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DEAD WOOD IN MANAGED BEECH FORESTS IN SERBIA

MRTVO DRVO U GOSPODARENIM BUKOVIM ŠUMAMA NA PODRUČJU SRBIJE

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Abstract:

Dead wood in forests of Serbia hasn`t been studied so far, although it is an important component of forest ecosystems. This paper presents results of investigating volume, biomass, and carbon stock bound in the dead wood of beech high forests. The sample includes eleven pure beech stands selected in six forest regions. They are all uneven-aged stands that have been managed for the last several decades, mostly under selection or group-selection. Their site class is I/II–III/IV. The altitude ranges from 400 to 1380 m. One stand belongs to submontane (Fagetum moesiacae submontanum B. Jov. 1967) and ten to montane (Fagetum moesiacae montanum B. Jov. 1953) beech forests. A systematic sample was used to determine the presence, quantity, diameter structure of volume, and state of dead wood considering its degree of decomposition both in standing and lying position. Sample plots of 500 m^2, at a distance of 100 x 100 m were used as elements of the sample. Altogether 242 sample plots were established. The volume of aboveground dead wood was determined by applying familiar dendrometric methods, while the dry biomass was calculated on the basis of its volume and wood density at different degrees of decomposition. The biomass of belowground dead wood i.e. roots of stumps and snags was obtained directly using the relevant regression equations. The quantity of the carbon bound in dead wood was calculated by multiplying dry biomass of dead wood by 0.5 coefficient. A simple and a stratified sample were used for the purposes of estimating the average and total volume, biomass, and carbon stock of dead wood. It was concluded that the average aboveground deadwood volume in all studied stands amounted to 19.24 $m^3\,ha^{-1}$. The aboveground biomass of dead wood was 6.06 t ha^{-1} and belowground 17.34 t ha^{-1}, or 23.40 t ha^{-1} in total. The carbon-bound stock in the total estimated dry biomass of dead wood was 11.70 t C ha^{-1}.

KEY WORDS: dead wood, managed beech forests, stand, volume, biomass, carbon, sample

Introduction
Uvod

With the aim of resolving complex problems of mankind, energy crisis and climate changes, scientists worldwide have recognised the importance of studying biomass, as well as carbon stock and cycling in forest ecosystems. The most commonly researched problem refers to effects of climate changes and management systems on development and stability of forest ecosystems and their contribution to mitigating the adverse effects of climate changes on living environment, through capturing carbon from the atmosphere and storing it in living and dead wood, organic layer and soil (Cannell, 1995; Lebaube *et al.*, 2000; Joosten *et al.*, 2004, Mund, 2004; Mund and Schulze 2006; Liski *et al.*, 2006).

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Dead wood is an important component of forest ecosystems because it is used as a source of food and habitat by a great number of plants and animals. The data on presence, quantity, and quality of dead wood provide important information on: unexploited growing stock, state and quality of the living space, diversity and structure of forest stands, cycling of matter and amount of carbon bound (Lojo *et al.,* 2008). In Europe, the volume of standing and lying dead wood in managed or economic forests is regarded as an important indicator of sustainable management and biodiversity conservation (MCPFE, 2003).

Despite the great importance of its presence in forest ecosystems, dead wood has only recently become a topic of scientific research studies in Serbia (Koprivica *et al.,* 2013). On the other hand, dead wood has been studied with great interest worldwide. In Europe, dead wood has been studied mostly in virgin forests, i.e. in beech forest reserves. Christensen *et al.* (2005) have made a detailed analysis of dead wood based on the research results of numerous studies that cover 86 European beech (*Fagus sylvatica* L.) reserves. Furthermore, dead wood has been studied in near-natural beech forests (Beneke and Manning, 2003; Mountford, 2002) and in managed beech forests (Green and Peterken, 1997; Fridman and Walheim, 2000; Ferguson and Archibald, 2002; Mund, 2004; Mund and Schulze, 2006). The characteristics of dead wood in natural or unmanaged forests have been compared with the characteristics of dead wood in managed forests (Andersson and Hytteborn, 1991; Kirby *et al.,* 1998). Apart from the quantity and quality, the changes in dynamics of dead wood in beech forests have also been studied (Hahn and Christensen, 2004; Mountford *et al.,* 1999; Mataji *et al.,* 2011). Dead wood has often been analyzed within the general studies of beech forests biodiversity (Samuelsson *et al.,* 1994; Stevens, 1997; Stokland, 2001).

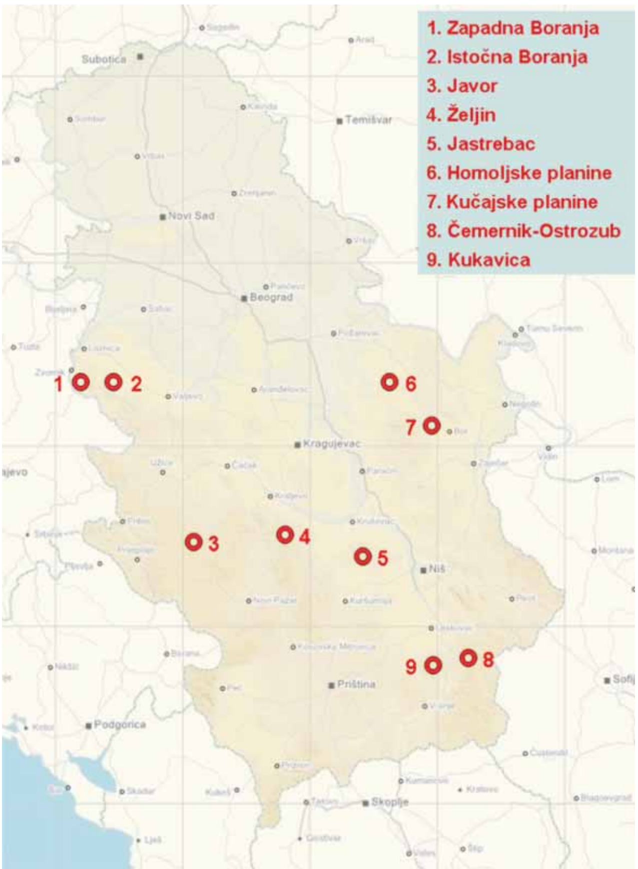

Figure 1 Localities of the investigated beech high stands in Serbia (2005–2007)

Slika 1. Lokaliteti s istraživanim visokim bukovim sastojinama u Srbiji (2005–2007)

Due to the increasing importance of the presented problem, the authors of this paper devoted special attention to studying dead wood in managed beech high forests on the territory of Serbia. The first task was to determine the quantity and structure of dead wood above ground, its dry biomass and carbon stock bound. The next task was to determine the biomass and carbon stock bound in belowground dead wood, i.e. in the roots of old stumps and snags. The aim of the research was to obtain reliable information on the most important characteristics of dead wood (volume, biomass and carbon) in managed beech forests.

Material and method
Materijal i metode

Investigation of state-owned beech high forests was carried out in the period from 2005 to 2007 on nine localities in Serbia (Figure 1). The statistically representative method (sample method) was applied.

Beech is a dominant tree species in the growing stock of Serbia since it accounts for 60 % of the total tree volume of all high forests (Stojanović *et al.*, 2005). The investigated beech stands have a specific structural form. Different management systems of beech forests used to be applied in the past. The main ones were: selection felling system, regeneration felling system, and group selection system.

When, at the beginning of the twentieth century, planned conversion of beech virgin forests into an economical form of forests was started, the selection management system was solely applied (single tree selection). It was applied until the sixties of the last century. The selection system was then assessed as unsuitable for beech forests and it was replaced with the management system of group selection felling (with so called silvicultural groups). This system was defined both in theory and in practice by Milin (1988), and it was applied in the period from 1960 to 1990. The new management system was later assessed as unsuitable for beech forests, too and a new change of management system was implemented. The system of forest management by regeneration felling with short regeneration periods (so called stand management) was proposed. This system is still most commonly prescribed in management plans, but it is seldom put into practice. Generally, there is a great difference between planning the management of beech high forests in Serbia and putting these plans into operation.

Implementation of different management systems of beech high forests in Serbia and their frequent changes have resulted in exceptionally heterogenous structural development of beech high stands, which has had a particularly unfavourable influence on the quality and natural regeneration of the stands.

The sample consisted of eleven beech high stands, whose site and structural characteristics are representative of beech high forests in Serbia. The stands were selected in six forest areas, or nine management units. It has been 7 to 10 years since the last harvesting operations were performed in the selected stands.

These eleven stands are pure uneven-aged beech high stands. Other broadleaved species occur in two stands and they account for 3–5 % of volume. One stand is classified as submontane (*Fagetum moesiacae submontanum B. Jov. 1967*), and the other ten as montane (*Fagetum moesiacae montanum B. Jov. 1953*) beech forests. The forests developed on different parent rocks (sandstone, limestone, gneiss, andezite, rafter, granite, granodiorite, schists) and different soil types (dystric ranker, dystric cambisol, calcomelanosol, calcocambisol, luvisol, pseudogley, brunipodzol), which are 20–120 cm deep. The climate is temperate continental. The average annual temperature air in submontane beech forests (up to 700 m above sea level) exceeds 8.5 °C, while in the vegetation period it reaches approximately 14 °C. The annual precipitation typically ranges between 650 and 1000 mm. The average annual temperature in montane beech forests (from 700 to 1400 m above sea level) ranges from 6.2 to 9.5 °C, with 12.2–14.8 °C in the vegetation period. The annual precipitation typically ranges between 650 and 1100 mm (Stojanović *et al.*, 2005).

The stands are most commonly characterized by irregular declining distribution of trees per diameter classes, typical of heterogeneous uneven-aged stands. There are trees with diameter at breast height (dbh) above 60 cm in all stands, while trees in one of the stands reach 80 to 100 cm in diameter. Regarding the age, the stands are typically uneven-aged with specific age structure. There is a significant percentage of trees above 200 years of age, while some trees are as old as 300–400 years. Ellenberg (1996) states that old-growth broadleaved forests in Europe are usually not even-aged, which corresponds to the characteristics of the studied beech stands.

The age of trees was determined on sample areas established in the stands at the distance of 200 x 200 m. The trees were bored to the center with Pressler borer at breast height. In order to determine the total age, ten years were added to the number of years calculated on the obtained increment core.

The total area of the stands is 241.9 ha. The average values of the structural elements of all stands together per hectare at the time of measuring were as follows: number of trees 298, basal area 27.0 m^2, volume 383.9 m^3 and volume increment 8.3 m^3. Stand quadratic mean diameter is 34.2 cm and Lorey's mean height 28.5 m. The area of individual stands is 9.8–32.3 ha. Their site class is I/II–III/IV. The altitude ranges from 400 to 1380 m. The average slope is 11–27°, the aspect is mostly north-western and the canopy closure degree is 69–94 %. The stand quadratic mean diameter ranges from 30 to 42 cm, while Lorey`s mean height amounts to 22–34 m. The number of trees is 214–308 per ha, basal area 22–33 $m^2 ha^{-1}$, volume 290–522 $m^3 ha^{-1}$ and volume increment 5.0–10.5 $m^3 ha^{-1}$. The quality and assortment structure of the investigated beech stands is poor. According to Matić`s classification (Matić, 1977) the percentage of the trees of the third (the lowest) silvicultural class in the existing volume is 45.0 %, individually from 26.5 % do 72.1 %. The percentage of the trees of the third and fourth technical class (the lowest classes) in the existing volume is approximatelly 28.6 %, individually from 11.0 % to 58.8 %. Logs are represented by about 40 % (Koprivica *et al.*, 2010*b*).

A systematic sample was applied for the purposes of collecting and processing stand data. Circular sample plots of 500 m^2 were arranged in a grid of 100 x 100 m. A set of 242 sample plots was established in the following stand arrangement: 20 (27a), 29 (122a), 16 (8a), 10 (8b), 23 (44a) 33 (116a), 23 (33a), 18 (42a), 10 (42b), 32 (31a) and 28 (46a).

Measurements that were performed in all sample plots included all dead wood that was completely or partly on the sample area. If those were whole trees or longer tree parts in a lying position, they were measured in sections, with roots being excluded from the measurements. It is a well-known fact that dead wood can occur both in a standing and in a lying position. The trees with a dbh above 5 cm and the old stumps with a top diameter above 7 cm were used for the measurements of standing dead wood. Lying dead wood was measured in all tree parts that were at least 3 cm in top diameter and more than 0.3 m long. These criteria were determined by the parallel measurements of living trees (diameter threshold of 5 cm and volume of wood above 3 cm in diameter).

Standing dead wood included elements of different types: a) whole standing dead trees (snags), b) snapped dead trees (at a height of 2.6 m and more) and c) old stumps (older than one year).

For whole dead trees (a), their breast diameters and heights were measured. When measuring the snapped snags at a height above 2.6 m (b), apart from the dbh and the height to the snapped point, the length of the missing tree part was assessed if possible. It was naturally important not to measure this part in the lying position. In the subsequent assessment of wood volume, the estimated length of the missing part was added to the height of the snapped tree in order to determine the total tree height. When it was not possible to assess the length of the missing part, only the tree height below the point of snapping was measured. The measurements of old stumps and trunk parts of snapped trees below 2.6 m in height (c) included the measurements of heights and mid diameters. The volume of dead trees whose dbh and height had already been determined, i.e. we knew the sample plot tariff series, was determined in the same way as the volume of living trees, i.e. by applying the regression equations that are an analytical expression of the volume tariffs for beech in Serbia, calculated after Mirković (Koprivica and Matović, 2005). The volume of old stumps and dead trees snapped at a height up to 2.6 m was calculated using Huber`s simple formula.

In the lying position, dead wood occurred in several forms: a) whole uprooted trees, lying trunks, trunk parts or branches, b) old uprooted stumps (more than a year old), c) lying processed but abandoned assortments, d) stacks of cordwood. The measurements didn't include trees from recent cutting operations or operations that are still underway, stumps up to one year of age, as well as processed assortments that were about to be removed from the stand.

Measurements included all unprocessed (a, b) and processed (c) tree parts whose length was above 0.3 m and top diameter above 3 cm. The diameter was measured halfway along the length of the trees. The length was measured with an accuracy of up to one decimeter and the diameter of up to one centimeter. Several cross diameters were measured halfway along the length of processed wood to obtain the approximate value of the mean diameter. The volume of all measured tree pieces was determined by Huber simple formula.

A stack of cordwood (d) was measured by determining its length and height. On sloping terrains, the length of a stack was measured horizontally and its height vertically. The volume of a stack expressed in cords (stacked cubic meters) was subsequently converted (with appropriate coefficients) into the volume expressed in cubic meters.

The volume of each piece of dead wood in the lying position, snags and old stumps was individually converted per hectare, by multiplying it with a coefficient 20 (10000/500). The data were then statistically processed and sorted.

Apart from measuring, the state or degree of dead wood decomposition was determined. The following categories can be distinguished: a) sound wood, b) weakly decayed wood and c) decayed wood.

The state of dead wood was determined by applying ocular assessment and mechanical wood pressing. It is accepted that sound wood (a) is fresh dead wood with the bark attached, but without live branches and signs of serious decay (less than 10 % of volume). Weakly decayed wood (b) is wood with the signs of initial decomposition, with or without the attached bark; the wood is still hard and up to 1/3 of the diameter is affected by decay (10–40 % of volume). Decayed wood (c) is in the later stages of decomposition (over 40 % of volume) with soft sapwood and partially hard heartwood and more than 1/3 of diameter affected by decay.

All pieces of dead wood were either with or without the attached bark. If they had bark, it was included in the measurement of diameter.

For the purpose of estimating deadwood biomass, i.e. converting its volume into biomass, we used the wood density that was empirically determined as a ratio of its weight in the dry-oven state (105 °C) and the volume of wood in the original state (Marjanović *et al.,* 2010). According to these authors, depending on the degree of decomposition (1–5), beech has the following wood density values:

Degree of wood decomposition	1	2	3	4	5
Wood density (t m – 3)	0.6367	0.5252	0.4137	0.3022	0.1907

Degree of decomposition 1 relates to living wood above ground, and degree 5 to completely decomposed wood. In our case, the degrees of deadwood decomposition are as follows: 2 (sound wood – less than 10 % of decayed volume), 3 (weakly decayed wood, 10–40 % of decayed volume) and 4 (decayed wood, more than 40 % of decayed volume).

Biomass of the roots of stumps and snags was determined by regression equation for European beech (Wutzler *et al.,* 2008)

$$m = 0.0282\, d^{2.39} \qquad (1)$$

where

m – root biomass in kg

d – dbh in cm

Dbh of felled trees was calculated from the stump diameter by applying the regression equation for beech trees (2) based on Panić's data (Nikolić and Banković, 1992).

$$d_{1,3} = 0.651965\, d_p + 0.000766\, d_p^{\,2} + 0.000013\, d_p^{\,3} \qquad (2)$$

where,

$d_{1,3}$ – dbh in cm

d_p – stump diameter in cm (at the height of 0.2–0.3 m)

Biomass of each individual snag and stump root was multiplied by a coefficient 20, in order to convert it into biomass per hectare (t ha^{-1}).

Carbon content was calculated by multiplying the weight of dry deadwood biomass with 0.5 coefficient (IPCC, 2003).

The field data were processed in the laboratory of the Institute of Forestry in Belgrade. Dendrometric analysis was carried out using the computer software EXCEL Microsoft office, 2010, while STATGRAPHICS software, version Plus 5.0, 2000 Statistical Graphics Corp. was used for the statistical data processing.

Results and discussion
Rezultati i rasprava

Deadwood volume – Volumen mrtvog drveta

Using the above described method of work, the data were first processed for each beech stand separately and then for all stands together. Due to high variability of dead wood on the area of the investigated stands and due to the small size of the sample of sample plots (Table 1), the resualts obtained for stands are unreliable. However, the results obtained for all investigated stands together are sufficiently reliable.

The average volume of living and dead wood above ground per hectare in the individual stands and in all investigated beech stands is given in Table 2.

The data in Table 2 indicate the following:

- Average volume of dead wood in all beech stands together is 19.24 m^3 ha^{-1}, or 9.73–28.01 m^3 ha^{-1} per stands. Lying wood accounts for 11.21 m^{3}ha^{-1} or 58.3 %, or 1.24–24.53 m^{3}ha^{-1} per stands. Standing wood accounts for 8.03 m^{3}ha^{-1} or 41.7 %, or 2.41–12.45 m^{3}ha^{-1} per stands.
- In the average volume of dead wood of all beech stands together, unprocessed wood acccounts for 9.35 m^{3}ha^{-1} or 48.6 %, old stumps for 6.73 m^{3}ha^{-1} or 34.98 %, processed wood for 1.86 m^{3}ha^{-1} or 9,67 %, and snags for 1.30 m^{3}ha^{-1} or 6.75 %.
- With regard to the average volume of living wood of all beech stands together (383.9 m^3 ha^{-1}) total dead wood accounts for 5.01 %, and snags only for 0.34 %. The share of the total dead wood per stands ranges from 1.93 % to 9.10 % and the snags from nothing to 2.27 %.

The analysis of variance (Table 3) was used to test the statistical significance of the difference between the average values of the aboveground volume of the total stand dead wood per hectare. The difference was proved to be statistically significant, because the obtained value $F = 2.68$ ($p < 0.005$).

Duncan`s test shows that all stands can be theoretically classified into two statistically homogeneous groups:

(1)	122a	44a	27a	8a	42b	116a	8b	42a			
(2)			27a	8a	42b	116a	8b	42a	33a	31a	46a

In practice, according to the average quantity of dead wood per hectare, the stands can be classified into four groups (Table 4).

Using the average amount of dead wood per hectare, the stands are indirectly classified based on the different variability of deadwood volume in them. In other words, there is a statistically significant linear correlation ($r = 0.8304$, $p < 0.01$) between the standard deviation (m^3 ha^{-1}) and the average volume of dead wood in the investigated stands (m^3 ha^{-1}).

Statistically speaking, these are four strata. Therefore, the assessment of the average and total volume of dead wood of all investigated beech stands together used not only the simple, but also the stratified sample.

However, there is no relationship between the determined volume of living and dead wood per hectare in the studied beech stands (for sample plots $n = 242$, $r = -0.1607$ and for stands $n = 11$, $r = -0.46$) because it is considerably disturbed by extracting a great quantity of wood from the stands after felling. This relationship exists in natural beech forest reserves and it is statistically very significant (Christensen *et al.,* 2005).

Table 1 Average volume and variability of dead wood in the investigated beech stands in Serbia (2005–2007)
Tablica 1. Prosječni volumen i varijabilitet mrtvog drveta istraživanih sastojina bukve u Srbiji (2005–2007)

Parameter /Stand	27a	122a	8a	8b	44a	116a	33a	42a	42b	31a	46a	All
n (sample size)	20	29	16	10	23	33	23	18	10	32	28	242
$V_{av.}$ (m^3 ha^{-1})	14.18	9.73	14.20	20.03	10.30	19.27	26.94	21.56	15.62	26.48	28.01	19.24
S (m^3 ha^{-1})	12.69	4.67	6.43	24.85	9.01	16.75	33.37	32.31	11.12	23.36	21.37	20.78
CV (%)	89.5	48.1	45.3	124.1	87.4	86.9	123.9	149.8	71.3	88.2	76.3	108.0

Table 2 Average volume and standard error of living and dead wood in the investigated beech stands in Serbia (2005–2007)
Tablica 2. Prosječni volumen i standardna greška živog i mrtvog drveta istraživanih sastojina bukve u Srbiji (2005–2007)

Stand/sample size	Living wood volume (m^3/ha)	Volume of dead wood above ground ($m^3 ha^{-1}$)						
		Unprocessed wood	Processed wood	Lying wood	Snags	Old stumps	Standing wood	Lying + Standing dead wood
27a	353.7	8.11	0.19	8.30	0.33	5.55	5.88	14.18
20	+/–38.2	+/–2.27	+/–0.12	+/–2.27	+/–0.26	+/–1.31	+/–1.18	+/–2.84
122a	503.6	2.54	0.09	2.63	–	7.10	7.10	9.73
29	+/–34.5	+/–0.59	+/–0.09	+/–0.58	–	+/–0.75	+/–0.75	+/–0.87
8a	385.2	1.24	–	1.24	–	12.96	12.96	14.20
16	+/–29.3	+/–0.75	–	+/–0.75	–	+/–1.24	+/–1.24	+/–1.61
8b	361.0	7.58	–	7.58	1.29	11.16	12.45	20.03
10	+/–20.5	+/–6.04	–	+/–6.04	+/–1.18	+/–1.98	+/–2.50	+/–7.86
44a	502.0	3.30	0.02	3.32	0.06	6.92	6.98	10.30
23	+/–36.7	+/–1.36	+/–0.02	+/–1.36	+/–0.04	+/–1.49	+/–1.50	+/–1.88
116a	289.9	9.42	1.96	11.38	0.81	7.08	7.89	19.27
33	+/–21.4	+/–2.40	+/–1.88	+/–2.87	+/–0.61	+/–0.66	+/–1.06	+/–2.92
33a	522.4	24.21	0.32	24.53	0.57	1.84	2.41	26.94
23	+/–34.1	+/–6.77	+/–0.32	+/–6.98	+/–0.42	+/–0.46	+/–0.65	+/–6.96
42a	379.6	9.45	–	9.45	8.62	3.49	12.11	21.56
18	+/–20.8	+/–2.20	–	+/–2.20	+/–7.70	+/–0.82	+/–7.76	+/–7.61
42b	333.2	11.08	–	11.08	0.54	4.00	4.54	15.62
10	+/–28.5	+/–3.57	–	+/–3.57	+/–0.54	+/–1.58	+/–1.51	+/–3.52
31a	290.8	10.82	5.72	16.54	2.97	6.97	9.94	26.48
32	+/–18.5	+/–2.81	+/–2.00	+/–4.12	+/–1.31	+/–0.77	+/–1.19	+/–4.13
46a	316.0	12.95	6.72	19.67	–	8.34	8.34	28.01
28	+/–25.0	+/–4.16	+/–2.05	+/–4.35	–	+/–1.03	+/–1.03	+/–4.04
All	383.9	9.35	1.86	11.21	1.30	6.73	8.03	19.24
242	+/–10.5	+/–1.08	+/–0.46	+/–1.22	+/–0.61	+/–0.35	+/–0.68	+/–1.34

Table 3 Analysis of Variance for the volume of dead wood per hectare
Tablica 3. Analiza varijanse za volumen mrtvog drveta po hektaru

Source	Sum of Squares	Df	Mean Square	F – Ratio	P – Value
Between groups	10804.8	10	1080.48	2.68	0.0041
Within groups	93222.2	231	403.559		
Total	104027.0	241			

Table 4 Classification of beech stands according to average volume of dead wood
Tablica 4. Grupiranje sastojina bukve po prosječnoj zapremini mrtvog drveta

Stand Group	Mean volume of dead wood ($m^3 ha^{-1}$)	Stand		
1	10	122a	44a	–
2	15	27a	8a	42b
3	20	116a	8b	42a
4	25	33a	31a	46a

The volume of dead wood with regard to its mode of existence and degree of decomposition is given in table 5.

Considering the degree of dead wood decomposition, decayed wood is the most frequent (90.5 %), then weakly decayed (7.6 %) and sound wood (1.9 %).

Apart from the deadwood volume structure with regard to the degree of decomposition, the deadwood volume structure per diameter classes is also provided (Table 6).

The data presented in Table 6 show that unprocessed wood occurs in all diameter classes below 100 cm, in the following percentages: up to 30 cm with 45.24 %, from 31 to 60 cm with 43.10 % and above 60 cm with 11.66 %. Processed wood occurs in all classes up to 80 cm, in the following percentages: up to 30 cm with 27.41 %, from 31 to 60 cm with 67.21 % and above 60 cm with 5.38 %. The wood of snags occurs in all classes up to 40 cm, as well as in the classes 51–60 and 71–80 cm, while the wood of old stumps occurs in all classes below and above 100 cm. Distribution of the

Table 5 Average volume of dead wood in the investigated beech stands together in Serbia (2005–2007)

Tablica 5. Prosječan volumen mrtvog drveta u istraživanim sastojinama bukve zajedno u Srbiji (2005–2007)

Wood state	Dead wood volume ($m^3\,ha^{-1}$)					
	Unprocessed wood	Processed wood	Snags	Old stumps	Total	%
Sound	0.33	0.03	–	–	0.36	1.87
Weakly decayed	0.36	0.09	0.09	0.92	1.46	7.59
Decayed	8.66	1.74	1.21	5.81	17.42	90.54
Total	9.35	1.86	1.30	6.73	19.24	100.00
%	48.60	9.67	6.75	34.98	100.00	

Table 6 Diameter structure of deadwood volume in the investigated beech stands in Serbia (2005–2007)

Tablica 6. Debljinska struktura volumena mrtvog drveta u istraživanim sastojinama bukve u Srbiji (2005–2007)

Diameter (cm)	Deadwood volume ($m^3\,ha^{-1}$)					
	Unprocessed wood	Processed wood	Snags	Old stumps	Total	%
5–10	0.51	0.01	0.03	–	0.55	2.86
11–20	1.85	0.16	0.22	0.12	2.35	12.22
21–30	1.87	0.34	0.33	0.26	2.80	14.55
31–40	1.81	0.46	0.10	0.35	2.72	14.14
41–50	1.58	0.53	–	0.63	2.74	14.24
51–60	0.64	0.26	0.05	1.00	1.95	10.13
61–70	0.44	0.03	–	1.25	1.72	8.94
71–80	0.55	0.07	0.57	1.25	2.44	12.68
81–90	0.05	–	–	1.07	1.12	5.83
91–100	0.05	–	–	0.54	0.59	3.06
> 100	–	–	–	0.26	0.26	1.35
Total	9.35	1.86	1.30	6.73	19.24	100.00

total dead wood per diameter classes is irregular, with the greatest percentages in classes 11–80 cm (86.9 %).

A sample of 242 sample plots shows that the distribution of the total dead wood above ground per hectare is highly positively skewed ($\alpha_3 = 2.96$) and highly elongated ($\alpha_4 = 11.05$) in comparison to the normal distribution. Arithmetic mean is 19.24 $m^3\,ha^{-1}$. Standard deviation is 20.78 $m^3\,ha^{-1}$. Standard error is 1.34 $m^3\,ha^{-1}$. Coefficient of variation is 108 %. With the probability of 95 % and degree of freedom 241 (z = 1.96), the relative sampling error is +/– 13.61 %. If we apply the stratified sample, with the probability of 95 % and degree of freedom 238 (z = 1.96), the relative sampling error is +/– 13.01 %.

It follows that the data on deadwood volume obtained by applying a simple sample and a stratified sample in all beech stands together of about 240 ha are reliable. According to the stratified sample, the confidence interval (p = 0.95, n-4 = 238), for the average deadwood volume is 16.74–21.74 $m^3\,ha^{-1}$, and for the total volume 4049–5259 m^3.

Based on the data from 86 investigated beech forest reserves across Europe, Christiansen et al. (2005) have showed that the average volume of dead wood amounts to 130 $m^3\,ha^{-1}$ and it varies from almost nothing to 550 $m^3\,ha^{-1}$. However, the volume of dead wood is 10 to 20 times lower in managed (production) forests. In other words, the results of the investigations conducted in Finnland, Sweden, Germany, France, Belgium and Switzerland show that the average volume of dead wood in managed forests was less than 10 $m^3\,ha^{-1}$ (Christensen *et al.*, 2005). In comparison to these results, the determined deadwood volume in the managed beech stands in Serbia is almost two times higher, which can be of great importance for the conservation of the general biological diversity. There is only the question whether the determined quantity and structure of deadwood volume per hectare is the optimal one, with regard to soil fertility maintenance and needs of different plant and animal species.

The results of volume of dead wood in the beech stands of Serbia are similar to the results obtained by Atici *et al.* (2008). Namely, according to these authors the total volume of dead wood of managed native Oriental beech stands is 22.87 ± 4.34 $m^3\,ha^{-1}$.

Stojanović *et al.* (2005) state that there are about 350 000 ha of beech high forests in Serbia. Therefore, based on the obtained results, the deadwood volume in beech high stands can be expected to amount to about 6.73 million m^3 or to range in the confidence interval (p = 0.95) from 5.81 to 7.65 million m^3.

Deadwood biomass and carbon – Biomasa i zaliha ugljika mrtvog drveta

The average dry biomass of dead wood and carbon stock per hectare in the individual stands and in all investigated beech stands is given in Table 7.

The data in Table 7 indicate the following:

- The average dry biomass of the aboveground dead wood of all beech stands together is 6.06 t ha^{-1}, and 2.95–9.20 t ha^{-1} per stands. The average carbon stock in this biomass amounts to 3.03 t C ha^{-1}, or 1.47–4.60 t C ha^{-1} per stands.
- The average biomass of the belowground dead wood of all beech stands together is 17.34 t ha^{-1}, or 3.44–31.56 t ha^{-1} per stands. The average carbon stock in this biomass is 8.67 t C ha^{-1}, or 1.72–15.78 t C ha^{-1} per stands.
- The average biomass of the belowground and aboveground dead wood of all beech stands together is 23.40 t ha^{-1},

Table 7 Average dry biomass and carbon stock with the standard error per hectare in the investigated beech stands in Serbia (2005–2007)
Tablica 7. Prosječna suha biomasa i zaliha ugljika sa standardnom greškom po hektaru u istraživanim sastojinama bukve u Srbiji (2005–2007)

Stand	Sample size	Biomass (t ha^{-1})			Carbon (t C ha^{-1})		
		Above ground	Below ground	Above + Below ground biomass	Above ground	Below ground	Above + Below ground carbon
27a	20	4.45 +/–0.89	14.92 +/–3.84	19.37 +/–4.41	2.23 +/–0.45	7.46 +/–1.92	9.69 +/–2.20
122a	29	2.95 +/–0.26	18.26 +/–2.48	21.21 +/–2.65	1.47 +/–0.13	9.13 +/–1.24	10.60 +/–1.32
8a	16	4.45 +/–0.50	25.78 +/–2.76	30.23 +/–3.17	2.23 +/–0.25	12.89 +/–1.38	15.12 +/–1.58
8b	10	6.23 +/–2.44	31.56 +/–6.01	37.79 +/–7.65	3.115 +/–1.22	15.780 +/–3.00	18.895 +/–3.82
44a	23	3.11 +/–0.57	20.90 +/–4.99	24.01 +/–5.38	1.55 +/–0.28	10.45 +/–2.49	12.00 +/–2.69
116a	33	5.82 +/–0.88	18.15 +/–2.72	23.97 +/–3.00	2.91 +/–0.44	9.08 +/–1.36	11.99 +/–1.50
33a	23	9.20 +/–2.38	3.44 +/–1.00	12.64 +/–2.70	4.60 +/–1.19	1.72 +/–0.50	6.32 +/–1.35
42a	18	6.66 +/–2.35	9.76 +/–2.45	16.42 +/–4.32	3.33 +/–1.17	4.88 +/–1.22	8.21 +/–2.16
42b	10	4.72 +/–1.06	10.20 +/–4.20	14.92 +/–4.53	2.36 +/–0.53	5.10 +/–2.10	7.46 +/–2.26
31a	32	8.50 +/–1.32	15.92 +/–1.63	24.42 +/–2.17	4.25 +/–0.66	7.96 +/–0.82	12.21 +/–1.08
46a	28	8.74 +/–1.26	24.82 +/–4.00	33.56 +/–4.04	4.37 +/–0.68	12.41 +/–2.00	16.78 +/–2.02
All	242	6.06 +/–0.43	17.34 +/–1.06	23.40 +/–1.20	3.03 +/–0.21	8.67 +/–0.53	11.70 +/–0.60

or 12.64–37.79 t ha^{-1} per stands. The average carbon stock in this biomass is 11.70 t C ha^{-1}, or 6.32–18.89 t C ha^{-1} per stands.

– Thus, the average biomas of aboveground and belowground dead wood in the management class amounts to 23.40 t ha^{-1}. Out of this biomass, 6.06 t ha^{-1} or 25.90 % is above ground and 17.34 t ha^{-1} or 74.10 % below ground. It participates with the same percentages in the total carbon stock of 11.70 t C ha^{-1}.

Variation coefficient of the biomass of stump and snag roots is 95 %, and the relative sampling error with the probability of 95 % and degree of freedom of 241 amounts to +/– 12.21 %.

Mund and Shultze (2006) state that according to numerous studies the amount of carbon stored in the aboveground dead wood in managed pure broadleaved forests doesn't exceed 5 t C ha^{-1}, or according to their study 2 t C ha^{-1}. The beech stands we investigated have the average carbon stock in the aboveground dead wood of approximatelly 3 t C ha^{-1}, which corresponds to the results of other investigations. The quantity of carbon stored in dead wood is naturally much higher in unmanaged broadleaved forests and in virgin forests.

With the same limits as in the assessments of the total deadwood volume above ground, the dead wood of high beech forests in the territory of Serbia (350 000 ha) has about 4.09 million t C stored, 3.03 million of which is below and 1.06 million above ground.

Conclusion
Zaključak

In the investigated beech stands, the average volume of dead wood above ground ($p = 0.95$, $n-1 = 241$) accounts for 19.24 +/– 2.63 m^3 ha^{-1} or 5.01 % of the average living wood volume (383.9 +/– 20.58 m^3 ha^{-1}). Snags participate in the living wood volume with only 0.34 %. In the aboveground dead wood (19.24 m^3 ha^{-1}) lying wood accounts for 11.21 m^3 ha^{-1} or 58.03 % and standing wood with 8.03 m^3 ha^{-1} or 41.7 %. With regard to its mode of existence, unprocessed wood is the most frequent (48.60 %), then the wood of old stumps (34.98 %), processed wood (9.67 %) and snag wood (6.75 %). With regard to degree of decomposition, decayed wood is the most common (90.54 %), then weakly decayed wood (7.59 %) and sound wood (1.87 %). Distribution of the total aboveground deadwood volume per diameter classes is irregular, the most frequent being dead wood with diameter up to 60 cm (65.3 %).

The average deadwood biomass above ground in the investigated beech stands is 6.06 +/– 0.84 t ha^{-1} ($p = 0.95$), and the average carbon stock in this biomass is 3.031 t C ha^{-1}. The average biomass of dead wood below ground is 17.34 +/– 2.08 t ha^{-1}, and the average carbon stock in this biomass is 8.671 t C ha^{-1}. Thus, the average biomass of above and belowground dead wood together is 23.40 +/– 2.35 t ha^{-1}. Aboveground biomass amounts to 6.06 t ha^{-1} or 25.90 % and belowground biomass to 17.34 t ha^{-1} or 74.10 %. The average carbon stock in the total dry biomass is 11.702 +/– 1.18 t C ha^{-1} and the ratio between aboveground and belowground carbon is the same as in the biomass.

Investigated managed high beech stands in Serbia have higher volume, biomass and carbon stock bound in dead wood per hectare in comparison to intesively-managed beech stands in Europe. The current state of the stands with regard to dead wood is the result of long-standing negligent management and frequent changes of the management systems in beech forests (selection, group-selection, regeneration, etc).

On the basis of these investigations it can be estimated that there is approximately (p = 0.95, n-1 = 241) 6.73 +/– 0.92 million m^3 of aboveground dead wood in managed high beech forests in Serbia (350 000 ha). The dry biomass is about 2.12 +/– 0.29 million tonnes and the carbon stock is 1.06 +/– 0.14 million tonnes. The biomass of the belowground dead wood os around 6.07 +/– 0.73 million tonnes and the carbon stock is 3.03 +/– 0.36 million tonnes. Finally, the total biomass of dead wood below and above ground is around 8.19 +/– 0.82 million tonnes and the carbon stock is around 4.10 +/– 0.41 million tonnes.

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Sažetak:

U cilju rješavanja problema energetske krize i klimatskih promjena u svijetu se pridaje veliko značenje proučavanju biomase, odnosno zalihe i kruženja ugljika u šumskim ekosustavima. Proučavan je najčešće utjecaj klimatskih promjena i načina gospodarenja na razvoj i stabilnost šumskih ekosustava, kao i njihov doprinos ublažavanju negativnih utjecaja klimatskih promjena na životni okoliš (Cannell 1995., Lebaube et al. 2000., Joosten et al. 2004., Mund 2004., Mund and Schulze 2006., Liski et al. 2006). Mrtvo drvo je najviše proučavano u prašumama, odnosno rezervatima bukovih šuma (Christensen et al. 2005). Uz to, proučavano je u približno prirodnim bukovim šumama (Beneke and Manning 2003., Mountford 2002) i u gospodarenim bukovim šumama (Green and Peterken 1997., Fridman and Walheim 2000., Ferguson and Archibald 2002., Mund 2004., Mund and Schulze 2006). Rađena je i komparacija karakteristika mrtvog drveta u prirodnim – negospodarenim i gospodarenim šumama (Andersson and Hytteborn 1991., Kirby et al. 1998). U Europi, volumen dubećeg i ležećeg mrtvog drveta u uređivanim – proizvodnim šumama označena je kao važan indikator za održivo gospodarenje i očuvanje biodiverziteta (MCPFE 2003). Prema tomu, mrtvo drvo je važna komponenta šumskih ekosustava. Međutim, u šumama Srbije do sada nije detaljnije proučavano. Zbog toga, cilj ovog rada bio je dobivanje pouzdanih informacija o najznačajnijim karakteristikama mrtvog drveta (volumenu, biomasi i ugljiku) u visokim gospodarenim bukovim šumama koje su u državnom vlasništvu.

Istraživane sastojine bukve po strukturnoj su izgrađenosti specifične, a početkom dvadesetog stoljeća bile su pretežito prašume, pa su neurednim prebornim sječama prevedene u privredne šume. Radi se o izrazito raznodobnim sastojinama bukve, specifične starosne strukture. Uzorkom je obuhvaćeno jedanaest čistih sastojina bukve izabranih u šest šumskih područja (Slika 1). Jedna sastojina pripada brdskoj (Fagetum moesiacae submontanum B. Jov. 1967) a deset sastojina planinskoj šumi bukve (Fagetum moesiacae montanum B. Jov. 1953).

Klima je umjereno kontinentalna. Površina sastojina je 9,8–32,3 ha (ukupno 241,9 ha). Bonitet staništa je I/II–III/IV, nadmorska visina 400–1380 m, prosječan nagib terena 11–27°, najčešća ekspozicija sjeverozapadna, stupanj sklopa 69–94 %, srednji promjer po temeljnici 30–42 cm, srednja visina po Loraju 22–34 m, broj stabala 214–308 po ha, temeljnica 22–33 m^2 ha^{-1}, volumen 290–522 m^3 ha^{-1} i volumni prirast 5,0–10,5 m^3 ha^{-1}. Kvalitativna i sortimentna struktura istraživanih sastojina bukve bila je loša (Koprivica et al. 2010b).

Za utvrđivanje prisutnosti, količine, debljinske strukture volumena i stanja mrtvog drveta glede stupnja raspadanja u dubećem i ležećem položaju primijenjen je sistematski uzorak. Kao elementi uzorka u sastojinama korištene su probne plohe veličine 500 m^2, raspoređene na rastojanju 100 x 100 m. Postavljene su ukupno 242 probne plohe. Volumen mrtvog drveta na probnim plohama iznad zemlje određen je po klasičnim dendrometrijskim metodama, a suha biomasa na bazi njegovog volumena i gustoće drveta pri različitom stupnju raspadanja (Marjanović et al. 2010). Biomasa mrtvog drveta ispod zemlje (korijena panjeva i suvih stabala) određena je izravno po regresijskoj jednadžbi (Wutzler et al. 2008). Sadržaj vezanog ugljika u mrtvom drvetu dobijen je množenjem suhe biomase mrtvog drveta s koeficijentom 0,5 (IPCC 2003). Za procjenu prosječnog i ukupnog volumena, biomase i zalihe ugljika primijenjen je jednostavni i stratifikacijski uzorak.

Prosječan volumen živog i mrtvog drveta iznad zemlje po hektaru u sastojinama i za sve istraživane sastojine zajedno prikazan je u tablici 2. Za sastojine dobiveni su podaci nedovoljne točnosti. Međutim, podaci dobiveni za sve istraživane sastojine zajedno su dovoljno točni – pouzdani. Prosječan volumen mrtvog drveta iznad zemlje svih istraživanih sastojina bukve zajedno (p = 0,95, n-1 = 241) je 19,24 +/– 2,63 m^3 ha^{-1} ili 5,01 % od prosječnog volumena živog drveta (383,9 +/– 20,58 m^3 ha^{-1}). Metodom analize varijance utvrđeno je da je razlika između sastojina, s obzirom na prosječan volumen mrtvog drveta po hektaru, statističi značajna. Volumen mrtvog drveta s obzirom na način javljanja i stupanj raspadanja prikazant je u tablici 5, a s obzirom na debljinsku strukturu volumena u tablici 6. Na osnovi jednostavnog uzorka od 242 probne plohe utvrđeno je da je raspored mrtvog drveta iznad zemlje po hektaru jako pozitivno asimetričan i jako izdužen u odnosu na normalni raspored. Koeficijent varijacije je 108 %. Relativna greška uzorka (p = 0,95) je +/– 13,61 %. Primjenom stratifikacijskog uzorka dobivena je relativna greška uzorka +/– 13,01 %. Na osnovi stratifikacijskog uzorka, interval povjerenja (p = 0,95, n-4 =238) za prosječan volumen mrtvog drveta je 16,74–21,74 m^3/ha. Prosječna suha biomasa mrtvog drveta i zaliha ugljika po hektaru u istraživanim sastojinama bukve prikazana je u tablici 7. Biomsa istraživanih sastojina zajedno iznad zemlje je 6,06 t $ha^{-1,}$ a ispod zemlje 17,34 t ha^{-1}, odnosno ukupno 23,40 t ha^{-1}. Zaliha vezanog ugljika u ukupno procijenjenoj suhoj biomasi mrtvog drveta iznad zemlje je 3,03 t C ha^{-1} a ispod zemlje 8,67 t C ha^{-1}, odnosno ukupno 11,70 t C ha^{-1}.

Gospodarene visoke sastojine bukve u Srbiji imaju veći volumen, biomasu i zalihu vezanog ugljika u mrtvom drvetu po hektaru u odnosu na intenzivno gospodarene sastojine bukve u Europi. Sadašnje stanje je posljedica dugogodišnjeg provođenja neurednog gospodarenja i česte promjene načina gospodarenja bukovim šumama (preborni, grupimični, naplodni i sl.). Na bazi provedenog istraživanja procijenjeno je (p= 0,95, n-1 = 241) da se u visokim gospodarenim bukovim šumama na području Srbije (350.000 ha) nalazi 6,73+/– 0,92 milijuna m^3 mrtvog drveta iznad zemlje, čija je suha biomasa 2,12 +/– 0,29 milijuna tona a uskladišteni ugljik u ovoj biomasi 1,06 +/– 0,14 milijun tona. Biomasa mrtvog drveta ispod zemlje je 6,07 +/– 0,73 milijuna tona, a uskladišteni ugljika u ovoj biomasi 3,03 +/– 0,36 milijuna tona. Prema tomu, ukupna procijenjena biomasa mrtvog drveta iznad i ispod zemlje je 8,19 +/– 0,82 milijuna tona, a uskladišteni ugljik 4,10 +/– 0,41 milijuna tona.

KLJUČNE RIJEČI: mrtvo drvo, gospodarene bukve šume, sastojina, volumen, biomasa, ugljik, uzorak