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Down dead wood in a montane beech forest stands on Deshat mountain. 4. Decomposition of down dead wood

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Abstract

This study focuses on decomposition of down dead wood (logs and branches) in a montane beech (*Fagus sylvatica* L.) forest on Deshat Mountain (Mavrovo National Park), North Macedonia. The decomposition of down dead wood was followed through decay classes and the dynamics of different chemical compounds (C, Ca, Mg, K, Na, Zn, Fe, Mn and Cu). Down dead wood was classified into five decay classes. The concentration of analyzed elements usually shows increase (accumulation) from the second to the fourth decay class and decrease towards the last decay class (release). Only K and Ca showed steady increase of concentrations during the decomposition.

Wood density also correlated well with the concentration of elements. Concentrations of C, Ca, Fe, Na and Cu tend to decrease exponentially with density. In the case of K and Mg a two-stage pattern was observed.

The average age within decay classes was estimated with a simple exponential model (derived from literature data) that explains dependence of age-wood density for beech. We estimated that decay classes D2, D3, D4 and D5 show average age of 17.6, 21.0, 32.5 and 54.9 years. The calculated decomposition constant (k) for logs is 0.034, which shows slow decomposition processes of coarse down dead wood.

Key words: Deshat Mountain, beech forest, decomposition, down dead wood, elements destribution

Introduction

The decomposition (decay) of down dead wood (DDW) in forest ecosystems is one of the crucial processes in nutrient cycling, carbon sequestration, pedogenesis and support of biodiversity (Christensen et al. 2005; Harmon et al. 1986; Müller-Using and Bartsch 2009; Oberle et al. 2014). The sequestration of carbon and storage of nutrients in DDW is stimulated by the longevity of dead wood – radiocarbon dating of coarse DDW in a coniferous forests in USA showed ages of up to 600 years (Kueppers et al. 2004). The rate and patterns of the decay process is influenced by number of factors: quality and physical properties of decomposing wood, climate (especially temperature, humidity and rainfall), vegetation, relief, soil properties, disturbances, etc. (Zhou et al. 2007).

One of the widely used approach to study the decay of DDW is subjective assigning the woody debris into decay classes by visual inspection during the field work. This approach is not standardized across different studies and ecosystems but remains on of the most useful measures to connect decay class and decomposition stage (Russell et al. 2015).

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Thus far, there are only few studies that deal with the decomposition of fine litter in oak and beech forests in North Macedonia (Grupče et al. 1983; Hristovski et al. 2014). Studies on the decomposition of DDW from North Macedonia are not available.

In 2015, we conducted research of DDW in a montane beech forest on Deshat Mountain. The research focused on estimation of DDW biomass, carbon content and mineral composition, decomposition stages and impact of forestry practices on the quantity of DDW. The methodology used during the fieldwork as well as the results on DDW biomass and carbon sequestration (both logs and coarse branches) have already been published (Veapi et al. 2018a; b). The main goal of this paper is to present the decomposition patterns (wood density, carbon and metallic nutrients) of down dead wood in a montane beech forest.

Material and methods

Study area

Deshat Mountain is situated in the west part of North Macedonia. Beech forests are the dominant forest type on the mountain. Natural beech forests are the dominant forest type. The climate is montanuous with an influence from the continental climate as well as the Mediterranean climate at lower altitudes (Filipovski et al. 1996). The mean annual temperature is 7.1 °C and drops for 0.5 °C every 100 m in altitude (Lazarevski 1993). Mean monthly temperatures during winter months are below zero (-2.2°C in January). The temperature during spring months is 5.8 °C. The highest mean monthly temperature occurs in July (8.2 °C). The absolute minimal temperature (January) is -25°C and the absolute maximum temperature (August) is 33.0 °C. Annual precipitation amounts to 1103 mm. The average duration of snow cover is 166 days.

Five stands were selected on 08.06.2015, based on the differences in forest management and the general structure of the stands. They were named as follows: Degraded forest (DF) – 1.15 ha, Coppice forest (CF) – 1.63 ha, Good forest (GF) – 1.76 ha, Preserved forest (PF) – 1.07 ha and Old-growth forest (OF) – 3.12 ha. DBH of live trees ranged from 3 to 85 cm. The main field research was conducted in the period 28.09-01.10.2015. Coarse DDW was measured on the whole surface of the five forest stands while the biomass of dead branches was measured by line transects (Veapi et al. 2018a).

Decay class and wood density

The decay classes were determined based on the different stages of wood decay assessed by visual inspection of the down dead wood. We categorized fallen tree logs and fallen branches in five categories: D1-D5 (Lombardi et al. 2008).

Wood density was estimated for both logs and branches. Discs from logs were cut during the fieldwork. They were photographed and their surface (s) including bark was estimated using Photoshop CS6 v13.0. The thickness of the discs (h) was measured by calliper. The volume of the discs (v) was calculated by multiplying the surface and thickness (s·h). The discs were measured after drying at 105 °C to constant mass. The density (ρ) was calculated by dividing the mass with the volume of the discs: $\rho = m/v$.

Chemical analyses

Chemical analyses were performed for 17 logs of different decay classes as well as 39 samples of branches with different diameters and decay classes.

Carbon content (% w/w) was determined by using the Kotzman method (Bogdanović et al. 1966) using 56 wood samples (39 branches and 17 logs) belonging to the five different decay classes. All dried wood samples were analyzed in three replicates and average value was calculated.

Methods of wet digestion were used for preparation of plant material for analyses of metallic nutrients (K, Ca, Mg, Na, Zn, Fe, Mn, Cu). A portion of the dry powder material of DDW was digested in an oxi-acidic mixture of HNO3/H2O2 (2:1,12 ml for a 0.5 g sample and then heated up to 1200 °C for 24 hr in sand bath (Soylak et al. 2004). Blanks were prepared following the same procedure. The contents of heavy metals in the solutions was determined by atomic absorption spectrometry (Agilent AAS 55A). All elements' concentrations are presented on dry matter.

Statistical analyses

Statistical analyses were performed with Statgraphics. The differences between groups in non-parametric tests were assessed by Fisher's Least Significance Difference test (LSD). Parametric correlations of wood density and concentration of elements were analyzed with simple regressions or 2-stage polynomial regressions (mathematical models, p-values and correlation coefficients – r or R^2 are presented).

Results and discussion

Wood density and water content

Wood density of fallen tree logs and branches varied between the decay classes. Statistical nonparametric analysis showed significant decrease of wood density from category I to V ($p<0.05$; $p=-0.897$).

Table 1. Wood density of fallen tree logs and large branches according to decay class

Decay class	Number of samples	Wood density, ρ (kg·dm^{-3})	Water content (%)
live		0.72*	
D1	/	/	
D2	8	0.54±0.083^{a}	16.20±4.77
D3	2	0.47±0.028^{a}	22.09±9.92
D4	10	0.32±0.136^{b}	36.06±13.97
D5	4	0.11±0.031^{c}	31.08±14.38

* The value of wood density for category "live" was taken from Hristovski (2007). Letters a, b and c denote statistically homogenous groups (Fisher's least significance difference test).

Decay classes are clearly defined by the wood density and continuous loss of volume and mass (Christensen 1977; Mackensen et al. 2003). The decomposition of DDW is a result of decrease in density in the first 12 years with parallel decrease in the volume of dead logs (Christensen 1984). The density of beech DDW in our study varied between 0.11 and 0.54 g·cm^{-3} which is very close to other published data: 0.52-0.22 g·cm^{-3} (Assmann 1961), 0.77-0.25 g·cm^{-3} (Kraigher et al. 2002), 0.52-0.09 g·cm^{-3} (Christensen and Vesterdal 2004), 0.50–0.25 g·cm^{-3} (Kahl 2008) and 0.52-0.22 g·cm^{-3} (Weggler et al. 2012).

The decomposition rate tends to increase when mean annual temperature is 12-13 °C (Mackensen et al. 2003). The mean annual temperature at study sites is 5.3-6.8 °C (data from Meteorological station in Mavrovo) which points out to low decomposition rates.

Dead wood tends to increase its water-retention capacity with ageing and advancement of the decay processes (Christensen & Vesterdal 2004). This is shown by the values for water content in Table 1. However, our data suggest that the water capacity diminishes in the final decay stages i.e. the water content of D5 is lower than the one of D4.

Most of the elements show distinct pattern of increase from live to D4 and conspicuous decrease towards D5 (Figure 1). These pattern resembles the 3-phase decomposition patterns (initial, late and final stage) derived from litter-bag experiments (Berg & Matzner 1997). Most of these elements show dominant increase of concentrations (live-D4) and release in the final stages (D4-D5) of decomposition. Such pattern was observed for C, Na, Mg, Zn, Fe, Mn and Cu. In case of C and Cu there was slight decrease from D2 towards D3 which usually refers to water-soluble fraction which were leached by rainfall. Actually, the decrease for Mg, Zn and Mn from D2 towards D4 is more pronounced in case of logs (Table 2).

Continuous increase from live towards D5 was noted for K and Ca. The rapid increase from D4 to D5 is evidenced for K.

An increasing trend concentration of Ca, Mg and Mn was also observed during the first 18 months of decomposition of beech in one study in Germany (Herrmann and Bauhus 2018).

Density vs concentration of elements

Significant correlation was confirmed between the wood density (ρ) as independent variable and concentration of elements as dependent variable, with the exception of Mn, Pb and Zn (Table 3). Exponential model ($a \cdot e^{b}$) proved to be the best fist in most of the cases i.e. for C, Ca, Cu, Fe and Na (Table 3a). Two-order polynomial models showed the highest power in explaining the correlation between concentrations of K and Mg versus wood density (Table 3b).

Table 2. Concentration of elements in branches and logs

Organ	Decay class	C	K	Ca	Mg		Na	Zn	Fe	Mn	Cu
		%					mg·kg^{-1}				
Branches	II	50.11^{a}	0.048	0.68	0.025		68.40	4.09	23.97	78.58	1.25
	III	50.01^{a}	0.081	0.91	0.040		78.54	8.76	49.09	101.75	2.55
	IV	50.34^{a}	0.092	1.55	0.080		142.71	16.70	273.95	250.49	4.54
Logs	II	49.45	0.090	0.84	0.051		56.56	6.34	19.09	71.58	1.29
	III	50.05	0.174	0.51	0.039		56.88	3.97	72.35	59.62	1.44
	IV	51.24	0.101	1.01	0.071		56.33	7.68	148.56	111.33	3.03
	V	49.25	0.317	1.88	0.076		99.96	12.55	173.92	94.48	3.51

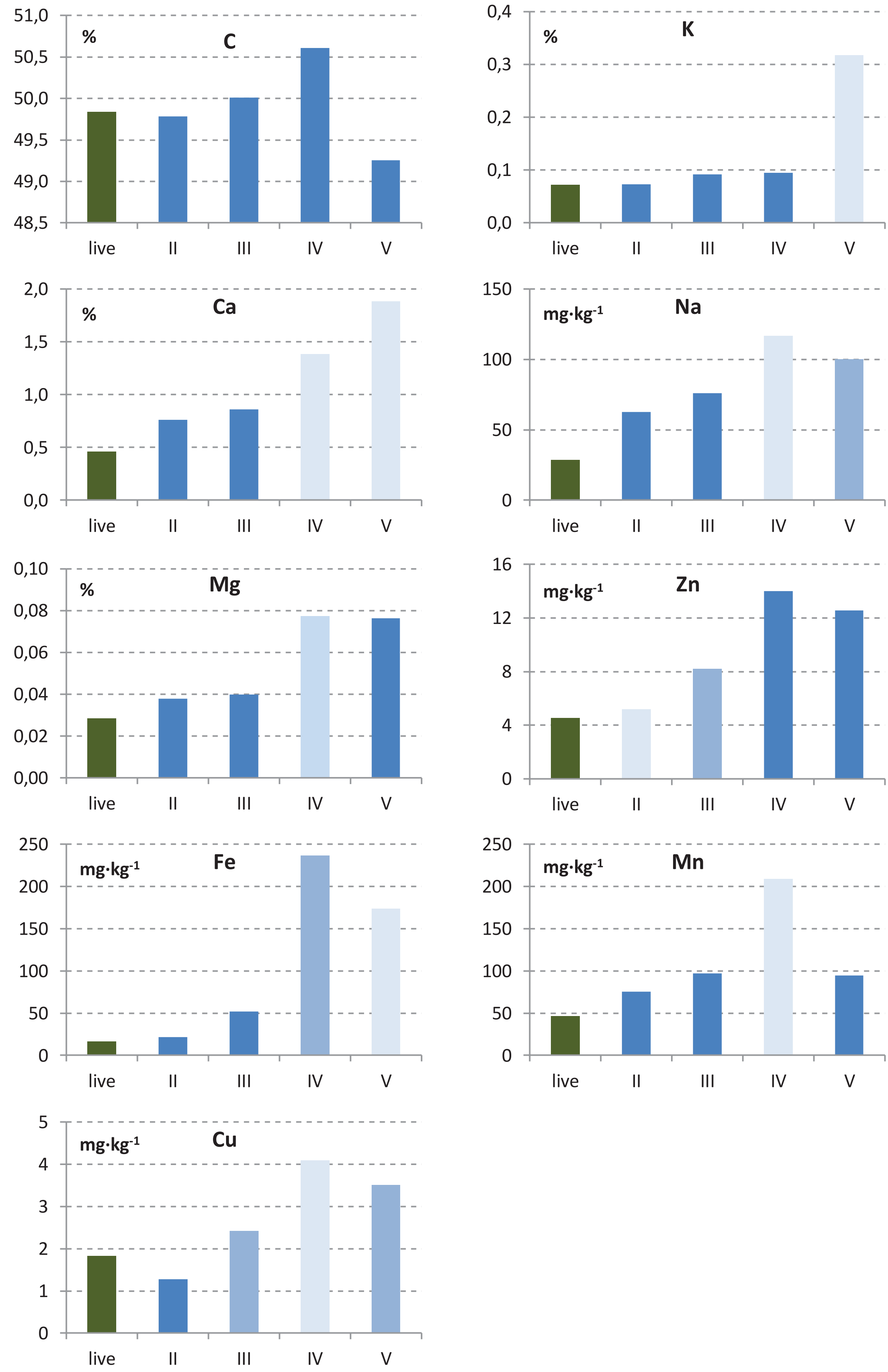

Figure 1. Average concentrations of analyzed elements in different decay classes. The values for category "live" were taken from Hristovski (2007). Same colors of the bars represent statistically homogenous groups (Fisher's least significance difference test).

Table 3. Correlation model of density vs concentration of elements

a) Exponential models

Element	Model	a	b	p	r	n
C (%)	$a \cdot e^{b \cdot \rho}$	52.867	0.120	0.0260	-0.537	17
Ca ($mg \cdot kg^{-1}$)	$a \cdot e^{b \cdot \rho}$	1.500	1.746	0.0181	-0.600	16
Cu ($mg \cdot kg^{-1}$)	$a \cdot e^{b \cdot \rho}$	5.968	2.780	0.0008	-0.736	17
Fe ($mg \cdot kg^{-1}$)	$a \cdot e^{b \cdot \rho}$	116.587	3.363	0.0222	-0.566	16
Na ($mg \cdot kg^{-1}$)	$a \cdot e^{b \cdot \rho}$	90.168	1.156	0.0098	-0.624	16

b) Two-order polynomial models

Element	Model	a	b	c	p	R^2 (%)	n
K (%)	$a+b \cdot \rho - c \cdot \rho^2$	-0.103	1.268	1.638	0.0522	34.41	17
Mg (%)	$a+b \cdot \rho - c \cdot \rho^2$	-0.039	0.653	0.897	0.0458	35.63	17

Reconstruction of age and estimation od decomposition constant (k)

Our study does not provide information of time parameter. This chapter aims to give some estimates on time needed for decomposition and decomposition constant. Usually, it takes decades for DDW to pass through decay classes 1-5 as was the case in Danish forests (Christensen & Vesterdal 2004). A dendrochronological study of beech forest in Italy revealed the average time for the DDW to reach D1 - 17, D2 - 29 and D3 - 40 years (no data were obtained for D4 and D5 due to the frafility of wood samples) with weak correlation between decay class and time of death (Lombardi et al. 2008). On the other hand, van Hees & Haar (2003) reported shorter times to reach terminal decay classes (six decay classes system): e.g. it take 27 years for a dead log of 60cm in diameter to reach D5.

Kraigher et al. (2002) also provided information on six decay classes, but with the associated values for density and age (measured dendrocronometrically). The estimated ages for D1 to D6 are 8, 12, 17, 24, 35 and 51 years. Based on these data (Kraigher et al. 2002) we have calculated simple exponential model based on values for wood density to estimate age (age = $76.288^{e-2.758 \cdot \rho}$). The extrapolated values for logs in D2, D3, D4 and D5 in our study show average age of 17.6, 21.0, 32.5 and 54.9 years. D2 and D3 have similar estimated ages, their densities are similar and not statistically significant (Tab. 3), which points out to a classification difficulties during the field work.

Age values were then correlated with measured densities. Derived exponential model allowed calculation of the decomposition constant (k) of 0.034. In reality, the decomposition constant of beech DDW was estimated by direct measurements only in few studies (Table 4). As expected, large size woody parts decompose at lower rates. This is very important fact in estimates of carbon sequestration as well as storage of other nutrients in beech forests.

Table 4. Overview of decomposition constants (k) for beech woody litter in Europe

Organ/size	k	Site	Reference
Branches, < 1cm	0.142-1.118	Blean, Canterbury, England	(Boddy and Swift 1984)
Branches, 2-3 cm	0.209		
Branches, >3 cm	0.029		
Wood,<1 cm	0.22	Solling, Germany, 500 m a.s.l., 7 °C, 1032 mm	(Müller-Using and Bartsch 2009)
Bark, <1 cm	0.18		
Wood, 1-10 cm	0.178		
Bark, 1-10cm	0.350		
Wood, >10 cm	0.089		
Bark, >10cm	0.109		
Branches, 0.5-1.5 cm	0.172	North Macedonia, Mavrovo National Park, 1350 m a.s.l., 7.1 °C, 1103 mm	(Hristovski et al. 2001; Hristovski 2004)
Wood blocks (2x5x5 cm)	0.328-0.435	Majella National Park, Italy, 1170-1480 m a.s.l., 6.1-10.2 °C, 950-1100 mm	(Fravolini et al. 2018)

Conclusions

The decomposition of down dead wood (logs and branches) is a process that may be followed by visual and tactile properties (decay classes) and by following of the dynamics of different chemical compounds.

Down dead wood branches and logs were classified into five decay classes. The decrease of wood density of beech dead wood is well related to the decay classes although the subjective assignment of the decay class during the field work may lead to inconsistencies. The concentration of analyzed elements usually shows increase (accumulation) from the second to the fourth decay class and decrease towards the last decay class (release). Only K and Ca showed steady increase of concentrations during the decomposition.

Wood density also correlated well with the concentration of elements. Concentrations of C, Ca, Fe, Na and Cu tend to decrease exponentially with density. In the case of K and Mg a two-stage pattern was observed.

By using a simple exponential model (derived from literature data) that explains age - wood density dependence in beech (*Fagus sylvatica*) we estimated that decay classes D2, D3, D4 and D5 show average age of 17.6, 21.0, 32.5 and 54.9 years. Consequently, the calculated decomposition constant (k) for logs is 0.034 which shows slow decomposition processes of coarse down dead wood.

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