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Down dead wood in a montane beech forest stands on Deshat Mountain. 5. Impact of forestry management practices

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Abstract

Down dead wood (DDW) is a crucial component of forest ecosystems contributing to decomposition, nutrient cycling, soil formation and biodiversity. Despite its ecological significance, historical and ongoing forest exploitation has led to a decline in DDW, particularly in coppice forests. This study was conducted in montane beech forests on the eastern slopes of Deshat Mountain, in the Mavrovo National Park in North Macedonia. Its aim was to assesse the impact of traditional forestry practices on the amount of down dead wood and other forest parameters. Five forest stands were selected based on differences in forest management and stand structure. In each stand, three sampling plots (15 in total) were established to assess tree density, diameter at breast height (DBH) and shrub presence. Down dead wood (DDW) biomass was estimated by recording all fallen tree logs and categorizing their decay into five classes. Tree density in the investigated beech forests on Deshat Mountain varied significantly, with the highest recorded in coppice forest (7817 trees/ha) and the lowest in old-growth forest (1356 trees/ha). DBH ranged from 3 to 85 cm, with smaller trees (DBH 3–17 cm) dominating across all stands. A significant negative correlation was observed between stand density and dead branch biomass, indicating that intensive forest use near villages has reduced DDW availability. The spatial gradient of DDW accumulation suggests that human impact, particularly firewood collection by the local community has shaped forest structure. Historical and ongoing anthropogenic influences, coupled with rural depopulation, have altered DDW dynamics, with remote stands retaining more deadwood due to limited accessibility. These findings highlight the need for forest management strategies that balance conservation with sustainable resource use.

Key words: Mavrovo, firewood, tree density, suistainable forestry, down dead wood

Introduction

Down dead wood (DDW), along with standing dead trees, makes up what is known as coarse dead wood in forest ecosystems. Of these two components, down dead wood typically accounts for a much larger share in terms of quantity (Hottola and Siitonen 2008; Christensen et al. 2005). Down dead wood is a vital element of natural forest ecosystems, playing a key role in numerous ecological processes. It contributes significantly to decomposition, pedogenesis, erosion control and the biogeochemical cycles of carbon and nutrients (Harmon et al. 1986; Harmon 2009; Krankina and Harmon 1995). Additionally, it supports natural regeneration and other essential forest functions (Næsset 1999; Brozek and Wanic 2002). Down dead wood has also important part for biodiversity in forest ecosystems. It provides key microhabitat for many

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species of invertebrates, fungi, birds and mammals as well as many other species that use down dead wood as a food source or shelter (Christensen et al. 2005). It is well known that proper management of down dead wood in forest ecosystems (sustaining varied down dead wood or even creating dead logs by cutting living trees) is of great importance for the survival of many species (Lindhe et al. 2005; Hottola and Siitonen 2008).

The long history of forest exploitation across Europe has resulted in reduced quantities of down dead wood. At present, the volume of down dead wood is generally higher in European upland forests, despite the fact that, under natural conditions, lowland forests would typically have a greater potential for dead wood accumulation (Christensen et al. 2005). The quantity and biomass of dead trees are widely recognized as important indicators of sustainable forest use and management, as well as the degree of forest preservation and biodiversity conservation (MCPFE 2003).

Republic of North Macedonia has a long history in forest exploitation that until the mid-20th century was often carried out without planning or legal restrictions. Intense anthropogenic pressure, including widespread logging for export, led to the degradation of large forest areas and the conversion of many high forests into low-stemmed forests of vegetative (coppice) origin (Kolevska et al. 2017).

Planned forest management based on sustainability principles introduced after World War II somewhat contributed to the preservation of forests in their generative form (Baumgartner and Stojanovska 2014). However, clear-cutting of low-forests has remained a common practice, and today around two-thirds of the country's forests are of coppice origin, typically lacking sufficient down dead wood (Stevanov et al. 2018; Trajkov et al. 2019). The situation is somewhat better in forests managed through thinning and selective cutting, while the highest amounts of dead wood are found in areas with no economic activity, such as virgin forests, old-growth stands, remote enclaves, and sacred or religious forests (Matović et al. 2018). Currently, there is no comprehensive national inventory of forest deadwood in North Macedonia, whether standing or downed. Modern forest management concepts, such as Sustainable Forest Management or Close-to-Nature Forestry, have yet to be fully integrated into forestry practices in North Macedonia (Andonovski and Velkovski 2019). However, in recent years, deadwood dynamics have begun to receive attention in forestry planning, particularly through their inclusion in management plans for areas such as National Park Pelister, the Bregalnica watershed and identified potential Natura 2000 sites. These initiatives aim to quantify the role of deadwood in carbon sequestration and to promote biodiversity conservation by safeguarding this critical habitat component.

Although conservation is prioritized in protected areas, national parks in North Macedonia were until recently solely self-financed, heavily relying on logging for revenue–a practice that continues in Mavrovo National Park (Tiepolo 2007). This practice has contributed to degradation, particularly near villages where locals also collect firewood. Hence, the lower oak forest region has been disproportionately exploited, leaving most stands degraded or coppiced, while beech forests are relatively better preserved, especially in less accessible areas.

In 2015, the biomass was assessed (Veapi et al. 2018a), as well as carbon content (Veapi et al. 2018b), mineral composition (Veapi et al. 2023a) and decomposition stages (Veapi et al. 2023b) of down dead wood in beech forest stands at varying degradation stages on Deshat mountain, within the National Park Mavrovo. In continuity, this paper explores the impact that forestry practices of local population and the Mavrovo National Park's forest management have on down dead wood in Deshat Mountain's beech forests.

Materials and methods

Study area

Deshat Mountain is situated in the west part of North Macedonia where natural beech forests are the dominant forest type. The montane beech forest belt spreads between 1300 and 1600 m a.s.l. The climate is montanuous with an influence from the continental climate as well as the Mediterranean climate at lower altitudes (Filipovski et al. 1996) While the dominant soil type is calcomelanosol (MASIS 2015).

Five stands were selected on the eastern slopes of Deshat, above Radika river gorge (Figure 1) based on the differences in forest management and the general structure of the stands. The main field research was conducted in the period 28.09-01.10.2015. All selected stands were of montane beech forest type, association *Calamintho grandiflorae-Fagetum* (Em 1965) Rizovski & Džekov ex Matevski (syn: *Fagetum montanum* Em).

The nearest rural settlements are villages Trebishte and Bitushe, with Trebishte being more accessable to the surveyed forest stands. The rural environments of Trebishte and Bitushe fall within the Reka mountain continental rural landscape, intersected within the surrounding mesophilous oak and beech forests (Melovski et al. 2019). Existing forest trails used by locals were digitized and measured in ArcGIS.

Sampling design

From each of the five forest stands, three plots were selected making a total of 15 studied plots. The selection of these plots aimed to represent the variability within the stands assessed by on-site observations. Tree density for each stand was calculated as the average density

Figure 1. Geographic position of the five investigated stands in relation to the villages of Trebishte and Bitushe on Deshat Mountain, North Macedonia.

from the three sampling plots within that stand. The surface of the plots depended on tree density and ranged between 100 and 300 m^2 (Table 1). In each of the 15 plots the number of trees was recorded and DBH (diameter at breast height) of each tree was measured. Notes for the human activity in the stands were also taken: signs of woodcut, woodpiles in the vicinity, types of human activity (sheepbreeding, hiking, etc.).

All of the fallen tree logs within the five investigated stands were recorded. The area covered ranged from 1.07 to 3.12 ha. The biomass of fallen branches was estimated in three line transects (30-60m in length) in all of the five investigated stands. Each of the 15 transects consisted of 10-20 sampling quadrats with surface of $1m^2$. Sampling quadrats were places in 3m distance of each other. All of the branches in the sampling quadrats were classified into three diameter classes (3-5, 5-10 and 10-20cm), weighed on a field scale (0.5g accuracy) and their decomposition category was noted (for more details see: Veapi et al. 2018a).

Results and discussion

The highest tree density was recorded in the CF (7817 trees/ha) and the lowest in OF (1356 trees/ha). DBH of trees ranged from 3 to 85 cm where trees with DBH of 3-17cm dominated in all of the investigated stands. One has to bare in mind that high figures of tree density is also due to the presence of very small trees (*vsm*) although forestry practice in North Macedonia considers trees with DBH larger than 10cm. PF was characteristic by the presence of trees with DBH of 17-25cm. According to the division categories provided by Alessandrini et al. (2011), the participation of very small trees (*vst*) was the highest in CF, lower in GF, PF and DF and the lowest in OF (Figure 2). In contrary, the number of very large trees (*vlt*) was the highest in OF, lower in PF and DF. No *vlt* were present in GF and CF. The largest DBH was calculated in PF (13.06 cm) and the lowest in GF (8.50 cm).

The highest down dead wood biomass (fallen trunks + branches) was accumulated in OF (19.04 $t \cdot ha^{-1}$) and it decreased in the following order: OF>PF>GF>CF>DF (Table 1). The average down dead wood biomass was 10.04 $t \cdot ha^{-1}$.

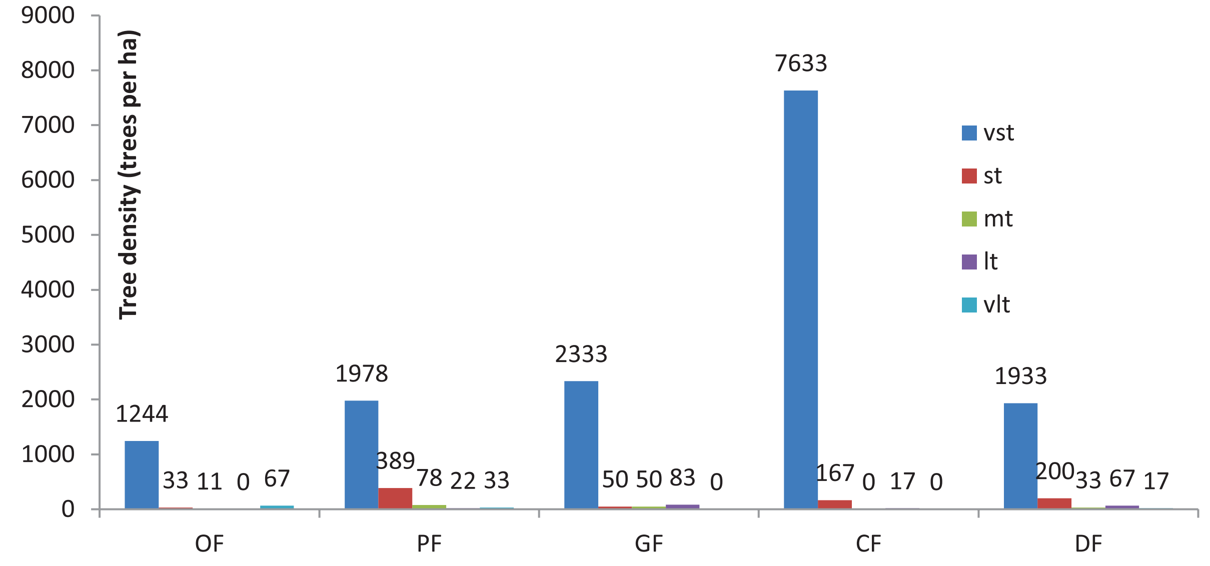

Figure. 2 Number of trees per hectare according the DBH in the five investigated beech stands (*vst* – very small trees, DBH = 2.5-17.5 cm; *st* – small trees. DBH 17.5-27.5 cm; *mt* – medium trees. DBH 27.5-42.5 cm; *lt* – large trees. DBH 42.5-57.5 cm; *vlt* – very large trees. DBH > 57.5 cm)

Table 1. Characteristics of the five investigated forest stands on Deshat Mountain

Parameter	Old forest (OF)	Preserved forest (PF)	Good forest (GF)	Coppice forest (CF)	Degraded forest (DF)
Stand description	Presence of many old trees in good health condition and very large fallen logs. Canopy cover of ~70%. Mild inclination.	Middle aged trees are dominant with scattered old trees. Presence of a number of large fallen logs. Mild inclination.	In a vicinity of sheepfold, next to Osmanova Livada locality. Steep inclination.	The forest consists of resprouting trees with great tree density. Mild inclination.	Few old trees left in a matrix of young and coppice trees and shrubs. Medium inclination.
Stand surface (ha)	3.12	1.07	1.76	1.63	1.15
Coordinates (decimal degrees)	E 20.562335 N 41.638982	E 20.559909 N 41.637849	E 20.558012 N 41.632271	E 20.561728 N 41.636545	E 20.576259 N 41.628454
Altitude (m)	1580-1595	1570-1590	1635-1680	1575-1595	1305-1350
Average DBH	12.0	13.5	9.2	9.1	11.8
Tree density	1355.6 (800-1933)	2500.0 (1733-3433)	2516.7 (1550-3750)	7816.7 (7350-8700)	2250.0 (1600-3100)
Estimated live tree biomass ($t \cdot ha^{-1}$)	527.1 (362.1-629.2)	518.7 (316.7-762.0)	290.3 (93.7-546.6)	373.6 (352.3-401.4)	397.7 (273.7-531.8)
Average number of logs per hectare	23.4	43.0	23.9	38.6	41.7
Volume of tree logs ($m^3 \cdot ha^{-1}$)	91.26	40.37	24.65	6.18	5.72
Biomass of dead logs ($t \cdot ha^{-1}$)	9.31	11.62	5.14	1.15	1.65
Biomass of dead branches ($t \cdot ha^{-1}$)	9.73 ± 0.76	4.32 ± 1.47	3.22 ± 0.21	2.97 ± 0.16	1.03 ± 0.21
Total down dead wood biomass ($t \cdot ha^{-1}$)	19.04	15.96	8.11	4.38	2.68
Human impact	No recent human activities, although collection of dead wood is taking place.	Few signs of wood cut and probably collection of dead wood.	Visible signs of continuous use, mostly collection of branches by the shepherds.	Intensive human use (firewood for the sheepfold that existed in the vicinity), especially in the last 50 years.	Intensive use by the inhabitants of villages Trebishte and Bitushe was observed.
Distance from village of Trebishte (km)	2.04	1.90	1.94	1.66	1.19
Elevation gain from village of Trebishte (m)	540	535	600	535	275

Table 2. Quantity of DDW ($m^3 \cdot ha^{-1}$) in managed and unmanaged forests in Europe

DDW in unmanaged forests ($m^3 \cdot ha^{-1}$)	DDW in managed forests ($m^3 \cdot ha^{-1}$)	Country	Reference
73	11	Sweden	Andersson and Hytteborn, 1991
44-91	1.7	Sweden	Lämås & Fries, 1995 (in Fridman et al. 2000)
11-15	0.5-1.0	Sweden	Linder & Östlund, 1998 (in Fridman et al. 2000)
81	2,3	Sweden and Russia	Majewski et al., 1995 (in Fridman et al. 2000)
54	14	Scotland	Reid et al. 1996
47-128	4-39	Great Britain	Green & Peterken, 1997
23	10	Switzerland	Guby & Dobbertin, 1996 (in Fridman et al. 2000)
24-91	5.7-6.2	North Macedonia	OF, PF and GF are presented as unmanaged, CF and DF as managed stands (Veapi et al. 2018a)

The average volume of down dead wood in the investigated beech forests on Deshat Mt. was 33.63 $m^3 \cdot ha^{-1}$ (Veapi et al. 2018a). Down dead wood in European beech forests ranges between 32 and 310 $m^3 \cdot ha^{-1}$ (Saniga and Schütz 2001) with higher amounts in European beech forest reserves of about 130 $m^3 \cdot ha^{-1}$ (Hahn and Christensen 2004; Christensen et al. 2005; Ódor et al. 2006). Only the OF (91.26 $m^3 \cdot ha^{-1}$) approaches the European average of beech reserves while DF (5.72 $m^3 \cdot ha^{-1}$) represents highly exploited forests with very small amount of DDW. The amount of DDW depends on several factors from which the forest age, managements and use, soil, climate and decomposition are the most important (Stokland 2001; Hahn and Christensen 2004). Nevertheless, the results of the investigation conducted in beech forests on Deshat Mountains show that the old forests are important storages of down dead wood, both trunks and branches (Veapi et al. 2018a; b).

There are several studies that aimed to show the differences in DDW between managed and unmanaged forests. Unmanaged forest have much higher DDW biomass than managed forests (Table 2). The DDW quantity in unmanaged old forests in Europe and North America averages at 104.4 $m^3 \cdot ha^{-1}$ while unmanaged young forests hold 38.0 $m^3 \cdot ha^{-1}$ in average; the managed forests have the lowest amount of 23.9 $m^3 \cdot ha^{-1}$ (Green and Peterken 1997).

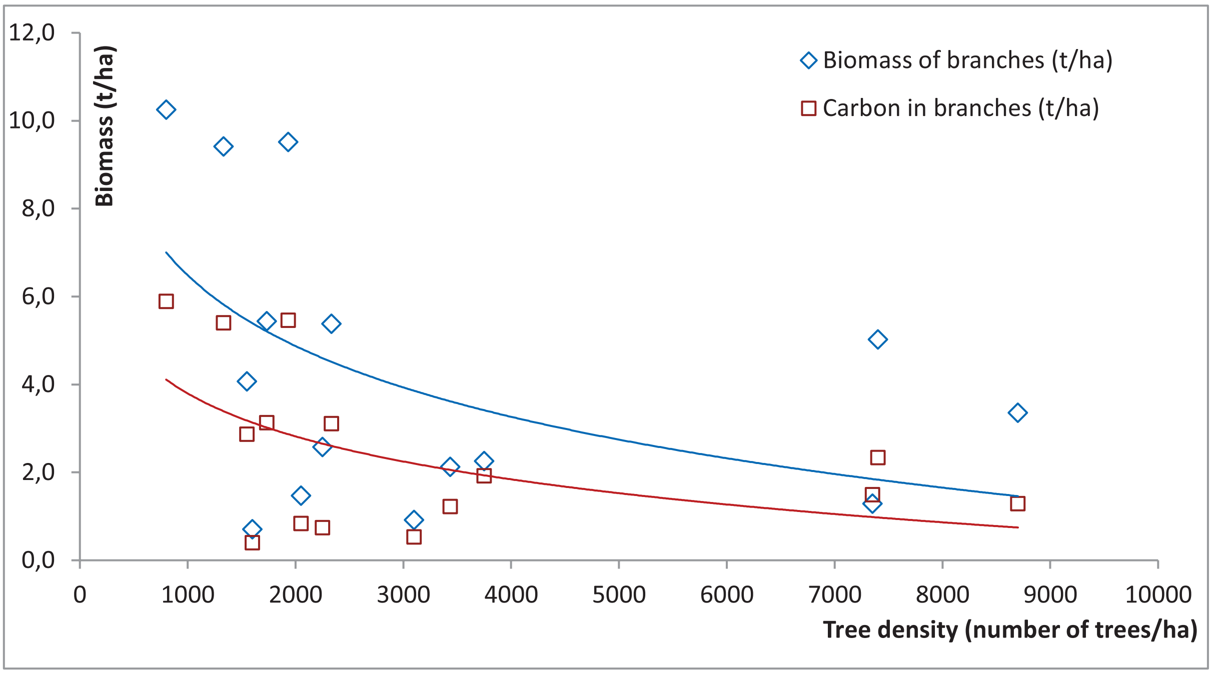

Figure 3. Correlation between biomass ($p<0.05$; $r=0.618$) and carbon ($p<0.05$; $r=0.637$) of dead branches with live tree density in the 15 experimental plots

It may be expected that DDW biomass is correlated to the parameters of live biomass. There is statistically significant correlation between the biomass of dead branches and stand density (Figure 3). The larger the density of trees the smaller the biomass of dead branches.

Most of the research conducted in Europe did not establish clear correlations between live and dead biomass (Siitonen et al. 2000) due to the apparent human impact (woodcut, collection of dead wood, forest fires, soil erosion, changes in the population of herbivores, etc.). The case of forest stands on Deshat is more similar to other European forests. The results suggest that the exploitation of forests by the local population has significant impact on both live and dead biomass. It can be inferred that the characteristics of the five investigated forest stands are a result of both natural processes and the longstanding influence of human activity. Overall, there is a noticeable increase in the amount of dead branch biomass with greater distance from the village of Trebishte (Figure 4). This pattern suggests a gradient of human impact, likely driven by the accessibility of these areas. Since there are no roads in this part of the region, the investigated stands are not accessible by vehicles which limits the intensity of forest use by the national park authorities themselves. As a result, it is reasonable to assume that local inhabitants have historically collected firewood (particularly dead branches) more intensively from the stands closest to the village, where access is easier rather than official national park management. In the past, inhabitants of the nearby village of Trebishte collected deadwood, including logs and branches, to meet household firewood needs. This practice was further encouraged by the Mavrovo National Park (MNP), as the collection of DDW was subject to the lowest taxation rates, making it an economically viable source of fuel for local communities. Consequently, there was once intensive gathering of DDW from the forests surrounding Trebishte. Over the years, rural-urban migration and emigration have led to a steady population decline in most villages across in Reka region (State Statistical Office of the Republic of Macedonia 2012). According to the most recent census, the combined population of Trebishte and Bitushe is less than 700 people (State Statistical Office 2022). Factors such as rural depopulation, the labor-intensive nature of wood collection and the challenges of transporting firewood (typically by animals) have contributed to the abandonment of regular firewood harvesting in these remote stands. However, the remaining residents continue to rely on their surrounding environment to sustain their livelihoods. Traditional stockbreeding and farming practices, which historically left a significant and lasting imprint on the region's grasslands and forest ecosystems have diminished in both scale and intensity over time, but still persist.

The largest average log volume was recorded in OF, PF and GF and the lowest log volume (smallest logs) were found in DF and CF (Table 1). Also, the greatest number of dead logs were found in GF and the lowest in DF. It is clear that the old and less exploited forests (OF, PF, GF) have larger DDW biomass and the number of logs is lower in the exploited forests (CF, DF) for timber. The

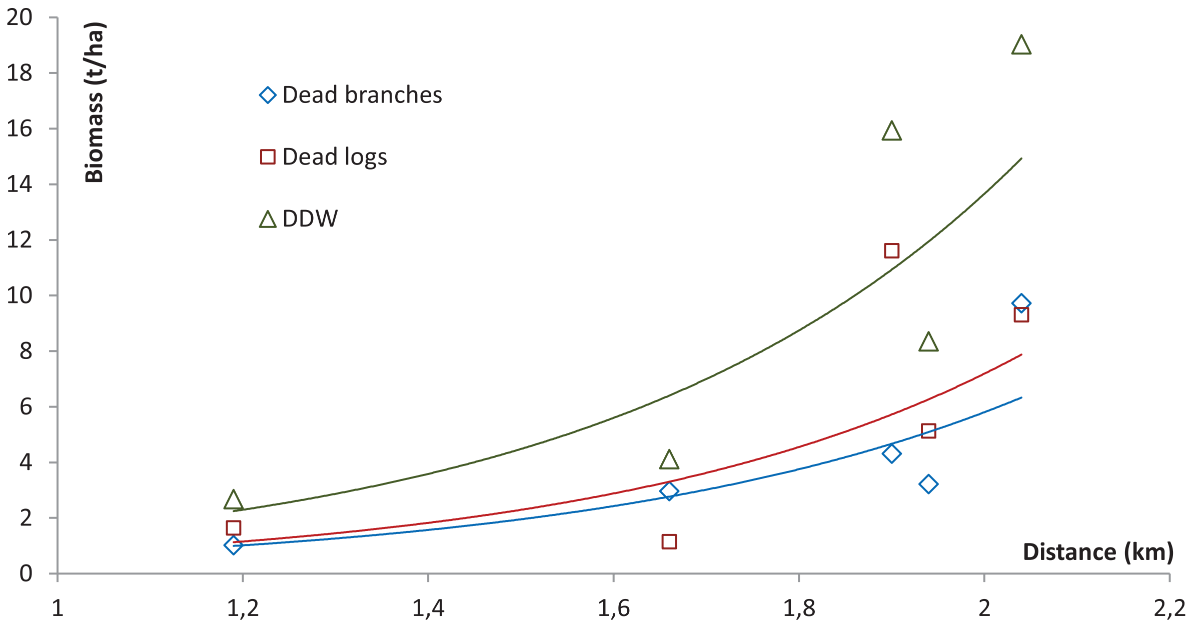

Figure 4. Dependence of DDW biomass ($p<0.05$; $r=0.098$), biomass of dead branches ($p<0.05$; $r=0.918$) and biomass of logs (n.s.) from the distance from the village of Trebishte

DDW biomass was lowest in DF which is closest to the village of Trebishte. DDW biomass in CF is also low due to the firewood exploitation by former sheepfold for at least 50 years (Table 1).

The forests of Deshat Mountain are managed by the Mavrovo National Park administration in accordance with 10-year silviculture and forest protection plans for protected areas (Tiepolo 2007). While these plans permit the harvesting of a limited volume of wood, their primary focus is on improving forest health through silvicultural and protection measures. On the positive side, intensive logging and clear-cutting are prohibited; however, thinning operations of low to moderate intensity are allowed. In practice, dead trees uprooted by snow avalanches or windstorms are also collected by locals, particularly for firewood. Branches with a diameter smaller than 7 cm are typically left piled in the forest or used by shepherds.

Conclusions

Past forest management practices on Deshat Mountain have significantly influenced the current state of forest down dead wood. Our results show that the amounts of forest down dead wood per unit area are low, highlighting the need for targeted actions to increase its amount, particularly in degraded forests and those of coppice origin. Despite regulations, the current management approach in Mavrovo National Park does not place sufficient emphasis on biodiversity conservation or the preservation of deadwood, both of which are key components of sustainable forest management. Adopting more modern forest management approaches, such as 'Sustainable Forest Management','Close-to-Nature Forestry' or 'Nature-Based Solutions' could play a crucial role in improving down dead wood levels. These practices would enhance the quantity of forest down dead wood and contribute to the broader goal of preserving biodiversity within the beech forests of Deshat Mountain. In this context, the assessment of deadwood in the forests of Deshat Mountain provides valuable baseline data that can inform future management strategies, contribute to national monitoring efforts and support the adoption of sustainable forest management practices that integrate deadwood conservation as a key ecological indicator.

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