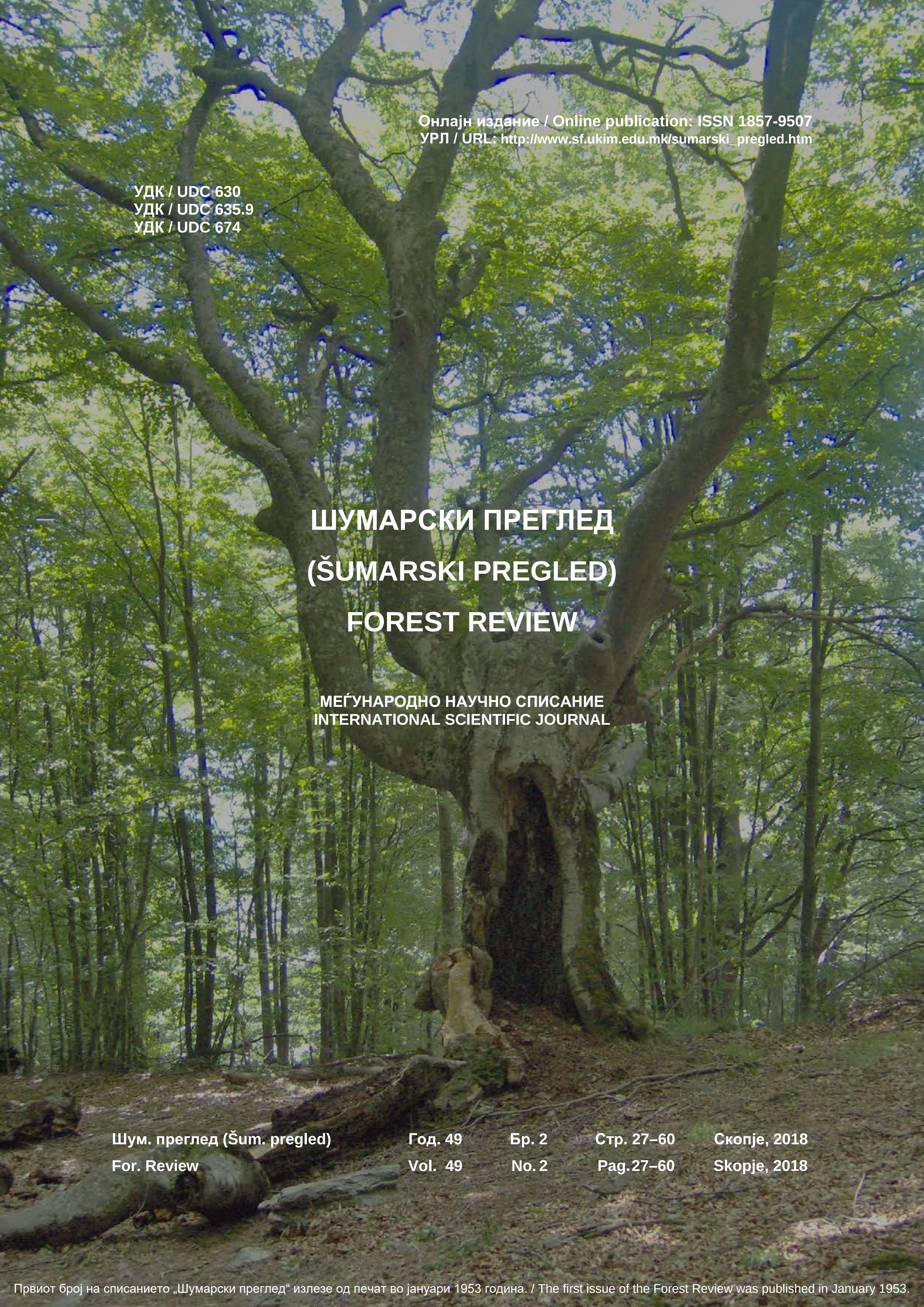

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Original scientific article

Down dead wood in a montane beech forest stands on Deshat Mountain: Carbon sequestration

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ABSTRACT: Knowledge on carbon cycling and its sequestration in forest ecosystems is invaluable for understanding of climate change and consequences on the management of forest resources. The paper deals with the results on the content and quantity of carbon in down dead wood in five montane beech forest stands on Deshat Mountain in Mavrovo National Park. The stands were selected to represent five different types of degradation and management practices in beech forests (from highly preserved forest stands with old thick standing trees and large numbers of fallen trees with accumulated biomass, to degraded forest stands represented by a resprouting trees and small amount of coarse biomass). Carbon content was determined by using the Kotzman method. Carbon quantity was calculated based on carbon content and the biomass of dead wood (logs and branches of different sizes and decomposition stages). The highest quantity of carbon in down dead wood was found in the most preserved forest (9.7 $t \cdot ha^{-1}$), and the lowest - in the most degraded forest (1.4 $t \cdot ha^{-1}$). Carbon quantity in large branches ranged between 0.52 and 4.91 $t \cdot ha^{-1}$, while the carbon content of fallen trees varied between 0.59 and 5.98 $t \cdot ha^{-1}$. It can be concluded that the old forests represent very important storage of down dead wood carbon.
Keywords: forestry management, dead wood, biomass, carbon sequestration

1 INTRODUCTION

Forest biomass plays a key role in energy supply and climate change connected to carbon cycle in the biosphere and ecosystem processes. Scientific contributions in the past few decades were targeted towards the impacts of climate change on the resilience of forest ecosystems by measuring the sequestration of atmospheric carbon into live and dead biomass as well as soil carbon transformations [1]. The increase in temperature and more severe droughts may increase the dead wood and alter the biogeochemical processes in forest ecosystems [2].

This is highly relevant for the coarse dead wood in forest ecosystems that consists of standing trees, down dead wood (DDW) and stumps [3]. The accumulated DDW is important for all ecosystems, although its quantity is particularly emphasized preserved forest ecosystems for their high biodiversity value [4,5].

The research of carbon in forest dead wood of Macedonia is very scarce. Few research projects dealing with dead wood biomass have provided data for carbon quantities in litterfall and forest floor (including large branches, without logs) of oak [6,7] and beech forest ecosystems [8,9]. The latter estimated the carbon in dead standing biomass of large branches of 3.4 $t \cdot ha^{-1} yr^{-1}$ in the beech forest ecosystem in Mavrovo [9].

Being a party of the United Nations Framework Convention on Climate Change and Kyoto Protocol, Macedonia is committed to submit reports on carbon emissions. The changes in landuse and forestry practices impact the total emissions and storages of carbon (aboveground and belowground biomass, dead wood, soil carbon, etc.) and these parameters should be measured, estimated and reported. One of the priorities is to estimate carbon in different decomposition stages of dead wood as well as to assess carbon quantities in old forests (usually, forests in protected areas).

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 (both logs and coarse branches) have already been published [10]. In this article, the focus is on the carbon sequestration in DDW of a montane beech forests.

2 MATERIAL AND METHODS

2.1 Study area

Deshat Mountain is situated in the west part of Macedonia. Beech forests are the dominant forest type in the mountain.

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. 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 stands while the biomass of dead branches was measured by line transects [10].

Three plots (15 in total) were selected in each of the five forest stands. All of these plots were selected based on field observations and they represent the variability within the forest stands. Stand tree density was estimated as an average of tree density of the three sampling plots within each of the five investigated stands. In each of the 15 plots we recorded the number of trees and we measured DBH (diameter at breast height) of each tree. DBH of trees ranged from 3 to 85 cm. In the same time we recorded the number of shrubs in each of the 15 plots. The applied methods were already published in detail [10].

2.2 Determination of decay classes of 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 (I-V). Most of the similar studies defined four decay classes and their description corresponds to our classification [11–14]. However, we added category V which refers to dead wood in the last stages of decomposition with very low wood density (sponge-like wood).

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. 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: $\rho = m/(s.h)$.

2.3 Carbon determination

Carbon content (% w/w) was determined by using the Kotzman method [15]. Carbon content was determined in 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.

Carbon quantity in tons per hectare was calculated based on the carbon content and biomass of corresponding down dead wood fractions and decay classes.

3 RESULTS

3.1 Carbon content

Carbon content varied among the different decay classes of logs (Tab. I). During the research we did not collect dead log of D1 for analysis of carbon (for calculation of carbon quantity in D1 we used the value for carbon content in D2). The highest content of 51.80% was determined in D4 and the lowest in D2 (50.44%). The average carbon content was 50.94%.

Table I: Carbon content in different decay classes of dead logs

Decay classes	Carbon content (%)
D2	50.44
D3	50.49
D4	51.80
D5	51.02
Average	**50.94**

The average carbon content in dead branches was 50.00%. Carbon content in different decay classes and diameter fractions is presented in Tab. II. In average, the carbon content in DDW (logs+branches) was 50.78%.

Table II: Carbon content in different decay classes (D2-D4) of dead branches

Diameter of fractions	**3–5 cm**				**5–10 cm**				**10–20 cm**		
Decay classes	D2	D3	D4	**average**	D2	D3	D4	**average**	D3	D4	**average**
Carbon content (%)	49.75	49.81	50.56	**50.07**	50.44	50.49	50.97	**50.71**	50.54	49.46	**50.00**

3.1.1 Down dead wood carbon of fallen tree logs

Carbon quantity follows the biomass in down dead wood of tree logs (Tab. III). The highest carbon quantity was estimated in PF with 5.98 $t{\cdot}ha^{-1}$. The lowest was estimated in CF (0.59 $t{\cdot}ha^{-1}$). The average carbon quantity in the five investigated beech stands amounted to 2.96 $t{\cdot}ha^{-1}$. The highest carbon quantity was estimated in D4 (1.88 $t{\cdot}ha^{-1}$) and the lowest in D5 (0.01 $t{\cdot}ha^{-1}$)

Table III: Carbon quantity ($t{\cdot}ha^{-1}$) in tree logs according to decay classes (D1-D5)

Forest stand	**Decay classes**					**Total**
	D1*	**D2**	**D3**	**D4**	**D5**	
OF	0.01	0.71	1.23	2.77	0.05	**4.77**
PF	0.06	0.56	1.27	4.09	0.00	**5.98**
GF	0.00	0.18	0.70	1.76	0.00	**2.64**
CF	0.00	0.04	0.22	0.33	0.00	**0.59**
DF	0.00	0.05	0.34	0.45	0.00	**0.84**
Average	0.01	0.31	0.75	1.88	0.01	**2.96**

3.1.2 Down dead wood carbon of fallen large branches

The average carbon quantity in down dead branches in the five investigated beech stands is 2.14 $t{\cdot}ha^{-1}$. The highest carbon quantity was recorded in OF (4.91) and the lowest in DF (0.52 $t{\cdot}ha^{-1}$). The highest carbon quantity was recorded in the fraction of 3-5 cm and in decay classis D3 (Tab. IV)

Table IV: Carbon quantity in different size and decay classes of branches in the investigated beech stands ($t{\cdot}ha^{-1}$)

Forest stand	**3–5 cm**				**5–10 cm**				**10–20 cm**			**Total**
	2	3	4	Total	2	3	4	Total	3	4	Total	
OF	0.13	0.91	0.07	1.11	0.00	1.51	0.86	2.37	1.32	0.10	1.42	**4.91**
PF	0.07	0.92	0.07	1.07	0.37	0.30	0.44	1.10	0.00	0.00	0.00	**2.17**
GF	0.09	0.67	0.29	1.05	0.23	0.16	0.05	0.44	0.00	0.00	0.00	**1.49**
CF	0.48	0.64	0.33	1.45	0.00	0.00	0.16	0.16	0.00	0.00	0.00	**1.61**
DF	0.12	0.15	0.04	0.30	0.00	0.22	0.00	0.22	0.00	0.00	0.00	**0.52**
Average	**0.18**	**0.66**	**0.16**	**1.00**	**0.12**	**0.44**	**0.30**	**0.86**	**0.26**	**0.02**	**0.28**	**2.14**

3.1.3 Total down dead wood carbon

The average carbon quantity in down dead wood in the five investigated beech stands is 5.80 t·ha^{-1}. OF had the highest value (9.7 t·ha^{-1}) while DF (1.4 t·ha^{-1}) had the lowest one (Fig. 1).

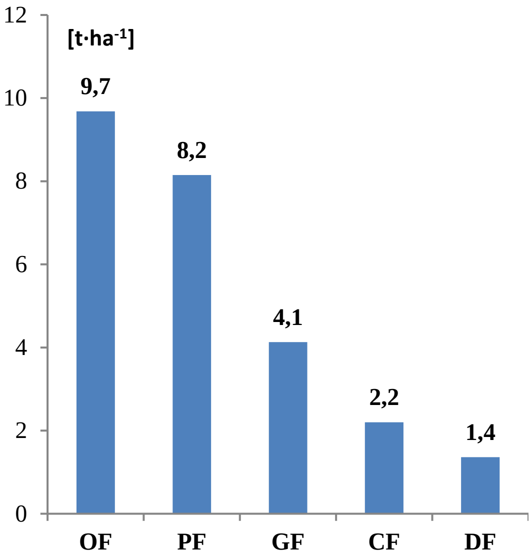

Figure 1: Total down dead wood carbon (logs+branches) in the investigated beech stands

4 DISCUSSION

4.1 Carbon content in DDW

Carbon quantity in DDW varies among different tree species (e.g. carbon content is different in *Picea abies* and *Fagus sylvatica* - [16]). Numerous studies have showed that the carbon content in DDW varies depending on the decomposition process intensity (according to the dominated tree species, wood properties, microorganisms abundance, soil properties, climate etc.) [17–20]. Some ecological factors are considered as specific triggers for certain decomposition stages, such as precipitation between D1 and D3 [16], microorganisms in the initial decomposition stage and temperature in the stages between D1 and D4 [21, 22].

Some of the studies show that the carbon content increases with decomposition [23], some of them recorded no significant changes [16]. The results from our study suggest increase in carbon content in the initial stages of decomposition (D2-D4) and rapid decrease in the late stages (D4-D5). The similar pattern was observed for the carbon content in small branches (0.5-1.5 cm) and leaf litter in another beech forest ecosystem in Mavrovo National Park [8,24].

Some studies on carbon quantities use DDW conversion factors instead of direct measurements of carbon content. For Russian boreal forest a content of 51% was used [11], while IPCC recommends simple conversion factor of 50% [25]. This value was used in the estimation of carbon in dead wood in beech forests in Serbia [14]. The commented conversion factors can be applied for estimation of carbon quantity in DDW in most forest ecosystems since the carbon content shows very small variations in different decay classes of logs and branches of different size.

4.2 Carbon quantity in DDW

The carbon quantity in logs in the investigated beech stands ranged between 0.59 and 5.98 t·ha^{-1} with average value of 2.96 t·ha^{-1}.

Carbon quantity in coarse branches ranged between 0.52 and 4.91 t·ha^{-1}. For the well preserved stands (OF and PF), the largest quantity of carbon was stored in the fraction 5-10 cm and D3. In the more degraded beech stands, the branches with diameter of 3-5 cm prevailed.

The total quantity of carbon in DDW varied between 1.4 and 9.7 t·ha^{-1}. OF and PF with 9.7 and 8.2 t·ha^{-1} had 2-7 times more carbon than the quantity stored in GF, CF and DF. These values clearly show that the old-growth and better preserved forests are much more important as storage of carbon in DDW. By the published data for forests in USA, the carbon in DDW range from 5 to 25 t·ha^{-1} [26]. Carbon stock in aboveground dead wood (down dead wood+stumps) of beech forests in Serbia was estimated at 3.03 t·ha^{-1}, or 1.47-4.60 t·ha^{-1} [14].

The power for carbon sequestration of forest ecosystem depends on annual net productivity, especially annual increment and carbon stored in DDW. The capacity of forest ecosystems for carbon sequestration through annual net productivity is enormous. Previous study in one beech forest in Mavrovo National Park reported value for carbon sequestration of 4.2 t·ha^{-1}·yr^{-1} [9]. Nevertheless, the potential of carbon sequestration in DDW is also very significant. We also calculated the total quantity of carbon stored in DDW in montane beech forests on Deshat by multiplying the values of carbon per hectare with the area of montane beech forests of 29.44 km^2 [27]. We found that carbon in logs and branches amounts to 8714.2 t and 6300.2 t, respectively.

Republic of Macedonia is a party of the United Nations Framework Convention on Climate Change and assessments of carbon in DDW are needed to report greenhouse gas emissions and carbon sequestration from land use and forestry sectors [3]. The quantity of sequestered carbon in fine litter fractions of forest floor of montane beech forests is 868 Kt [28]. This calculation was based on the value of 8.79 t·ha^{-1}, which contains fine litter fractions and coarse branches [29]. The value of 8.79 t·ha^{-1} should be increased for the quantity of carbon in logs which amounts to 2.96 t·ha^{-1} for the montane beech forests on Deshat Mt.

Having in mind the magnitude of DDW for carbon sequestration, it is very important to implement proper forestry management which will maintain and increase DDW in forest ecosystems. The forest growth i.e. annual net productivity plays significant role in sequestration of atmospheric carbon. Hence, the forest management should be a compromise between climate change mitigation and resource use priorities [30].

5 CONCLUSIONS

The studied old-growth and preserved beech forests stored more carbon than the young and degraded beech forests. As the rate of forest degradation increased, the quantity of stored carbon in the total biomass continuously decreased.

The average carbon content in dead branches was 50.00%. In average, the carbon content in down dead wood (logs+branches) was 50.78%. Carbon quantity followed the biomass in down dead wood of tree logs. The carbon quantity of logs in the investigated beech stands ranged between 0.59 and 5.98 t·ha^{-1} with average value of 2.96 t·ha^{-1}.

In the case of dead branches, the average carbon quantity in five investigated beech stands was 2.14 t·ha^{-1}. The highest carbon quantity was recorded in old-growth forests (4.91 t·ha^{-1}) and the lowest - in degraded forest (0.52 t·ha^{-1}). The highest carbon quantity was recorded in the fraction of 3-5 cm and in decay classis D3. The average carbon quantity in total down dead wood (logs+branches) in five beech stands was 5.80 t·ha^{-1}.

The total quantity of carbon in down dead wood varied between 1.4 and 9.7 t·ha^{-1}. Old-growth and preserved forests with 9.7 and 8.2 t·ha^{-1} had 2-7 times more carbon than the quantity stored in good forest, coppice forest and degraded forest stands. These values clearly showed that the old-growth and better preserved forests were much more important as storage of carbon in down dead wood.

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