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Dead wood volume in Beech forests in Vitosha and Stara Planina Mountains in Bulgaria

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Abstract. Dead wood is an important structural and functional component in forest ecosystems. It is a major factor in the protection and maintenance of biodiversity. In this regard, the aim of the present study is to determine the stocks of dead wood in beech forests in Vitosha and Stara Planina Mountains in Bulgaria. The standing biomass was calculated using height rates tables, the lying biomass - using the method of intersecting lines, and the stumps - by height and diameter. Degrees of decomposition are on standard scales. The obtained results are in the range of 9.93 - 34.72 $m^3 \cdot ha^{-1}$, with the predominant share being the lying dead biomass, which varies between 96% and 51%. Dead trees of all stages of decay are observed. In the lying biomass, the initial decomposition stages A (35%) and B (46%) predominate. For the stumps, the last degree of decomposition D (44%) prevails. The obtained results show insufficient amounts of dead biomass from an environmental point of view.

Key words: dead biomass, beech forests, decomposition.

Introduction

Dead wood is an important structural and functional component in the forest ecosystems. It is a major factor in the protection and maintenance of biodiversity. It provides habitats and food base for saprophytic species, fungi, insects, birds, bats and other small mammals, which can only exist in the presence of sufficient amounts of dead wood of various sizes and in various stages of decomposition (Dudley & Vallauri, 2004). It is also an important link in the carbon cycle and the cycle of nutrients.

Many authors investigate the importance of dead biomass (Pedlar et al., 2002; Larrieu et al., 2014; Jonsson et al., 2016; Runnel & Lõhmus, 2017; Vítková et al., 2018; Sacher et al., 2022; Tavankar et al., 2022; Lasota et al., 2022, etc.), but here we will specifically focus on studies related to its quantity, since the purpose of the present study is to establish the stocks of dead wood in beech forests in Vitosha and Stara Planina Mountains in Bulgaria.

Christensen et al. (2005) analyzed dead biomass stocks in 86 beech reserves in Europe. The quantities range from 0 to 550 $m^3 \cdot ha^{-1}$ depending on the year the reserve was declared, the type of forest and the stock of live wood. More dead wood is observed in the highlands than in the lowlands. In general, lying wood contributes more to the total deadwood biomass than standing wood.

The quantitative and qualitative structure of dead standing trees and large woody debris, as well as the occurrence of associated macromycetes, were analyzed in beech stands in Poland, where an average amount of 55.55 m^3 ha^{-1} dead wood was measured, 64% of which coarse wood residues (Kacprzyk et al., 2014). Elevation and distance from the upper forest line were found to have a significant effect on the amount and structure of dead wood in stands. When approaching the upper limit of the forest, the thickness of large woody debris decreases, and the proportion of dead standing trees increases.

An assessment of dead biomass stocks in *Luzulo pilosae-Fagetum* beech forests in two reserves in Poland yielded stocks of 41.9 to 165.8 m^3 ha^{-1} (Maślak & Orczewska 2010), with the authors citing as average stocks for the country for the same communities 5-10 m^3 ha^{-1}. Fallen stems and stumps of the second degree of decomposition predominate.

The issue of removal of dead wood from forests by the local population is being investigated (Monaco et al., 2022). Naturally, quantities are directly related to road accessibility. The authors point out that a sustainable management of forests is necessary, in which the social factor is also included.

In Bulgaria, Zlatanov et al. (2016) propose to use the indicator "accumulation of dead wood" as an index for the complex assessment of forests in old phase. It is expressed as the presence of standing and fallen dead trees in varying degrees of wood decomposition, in an amount of at least 70 m^3 ha^{-1} for beech - grade "2"; in an amount of at least 35 m^3 ha^{-1} - score "1" and in an amount less than 35 m^3 ha^{-1} - score "0".

Dead trees are also seen as microhabitats for various species of animals. Leaving them in forest communities is practiced as a biodiversity conservation measure. Of particular importance are decaying whole stems (Spînu et al., 2022). The process of dead wood decomposition is influenced by temperature, humidity and the ratio of O_2 to CO_2 in the environment, by qualitative characteristics such as dead wood size, wood species, as well as by the presence of dead wood-dependent (saproxylic) species (Bače et al., 2019). Average wood relative humidity, mass loss and decay rate differ significantly between different decay stages (Hoppe et al., 2015).

The territory of the communities we studied were also examined for the presence of saproxylic fungi and insects. The results will be published later.

As we can see the issue about dead wood is very actual in international aspect but in Bulgaria we have insufficient data, which requires conducting of this research.

Materials and Methods

Object of the study

The object of research are natural beech communities in the Vitosha and Stara Planina Mountains in Bulgaria. The climate is moderately continental and mountainous. The soils are cambisols (WRB, 2006). Four sample plots (SP) - two in each mountain with dimensions of 50x50 m were laid out in 2022. Their location is shown in Fig. 1, and the main characteristics of the compartments are in Table 1.

SP 1 is situated in a beech phytocenosis with a tree layer with 70% total vertical projec-tion. It is dominated by *Fagus sylvatica* L., but also there are *Quercus petraea* (Matt.) Liebl., *Populus tremula* L., *Pyrus pyraster* Burgsd., *Carpinus betulus* L. and *Acer pseudoplatanus* L. A shrub floor does not form, but the species *Corylus avellana* L. with low projective cover is present. The total projective coverage of phytocenotic horizon III is 80%, and it includes 26 plant species. More common representatives of the mixthoherbosa group are: *Galium odora-tum* (L.) Scop., *Aegopodium podagraria* L. and *Prenanthes purpurea* L. The species such as *Ajuga genevensis* L. and *Tanacetum vulgare* L. have low coverage. Of the ferns, *Pteridium aquilinum* (L.) Kuhn., and from legumes – *Lathyrus niger* (L.) Bernth. are present. SP 1 refers to habitat 9130 *Asperulo-Fagetum*. There are 312 living trees per ha and their biomass is 354.91 m^3 ha^{-1}.

Fagus sylvatica L. is dominant in SP2 in the first phytocenotic horizon, and *Betula pendula* Roth is found individually. Total coverage is 70%. A phytocenotic horizon of the shrubs is not formed. The total coverage of phytocenotic horizon II is 80%, including 12 plant species. More common species of the mixoherbosa group are *Galium odoratum* (L) Scop. and *Mycelis muralis* (L.) Dumort. With low coverage are species such as *Actea spicata* L., *Luzula luzuloides* (Lam.). Dandy is found from the cyperaceous grasses, and *Poa nemoralis* L. from the gramineous group. SP 2 refers to habitat 9130 *Asperulo-Fagetum*. There are 320 living trees per ha and their biomass is 310.80 m^3 ha^{-1}.

The first phytocoenotic horizon in SP3 is represented only by *Fagus sylvatica*. Its total coverage is 80%. A shrub floor does not form. The total coverage of the second phytocenotic horizon is 80%, including 19 plant species. More common species of mixoherbosa are *Anemone nemorosa* L., *Rubus hirtus* Waldst. & Kit. and *Cardamine bulbifera* L. (Grantz). With low coverage are species such as *Paris quadrifolia* L. and *Telekia speciosa* (Schreb.) Baumg. An undergrowth of *Fagus sylvatica* is present. Among the ferns, there is *Athyrium filix-femina* (L.) Roth; from gramineous – *Hordelymus europaeus* (L.) Jess. ex Harz. Representatives of cyperaceous grasses and legumes were not found. SP 3 refers to habitat 9130 *Asperulo-Fagetum*. There are 492 living trees per ha and their biomass is 616.28 m^3 ha^{-1}.

The tree layer in SP4 is dominated by *Fagus sylvatica*, and *Carpinus betulus* L. is rarely found. The total coverage of the first phyto-cenotic horizon is 60%. The total coverage of phytocenotic horizon II is 90%, and it includes 17 plant species. More common types of mixoherbosa are *Cardamine bulbifera*, *Galium odoratum*. With low coverage are species such as *Physospermum cornubiense* (L.) DC. and *Anemone ranunculoides* L. An undergrowth of *Carpinus betulus* and *Fagus sylvatica* is present. Among the ferns, there is *Pteridium aquilinum* (L.) Kuhn.; from gramineous - *Melica uniflora* Retz., and from cyperaceous grasses - *Luzula luzuloides* (Lam.) Dandy. SP 4 refers to habitat 9130 *Asperulo-Fagetum*. There are 312 living trees per ha and their biomass is 224.14 m^3 ha^{-1}.

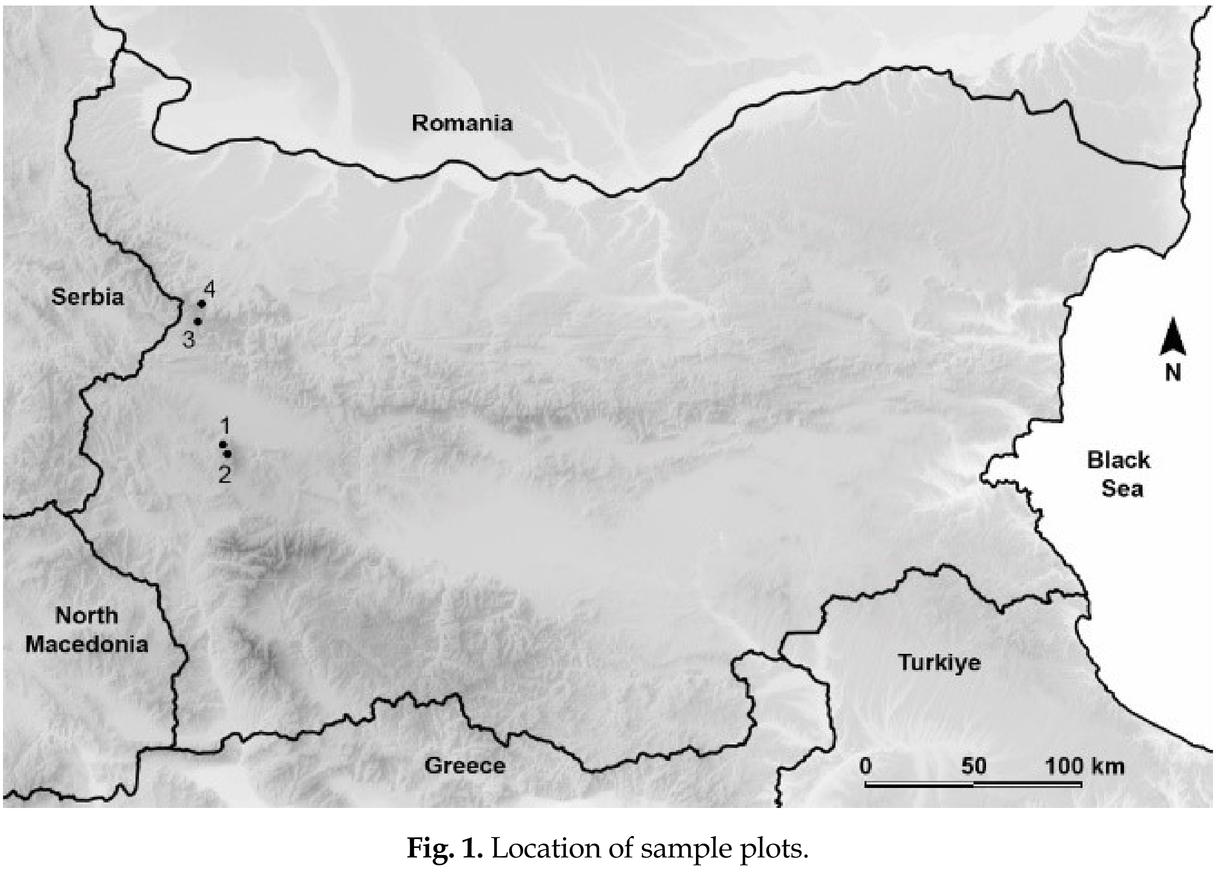

Fig. 1. Location of sample plots.

Table 1. Stands characteristics in sample plots.

Sample plot	Altitude, m	Geographic coordinates	Age, years	Canopy	Slope	Exposition	Average height, m	Average diameter at 1.30 cm
Vitosha, Tihia kat, SP 1	1100	N 42°63'13.1″ E 23°22'43.8″	90	0.7	20°	NE	23	30
Vitosha, Zlatni mostove, SP 2	1400	N 42°61'27.5″ E 23°23'578″	110	0.7	35°	W	25	40
Stara Planina, Petrohan, SP 3	1440	N 43°07' 15.2″ E 23°07' 17.8″	130	0.8	45°	SE	27	32
Stara planina, Barzia, SP 4	750	N 43°09' 19.1″ E 23°08' 50.8″	150	0.6	30°	SE	29	42

Methods

The dead wood was divided into three main components:

1) standing dead wood – standing withered trees and broken stems, resulting from natural processes of loss;

2) lying dead wood - fallen and uprooted trees, stems and branches as a result of natural processes and logging activities:

a) coarse debris - wood with a length of more than 1 m and diameter - larger than 10 cm;

b) fine wood - wood with diameter less than 10 cm;

3) stumps - part of the base of the stem which remains after its cutting.

Standing dead wood

To establish the volume of dead wood a sample plots with square shape and size 50 × 50 m (2500 m^2) were established. The diameter of 1.30 m height and the height of all standing dead trees were measured in order to determine the amount of standing dead wood. Their volume was then calculated with height rates tables Duhovnikov (Poriazov et al., 2004). The height order was determined according to the diameter of 1.30 m height and the height of each tree stem with help of tables for natural common beech stands. Then the volume (m^3) value for each tree according its diameter from each height order was taken and the sum of volumes of dead standing trees was given (m^3 ha^{-1}).

Lying dead wood

The method of line intersect sampling (Warren & Olsen, 1964), adapted by Lazarov et al. (2012) and approved by Ministry of Environment and water was used for determination of the lying dead wood stocks. The diagonals that intersect randomly fallen and lying on the surface tree trunks and branches were outlined. The diameter at the intersection was measured.

The volume of fallen deadwood was calculated as follows:

$$V = \pi^2 \sum_{n_i=1} \frac{di^2}{8L} \qquad (1)$$

where: V – volume of lying dead wood (m^3 ha^{-1}); di – diameter in the point of intersection (cm); L – length of transect (m).

Stumps

The diameter and height of each stump were determined. The volume of the stumps was calculated as follows:

$$V = \pi r^2 h \qquad (2)$$

where: V – volume of dead stumps (m^3 ha-1); r – radius (m); h – height of the stump (m).

Thomas scale (Thomas, 1979) was used to assess the degree of decomposition of standing dead biomass and a 4-point harmonized scale (Rondeux et al., 2012) for lying biomass and stumps.

Results and discussion

The amounts of dead wood biomass in beech forests established as a result of the research are shown in Tables 2-4. The average total amount is 22.51 m^3 ha^{-1}.

Living standing trees predominate in all investigated sites. The dead are represented by about 1 to 10% of the total amount (Fig. 2). Most of the observed standing dead trees are dry with broken branches.

In SP 1, lying dead biomass predominates - 94.9%, standing biomass is representted by 3.9% and stumps are 0.5%. In the lying dead biomass, fine and coarse woody debris are approximately the same – about 7 m^3 ha^{-1} (Table 2). Regarding the degree of decomposition, the predominant amount in this phytomass fraction is from class B - 43%, and the least - from class D - 7% (Table 3). The standing biomass is represented by an insignificant number of trees (4 per ha) of 1 degree of decomposition. Stumps are also few (4 per ha) and are of degree of decomposition B (100%) - significantly decomposed.

On the territory of SP 2, lying dead wood biomass also prevails quantitatively - 51%, standing dead wood is represented by 38%, and stumps are - 11% of the total amount. In the case of lying dead biomass, the amounts of fine and large-sized woody debris are similar – about 2 m^3 ha^{-1}. The degree of decomposition B predominates - 80%, which indicates that the decomposition processes are still at an initial stage. In the standing biomass, mainly trees of the 1st degree of decomposition with broken tops are observed. Their quantity is 16 per ha. No trees with hollows are observed. The number of stumps is 32 per ha, with those from the degree of decomposition D (50%) and C (37%) predominating.

In SP 3, the amount of lying dead biomass (74%) again prevails over standing biomass (13%). Stumps are about 13%. A significant excess of the amount of coarse woody debris (23 m^3 ha^{-1}) compared to fine wood was observed in the lying dead bio-mass. Dead wood of degree of decomposition A prevails - 42%. In the standing biomass, trees of the 3rd, 4th, 5th degree of decomposition with the presence of fungal bodies are observed. The amount of standing dead trees is 40 per ha. The number of stumps is 52 per ha, and they are found in all degrees of decomposition, but most are of degree D (58%).

SP 4 is characterized by the following distribution of the individual components of dead wood biomass: standing - 50%, lying - 33%, stumps - 17%. The lying dead biomass is represented by fine and coarse wood debris in equal amounts (5.5 m^3 ha^{-1}). The predominant degree of decomposition is A - 65%, but all other grades are available. In the standing biomass, only trees of the 1st and 2nd degree of decomposition were observed, without branches with broken tips. The amount of standing dead trees is 36 per ha. The number of stumps is 96 per ha, with the predominant degrees of decomposition being D (58%) and C (21%), but all groups are represented.

SP 1 and SP 2 are located in Vitosha Nature Park. It was one of the first protected sites declared as early as 1934. The restored beech forests are of coppice origin in places with excessive use until 100 years ago for the smelting of metals since antiquity. Due to the erosion processes operating during the last millennia and the coppice management of beech forests, the depth of the main soil horizons has decreased, which reflects the growth of the main tree species and deterioration of the general condition of these recovering phytocenoses (unpublished data). In the last 80 years, logging has been of very low intensity because of the protected and park status of these forests. A very long period of time, about 200-300 years, is needed for these phytocenoses to fully approach the natural forests in the old age phase, and to prohibit and control the unregulated removal of dry and fallen mass from SP 1 and SP2.

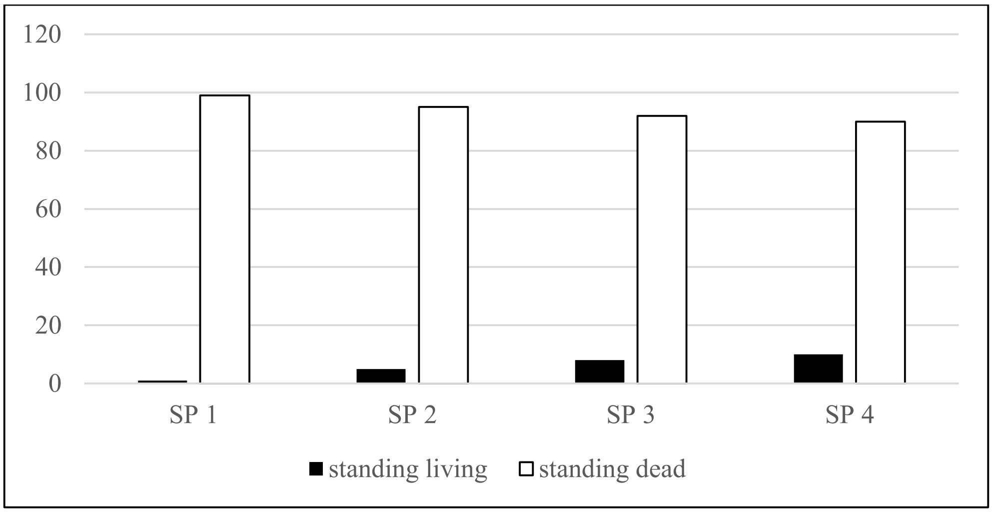

Fig. 2. Ratio (%) between dead and live trees in the sample plots.

Table 2. Dead wood biomass volume at sample plots (V, m^3 ha^{-1}).

Sample plot	Standing	Lying			Stumps	Total
		coarse woody debris	fine wood	total		
SP 1	0.6	7.79	6.89	14.68	0.07	15.35
SP 2	3.8	2.3	2.8	5.1	1.03	9.93
SP 3	4.5	23.2	2.5	25.7	4.52	34.72
SP 4	14.84	5.5	5.5	10	5.2	30.04

Table 3. Degrees of decomposition of different fractions of dead wood biomass (%).

Class	Standing biomass			
	SP 1	SP 2	SP 3	SP 4
1	100	75	0	78
2	0	25	0	22
3	0	0	20	0
4	0	0	60	0
5	0	0	20	0
Class	Lying biomass			
	SP 1	SP 2	SP 3	SP 4
A	21	11	42	65
B	43	80	33	29
C	29	9	17	4
D	7	0	8	2
Class	Stumps			
	SP 1	SP 2	SP 3	SP 4
A	0	0	8	13
B	100	13	31	8
C	0	37	38	21
D	0	50	23	58

SP3 is an elite beech stand used over the decades for various studies as a long-term sample area by various researchers. It is typical according to altitude, humidity, growth and productivity. Its peculiarity is the presence of a major road from the national road network in the immediate vicinity, which can lead to an increased anthropogenic impact - unregulated collection of dry and fallen mass and its removal beyond the limits of the sample plot. The presence of a major road is a prerequisite for unregulated illegal logging.

There is a complex of unfavorable factors in SP4. The stand is single-aged, on a slope with a significant inclination, being at the lower limit of the beech vegetation belt according to the altitude. It was managed by high-intensity clear-cutting over large areas in the past so today we have unsustainable single-aged stands. In the newly emerged stand, correct mature cuttings were not applied with the required intensity and during the required time interval. There are special geographical features of the landscape - strong winds with accumulation of wet snow as well as rains of high intensity for a short time in SP 4. In cases of started or unfinished vegetation, in the beech phytocenoses in SP 4 there are conditions for the breakage and uprooting of individual trees as well as for whole groups, as a result of unfavorable climatic factors.

Another unfavorable factor is the presence of high-intensity felling around the tractor transport roads and clearings, and at the same time the lack of use in hard-to-reach places, mainly steep ravines. This contributes to the formation of groups of beech trees of seed origin, but without cultivation (lack of cultivation cuttings). These groups have high coverage and thin stems, that is, with low physical and mechanical properties and are more susceptible to adverse climatic factors.

When comparing the data from the four sample plots, it can be seen that in Stara Planina, larger amounts were obtained - on average 32.38 m^3 ha^{-1}, while for Vitosha they were 12.64 m^3 ha^{-1}, respectively. This is most likely due to the fact that in SP 3 and SP 4 the forests are older, 130 and 150 years, respectively, and the quantities are larger, which is natural, as well as the fact that the stand in SP 4 has suffered from an abiotic disturbance i.e. intensive snowfall. SP 4 Due to the specifics of the relief in this part of the mountain the stand in SP 4 is exposed to wind and snowfalls. Improper cuttings have created a single-age stand that is more susceptible to disturbance.

The small amount of fallen biomass in SP 2 may be due to the shape of the terrain - steep, convex and the anthropogenic factor. Due to the proximity of small restaurants, it is likely that people retrieved the fallen dead wood and used it for heating.

In almost all sample areas (except SP 4), the predominant share of the dead biomass is represented by the lying biomass. For most SP, the coarse and fine wood are of similar amounts. The exception is SP 3, where the coarse debris are of significantly larger quantities, due to trees damaged by a windstorm. Standing stocks are in second place after the lying biomass. The most common damages are breakage and drying. Stumps are the least present.

Some authors observed a decrease in the amount of dead biomass with increasing altitude (Kacprzyk et al., 2014), mainly reducing the amount of coarse debris and increasing the amount of dead standing trees. In our research, this applies to the sample plots located in Vitosha Mountain - the stand at a lower altitude, SP 1, has a greater total amount of dead biomass. In Stara Planina, such a trend is not observed. There, the total volumes are similar.

In our previous studies in beech forests on the territory of the Western Stara Planina, average amounts of 14.48-41.8 m^3 ha^{-1} were estimated (Dimitrova, 2018). Standing dead biomass was 6.7 - 17.5 m^3 ha^{-1}, lying - 3.4 - 26.5 m^3 ha^{-1}, and stumps - 0.28 - 6.4 m^3 ha^{-1}. The present results are similar.

When comparing our results with those of other authors, it can be seen that the amounts obtained in the present study are smaller, since Zlatanov et al. (2016) indicate quantities of the order of 50 m^3 ha^{-1}, as typical of many of the old oak and beech forests in Bulgaria. For example, in relatively presserved beech forests, in the reserves "Kongura" and "Silkosia", the total amounts of dead wood vary from 40 to 140 m^3 ha^{-1}. For the Steneto reserve, 150 m^3 ha^{-1} is indicated (Asenova et al., 2019).

On the other hand, Monaco et al. (2022) investigated the amount and quality of dead wood in beech forests in a reserve in Italy and reported amounts of 9.58 m^3 ha^{-1}. Christensen et al. [2005] analyzed dead biomass stocks in beech reserves in Europe and reported average amounts of 130 m^3 ha^{-1}. In Poland, stocks from 41.9 m^3 ha^{-1} to 165.8 m^3 ha^{-1} (Maślak & Orczewska, 2010) and 55.55 m^3 ha^{-1} (Kacprzyk et al., 2014) were obtained. Veapi et al. (2018) in their investigation of Macedonian beech forests were estimated the highest amount of down dead wood in the most preserved forest (19.04 t·ha^{-1}), and the lowest - in the most degraded forest (2.68 t·ha^{-1}).

At this stage, it is considered that the minimum amount of dead biomass that must be available in a stand for it to be in a favorable conservation status, if we use the methodology for habitats from the Natura 2000 network (Zingstra et al., 2009) is 8% of its yield. And at least 10 trees per ha has to be standing dead trees.

In our research, we could tentatively use these criteria for evaluating the amounts of dead wood, with the clarification that it was not evaluated on the territory of the entire habitat. The obtained results are shown in Table 4.

It shows that the percentage of total dead wood relative to the stock of the entire stand is insufficient from a conservation point of view in sample areas 1, 2 and 3, although the number of standing dead trees in SP 2 and 3 reaches the criterion specified in the methodology for the assessment of a favorable environmental status.

Table 4. Ratio of deadwood stock to total stand stock.

Dead wood	SP 1	SP 2	SP 3	SP 4
Standing dead trees, number per ha	4	16	40	36
Total dead wood, % of stand stock	4.3	3.2	5.6	13.4

Conclusions

The total amount of dead wood in the studied forests is not sufficient from an environmental point of view. Most likely, the stocks do not provide very good conditions for saproxylic and other organisms related to it. There is a need for further similar studies in preserved beech forests to better estimate the minimum amount of dead wood that needs to be left in managed forests to contribute the biodiversity increased.

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