of the study plots

forest, which was a plantation in the 19th century, and, in addition, it grows naturally in a vegetation belt at a height of 1,000-1,250 m a.s.l., i.e. in the upper forest belt of the Karkonosze forest. Besides, it quite frequently occurs in other parts of the area. Some of the forests have been protected as the KNP since 1959 (total area is 55.76 km^2; 17.18 km^2 of which are under strict protection, forest area is 33.80 km^2). Since 1992, the KNP and the Czech Krkonošský Narodní Park have formed the UNESCO Biosphere Reserve Karkonosze/Krkonoše (MaB). In the foothills, the following patches of forest communities have survived: *Galio sylvatici-Carpinetum betuli* Oberd. 1957, *Leucobryo-Pinetum* W. Mat. (1962) 1973, *Alnetum incanae* Lüdi 1921 and *Lunario-Aceretum* Grüneberg et Schlüt. 1957 but only on very small areas. In the lower montane forest zone (500-1000 m), there is a so-called anthropogenic planted spruce forest, which grows mainly in the habitats of an acidophilic mountain beech forest. This forest is the result of intensive forest management in the past. Hereafter, it is referred to as a planted spruce forest (PA_F). In the lower montane forest belt, there is a mixture of stands of montane acidophilus beech forests *Luzulo luzuloidis-Fagetum* (Du Rietz 1923) Markgr. 1923 *em*. Meusel 1937 (NATURA 2000, code 9110) and montane neutrophilous beech forests *Dentario enneaphylli-Fagetum* Oberd. 1957 ex W. *et* A. Matuszkiewicz 1960 (NATURA 2000, code 9130). They are both referred to as beech communities from the *Fagetalia* order (F). This belt is also occupied by a montane fir-spruce forest *Abieti-Piceetum montanum* Szaf., Pawł. *et* Kulcz. 1923 *em*. J. Mat. 1978 (AP), which is also included in the NATURA 2000 Habitat Directive (code 9410-3). The upper forest belt is covered by a subalpine spruce forest *Calamagrostio-villosae Piceetum abieti*s Schlüter 1969 (CVP, NATURA 2000, code 9410-1). All of these phytocoenoses are of a natural character except for the PA_F. The four distinguished forest communities (CVP, AP, F and PA_F) were the subjects of the research. Intensive atmospheric pollution from 1960-1980 contributed to an ecological disaster in spruce stands in 1980s, especially in the upper-mountainous spruce forests. Gases such as sulphur dioxide, nitrogen and dust that were contained in the atmospheric air and acid rain damaged the leaves and stoma of trees, thereby making them susceptible to insect pests and parasitic fungi. In addition, there were further factors such as changing climatic conditions, especially an increase in air temperature and strong winds, which spruce are not able to withstand (Korzybski et al. 2013). One consequence of this phenomenon was a massive dieback of spruce trees (Fabiszewski and Wojtuń 1994, Stachurski et al. 1994). Thus, when factors causing mortality of *Picea abies* ceased foresters and conservationists implemented revitalization programmes of forest ecosystems. Among others, snags and uprooted trees were left in forests and let forests regenerate in a natural way. Although reconstruction is also conducted in managed forests, cuttings and planting trees also take place (Danielewicz et al. 2013, Staniaszek-Kik et at. 2016, 2019).

In 2003-2006, 180 research study plots (squares) with 10-m sides were established (100 in the KNP, in the protected forest, and 80 in the buffer zone, in a managed forest, Figure 1). They were randomly selected so as to cover all of the forest communities (Staniaszek-Kik et al. 2014, 2016, Chmura et al. 2016, 2017). The deadwood resources on the study plots were analysed both in terms of their quantity as well as their structure. Logs were distinguished as fragments of lying deadwood that were longer than 0.5 m; stumps (broken or cut trees up to 2 m in height) and snags (standing dead trees more than 2 m in height). The research covered 1366 deadwood elements. The degree of the decomposition of the wood was assessed on a five-point scale (Hunter 1990) and the basic dendrometrical parameters, e.g. for snags DBH (diameter at breast height equalling to 1.3 m) and in the case of logs, the average of the two diameters, the lower and upper ones. The length, i.e. the height of a snag and a stump or the length of a log, was measured. The area and the volume of each element were calculated using the formulas for the surface and volume of a cone (Chmura et al. 2016).

Data analysis

For the purpose of the analysis of the compositional diversity of CWD, the Shannon-Wiener index (*H'*), evenness (*E*) and Simpson's diversity index (*D*) were calculated for each study plot. The formula for calculating *H* was:

$$H = -\sum_{i=1-n}^{n} p_i \log_2 p_i ,$$

where p_i is the ratio of the i^{th} element in the total number of CWD elements.

The formula for calculating evenness was:

$$E = H/H_{max}$$

based on $H_{max} = \log_2 S$, where S is the total number of CWD categories per plot.

The formula for calculating D was:

$$D = 1 - \sum_{i=1}^{S} (p_i^2) ,$$

where p_i is the ratio of the i^{th} element in the total number of CWD elements.

The Pearson *chi-square* test was used to compare the differences in the frequency of the particular types of deadwood, structural elements between the protected forests in the KNP and those in the managed zone, and within them among the types of forests. The two-way nonparametric Scheirer-Ray-Hare test, which is equivalent to a two-way ANOVA, was used to analyse the effect of the status of a forest (protection vs management) and the type of forest community.

The significance level was assumed to be $p < 0.05$. All of the statistical calculations and visualisations were performed using the R program (R Core Team 2017).

Results

Among the elements of deadwood that were examined, spruce (80.3%) and beech dominated (14.3%) and the remaining species shared 5.3% (Table 1). The managed and protected forests in the Karkonosze Mts. differed significantly (*Chi-square* = 13.59, $p = 0.001$) in the contribution of snags, stumps and logs. There are more decaying logs (57.3%, i.e. 276) in the protected forests than in the managed forests (42.7%, 206). However, snags and stumps occurred more frequently in the managed forests 56.9% (29) and 52.8% (440), respectively, compared to 43.1% (22) and 47.2% (393) in the protected forests, respectively. There were also differences in the frequency of the forest communities between the protected and managed forests (*Chi-square* = 19.47, $p < 0.001$). The frequencies of logs, snags and stumps differed significantly among the types of forest communities within the managed forests (*Chi-square* = 60.191, $df = 6$, $p < 0.001$) and the protected part (*Chi-square* = 58.89, $p < 0.001$) (Figure 2).

The number of logs did not differ between the protected and managed forests or among the forest communities, whereas the number of snags differed significantly between the forest communities with the highest values recorded in the CVP forest. The number of stumps differed significantly between the status of a forest and the type of forest communities. There was a higher mean number of snags in the managed forests and in the AP and PA_F forests (Figure 3). The Shannon-Wiener index and Simpson's index differed significantly among the types of forests (Table 2). In the managed forests and in the CVP forest, the values of both indices were the high-

Table 1. Species composition [n] of the deadwood elements in the study area

	Picea abies	*Fagus sylvatica*	*Betula pendula*	*Larix decidua*	*Sorbus aucuparia*	Not determined
Total	1097	195	45	15	4	10
Protected forests (KPN)	533	130	12	7	0	9
Buffer zone Managed forests	564	65	33	8	4	1

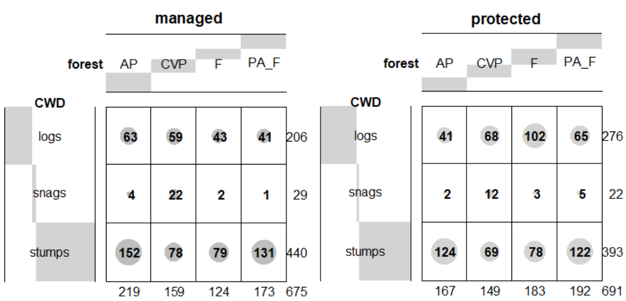

Figure 2. Frequency of the CWD elements among the forest types in the protected part (KNP) and in the managed forests (buffer zone)

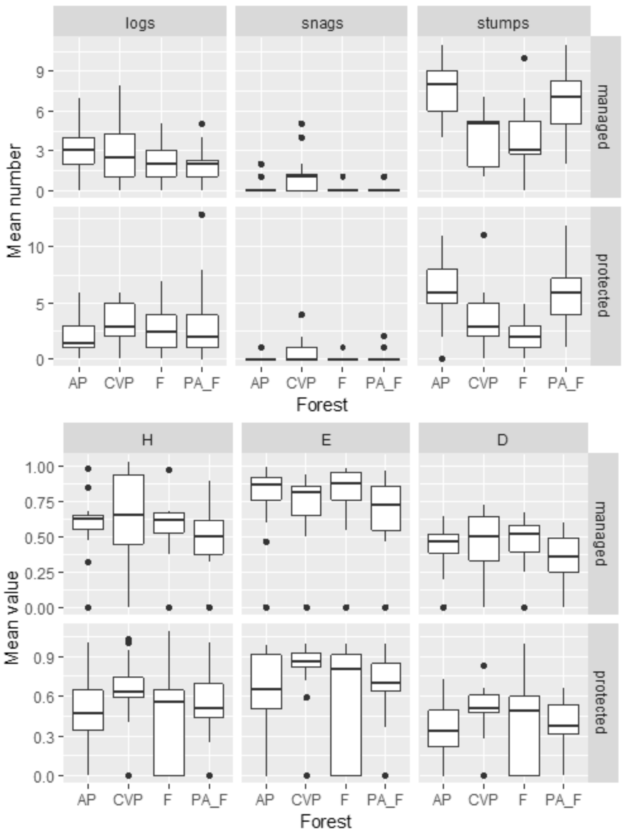

Figure 3. Comparison of the mean number of CWD±SD elements and its compositional structure among the type of forests in the Karkonosze National Park (protected) and in the forests situated in the buffer zone (managed forests)

Table 2. Results of the two-way nonparametric Scheirer-Ray-Hare test of the effect of the type of forest and status on the mean number of elements and the compositional structure of CWD

		Df	Sum Sq	H	*p*-value
Number of logs	Status	1	587	0.2225	NS
	Forest	3	10517	3.9872	NS
	Status × Forest	3	19195	7.2773	NS
	Residuals	172	441837		
Number of snags	Status	1	1345	1.045	NS
	Forest	3	41094	31.918	<0.001
	Status × Forest	3	5628	4.371	NS
	Residuals	172	182397		
Number of stumps	Status	1	37471	13.952	0.00019
	Forest	3	174519	64.981	0.001
	Status × Forest	3	6712	2.499	NS
	Residuals	172	262034		
H	Status	1	2670	0.9886	NS
	Forest	3	27512	10.1857	<0.001
	Status × Forest	3	10827	4.0085	NS
	Residuals	172	442486		
E	Status	1	741	0.2744	NS
	Forest	3	9541	3.5322	NS
	Status ×Forest	3	19214	7.1136	NS
	Residuals	172	453990		
D	Status	1	762	0.2819	NS
	Forest	3	33358	12.3441	<0.01
	Status × Forest	3	6101	2.2576	NS
	Residuals	172	443497		

est. The total volume differed significantly among the forest communities (Table 3) and the highest value was in the beech forests (Table 4). The volume of logs differed significantly between both the status of a forest and among the forest communities. The highest volume of logs was recorded in the protected forest and in the beech forests (Tables 3-4). The highest volume of stumps was recorded in the managed forests (Tables 3-4). The highest volume of snags was recorded in the CVP forest (Tables 3-4). The mean decay stage differed significantly between the status of a forest and the forest communities and as the result of the interactions among these factors. In general,

Table 3. Results of the two-way nonparametric Scheirer-Ray-Hare test of the effect of the type of forest and the status on the volume and decay of CWD

		Df	Sum Sq	H	p-value
Total volume	Status	1	9202	3.3897	NS
	Forest	3	72518	26.7143	0.00001
	Status × Forest	3	9332	3.4378	NS
	Residuals	172	394857		
Volume of logs	Status	1	17963	6.6267	0.010046
	Forest	3	36233	13.3671	0.003906
	Status × Forest	3	11311	4.1727	NS
	Residuals	172	419699		
Volume of stumps	Status	1	26002	9.5939	0.00195
	Forest	3	9059	3.3425	NS
	Status × Forest	3	19241	7.0994	NS
	Residuals	172	430829		
	Status	1	1074	0.829	NS
	Forest	3	38005	29.3307	0
	Status × Forest	3	5011	3.8671	NS
	Residuals	172	187850		
Decay	Status	1	1026424	7.046	0.007943
	Forest	3	12067044	82.838	0
	Status × Forest	3	2481305	17.034	0.000696
	Residuals	1358	1.83E+08		

Table 4. Comparison of the volume and decay of CWD

	Managed	Protected
Logs	Mean±sd	Mean±sd
AP	0.30±0.19	0.30±0.30
CVP	0.49±0.61	0.89±0.59
F	0.74±0.84	1.16±1.45
PA_F	0.36±0.47	0.53±0.62
Snags	Mean±sd	Mean±sd
AP	0.04±0.10	0.02±0.05
CVP	0.22±0.25	0.52±1.52
F	0.06±0.20	0.19±0.83
PA_F	0.01±0.06	0.06±0.14
Stumps	Mean±sd	Mean±sd
AP	0.14±0.06	0.12±0.06
CVP	0.19±0.15	0.22±0.19
F	0.27±0.22	0.14±0.16
PA_F	0.17±0.10	0.10±0.04
Total CWD	Mean±sd	Mean±sd
AP	0.47±0.22	0.44±0.32
CVP	0.90±0.78	1.63±1.82
F	1.06±0.89	1.49±1.84
PA_F	0.55±0.53	0.69±0.62
Decay	Mean±sd	Mean±sd
AP	2.42±1.29	2.80±0.99
CVP	3.35±1.06	3.13±0.91
F	2.94±1.06	2.90±0.99
PA_F	2.39±1.16	2.76±1.04

the highest decay stage was recorded in the protected forests and among types of forest communities in the CVP forest in the managed part (Tables 3-4).

Discussion and Conclusions

The deadwood resources in the Karkonosze National Park

The research that was conducted proved the significant impact of forest management practices on the quantity and structure of dead wood. Studies by other authors showed that protected areas are characterised by a larger amount of deadwood. However, comparative studies of the forest areas that are covered by the NATURA 2000 and economic programmes that are not covered by the Habitats Directives indicate that their inclusion did not affect the amount of deadwood. Well-preserved NATURA 2000 areas usually contain more reserves and old forest stands as does the KNP (Danielewicz et al. 2013), which naturally accumulate more deadwood than the managed forests. Banaś et al. (2014) demonstrated that in the forests on NATURA 2000 areas, there were on average 8.4 $m^3 ha^{-1}$, in the reserves 26.6 $m^3 ha^{-1}$ and only 4.8 $m^3 ha^{-1}$ on other areas.

The estimated amount of deadwood was very high and varied greatly, from 5 to 956 $m^3 ha^{-1}$, which is similar to the values that were obtained by Russian researchers (Shorohova and Kapitsa 2015) in primeval boreal forests. The extreme individual values that are reported in the present study are the result of the accumulation of cut dead trees in the protected part. In such cases, the volume of deadwood exceeded the volume of living trees. However, Holeksa et al. (2014) claimed that in natural montane mixed forests, the mean volume of downed logs is estimated to be ca. 150 $m^3 ha^{-1}$. Therefore, the mean volume of CWD of ca. 114 $m^3 ha^{-1}$ in the protected forests in the KNP is even below expectations about the recommended amount of deadwood; it concerns forests in the buffer zone, where total mean resources of CWD are ca. 70 $m^3 ha^{-1}$ more. Considering the average status of the deadwood in the Polish forest reserves, the state of the deadwood in the Karkonosze Mts. appears to be acceptable. Pasierbek et al. (2007) analysed the volume of CWD in selected nature reserves in the southern part of Poland and reported volumes that ranged from 6.8 to 300.0 $m^3 ha^{-1}$ in strictly protected forests, but the majority had less than 150 $m^3 ha^{-1}$. Various authors strongly disagree in their opinions about the minimal amount of dead wood that is required to maintain the proper ecological functioning of a forest ecosystem. The lowest value was suggested by Pawlaczyk and Mróz (2003), i.e. 5 $m^3 ha^{-1}$ and the highest amount was estimated to be more than 100 $m^3 ha^{-1}$ (Müller and Bütler 2010). The majority of the proposed values varied between 10 to 50 $m^3 ha^{-1}$ (Holeksa et al. 2014).

The compositional diversity of dead wood in the study area

The volume of logs and snags was significantly higher on the plots that were established in the national park. With regard to the structure of the dead wood, logs predominated in both the protected and managed forests. In the forest areas that were studied, the dominant species was spruce ca. 90%, which is reflected in the amount of dead wood from this species, which was also shown by Shorohova and Kapitsa (2015). Logs are usually the dominant type of dead wood in spruce forests in terms of volume, which is shown in our study, where logs dominated in other forest communities. Regarding the number of structural elements, a higher concentration of stumps was found in the managed forest, but this did not influence their volume when we took into account individual pieces of CWD. The larger number of stumps outside of the protected areas may result from the ongoing recovery of the tree stand, which is more intensive in the managed forests. Currently, foresters remove damaged and fallen spruce trees leaving only the stumps. Considering the forest community, there were differences between the protected and managed forests. The managed beech forest had the highest volume of stumps, whereas in the protected part forest, *Calamogrostio villosae-Piceetum* was characterised by the highest volume of these CWD elements. In both types of forests, spruce dominated. The difference could be the result of the higher representation of beech in the protected part. Many of these are remnants of trees that were cut after death and are not only the result of the recovery but also reconstruction. In the studied forests, the dead wood that was found was characterised by a higher degree of decomposition on average in the protected forest and some forest communities, which may indicate that it stays on the forest floor longer and is not being removed. This is also important because dead wood is a refuge for saproxylic organisms. A higher degree of decomposition results in greater accessibility for bryophytes as well as for the seeds and roots of higher plants (Harmon et al. 1986) and enhances the probability of colonisation (Chmura et al. 2018).

Differences in dead wood resources among forest communities

Our study demonstrated differences in both the quantitative and qualitative structure of CWD among the forest communities. There are no detailed data about the volume of CWD in specific plant communities. When there are any data about dead wood amounts, it is usually presented in cubic metres per hectare. The amount of CWD, after extrapolation, ranged from 45.3 $m^3 ha^{-1}$ in the *Abieti-Piceetum* forests to 134.8 $m^3 ha^{-1}$ in the *Fagetalia* forests. In the planted *Picea abies* forest, the volume of CWD was 62.1 $m^3 ha^{-1}$ and in *Calamagrostio villosae-*

Piceetum forest, it was 126.12 m^3 ha^{-1}. Only the beech forest and the subalpine spruce forest had amounts of dead wood that were similar to that of the natural montane forests that are protected within the nature reserves (Holeksa et al. 2009). The most natural and the deadest wood-rich forests had ca. 300 m^3 ha^{-1} of CWD but this was rather rare (Holeksa et al. 2008). According to other authors, the CWD in a beech forest in a protected area was close to 200 m^3 ha^{-1} and was about 150 m^3 ha^{-1} in a *Calamagrostio villosae-Piceetum* forest (Bobiec 2002, Jaworski and Podlaski 2006, Holeksa et al. 2009). Considering the unmanaged forests in the lowlands, the total amount of CWD was estimated to be ca. 26.5 m^3 ha^{-1} based on numerous study plots. Thus, in the present study, the values of CWD are very high. A much more striking difference was observed between the managed forests including particular forest communities, for instance, an acidophilus beech forest (NATURA 2000 code 9110) in the lowlands had 18.48 m^3 ha^{-1} and a fertile beech forest had 3.73 m^3 ha^{-1} (Banaś et al. 2014). In the present study, the CWD in these forest communities was higher than 130 m^3 ha^{-1}.

Conclusions

To sum up, the differences in the amount of dead wood and compositional structure of CWD among the forest types not only depend on the natural rate of the dead wood supply but also result from forest management practices, which is connected with the reconstruction of the tree stands in managed forests and the recovery of the tree stands in protected forests. This research confirms the hypothesis that the protective status of a forest affects the amount of dead wood, even in the case of a natural disaster or problems with the health of a forest. The areas and forest communities that are protected are characterised by a larger amount of dead wood, because it is removed less often than in managed forests. Sometimes, it is a beneficial situation for the maintenance of biodiversity when foresters' activity results in an increase in the amount of dead wood on the forest floor. Therefore, the only action to be taken is to reduce or even eliminate the removal of CWD.

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