Dead Wood Diversity in a Norway Spruce Forest from the Călimani National Park (the Eastern Carpathians)

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Abstract

The role of dead wood in forests encompasses the preservation of biodiversity, productivity, and the storage of carbon. In this study we aimed to investigate the variation of the dead wood volume in a subalpine Norway spruce forest. Using a regular grid, we recorded the size of the wood ordered in a five-class scale for snags and logs and a six-class scale for stumps. The relationship between the dead wood volume and a series of site and stand characteristics was modelled by means of some predictive factors (stand age, altitude, human influence and site productivity) using generalized linear/nonlinear models. Dead wood volume (74.3 $m^3 \cdot ha^{-1}$) accounted for 18.3 % of the volume (live trees and dead wood). Regarding the dead wood only, snags amounted to 44.8 % of the volume and logs and stumps amounted to 46.5, and 8.7 %, respectively. Snags (57.5 % of the total) and logs (42.8 %), were most common in the 2nd decay class, while stumps were most common in the 6th one (51.2 %). The distribution of the number of dead wood pieces, in terms of diameter, was obtained according to the Meyer theoretical distribution for snags and to the Gamma theoretical distribution for logs and stumps. This study completes the dead wood database from Norway spruce forests in the subalpine area to find the common features across the Carpathians Mountains. It contributes to the understanding of the dead wood dynamics in a young National Park, considering the year of establishment. This park consists of forests where forestry work was carried out and stands were exempt from cutting.

Keywords*:* *Picea abies*; dead wood; Carpathian Mountains

Introduction

Dead wood has been recognized as one of the most important components of forest ecosystems for sustainable forest management (timber production, biodiversity, soil and water protection) (McComb and Lindenmayer 1999, Ranius and Fahrig 2006). Within this context, previous research has emphasized highly important relationships in the cycle of nutrients, in the storage of carbon or nitrogen, or in terms of the presence of certain species in forest ecosystems (Harmon et al. 1986, Thomas, 2002, Patrick et al. 2006). The role of dead wood in forest ecosystems can be divided into four interdependent categories (Stevens, 1997, Anderson et al. 1986; Kirby et al. 1998). These refer to the preservation of biodiversity, the productivity of the tree stands, the geomorphology of the river beds and declivitous land, and the storage of carbon over long periods (Bütler et al. 2007, Pfeil et al. 2007).

In each ecosystem, the occurrence of necromass is caused by the transition of trees from living to dead wood, through the process of mortality (Larrieu et al.

2012, Blaser et al. 2013). This process is closely related to a series of natural causes (old age or inter- and intra-species competition) or accidental causes (strong winds, snow, draught, insect and fungal attacks) that act either separately or concurrently (Moroni 2006). The management of forest ecosystems is also well defined in the dynamics of dead wood (Floren et al. 2014, Juutilainen et al. 2014, Mazziotta et al. 2014, Siitonen, 2001).

The total amount of dead wood and the decay stage distribution are fundamental characteristics of dead wood that have been assessed in different Norway spruce forests (Linder and Östlund 1992, Svoboda and Pouska 2008, Motta et al. 2010). One of the important aspects, namely the quantitative diversity of the dead wood, showed which categories of the dead wood were the most widespread (Nordén et al. 2004, Du Cros and Lopez 2009, Söderberg et al. 2014).

Additionally, the variability of the snags, logs and stumps, in terms of the number of trees and the volume, has been established (Aakala et al. 2008, Nordén et al. 2004, Višnjić et al. 2014).

Several studies have reported on the qualitative diversity of the dead wood and have shown a wide variation in decay classes (Moroni 2006, Dahlström and Nilsson 2006). The research conducted in the Norway spruce forests located at the upper limits of vegetation in the Carpathian Mountains has shown various results (Zielonka 2006, Holeksa et al. 2007, Motta et al. 2010). As a consequence, the structure and dynamics of dead wood are regional characteristic.

Relatively few research studies have approached modelling on the dead wood and the distribution model of dead wood by categorizing the diameter. Modelling dead wood was made by simulation program based on stochastic equations in homogenous stands and in unmanaged forests dominated by Norway spruce (Ranius et al. 2004). Different diameter categories have been used previously (Zielonka 2006, Motta et al. 2010), and the empirical distributions of the dead wood categories was highlighted (Kuuluvainen et al. 1998, Rouvinen and Kouki 2002, Ranius et al. 2004).

As a biodiversity generator, tree mortality is a highly important process. Therefore, the study of the effects of this process and the understanding of the quantitative and qualitative distribution of dead wood in forest ecosystems in relation with past human activity are research objectives with a practical impact on the sustainable management and administration of forests and biodiversity.

The aim of this study was to analyse the quantity and quality as well as the spatial distribution of dead wood in a Norway spruce forest located in the Călimani National Park in the Eastern Carpathians. This is a young park considering the year of establishment (in 2000) with different levels of human activity in the past. The park consists of sustainable forests (forests, where forestry work has been conducted and where certain operations are still allowed) and fully protected forests (forests, where no forestry activities have been identified, and forests, where forestry work has previously been conducted and is currently restricted).

Therefore, the purpose of the present research was to highlight the following: (1) modelling the influence of several site and stand characteristics and human influence on the dead wood volume through some predictive factors (stand age, altitude, human influence and site productivity); (2) the quantitative (distribution of the dead wood categories) characteristics of dead wood; (3) the spatial distributions of the dead wood (snags, logs and stumps) in the research area, and (4) the theoretical distribution of the number of dead wood pieces (snags, logs and stumps) per diameter class. This research was performed to supplement the database referring to dead wood in the Norway spruce stands and to find the common features across the Carpathians Mountains sub-alpine forests.

Material and Methods

Study area

The research area is located in the Cćlimani National Park (47°19'26"N and 25°12'30"E), in the northern part of the Eastern Carpathians (Figure 1).

The proposal for the establishment of the Călimani National Park was made in 1975, and the study of its constitution was drawn up in 1976. In 1990, it was declared a park (15,300 ha), which was made official in 2000 (24,041 ha). The main purpose for the establishment of the Călimani National Park was the conservation of biodiversity, both flora and fauna, by maintaining the natural geographical framework and natural habitats.

The research in this article was carried out in the north-east region of the Călimani National Park in an area of 5,746 ha, of which 3,991.5 ha are covered with forest vegetation.

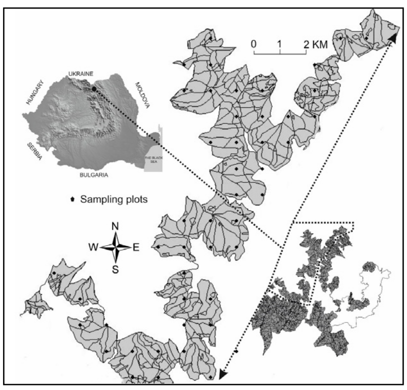

Figure 1. Research area and the locations of the forest sampling plots

According to the data from the forest management plans, of the area covered by forest, 378.5 ha out of the conservation area are made up of sustainable forests (certain forestry activities are still allowed), and 3,613 ha consist of fully protected forests. In these fully protected forests, 536.8 ha (15 %) are naturally occurring forests that have not been affected by forestry, of which 295.4 ha (55 %) are over 100 years old.

The climate is a wet and cold temperate-continental with local variations depending on the significant differences in altitudes. The temperature conditions vary, with an average annual temperature ranging between 4.2 ºC and -0.4 ºC. The average typical rainfall is approximately 1,000 mm. The paedogenetic processes have resulted in soils that include, in the order of amount, Cambisols, Spodosols and Umbrisols. Thus, the tree stands in the area under analysis are part of the *Picea abies* (*Vaccinio-Piceetea*) acidophilic forest habitat (Doniță et al. 1990).

Study designs

To inventory the dead wood, a regular grid was designed in a GIS, with a distance of 1,000 m, resulting in a total of 73 sampling points for the researched area in the Călimani National Park (Figure 1).

According to the forest management plans in the investigated area, the sampling plots were located in stands aged from 21 years up to 200 years. In terms of the number of sampling plots, the distribution by age class (20 years) is irregular. The largest proportion consists of stands aged between 81 years and 100 years (25.4 %), followed by those aged between 161 and 180 years (15.2 %), 101 and 120 years (15.2) % and 41 and 60 years (15.2) %. In the remaining age classes, the proportion of survey points is less than 10 %. There are fewer stands aged 141-160 years and 181-200 years (3.3 %). Sampling plots in stands older than 100 years comprise 42.4 % of the total.

The altitude of the sampling plots is between 1,294 m and 1,475 m. The research area in the Călimani National Park consists of four site types in the pre-subalpine zone.

The field data for snags and logs were collected in circular sample plots. The line intersection method was used for logs. The circular sample plots method entailed the circumscription of 500 m^2 sampling surfaces at each point in the sampling area. On the line intersection method, given that the precision of the results depends on the length of the transects and the structure of the diameter classes or the analysis of the individual parts, we set a 150-meter long area of the transects divided into three segments (50 m) and the individual piece counting, thus removing the source of the errors. One of these lines was in a northward direction. We adopted this method to avoid overlapping with the direction of the felled wood and to obtain higher accuracy results. Errors in the quantitative evaluation may also occur due to the unidirectional distribution of the pieces on the ground and the oval shape of the section at the intersection point; however, the choice of three transects arranged in three random directions instead of one and measuring the diameter perpendicular to the longitudinal axis of a piece largely diminishes this source of errors (Van Wagner 1968, Corrow 2010).

Variables, measurements and definitions

In this article, dead wood was considered to be all woody material, namely: trunks, treetops, branches or other woody debris that fell on the ground and the stumps, which, for various reasons, did not have the slightest trace of life. In this respect, the wood was divided into three categories according to its position on the ground, such as: snags, logs and stumps. Snags was considered to be dead wood on whole or broken trunk, with a minimum height of 1.3 m, a minimum diameter of 5 cm, at a height of 1.3 m, and without any trace of life. Logs were considered to be whole or broken dead wood and parts of trunk detached or not of stumps inclined more than 45 degrees to the vertical, or lying on the ground, with a minimum length of 0,5 m and a minimum diameter of 5 cm at the intersection point with the transect. Stumps was considered to be the upright wood in contact with the soil through its own roots, with a maximum height of 1.3 m and a minimum diameter of 5 cm, regardless of their origin (man-made or natural) (Marchetti 2004, Montes 2004, USDA 2005)

The snag characteristics that were measured were the diameter at breast height and the height. In the case of stumps, we measured the basal diameter, the top diameter and the height. According to the line intersection method used in calculation of logs volume, the recorded characteristics were the logs diameters measured at the intersection point and the length of the log. The quality of the deadwood was recorded based on five decay classes for snags and logs, while six decay classes were used for stumps (Marchetti 2004, Montes et al. 2004).

The management influences on the specific stand categories is a filter that depends on the present location of the stand and on each category of use for the areas encompassed by the Călimani National Park in respect to the level of human activity. The analysis of this factor is particularly important, as it traces the dynamics of dead wood depending on one of the most important elements that can equally hinder and favour the movement of dead wood into and out of the stand (i.e. the human activity). The research area was divided into three categories, depending on the level of human activity in the forest (which is highly important in terms of dead wood quantities). These are the divisions according to the forestry management planning conducted between 1961 and 2010: forests, where no forestry activities have been identified and, at present, any work has been restricted, as these areas are permanently protected (H1); forests, where forestry work had previously been conducted and is currently restricted, as these areas are permanently protected (H2); and forests, where forestry work has been conducted and where certain operations are still allowed, as these forests are currently the part of the sustainable conservation area (H3). In terms of human activity, 25.9 % of the sampling plots fall in the H1 category, 48.3 % fall in the H2 category and 25.9 % fall in the H3 category. The productivity of the sampling plots is given by the productivity of the four-forest sites identified in the study areas that are grouped into three categories: high productivity (P1), average productivity (P2) and low productivity (P3). Forest sites with high productivity account for 7 % of the research area, those with average productivity account for 76 %, and 17 % of the forest sites have a low level of productivity.

Statistical analysis

The statistical analyses aimed, primarily, to quantify the influence of some site and stand characteristics on the dead wood volume.

Generalized linear/nonlinear models, using the Poisson distribution and logarithmic as link function, were used to find the independent variables that most influenced the volume of dead wood. The tested variables were both continuous (stand age and altitude) and categorical (human activity and site productivity). First, we established four classes of models differentiated by the number of predictive factors. The first class of models encompassed four different variables (stand age, altitude, human activity and site productivity). The second and third classes of models consisted of combinations among the four variables, and the fourth class of models used all of the variables considered to be predictors. The selection of the optimal model was made by using the Akaike Information Criterion (AIC) (Burnham and Anderson 2004). The adjusted coefficient of multiple determinations was also calculated (R^2_a) (Quinn and Keough 2002). The modelling was done with Statistica 12 software package (StatSoft 2013).

The volume of the snags was estimated based on the available equations for Norway spruce stands (Giurgiu and Drăghiciu 2004). In order to obtain the values of the volume per 1 ha we used the intersecting logs diameters measured in intersection point and length of sample line, according to the line intersection method requirements (Van Wagner, 1968). The volume of the stumps was assessed by using the formula applied to a cone trunk.

The distribution of dead wood (number of trees and volume) in regard to the diameter of the trees was analysed and detailed by means of a theoretical distribution (the Meyer and Gamma ones) which best compensated the empirical distributions (Meyer 1952, Gupta and Kundu 2001). The significance of the difference between the chosen empirical and theoretical distributions was based on a χ^2 test.

Results

Influence of some site, stand characteristics and human activity on the dead wood volume

The volume of dead wood in relation to the age classes indicates that its highest value is recorded in stands between 141-200 years old (168.1 m^{3}ha^{-1}), 161-180 years old (101.9 m^{3}ha^{-1}), respectively in stands of 141-160 years old (103.9 m^{3}ha^{-1}). The smallest values are in stands between 1-20 years old (16.4 m^{3}ha^{-1}) and 21-40 years old (18.7 m^{3}ha^{-1}). Middle-age classes are characterized by values 56.7 m^{3}ha^{-1} (81-100 years old) and 80.7 m^{3}ha^{-1} (101-120 years old). The variation of dead wood according to the stands age indicates that it increases according to a linear regression ($y = ax + b$, where x represents stand age and y – dead wood volume; significant $r = 0.407$ at $p = 0.01$) (Figure 2).

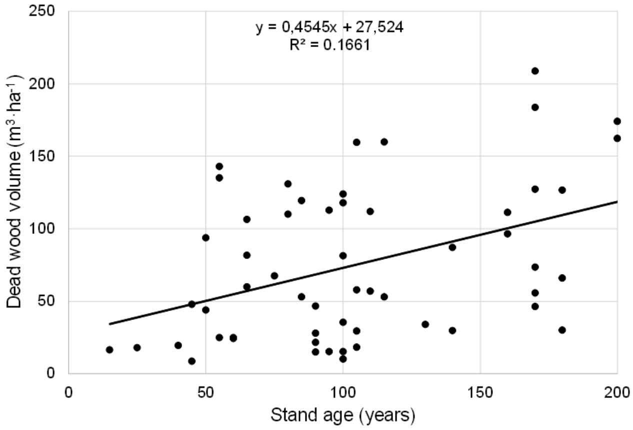

Figure 2. Relationship between stand age and total dead wood volume, including the snags of ≥5 cm DBH, logs ≥5 cm at the intersection point and stumps with a top diameter of ≥5 cm

The variation of dead wood according to altitude indicates that its value decreases from stands which vegetate at altitudes less than 1400 m a.s.l. (89.1 m^{3}ha^{-1}) to altitudes between 1501-1600 m a.s.l. (58.7 m^{3}ha^{-1}). The value of dead wood is significant in stands that vegetate at altitudes between 1601-1700 m a.s.l. (83.1 m^{3}ha^{-1}) and above 1700 m a.s.l. (126.6 m^{3}ha^{-1}). This is also due to the fact that most of the stands from older age classes are found here.

The mean volume of deadwood showed only small variations between the H1 and H2 categories (8 %), while between the H1 and H3 and, respectively, the H2 and H3 categories, these variations are high (48 % and 43 %, respectively). The values decreased from the H1 stands, in which no forestry work was performed (90.6±52.4 $m^3 ha^{-1}$), to the H3 stands, in which forestry work occurred in the past and some forestry work is currently allowed (46.9±34.7 m^3ha^{-1}). The volume of dead wood increased with the decrease in site productivity of type P1 (64.8±47.4 m^3ha^{-1}) and type P3 (90.6±58.6 m^3ha^{-1}). The mean and standard deviations of the dead wood values in the ecosystems with low, middle and high range productivity, when divided by human activity, indicated that the highest values were in the category H1-P3 (108.7±45.6 m^3ha^{-1}), and the lowest values were in the category H1-P1 (24.6±7.3 m^3ha^{-1}). The H3-P2 and H3-P3 categories were not identified in the field work (Table 1).

Table 1. The mean and standard deviation of the dead wood volume

Human activity	Site productivity	Mean ± Std. Deviation ($m^3 \cdot ha^{-1}$)
H1	P1	24.6±7.3
	P2	80.3±59.3
	P3	108.7±45.6
	Total	90.6±52.4
H2	P1	89.7±51.0
	P2	84.1±60.2
	P3	67.3±68.5
	Total	82.6±56.3
H3	P1	46.9±34.7
	Total	46.9±34.7
Total	P1	64.8±47.4
	P2	82.9±56.1
	P3	90.6±58.6
	Total	74.3±52.5

Note: H1, forests with no forestry activities; H2, forests currently restricted; H3, forests in the sustainable conservation area; P1, high productivity forests; P2, average productivity forests; P3, low productivity forests

The Pearson correlation values at the 0.01 level of confidence, between the predictors and the dead wood decay, indicated that the stand age and the dependent variable dead wood volume were correlated (Figure 2). There was no correlation between the altitude and the dead wood volume (r = -0.023).

With the combination of the independent variables of stand age and dead wood volume (P1, P2 and P3; and H1, H2 and H3), the correlation is positive and linear for H1 and P1, H1 and P3, H2 and P1, H2 and P2, H2 and P3, and negative for H3 and P1. When considering the altitude and the dead wood volume (P1, P2 and P3; and H1, H2 and H3) the correlation is positive and linear for H1 and P1, H1 and P3, H2 and P1, H2 and P2 and negative for H1 and P2, H2 and P3, H3 and P1 (Supplementary material, Figure 1 and Figure 2).

In the output tests analysis of the effects resulting from the predictive factors, the continuous variables – stand age and altitude – had an F value of approximately 8.634 and 11.790 at a level of significance of approximately <0.0001. A high level of stand age is associated with the high level of dead wood volume while a high level of altitude is associated with low level of dead wood volume. The categorical variables of human activity had an F value of approximately 4.957 at a level of significance of <0.01 (H1) and <0.0001 (H2). Site productivity respectively, had an F value of 4.790 at a level of significance of <0.01 (P1) and <0.05 (P2). That means a high levels of human activity and site productivity are associated with the high levels of dead wood volume (R^2_a = 0.581, adjusted R^2 = 0.360) (Table 2).

Table 2. Parameters of the final model of dead wood volume using generalized linear/nonlinear models

Parameters	Value	Standard error	$p > t$
Intercept	8.383	0.3283	<0.0001
Stand age	0.008	0.0004	<0.0001
Altitude	-0.003	0.0002	<0.0001
Human activity:			
H1	0.089	0.0299	<0.01
H2	0.176	0.0215	<0.0001
Site productivity:			
P1	0.075	0.0275	<0.01
P2	0.069	0.0293	<0.05

When using the continuous variable of stand age and altitude with the categorical variable of human activity and site productivity, there is a significant influence on the dependent variable (i.e. dead wood volume). Among the models based on the four predictors, the best combination of factors (stand age, altitude, human activity and site productivity) proved to be unbiased (bias<10^{-6}) and had a reduced RMSE (47.6 $m^3 \cdot ha^{-1}$).

Quantitative and qualitative characteristics of dead wood

The categories of dead wood were as follows: snags, with an average density of approximately 155 trees·ha^{-1} (15.2 % of the total number of pieces), logs (770 pieces·ha^{-1}, 70.7 %) and stumps (153 pieces·ha^{-1}, 14.1 %).

The average recorded volume of dead wood identified across the research area (74.3 m^3ha^{-1}) accounted for 18.3 % of the total volume (live trees, snags, logs and stumps). Snags amounted to 8.2 % of the total volume, logs 8.5 %, and stumps 1.6 %. Regarding the dead wood only, snags amounted to 44.8 % of the total volume, logs 46.5 % and stumps 8.7 %. In the same plots, all of the categories of dead wood or just a single category was identified; the volume ranged between 1.5 % and 100 % for snags and logs and between 0.2 % and 96 % for stumps.

Across the research area, the volume of snags and logs ranged between approximately the same values (between 0 m^3ha^{-1} and 147.4 m^3ha^{-1} and between 0 m^3ha^{-1} and 149.9 m^3ha^{-1}. The volume ranged between 0 m^3ha^{-1} and 50 m^3ha^{-1} in 77 % of the total number of samples (snags) and in 81 % (logs), while the volume of dead wood ranged between 100.1 m^3ha^{-1} and 150.0 m^3ha^{-1} and was composed of 5 % snags and 4 % logs (Supplementary material, Figure 3A and Figure 3B). For stumps, the category ranging between 0 m^3ha^{-1} and 10.0 m^3ha^{-1} was identified in 85 % of the total number of samples, while the category ranging between 20.1 m^3ha^{-1} and 33.0 m^3ha^{-1} was identified in 3 % of the total number of samples (Supplementary material, Figure 3C). Lastly, the dead wood found across the research area (snags, logs and stumps) had volumes ranging between 0 $m^3 \cdot ha^{-1}$ and 238.1 $m^3 \cdot ha^{-1}$. In 52 % of the cases analysed, the volume of dead wood ranged between 0 m^3ha^{-1} and 50.0 m^3ha^{-1}, while 4 % ranged between 200.1 m^3ha^{-1} and 250.0 m^3ha^{-1} (Supplementary material, Figure 3D).

In the case of snags and logs, the most frequent decay class was the 2nd one, accounting for 57.5 % of the total for the former and 42.8 % of the total for the latter. The smallest quantity of dead wood was found in the 4th decay class (0.6 %) for snags and in the 5th decay class (7.1 %) for logs. Most of the stump quantities were found in the 6th decay class (51.2 % of the total volume), while the least amount was found in the 1st decay class (5.1 %) (Table 3).

Table 3. The volume distribution of dead wood category (snags, logs and stumps) in relation to decay class

Dead wood	Decay class / Volume ($m^3 \cdot ha^{-1}$)					
	1	2	3	4	5	6
Snags	12.7	17.6	1.8	1.5		
Logs	5.2	11.0	7.1	6.2	5.7	
Stumps	0.2	0.5	0.4	0.5	1	2.9
Total	18.1	29.1	9.3	8.2	6.7	2.9

It was revealed that the volume of snags and logs were mostly accounted for in the 2nd and the 1st decay classes combined (72.7 %). The 2nd decay class accounted for 46.3 % of the total, and the 1st stage accounted for 26.4 %. The 3rd stage accounted for 11.0 % and the 4th for 8.7 %, while the 5th stage accounted for 7.7 %. Note that, in the case of snags, no trees were identified in the 5th decay class (Table 3). When the entire quantity of dead wood found across the research area was analysed (snags, logs and stumps), the 2nd decay class accounted for 43.0 % of the total volume of dead wood, the 1st stage for 24.4 %, the 3rd one for 10.7 %, the 4th one for 8.7 %, the 5th one for 8.6 %, and the 6th one for 4.6 %. Note that in the case of snags and logs, there were none in the 6th decay class in the current research (Table 3).

Structural elements of dead wood relative to diameter

The distribution of the number of trees per diameter class for snags is governed by the Meyer theoretical distribution, which is generally valid in the case of empirical distributions in natural forests (Figure 3A). The range of the diameters of standing dead wood varied between 8 cm and 76 cm. The 8 cm and 12 cm diameters accounted for approximately 60 % of the total number of trees included in the category of standing dead wood. The distribution of the number of pieces per diameter category for logs, relative to the size measured at the thicker end (encompassing all five-decay class), revealed that it follows the Gamma theoretical distribution (Figure 3B). The sizes within which diameters ranged when measured at the thicker end varied between 4 cm and 88 cm. The 8 cm and 12 cm diameter categories accounted for the largest part (approximately 35 %) of the total number of pieces identified in the field. The experimen-

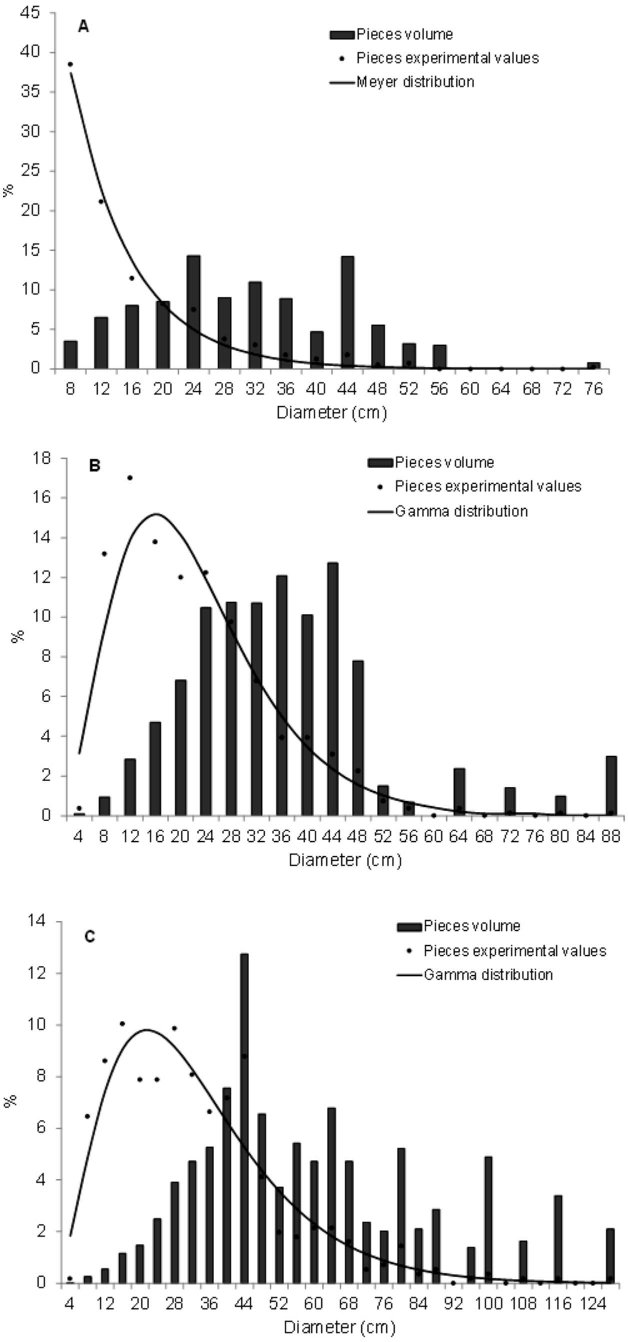

Figure 3. Distribution of the experimental values of dead wood volume and pieces, by the Meyer and Gamma theoretical distributions, by diameter category (A stands for snags; B stands for logs; C stands for stumps)

tal distribution of the number of stumps per diameter category (diameter measured at the base of the stump) for all six decay classes, complied with the Gamma theoretical distribution (Figure 3C). The diameters ranged between 4 cm and 128 cm. The 16 cm and 28 cm diameter categories accounted for the largest part (approximately 20 %) of the total number of stumps identified in the field. The χ^2 test showed that the difference between the empirical distribution and the theoretical one is insignificant for all categories of dead wood under analysis ($\alpha < 0.05$).

The volume distribution of snags (%) by diameter category showed that it ranged between two peaks of similar values for the 24 cm (14.2 %) and 44 cm (14.4 %) diameter categories. The lowest volume values were recorded for the 56 cm to 72 cm (0 %) diameter class (Figure 3A). The distribution of logs (%) by diameter category (considering the diameter measured at the thicker end) also exhibited two peaks, in the 36 cm (12.1 %) and 44 cm (12.7 %) diameter categories. The lowest values were found for the 60 cm, 68 cm, 76 cm, 84 cm and 88 cm (0 %) diameter categories (Figure 3B). The distribution of the stumps (included also cut stumps) (analysed in terms of the diameter measured at the stump base) revealed that the 44 cm diameter categories accounted for the largest part of the total volume (12.7 %). The diameters smaller than 20 cm and larger than 96 cm accounted for less than 2 %. The lowest values were found for the 92 cm, 104 cm, 112, 120 cm and 124 cm (0 %) diameter categories (Figure 3C).

Discussions and Conclusions

Quantitative characteristics of the dead wood

In our analysis the distribution of dead wood by categories in the Norway spruce forest stands of the Cćlimani National Park (in terms of the number of pieces per hectare) we show that the number of pieces of snags (15.2 %) and stumps (14.1 %) are approximately equal, while the number of pieces of logs is approximately five times higher (70.7 %). Values close to our research on logs have been obtained by Du Cros and Lopez (2009) that have shown that logs (73 %) and snags (22 %) were the most widespread types of deadwood, with stumps accounting for only 5 % of the total. In our case the value of snags is about 40 % higher, while stumps are three times higher compared to our values. Lower results on the logs were obtained from the previous research which revealed that the values for the different types of dead wood range from approximately 22 % for snags to 66 % for logs, 6 % for suspended dead wood and 6 % for stumps (Norden et al. 2004). In our case snags are larger by more than 30 % and stumps are less than half of our results. There were also lower values for logs (more than 25 %) in the results of the present article than the outcomes obtained in *Picea abies* forests in north-eastern Europe. Kuuluvainen et al. (1998) revealed a number of logs which accounts for 54 % of the volume under analysis, which is approximately 10.4 % and 8.9 % of the total number of trees (living and dead), while the snags vary in terms of the number of trees, between 89.4 and 229.4 trees·ha^{-1}; in terms of volume, the value are between 8.3 and 49.2 m^{3}ha^{-1}. On average, those values are close to the results obtained in the current article (e.g. 155 trees·ha^{-1} and 33.6 m^{3}ha^{-1}). Other two studies from the boreal and temperate zone, indicate that, on average, snags account for between 21.4 % and 34.0 % of the total number of standing trees (living and dead) (Aakala et al. 2008). Višnjić et al. (2014) showed that dead wood in Western Bosnia accounts for 18 % of the total volume (healthy wood and snags). Our research reveals that the proportion of dead wood in the Cćlimani National Park accounts for less than 20 % of the total average volume of wood (healthy trees and dead ones). This is the effect of park management in the past (forests, where no forestry activities have been identified, H1, and forests, where forestry work has previously been conducted, H2).

In our study, the most widespread volumes were found in the 2nd decay class for snags and logs and in the 6th decay class for stumps, different than reported in other research studies were broadleaf species generally prevailing in the first decay classes (the 1st and the 2nd ones), while coniferous species prevail in the last decay classes (the 4th and the 5th ones) (Dahlström and Nilsson 2006). In the case of dead wood resulted from natural disturbances a large amount was identified in the 4th and 5th decay classes. Dead wood in naturally disturbed sites is likely to be completely decomposed 40–60 years following natural disturbance. Considering the rapid reductions there will be no dead wood long-term accumulation (Mitchell and Preisler 1998, Moroni 2006).

In terms of quantitative values, other studies conducted in subalpine Norway spruce forests in the Carpathian Mountains, show that the volume of dead wood has a high variability between 27.6 m^{3}ha^{-1} and 311.0 m^{3}ha^{-1} (Holeksa, 2001, Zielonka 2006, Holeksa et al. 2007, Svoboda and Pouska 2008, Motta et al. 2010). In comparison to these, in our case (subalpine Norway spruce forests in the Călimani National Park), we have found that the dead wood volume (74.3 m^{3}ha^{-1}) ranges in the lower third of the presented variations in comparison within the values reported to studies in the boreal zone (the Tatra Mountains and the Valbona Forest Reserve). This could be the result attributable to the past forestry works (cutting) in stands previously managed.

Apart from the previous cuttings, the site quality (e.g. productivity) could not always be reported in the published studies or is not always comparable between sites but may explain the observed differences. Another research conducted in Norway spruce forests, particularly in those located at the upper limits of vegetation, shows that in the spruce forests from the southern boreal region west of the Ural Mountains, dead wood amount is twice our obtained values, with up to 145.1 m^3ha^{-1} (27.8 m^3ha^{-1} standing dead wood and 117.3 m^3ha^{-1} felled dead wood) (Kuuluvainen et al. 1998). Other research studies conducted in Sweden in mountainous Norway spruce forests estimate total dead wood to be close to those obtained by the present research, namely 79 $m^3 \cdot ha^{-1}$ (72 m^3ha^{-1} of logs and 7 m^3ha^{-1} of snags) (Linder and Östlund 1992). The research conducted by the Lilja et al. (2006) shows a volume close to double compared with the results of current research, amounts of dead wood reaching up to 139.4 m^3ha^{-1} (38.9 m^3ha^{-1} of standing dead wood and 100.5 $m^3 \cdot ha^{-1}$ of felled dead wood).

Structural elements of dead wood relative to diameter

The distribution of the number of trees for each studied diameter revealed the horizontal support structure and the intra-specific competition occurring in the research area.

The research conducted in the present paper has shown that the grouping of dead wood according to the number of trees (pieces of dead wood) into diameter category (by 4 cm) can be carried out by means of a series of continuous theoretical distributions (Meyer and Gamma) that are typical for each category of dead wood. Moreover, the distribution of the tree numbers in each diameter category for snags is in compliance with the laws governing living trees in natural forests (the Meyer distribution).

Relatively few studies have approached the issue of the specific distribution models of dead wood into diameter categories. For the sake of data comparability, some of the scientific research has chosen to divide dead wood into diameter categories of 10 cm, starting with the 10 cm diameter (Zielonka 2006, Ranius et al. 2004). Other scientific studies conducted on subalpine spruce forests used 5 cm diameter categories (Motta et al. 2010).

In terms of the values between which the diameter of dead wood varies, the conducted research indicates that the proper diameter ranges between 1 cm and 40 cm (Brin et al. 2011). Dahlström and Nilsson (2006) show that in natural forests, 59.3 % of the number of log pieces measured at the thinner end have a diameter of > 10 cm. The distribution of the dead wood diameters is influenced by the periodicity and intensity of the disturbances, with wider diameters found in the case of older disturbances (20-30 cm) and with narrower diameters (0-10 cm) of dead wood found in the case of more recent disturbances (Moroni 2006). The distribution of the trees that make up the category of standing dead wood is similar to that of living trees; trees from lower categories (< 10 cm) are dominant, but trees with wider diameters have also been found (Kuuluvainen et al. 1998, Rouvinen and Kouki 2002).

Kuuluvainen et al. (1998) and Ranius et al. (2004) show that the distribution of dead wood is very similar to a negative exponential distribution and to that of live trees. Similar models in terms of the aspects under consideration have been used by other research studies (Rouvinen et al. 2002, Uotila et al. 2002). The comparison between distributions (living and dead wood) in respect to the diameter has revealed that across the entire stand (all tree species), the distribution of the types of trees is similar to that of snags (Kuuluvainen et al. 1998, Rouvinen et al. 2002).

First of all, this study completes the dead wood database from Norway spruce forests located in the subalpine area to find the common features across the Carpathians Mountains. In addition, it contributes to the understanding of the dead wood dynamics in forests, where forestry work was carried out and in stands that were exempt from cutting. The particulars of the study are given by the analysis of these forests from the viewpoint of dead wood under the stands that are grouped in a young National Park, considering the year of establishment.

As a biodiversity generator, tree mortality is a highly important process. Therefore, studying the effects of this process and knowing the diversity of dead wood (quantitative and qualitative distribution) in forest ecosystems are research objectives with a practical impact on the sustainable management and administration of forests and biodiversity.

For the management of Norway spruce forests in subalpine areas, the quantity of existing dead wood is of particular importance because this wood has biogeochemical dynamics that are slower than in other forest formations. The problem is one of maintaining a significant amount of dead wood because of the effects it has on the creditworthiness of the site due to the reintegration of minerals from the soil, which frequently has not occurred in stands subjected to forest management.

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Appendix

Supplementary material

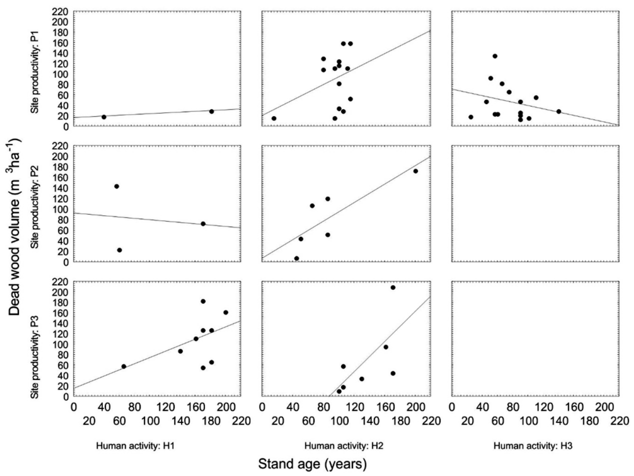

Figure 1. Relationship between stand age and dead wood volume in relation with human activity and site productivity

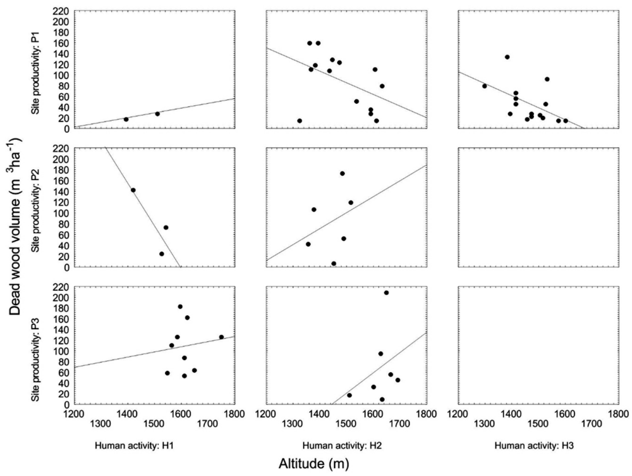

Figure 2. Relationship between altitude, m a.s.l., and dead wood volume in relation with human activity and site productivity

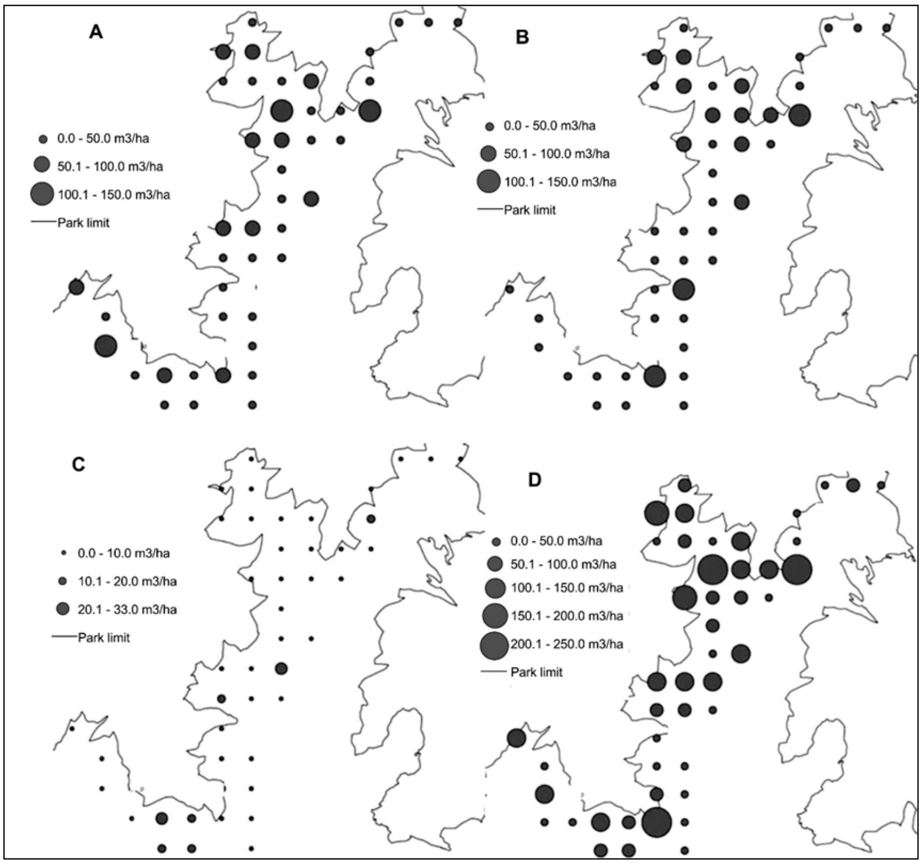

Figure 3. Spatial distribution of the volume of dead wood across the research area (A, snags; B, logs; C, stumps; D, total dead wood)