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ORIGINAL PAPER

Variation of deadwood density by decay class in pure and mixed Oriental spruce stands in Northeastern Black Sea

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Abstract

This study focuses on the identification and comparisons of the distribution of deadwood volumes in pure and mixed Oriental spruce stands in both the managed and protected areas of Savsat region according to decay and deadwood classes. Within the scope of the study, a total of 476 sample plots including the variability of age class, site class, canopy and stand type were taken from the area. In each sample plot, the number and size (diameter and height) of deadwood trees such as standing deadwood trees, stumps, downed deadwood trees as well as their detailed characteristics (deadwood tree classes and decay classes) were measured. The estimated average volume of the total deadwood and its ratio to the standing growing stock was 10.1 m^3/ha and 2.5% in the Veliköy Forest Management Unit (FMU) and 22.5 m^3/ha and 4.2% in the national park. The deadwood volumes in decay classes, from high to low, were calculated as 3.56, 2.26, 2.03, 1.85 and 0.41 m^3/ha in Decay Class 2 (DC2), Decay Class 3 (DC3), Decay Class 5 (DC5), Decay Class 4 (DC4) and Decay Class 1 (DC1) decay classes for Veliköy FMU; and 9.81, 6.13, 3.46, 2.59 and 0.47 m^3/ha in DC3, DC2, DC4, DC5 and DC1 decay classes for the Karagöl-Sahara National Park, respectively. The decay classes in which the deadwood volumes in the standing deadwood, downed deadwood and stump classes are the highest are DC2 (69%), DC4 (30%) and DC5 (33%) in the managed forests, respectively. In the protected forest, the decay classes in which the deadwood volumes in the standing deadwood, downed deadwood and stump classes are the highest are DC3 (52%), DC3 (47%) and DC5 (31%), respectively. The distribution of deadwood volume by deadwood and decay classes provides an indication of the temporal variation in tree mortality and can be used to estimate the optimal deadwood volume ratio in biodiversity integrated forest management planning.

Keywords Deadwood volume · Decay classes · Stand and physiographic parameters · Forest management · Managed and protected forests

Introduction

Nowadays, deadwood trees are considered as an indicator for naturalness in forest ecosystems. This concept has become more and more widespread in international arena related to forests ecosystem management. In fact, the deadwood trees are essential elements in sustainable forest management approach for many living things and a key factor in carbon and nutrient cycling (Motta et al. 2006; Karahalil et al. 2017; Puletti et al. 2019). For example, about 30% of the organisms living in forests needs old trees and dead tree trunks to survive. In fact, deadwood trees are an integral part of a healthy natural forest with the important ecological roles they play (Woodall and Westfall 2009). Dead and dying trees play a key role in the well-functioning and productivity of forest ecosystems, affecting on biodiversity, carbon storage, soil nutrient cycling, energy flows, hydrological processes and natural regeneration of trees (Ercanlı and Kahriman 2015; Herrero et al. 2016; Sonmez et al. 2016). Deadwood trees also help maintain the productivity of the forest (Puletti et al. 2019), facilitate the germination of pine trees in the mountain forest, provide habitat and food for all living organisms in the forest (Paletto et al. 2014), prevent the soil erosion by protecting the soil surface (Enrong et al. 2006), protect

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the soil against natural events such as storms and floods and reduce some negative effects of climate change by storing carbon for a long time (Stevens 1997).

The volume of deadwood trees in a forest depends on the productivity of the forest, the course of natural events, the successional stages, decomposition rate, the history of the forest and human intervention (Yatskov et al. 2022). The type of deadwood tree and its decay process vary depending on the causes of death of the tree (lightning, storm, drought, disease, etc.) (Senf and Seidl 2021). In addition, the amount and the volume of the deadwood trees vary according to the type of forest and its management. While some natural events such as dying out cause the formation of standing deadwood trunks, some events such as storms cause the formation of downed deadwood trees (Wolf et al. 2004).

The above-ground parts of deadwood trees in forest ecosystems are generally divided into three groups: standing deadwood trees, downed deadwood trees and stumps (Brassard and Chen 2006). In general, five decay classes are used to characterize the degree of decay in deadwood trees: newly dead (DC1), slightly dead (DC2), moderately dead (DC3), highly dead (DC4) and nearly completely dead (DC5) (Hunter 1990; Næsset 1999; Campbell and Laroque 2007; Bayraktar et al. 2020). It is accepted that the density of deadwood generally decreases with increasing decay classes (1–5) (Harmon and Sexton 1996). Decaying states can also vary depending on the location of the deadwood. According to Yatskov et al. (2003), "the downed deadwood trees decay more rapidly than standing and snags due to the increased humidity and proximity to the decaying organisms on the forest floor."

According to Ódor and Standovár (2001), "The level of deadwood decay is a very important variable because it affects the fungi living in the deadwood, the presence and diversity of algae." The time from the dying of the trees to their fall (falling time) affects the succession–sustainability of the species communities (Onodera and Tokuda 2015). Factors such as tree species, decay class, time elapsed since death, size, standing or downed are important factors that affect the decaying process (Vasile et al. 2017; Błońska et al. 2019; Senhofa et al. 2020). According to Dudley and Vallauri (2004), "Nearly one-third of forest species depend on old trees and dead tree trunks for their survival." The decomposition of the deadwood in the forest is a long-term process, and thus, the deadwood is a long-term carbon sink, which can be determined by the rate of decomposition. The speed and the rate of decomposition of deadwood also vary depending on the disintegration, washing, respiration, consumption of the deadwood by invertebrates and its relation to forest fires (Přívětivý and Šamonil 2021).

There are many assumptions regarding the minimum volume of deadwood in the protected and particularly managed forests. Proposals on the amount of deadwood required in forests depend on many factors. In a study conducted in 19 European countries, the average deadwood volume was found to be 15.8 m^3/ha, ranging from 5.6 to 33.1 m^3/ha, and accounts for 7.1% of the average volume of the growing stock (Puletti et al. 2019; Forest Europe 2020). According to the report in 2015, the average of the total deadwood volume for 28 European countries, including Turkey, varies between 2.3 m^3/ha (Portugal) and 28.0 m^3/ha (Slovakia), while the proportion of deadwood volume to standing stock volume varies from values below 3% (Denmark, Poland, Ukraine and Romania) to values above 10% (Latvia, France, Slovakia and Turkey) (Forest Europe 2020). The average deadwood volume in all Polish forest was 5.9 m^3/ha (Forest Europe 2020), while in Polish, protected forest was 9.4 m^3/ha (Bujoczek et al. 2018, 2021; Puletti et al. 2019). Müller and Bütler (2010) suggest that the volume of deadwood in European forests should be at least in the range of 20–50 m^3/ha.

As a result of the insurgent interest in forests and the effect of increasing environmental processes, it has been observed that the size and the number of protected areas have increased in the world, and Turkey is no exception. The protection status of protected areas (national park, nature reserve, nature monument, nature park, etc.) also varies from country to country. Approximately 4.7% (3,666,573 ha) of Turkey's surface area is classified as a protected area, and 908.543 ha (24.8%) of these areas are of 46 national parks (NCNP 2021).

Oriental spruce (*Picea orientalis* Link.), Scots pine (*Pinus sylvestris* L.) and Caucasian fir (*Abies nordmanniana* (Steven) Spach. subsp. *nordmanniana*) tree species are among the most important primary forest tree species in Turkey due to their increment and growth characteristics, their wider distribution areas and the economic value they create (Çakır and Kahriman 2018). According to the forest inventory data of the General Directorate of Forestry, in 2020, Oriental spruce covers nearly 365,845 ha (1.60%) of Turkey's total forest area, fir in 511,703 ha and Scots pine in 1,410,177 ha (6.15%). Oriental spruce is grown on the sea-facing slopes of the Northeastern Anatolian mountains of Turkey. Eastern spruce trees establish stands sometimes pure, often mixed with Scots pine, Caucasian fir and Oriental beech, in an area of 365,845 ha in Turkey. It mostly forms mixed stands between 900 and 1500 m of elevation and pure stands between 1500 and 2200 m of elevation (GDF 2022).

The primary objective of this study is to determine the deadwood classes (standing deadwood, downed deadwood, stump and total deadwood) of the deadwood volumes of pure and mixed Oriental spruce (Oriental spruce + Scots pine and Oriental spruce + Caucasian fir) stands both in the managed forests of Şavşat-Veliköy FMU and the protected areas in Karagöl-Sahara National Park. Secondly, the distribution of these decay classes according to the deadwood volume was determined by considering the compositional and topographic parameters of the stands. Finally, the amount of deadwood volume was compared according to the decay classes in the managed and protected stands.

Materials and methods

Materials

The case study area extends from the borders of Veliköy Forestry Planning Unit (FMU) to the borders of Karagöl-Sahara National Park within the Artvin Regional Directorate of Forestry (Fig. 1). The overall area of Veliköy FMU is 28,951.6 ha, of which 10,520.9 (36.8%) is forested. The area covered by pure Oriental spruce, mixed Oriental spruce–fir and Oriental spruce–Scots pine stands is 2095.7, 479.4 and 577.2 ha, respectively. The elevation of the Veliköy FMU ranges between 950 m and 3100 m from the sea level with highly rugged and sloping terrain (GDF 2013). The total area of Karagöl-Sahara National Park is 3251.0 ha, of which 1198.0 ha (36.8%) is forestland (Yavuz and Vatandaşlar 2018). In this national park, the area covered by pure Oriental spruce, mixed Oriental spruce–fir and Oriental spruce–Scots pine stands is 405.0, 270.0 and 184.0 ha, respectively (NCNP 2016). The elevation of Karagöl-Sahara National Park, declared as a national park in 1994, varies between 1150 and 2600 m from the seal level. This national park consists of two separate parts, Karagöl and Sahara. According to WWF/IUCN (1994), "Karagöl-Sahara National Park, with its rich biodiversity and natural forests, is located in the Caucasus hotspot, which is defined as one of the 35 biodiversity hotspots in the world by Conservation International" (CI 2018). This area has also been recognized as one of the 200 priority ecological regions in the world by the World Wide Fund for Nature (WWF) due to its biogeographical features.

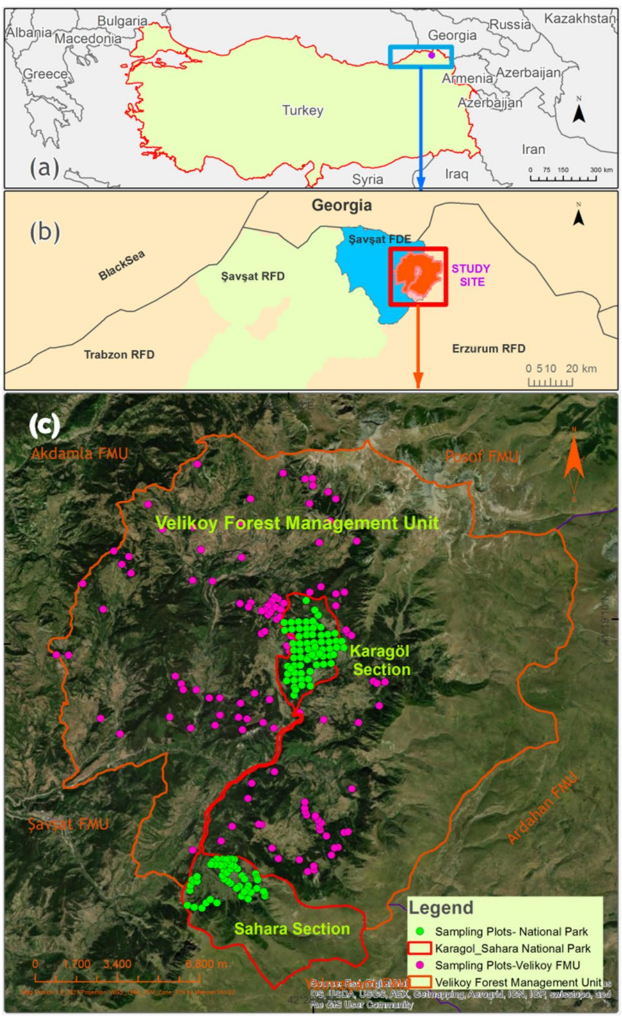


Fig. 1 General view of the research area (Turkey (**a**), Artvin-Şavşat State Forest Enterprise (**b**) and Veliköy FMU and Karagöl-Sahara National Park—The spatial distribution of the sampling plots over the case study area (**c**))

Since the case study area, located in the region right behind the Black Sea, is in the transition zone of continental climate and maritime climate; spring and autumn seasons are mild and rainy, winters are harsh and rainy and summer months are less rainy. The annual average relative humidity varies between 60 and 70%, and the average annual total precipitation is 653 mm (MGD 2022). The temperature is between −3.6 and 19.4 °C on a monthly basis and 8.6 °C on an annual basis. The lowest temperatures of the months vary between −7.8 and 12.9 °C. The highest temperature reaches up to 26 °C.

Within the scope of this study, a total of 476 sample plots were taken by considering the variability of age class, site class, canopy cover and stand types (pure spruce, spruce + Scots pine and spruce + fir). Half of the total sample plots (238) was taken from 40-m north of each sample area. The size of the circular sample plots was determined between 400 and 800 m^2, depending on the crown closure (< 11–40%: 800 m^2; 41–70%: 600 m^2 and > 70%: 400 m^2) according to the forest management planning guidelines (GDF 2023). First of all, the physiographic characteristics of the stands from which the sample areas were taken, such as slope, aspect and elevation, as well as the distance to the roads and settlements were measured. In the sample plots, the diameters at breast height of all trees over 8 cm ($d_{1.30}$ > 8.0 cm), the height of 10–15 trees evenly distributed on each diameter class, the height of the tallest trees according to the 100 trees per hectare method to determine the site class and the age of 2–3 trees close to the middle diameter of the stand were measured. As for the stumps, the stump diameter (thin diameter if $h < 30$ cm and medium diameter if $30 < h < 130$ cm), stump length and decay class were measured. The diameter at breast height, tree height and decay classes were measured in standing deadwood trees. Bottom, middle and tip diameters and section lengths and decay class were measured for the downed deadwood trees with a height of < 6 m and the diameter at breast height of more than 4 cm. Log diameter, diameter at breast height and trunk diameter, total height and decay classes were measured at 4-m intervals (e.g., 4.3, 8.3, 12.3…) for the downed deadwood trees with a height of > 6 m.

Three classes of deadwood trees were considered in this study: (1) standing deadwood trees: deadwood trees with a diameter at breast height more than 4 cm and a height of more than 1.30 m (Harmon and Sexton 1996), (2) stumps: height between 10 and 130 cm and with a diameter of more than 6 cm and (3) downed deadwood trees: those with a median diameter of ≥ 6 cm and a length of ≥ 15 cm from the fallen trees. The measurement method developed by Hunter (1990), Næsset (1999) and Bayraktar et al. (2020) was taken into account to estimate the decay classes of deadwood trees. They are DC1: recently dead tree (0–3 years), bark intact or loose after attacks, trunk wood intact and not rotten. DC2: loose bark, partially fragmented, small branches present, sapwood intact and wood of outer layers of the log has started to soften due to rot (0–3 cm). DC3: medium rot, only bark fragments, no small branches, sapwood slightly damaged, soft outer layers of log which can easily be disintegrated by a knife and core still solid. DC4: very rotten: no bark, no small branches, sapwood significantly decayed, wood soft, no solid core, outline of the log is partly deformed and often overgrown. DC5: nearly completely rotted or fragmented: no bark, no small branches, sapwood completely decomposed, core significantly decayed and rotten and overgrown with contours of completely decomposed log.

Methods

The stump diameter and stump length for the stumps and the diameter at breast height and tree height were measured for the standing deadwood trees. Bottom, middle and tip diameters and section lengths were measured for the downed deadwood trees with a height of < 6 m and the diameter at breast height of more than 4 cm. Stump diameter, diameter at breast height, trunk diameter and total height were measured at 4-m intervals (e.g., 4.3, 8.3, 12.3…) for the downed deadwood trees with a height of > 6 m. The volume was calculated with the cylinder volume equation by measuring the diameter of 30-cm high (thin tip), which is the cut surface of the logs up to 30 cm in length (Burrascano et al. 2008; Puletti et al. 2019). On the other hand, the median diameter and length of the logs between 30 and 130 cm were measured, and their volumes were calculated with the Huber equation (Sippola et al. 1998; Du Cros and Lopez 2009; Herrero et al. 2016; Puletti et al. 2019; Karahalil et al. 2017; Błońska et al. 2019). The diameter at breast height and the height of the standing deadwood trees and snags were measured, and their volumes were calculated using the breast height form factor method [the stem form is assumed to be between cone and paraboloid ($f_{1.3}$: 0.415:)] (Sippola et al. 1998; Paletto et al. 2014; Herrero et al. 2016; Puletti et al. 2019; De Meo et al. 2017; Senhofa et al. 2020).

The volumes of the downed deadwood trees with a height of < 6 m were calculated by the Newton-Riecke equation (Herrero et al. 2016) by measuring the bottom, middle and tip diameters and lengths. For the downed deadwood trees with a length of > 6 m, the stump diameter, the diameter at breast height, total height and the trunk diameter at 4-m intervals (e.g., 4.3, 8.3 and 12.3) were measured to calculate the volume. The volume of stump was calculated with the cylinder volume equation, the volume of the section was calculated with the average of the surfaces at the ends of the section (Smalian equation) and the volume of the tip was calculated with the cone equation (Laar and Akça 2007). After calculating the volumes of the stump, standing deadwood and downed deadwood, the total values in each sample plots were calculated and converted to per hectare values for the stands.

Single-entry tree volume equations developed by Çakır (2018) for Oriental spruce, by Yavuz et al. (2010) for Scots pine and by Yazıcı (2019) for Caucasian fir were used to calculate the volumes of standing live trees (i.e., growing stock) whose diameter at breast height was measured only. The volumes of standing live trees, in which both diameters at breast height and tree height were measured, were calculated using the double-entry tree volume equations developed by Akalp (1978) for Oriental spruce, by Yavuz et al. (2010) for Scots pine and by Yazıcı (2019) for Caucasian fir.

Single-entry tree volume equations for Oriental spruce, Scots pine and Caucasian fir:

$$\text{Oriental spruce}: \quad V = 0.000143d^{2.482109} \tag{1}$$

$$\text{Scots pine}: \quad \ln V = -8.209 + 2.324 \ln d - 3.664/d \tag{2}$$

$$\text{Caucasian fir}: \quad V = 0.0000424688d^{2.85763} \tag{3}$$

Double-entry tree volume equations for Oriental spruce, Scots pine and Caucasian fir:

$$\text{Oriental spruce:} \quad V = d^2(0.00032505 + 0.00002453h) \tag{4}$$

$$\text{Scots pine:} \quad \ln V = -9.769 + 1.872 \ln d + 0.987 \ln h + 5.784/h^2 \tag{5}$$

$$\text{Caucasian fir}: \quad V = d^2(0.000086534 + 0.0000367103h) \tag{6}$$

The volumes of single trees in each sample plot were calculated using the appropriate tree volume equations above.

The volumes of the stands were determined by converting the total volume values in each sample plot to the per hectare values. In addition, stand characteristics such as site index, stand age and density value of each sample plot were calculated. For the stand density, we have used the relative stand density equation developed by Curtis et al. (1981).

An independent two-sample t-test was conducted to investigate whether each decay class was different in the Veliköy FMU and Karagöl-Sahara National Park research areas. In order to test separately for both case study areas, that each decay class does not differ according to the stand characteristics such as age, site index, density, developmental stage and canopy closure and locational parameters such as slope, aspect, elevation, distance from road and settlement, a directional analysis of variance (ANOVA) was performed. In case of difference between groups, the Tukey HSD test was performed using SPSS package program to determine from which groups the difference arises (SPSS 19.0 Inc. 2010). In addition, ArcGIS 10.2.1 (ESRI 2013) software was used to perform the required spatial analysis and create the necessary thematic maps.

Results

Various statistical information about the stand and physiographic characteristics, the amount of deadwood and growing stock in 236 sample plots taken from Veliköy FMU and 240 sample plots taken within the borders of Karagöl-Sahara National Park are given in Table 1.

Table 1 shows that the ratio of total deadwood volume to the growing stock was calculated as 2.6% (10.1 m^3/ha) in Veliköy FMU and 4.2% (22.5 m^3/ha) in Karagöl-Sahara National Park. On the other hand, the highest stumps (3.8 m^3/ha) were determined in the Veliköy FMU, while the standing deadwood volume (10.8 m^3/ha) was determined in the Karagöl-Sahara National Park (Table 1). According to the results obtained within the scope of the study, the standing deadwood volume, stump and downed deadwood volumes of Veliköy FMU were 3.0 (29.4%), 3.8 (37.8%) and 3.3 (32.7%) m^3/ha, respectively, and 10.8 (47.8%), 5.1 (22.7%) and 6.6 (29.4%) m^3/ha in Karagöl-Sahara National Park.

The distribution of the deadwood volume according to decay classes is given below, taking into account the deadwood classes (standing deadwood, stump, downed deadwood and total deadwood) in both Veliköy FMU and Karagöl-Sahara National Park (Table 2, Fig. 2).

As it is shown in Table 2 and Fig. 2, when the standing deadwood is evaluated, the highest deadwood volume is observed in DC2 decay class (2.05 m^3/ha) in Veliköy FMU and in DC3 decay class (5.58 m^3/ha) in the Karagöl-Sahara National Park. In both areas, it was determined that the stump deadwood volumes were the highest in the DC5 decay class (1.25 and 1.59 m^3/ha, respectively). Considering the downed deadwood rates, it was determined that the deadwood volume was the highest in DC4 decay class (1.00 m^3/ha) in Veliköy FMU and in the DC3 decay class (3.13 m^3/ha) in the Karagöl-Sahara National Park. As for the ranking of volumes in the decay classes without making a distinction between the deadwood volume classes, from high to low, it is determined as 3.56, 2.26, 2.03, 1.85 and 0.41 m^3/ha corresponding to DC2, DC3, DC5, DC4 and DC1 decay classes in Veliköy FMU, respectively, and 9.81, 6.13, 3.46, 2.59 and 0.47 m^3/ha in DC3, DC2, DC4, DC5 and DC1 decay classes in the Karagöl-Sahara National Park, respectively. When the total deadwood

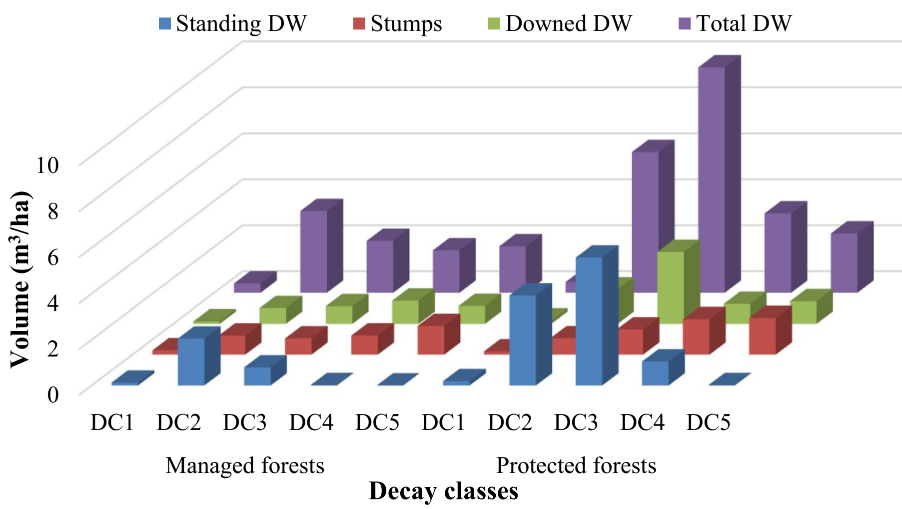
Table 1 Some statistical information on the sample plots and deadwood volume data

Variables	Veliköy FMU				Karagöl-Sahara NP			
	Min	Mean	Max	SD	Min	Mean	Max	SD
Mean diameter (cm)	11.4	25.0	47.4	5.9	16.0	25.0	49.9	3.9
Age (years)	31.1	88.0	199.0	28.4	44.0	100.5	143.0	19.3
Site index (m)	12.9	24.9	34.4	4.0	19.8	26.9	33.9	2.6
Stand density	2.37	8.0	15.90	3.1	2.2	9.6	15.9	2.5
Crown closure (%)	10.1	74.0	100.0	18.5	35.0	84.6	100.0	13.1
Slope (%)	1.0	51.2	140	28.5	3.0	65.7	140.0	32.1
Altitude (m)	1152.0	1795.7	2410.0	234.8	1424.0	1807.8	2117.0	143.7
Distance to road (m)	20.0	329.2	1090.0	270.6	25.0	305.0	1080.0	210.0
Dist. to settlement (m)	45.0	913.6	2450.0	479.0	100.0	849.8	2080.0	374.4
Standing DW (m^3/ha)	0.0	3.0	87.1	8.4	0.0	10.8	148.0	21.2
Stump (m^3/ha)	0.0	3.8	11.9	2.6	0.0	5.1	18.1	3.2
Downed DW (m^3/ha)	0.0	3.3	31.1	5.1	0.0	6.6	51.3	9.5
Total DW (m^3/ha)	0.2	10.1	96.2	11.3	0.2	22.5	175.4	26.5
DW to live wood (%)	0.0	2.6	27.5	2.7	0.0	4.2	33.7	5.3
Living volume (m^3/ha)	63.5	412.5	1000.5	212.7	61.1	589.7	1098.2	170.7

Table 2 Distribution of deadwood volume (m3/ha) according to decay classes

Decay classes	Standing DW		Stumps		Lying DW		Total DW	
	Managed	Protected	Managed	Protected	Managed	Protected	Managed	Protected
DC1	0.12	0.19	0.19	0.14	0.10	0.14	0.41	0.47
DC2	2.05	3.92	0.83	0.72	0.68	1.49	3.56	6.13
DC3	0.79	5.58	0.71	1.10	0.76	3.13	2.26	9.81
DC4	0.01	1.05	0.84	1.54	1.00	0.86	1.85	3.46
DC5	0.00	0.01	1.25	1.59	0.77	0.98	2.03	2.59
Total	2.98	10.75	3.82	5.10	3.31	6.60	10.11	22.45

Fig. 2 Distribution of deadwood volume by decay classes and deadwood classes



volume was evaluated, it was determined that both the Veliköy FMU and the national park had the lowest deadwood volume in the DC1 decay class (0.41 and 0.47 m^3/ha), respectively (Table 2).

According to the independent sample t-test results, the deadwood volumes in DC2 (t: −3.10, $p<0.05$), DC3 (t: −6.38, $p<0.05$) and DC4 (t: −2.38, $p<0.05$) decay classes in the national park were determined to be statistically higher than the values in the Veliköy FMU ($p<0.001$). On the other hand, deadwood volumes in the DC1 (t: −0.30, p: 0.766) and DC5 (t: −1.48, p: 0.141) decay classes did not differ statistically at 0.05 significance level according to the groups in managed forests and the national park area ($p>0.05$) (Table 2).

The amount of deadwood volume in each deadwood class is given in Fig. 3 as a percentage. As shown in Fig. 3, it has been determined that the highest amount of deadwood volume in Veliköy FMU is in DC2 decay class (69%) of standing deadwood, in DC5 decay class (33%) of stumps and in DC4 decay class (30%) of downed deadwood class. In the Karagöl-Sahara National Park, it is determined that the highest amount of deadwood volume is in DC3 decay class (52%) in standing deadwood class, DC5 decay class (31%) in stump and DC3 decay class (47%) in downed deadwood class (Fig. 3).

The distribution of deadwood volumes according to decay classes, one-way analysis of variance and Tukey test results is given below, taking into account stand and site parameters (Tables 3 and 4).

According to the results of the one-way ANOVA test on the *stand parameters*, in Veliköy FMU, the deadwood volume in the DC2 decay class differs statistically ($p<0.05$) according to the stand type, site index and density classes; the volume in the DC4 decay class according to the stand type, site index, density, development stage and crown closure and the volume in DC5 decay class according to all stand variable classes (Table 3). In Karagöl-Sahara National Park, the deadwood volume differs statistically ($p<0.05$) only according to the density classes in the DC5 decay class and according to the development stages in the DC4 decay class (Table 3). As for the results of Tukey test in Veliköy FMU, the SF (spruce + fir) classes in DC2 and DC4 decay classes, SF + SSp (spruce + Scots pine) classes in DC5 decay class; the age classes of 61–80, 81–100 and > 100 in the DC5 decay class; the best site class in DC2 and DC4 decay classes; medium, good and best site classes in DC5 decay class; > 12 density class in DC2 and DC5 decay classes and 10–12 density class in DC4 decay class; development stages over 36 cm in DC4 and DC5 decay classes and crown closure over 70% in the DC4 and DC5 decay classes have the highest

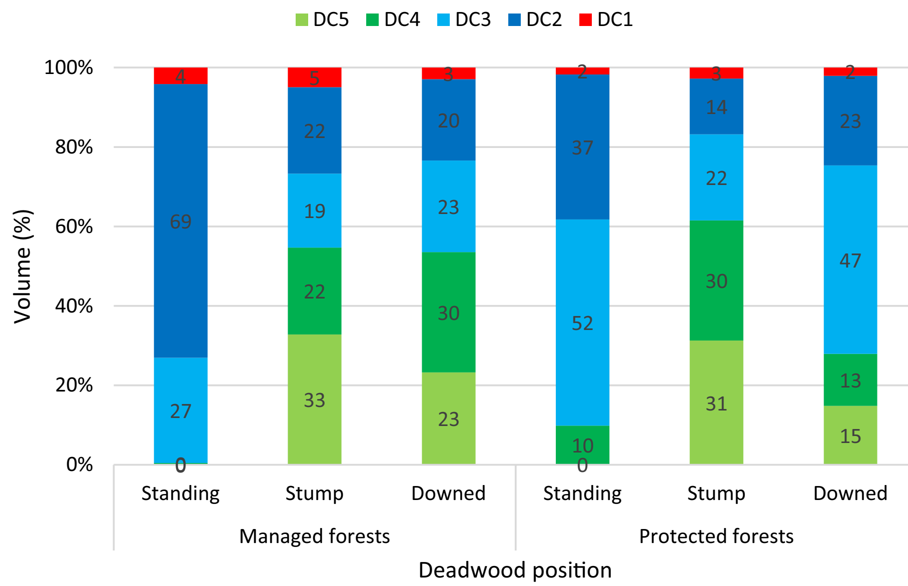


Fig. 3 Percent distribution of deadwood volumes according to decay classes in deadwood classes

deadwood volume values. According to Tukey test results in Karagöl-Sahara National Park, the SF (spruce + fir) stands have the highest deadwood volumes in DC3 decay class, the stands with the highest density have the highest volume in the DC5 decay class and the largest diameter stands have the highest volume in the DC4 decay class (Table 3).

According to the results of the one-way ANOVA test on the *locational parameters*, in Veliköy FMU, the deadwood volume in the DC2 decay class differs statistically ($p < 0.05$) according to the distance to the road; the volume in the DC3 decay class according to the distance classes from the settlement; the volume in the DC4 decay class according to the aspect, elevation, distance from the road and settlement and the volume in the DC5 decay class according to the elevation, distance from the road and settlement (Table 4). In the Karagöl-Sahara National Park, however, the deadwood volume in the DC1 decay class shows a statistically ($p < 0.05$) significant difference ($p < 0.05$) according to the slope and distance to the road classes; the volume in the DC2 decay class according to the distance classes from the settlement; the volume in the DC3 decay class according to the slope, aspect and distance to the road classes and the volume in the DC4 decay class according to the classes of aspect and distance from the settlement (Table 4). As for the results of Tukey test in the Veliköy FMU, the western aspect class in DC4 decay class; elevation classes of 1850–2050 m in DC4 decay class and 1650–1850 and 1850–2050 m in DC5 decay class; distance classes to the road > 500 m in DC2 and DC4 decay classes and 101–250, 251–500 and > 500 m in DC5 decay class and the distance class to the settlement > 1500 m in the DC3, DC4 and DC5 decay classes have the highest deadwood volume values. According to the Tukey test results in Karagöl-Sahara National Park, 0–9% slope class in DC1 decay class; west aspect class in DC3 decay class and north aspect class in DC4 decay class; distance class to the road 0–100 m in DC1 decay class and > 500 m in DC3 decay class and the distance class to the settlement > 1500 m in the DC2 and DC4 decay classes have the highest deadwood volume values (Table 4).

Discussion

The order of the deadwood volume in the decay classes, from high to low, is found to be 3.56 m^3/ha (35%), 2.26 m^3/ha (23%), 2.03 m^3/ha (203%), 1.85 m^3/ha (18%) and 0.41 m^3/ha (4%) in the DC2, DC3, DC5, DC4 and DC1 decay classes for the Veliköy FMU, respectively, and 9.81 m^3/ha (44%), 6.13 m^3/ha (27%), 3.46 m^3/ha (15%), 2.59 m^3/ha (12%) and 0.47 m^3/ha (2%) in DC3, DC2, DC4, DC5 and DC1 decay classes for the Karagöl-Sahara NP, respectively, without making any distinction between the deadwood volume classes (Tables 2 and 5).

It was determined that the deadwood volume was mostly in the DC2 (3.56 m^3/ha and 35%) decay class, without making any distinction between the deadwood volume classes in the Veliköy FMU (Table 5). Similar results were obtained in the study by Senhofa et al. (2020) on the older birch stands in Latvia (DC2: 22.5 m^3/ha and 39%), in the study by Paletto et al. (2020) on the birch stands (DC2: 5.74 m^3/ha and 24.1%) and in the study by Motta et al. (2006) on the European spruce stands (DC2: 8.2 m^3/ha and 35.2%) (Table 5). In the Karagöl-Sahara National Park, it was determined that the deadwood volume was mostly in the DC3 (9.81 m^3/ha and 44%) decay class, without making any distinction between the deadwood volume classes (Table 5). Similarly, the deadwood volume was obtained the highest in DC3 decay class in the study conducted by Błońska et al. (2019) in Poland

Table 3 Distribution of deadwood volume (m^3/ha) by some stand variables and decay classes analysis of variance and Tukey test results

Variable	Class	Veliköy FMU					Karagöl-Sahara NP				
		Decay classes					Decay classes				
		DC1	DC2	DC3	DC4	DC5	DC1	DC2	DC3	DC4	DC5
Stand type	S	0.3^{a}	2.9^{a}	1.0^{a}	1.0^{a}	1.0^{a}	0.9^{ab}	8.3^{a}	6.5^{a}	4.4^{a}	3.5^{a}
	S–Sp	0.6^{a}	2.4^{a}	3.4^{a}	1.1^{a}	2.5^{b}	0.3^{a}	5.2^{a}	7.4^{a}	1.9^{a}	1.9^{a}
	S–F	0.4^{a}	5.0^{b}	2.5^{a}	3.2^{b}	2.6^{b}	0.1^{a}	4.4^{a}	15.6^{b}	3.7^{a}	2.1^{a}
ANOVA	F	1.68	4.43	2.48	10.29	6.19	1.49	2.95	7.50	1.32	2.58
	p	0.19	**0.01**	0.09	**0.00**	**0.00**	0.23	0.05	**0.00**	0.27	0.08
Age (year)	21–40	0.2^{a}	1.6^{a}	1.0^{a}	0.1^{a}	0.0^{a}					
	41–60	0.3^{a}	1.9^{a}	1.2^{a}	0.4^{a}	0.1^{a}	0.3^{a}	0.9^{a}	9.1^{a}	1.1^{a}	0.2^{a}
	61–80	0.4^{a}	3.8^{a}	1.1^{a}	2.2^{a}	1.6^{ab}	0.3^{a}	4.9^{a}	8.1^{a}	2.4^{a}	3.7^{a}
	81–100	0.5^{a}	4.2^{a}	2.1^{a}	2.2^{a}	2.8^{b}	0.9^{a}	6.8^{a}	9.4^{a}	2.4^{a}	2.8^{a}
	> 100	0.4^{a}	3.8^{a}	4.0^{a}	2.2^{a}	2.4^{b}	0.3^{a}	6.2^{a}	10.6^{a}	4.5^{a}	2.2^{a}
ANOVA	F	0.29	1.22	1.74	2.78	6.65	0.74	0.53	0.21	0.98	1.18
	p	0.89	0.30	0.14	0.03	**0.00**	0.53	0.66	0.89	0.40	0.32
Site class (m)	30–33	0.5^{a}	7.3^{b}	3.0^{a}	4.3^{c}	3.1^{b}	0.3^{a}	3.6^{a}	13.9^{a}	3.2^{a}	4.1^{a}
	27–30	0.4^{a}	4.4^{ab}	2.8^{a}	3.3^{bc}	2.6^{b}	0.4^{a}	8.2^{a}	9.4^{a}	2.4^{a}	2.5^{a}
	24–27	0.4^{a}	3.3^{a}	2.8^{a}	1.9^{ab}	2.8^{b}	0.6^{a}	5.3^{a}	9.3^{a}	4.8^{a}	2.2^{a}
	21–24	0.5^{a}	3.9^{ab}	1.6^{a}	1.4^{ab}	1.9^{ab}	0.6^{a}	4.5^{a}	9.4^{a}	2.0^{a}	2.9^{a}
	18–21	0.3^{a}	1.3^{a}	1.7^{a}	0.3^{a}	0.3^{a}	0.0^{a}	4.4^{a}	2.6^{a}	7.9^{a}	1.2^{a}
ANOVA	F	0.24	4.03	0.48	7.03	6.45	0.09	1.41	0.53	0.94	0.90
	p	0.91	**0.00**	0.75	**0.00**	**0.00**	0.98	0.23	0.71	0.44	0.46
Density	< 6	0.4^{a}	2.1^{a}	2.1^{a}	0.8^{a}	0.4^{a}	0.1^{a}	2.6^{a}	6.2^{a}	1.0^{a}	1.2^{a}
	6–8	0.5^{a}	2.6^{ab}	1.5^{a}	1.4^{ab}	1.6^{ab}	1.4^{a}	4.4^{a}	8.8^{a}	2.6^{a}	1.4^{a}
	8–10	0.5^{a}	4.7^{ab}	1.7^{a}	2.2^{ab}	2.5^{bc}	0.3^{a}	5.3^{a}	9.4^{a}	5.4^{a}	2.0^{a}
	10–12	0.5^{a}	3.9^{ab}	2.0^{a}	3.3^{b}	3.4^{bc}	0.4^{a}	7.0^{a}	12.3^{a}	2.7^{a}	2.7^{ab}
	> 12	0.1^{a}	6.1^{b}	5.4^{a}	2.1^{ab}	4^{c}	0.3^{a}	9.5^{a}	9.2^{a}	2.4^{a}	5.2^{b}
ANOVA	F	0.82	3.17	1.69	3.77	11.23	1.07	1.80	0.58	1.41	4.35
	p	0.51	**0.01**	0.15	**0.01**	**0.00**	0.37	0.13	0.68	0.23	**0.00**
Development stages (cm)	8–20	0.3^{a}	1.9^{a}	0.7^{a}	0.3^{a}	0.3^{a}	0.0^{a}	0.9^{a}	12.5^{a}	3.7^{a}	0.3^{a}
	21–36	0.5^{a}	3.9^{a}	2.7^{a}	2.1^{ab}	2.4^{ab}	0.5^{a}	6.3^{a}	9.5^{a}	2.9^{a}	2.7^{a}
	> 36	0.0^{a}	4.8^{a}	2.6^{a}	4.0^{b}	2.7^{b}	0.0^{a}	2.5^{a}	18.6^{a}	23.2^{b}	1.0^{a}
ANOVA	F	0.88	2.38	1.62	7.08	9.53	0.12	0.64	0.86	13.68	0.64
	p	0.42	0.09	0.20	**0.00**	**0.00**	0.88	0.53	0.43	**0.00**	0.53
Crown closure (%)	11–40	0.0^{a}	3.8^{a}	0.6^{a}	0.2^{a}	0.8^{a}	0.0^{a}	0.6^{a}	7.5^{a}	0.9^{a}	0.4^{a}
	41–70	0.5^{a}	2.8^{a}	2.3^{a}	1.3^{ab}	0.7^{a}	1.6^{a}	7.0^{a}	10.1^{a}	2.5^{a}	1.2^{a}
	> 70	0.4^{a}	4.1^{a}	2.4^{a}	2.5^{b}	3.1^{b}	0.3^{a}	6.2^{a}	9.8^{a}	3.7^{a}	2.9^{a}
ANOVA	F	1.82	1.36	0.55	5.08	19.92	3.06	0.80	0.06	0.42	2.23
	p	0.16	0.26	0.58	**0.01**	**0.00**	0.05	0.45	0.94	0.66	0.11
Mean		0.4	3.6	2.3	1.9	2.0	0.5	6.1	9.8	3.5	2.6

(DC3: 48%), in the study conducted by De Meo et al. (2017) in the urban red pine forest in Italy (DC3: 37.55 m^3/ha and 50%), Paletto et al. (2014) in the oak forests in Italy (DC3: 25%) and in the study by Du Cros and Lopez (2009) in France (DC3: 15.2 m^3/ha and 49%) (Table 5).

Unlike the results in this study, it was identified that the deadwood volume was the highest in the DC1 (34%) decay class in the study conducted by Bayraktar et al. (2020) on oak–beech stands in Istanbul Belgrade, in the DC1 decay class in the study conducted across 19 countries in Europe by Puletti et al. (2019) (3.78 m^3/ha and 26%), in the DC5 decay class (31%) by Keren and Diaci (2018) in Southeastern Europe in the older beech–fir–spruce stands, in the DC4 class (43%) in the managed stands, DC4 (53%) in the study conducted by Parobeková et al. (2018) on fir–beech–spruce mixed aged stands in Slovakia, in the DC5 decay class (8.96 m^3/ha and 32%) in the study conducted by Behjou et al. (2018) on the hardwood stands, in the DC4 decay class

Table 4 Distribution of deadwood volume (m^3/ha) according to site characteristics and decay classes, analysis of variance and Tukey test results

Variables	Class	Veliköy FMU					Karagöl-Sahara NP				
		Decay classes					Decay classes				
		DC1	DC2	DC3	DC4	DC5	DC1	DC2	DC3	DC4	DC5
Slope (%)	0–9	0.3^{a}	2.1^{a}	1.3^{a}	0.5^{a}	1.5^{a}	4.0^{b}	8.6^{a}	3.3^{a}	1.9^{a}	0.7^{a}
	10–17	0.1^{a}	2.1^{a}	1.2^{a}	2.2^{a}	0.6^{a}	1.3^{ab}	8.9^{a}	2.7^{a}	8.9^{a}	3.1^{a}
	18–36	0.6^{a}	3.0^{a}	1.2^{a}	1.6^{a}	1.8^{a}	0.5^{ab}	5.8^{a}	5.6^{a}	2.4^{a}	2.4^{a}
	37–58	0.6^{a}	4.2^{a}	4.0^{a}	2.2^{a}	2.4^{a}	0.9^{ab}	4.7^{a}	4.2^{a}	3.0^{a}	2.5^{a}
	59–100	0.3^{a}	3.7^{a}	2.3^{a}	2.0^{a}	2.2^{a}	0.2^{a}	7.8^{a}	13.1^{a}	3.9^{a}	2.8^{a}
	> 100	0.1^{a}	6.9^{a}	1.8^{a}	2.3^{a}	2.5^{a}	0.2^{a}	3.2^{a}	15.4^{a}	1.9^{a}	2.3^{a}
ANOVA	F	1.20	1.09	1.12	0.71	0.80	1.48	1.37	3.93	1.20	0.16
	p	0.31	0.37	0.35	0.61	0.55	0.20	0.24	**0.00**	0.31	0.98
Aspect	North	0.6^{a}	4.2^{a}	1.9^{a}	2.2^{ab}	2.0^{a}	0.6^{a}	5.4^{a}	13.4^{ab}	7.4^{b}	1.8^{a}
	East	0.3^{a}	4.2^{a}	4.1^{a}	1.4^{ab}	2.1^{a}	0.7^{a}	6.0^{a}	6.0^{a}	3.4^{ab}	3.4^{a}
	South	0.5^{a}	2.3^{a}	1.9^{a}	0.9^{a}	1.5^{a}	0.5^{a}	6.2^{a}	7.7^{ab}	3.2^{ab}	2.4^{a}
	West	0.2^{a}	4.0^{a}	1.5^{a}	3.1^{b}	2.7^{a}	0.1^{a}	6.5^{a}	14.5^{b}	1.8^{a}	2.3^{a}
ANOVA	F	1.54	1.64	1.68	4.53	1.62	0.43	0.08	3.77	2.36	0.98
	p	0.20	0.18	0.17	**0.00**	0.18	0.73	0.97	**0.01**	**0.07**	0.40
Elevation (m)	< 1450	0.2^{a}	2.7^{a}	3.4^{a}	0.8^{ab}	1.1^{ab}	0.1^{a}	6.2^{a}	0.3^{a}	0.7^{a}	0.7^{a}
	1450–1650	0.4^{a}	1.6^{a}	3.7^{a}	1.1^{ab}	2.1^{ab}	1.9^{a}	4.3^{a}	4.7^{a}	4.9^{a}	1.1^{a}
	1650–1850	0.3^{a}	5.0^{a}	1.3^{a}	2.0^{ab}	2.2^{b}	0.2^{a}	7.7^{a}	8.0^{a}	2.9^{a}	3.1^{a}
	1850–2050	0.5^{a}	4.2^{a}	2.3^{a}	2.7^{b}	2.6^{b}	0.4^{a}	5.0^{a}	12.4^{a}	4.0^{a}	2.6^{a}
	> 2050	0.4^{a}	1.3^{a}	1.0^{a}	0.3^{a}	0.2^{a}	0.4^{a}	5.2^{a}	19.8^{a}	1.4^{a}	2.0^{a}
ANOVA	F	0.53	3.13	1.08	3.42	3.46	2.14	0.94	2.72	0.46	1.09
	p	0.71	0.02	0.37	**0.01**	**0.01**	0.08	0.44	0.03	0.76	0.36
Proximity to road (m)	0–100	0.6^{a}	1.6^{a}	1.6^{a}	0.9^{a}	0.5^{a}	1.9^{b}	6.4^{a}	4.2^{a}	2.1^{a}	3.2^{a}
	101–250	0.3^{a}	4.1^{ab}	1.9^{a}	1.5^{ab}	1.8^{b}	0.4^{a}	5.6^{a}	9.7^{ab}	4.5^{a}	2.4^{a}
	251–500	0.4^{a}	2.4^{a}	3.7^{a}	2.1^{ab}	2.1^{b}	0.2^{a}	7.5^{a}	10.1^{ab}	3.1^{a}	2.3^{a}
	> 500	0.3^{a}	5.3^{b}	2.3^{a}	2.9^{b}	3.5^{b}	0.1^{a}	3.4^{a}	13.9^{b}	3.1^{a}	3.3^{a}
ANOVA	F	0.99	4.56	0.86	3.27	9.71	3.12	1.22	1.76	0.54	0.57
	p	0.40	**0.00**	0.46	**0.02**	**0.00**	**0.03**	0.30	**0.16**	0.66	0.64
Proximity to settlements (m)	0–500	0.2^{a}	2.1^{a}	1.4^{a}	1.0^{a}	0.9^{a}	1.1^{a}	2.8^{a}	5.4^{a}	2.6^{a}	1.2^{a}
	501–1000	0.4^{a}	3.1^{a}	1.9^{a}	1.2^{a}	1.7^{ab}	0.4^{a}	5.0^{ab}	7.6^{a}	3.4^{ab}	2.8^{a}
	1001–1500	0.6^{a}	4.8^{a}	1.8^{a}	2.1^{a}	2.5^{bc}	0.3^{a}	8.5^{ab}	14.6^{a}	2.9^{a}	2.8^{a}
	> 1500	0.3^{a}	4.5^{a}	5.4^{b}	4.1^{b}	3.7^{c}	0.3^{a}	10.1^{b}	12.1^{a}	8.7^{b}	4.1^{a}
ANOVA	F	1.63	2.52	2.92	7.01	6.79	0.80	3.50	3.80	1.84	1.68
	0.18	0.06	0.03	**0.00**	**0.00**	**0.50**	0.02	**0.01**	0.14	**0.17**	0.18
Mean		0.4	3.6	2.3	1.9	2.0	0.5	6.1	9.8	3.5	2.6

(28%) by Vasile et al. (2017) on oak–beech stands in Romania, in the DC5 decay class (39%) by Rimle et al. (2017) on Swiss European spruce stands, in the DC5 decay class (2.23 m^3/ha and 24%) by De Meo et al. (2017) in Greek red pine urban forest, in the DC4 decay class (38.3 m^3/ha and 38%) by Motta et al. (2015) on the beech–fir–spruce mixed stands, in the DC4 decay class (7.2 m^3/ha and 38%) by Sippola et al. (1998) in the older pine stands and in the DC4 decay class (11.8 m^3/ha and 79%) in the managed pine stands (Table 5).

When these results are compared with the previous studies, it has been determined that similar results are generally obtained. The difference with the results of some studies is due to the ownership of the forest, the coverage of settlements and their distance from the forest, the difference in the need of those living close to the forest for forest products to be obtained from the forest (income level or the necessity of obtaining fuel from the forest), tree species, climatic conditions, different stand and topographic parameters.

When the distribution of deadwood volumes in each deadwood class is explored according to the decay classes, it can easily be seen that the highest volume is observed in DC2 (69%) in the standing deadwood trees, in the DC5

Table 5 Comparison of deadwood volume (%) according to decay classes and stages of decay in each deadwood class

Study	Tree	Country	Management type	Distribution of DWP by decay classes (%)					Distribution of DWP by DW types and decay classes (%)									
									SDT		LDW		Stump		CWD		Snag	
				I	II	III	IV	V	DC	%	DC	%	DC	%	DC	%	DC	%
This study	S-F-Sp	Artvin-Veliköy FMU	Managed	4	35	23	18	20	II	69	IV	30	V	33	–	–	–	–
		Karagöl-Sahara NP	Protected	2	27	44	15	12	III	52	III	47	V	31	–	–	–	–
Bayraktar ve ark. (2020)	Ok–Be	İstanbul Belgrad	Protected	34	17	13	19	1	I	73	I	26	V	58	–	–	–	–
Senhofa ve ark. (2020)	Bi	Latvia	Protected	23	39	21	13	4	–	–	–	–	–	–	–	–	–	–
Paletto ve ark. (2020)	Bi	Russia	Managed	17	24	19	23	17	–	–	–	–	–	–	–	–	–	–
Błońska ve ark. (2019a)	C–B	Poland	Protected	1	9	48	28	14	–	–	–	–	–	–	–	–	–	–
Puletti ve ark. (2019)	–	Europe—19 countries	Managed	26	24	20	20	10	II	23	II	30	IV	30	IV	22	III	23
Keren ve Diaci (2018)	Be–F–S	Southeast Europe	Protected	4	12	23	30	31	III	34	V	40	IV	61	–	–	–	–
Keren ve Diaci (2018)	Be–F–S	Southeast Europe	Managed	2	7	18	43	31	IV	34	V	44	IV	64	–	–	–	–
Parobeková ve ark. (2018)	F–Be–S	Slovakia	Protected	13	16	18	53	–	II	44	IV	48	–	–	–	–	–	–
Behjou ve ark. (2018)	B	Iranian	Managed	13	9	22	24	32	–	–	–	–	–	–	–	–	–	–
Vasile ve ark. (2017)	Ok–Be	Romania	Protected	7	24	22	28	19	II	55	IV	43	V	30	V	26	III	39
Rimle ve ark. (2017)	S	Switzerland	Managed	4	10	15	32	39	–	–	–	–	–	–	–	–	–	–
De Meo ve ark. (2017)	Cp	Greece	Protected	22	22	21	12	24	II	71	I	29	V	43	–	–	–	–
De Meo ve ark. (2017)	Cp	Italy	Protected	10	27	50	12	2	II	35	III	54	III	56	–	–	–	–
Motta ve ark. (2015)	Be–F–S	Montenegro	Protected	4	12	36	38	9	III	43	–	–	IV	87	IV	42	–	–
Paletto ve ark. (2014)	Ok	Italy	Managed	23	13	25	22	17	I	36	V	43	V	39	–	–	I	36
Du Cros ve Lopez (2009)	C–B	France	Managed	21	17	49	17	4	III	56	–	–	III	44	III	43	III	57
Motta ve ark. (2006)	S	Italy	Protected	21	35	28	16	0	–	–	–	–	–	–	–	–	–	–
Sippola ve ark. (1998)	P	Finland	Protected	4	15	24	38	19	–	–	–	–	–	–	–	–	–	–
Sippola ve ark. (1998)	P	Finland	Managed	1	1	7	79	12	–	–	–	–	–	–	–	–	–	–

STD: Standing deadwood, LDW: Lying deadwood, CWD: Coarse woody debris, TDW: Total deadwood, DWP: Deadwood proportion of total volume, FE: Forest enterprice, NP: National park, S: Spruce, F: Fir, Sp: Scots pine, Ok: Oak, Be: Beech, Cp: Calabrian pine, Bi: Birch, C: Conifers and B: Broadleaves

(33%) in stumps and in DC4 (30%) in downed deadwood trees in Veliköy FMU. For the Sahara National Park, it is determined that the highest deadwood volume is found in DC3 decay class (52%) of the standing deadwood trees, in the DC5 (31%) in stumps and in the DC3 (47%) in downed deadwood trees (Tables 2 and 5). Similar to the results in Veliköy FMU and Karagöl-Sahara National Park, the decay classes with the highest deadwood volume are; DC5 (58%) in stumps for the study of Bayraktar et al. (2020), DC2 (23%) in standing deadwood trees for the study of Puletti et al. (2019), DC3 (34%) in standing deadwood trees in the managed stands for the study of Keren and Diaci (2018), DC2 (44%) in standing deadwood trees and DC4 (48%) in downed deadwood trees for the study of Parobeková et al. (2018), DC2 (55%) in standing deadwood trees, DC4 (43%) in downed deadwood trees and DC5 (30%) in the stumps studied by Vasile et al. (2017), DC2 (71%) in standing deadwood trees for the red pine stands in urban in Greece, DC5 (43%) in stumps, DC2 (35%) in standing deadwood trees and DC3 (54%) in downed deadwood trees for the study by De Meo et al. (2017) conducted in the red pine urban forest in Italy, DC3 (43%) in standing deadwood trees for the study of Motta et al. (2015), DC5 (39%) in stumps for the study conducted by Paletto et al. (2014) and DC3 (56%) in standing deadwood trees for the study by Du Cros and Lopez (2009). When these results are compared with the outcomes of the previous studies, it is seen that similar results are generally observed.

While the deadwood volume shows an uneven distribution according to the decay classes for age, site index and density, the volume of deadwood increases in stages of decay as the development age and crown closure increase (Table 3). For the variables of slope, aspect, elevation, distance from the road and settlement, the amount of deadwood volume by the stages of decay generally shows an uneven distribution (Table 4). The deadwood volumes for the 0–100, 101–250, 251–500 and > 500-m proximity classes to the road in Veliköy FMU are at the highest in DC2, DC2, DC3 and DC2 decay classes, respectively, and DC2, DC3, DC3 and DC3 decay classes, respectively, in the Karagöl-Sahara National Park. On the other hand, the deadwood volumes for the proximity classes of 0–500, 501–1000, 1001–1500 and > 1500 m to the settlements are the highest in DC2, DC2, DC2 and DC3 decay classes in Veliköy FMU, respectively, and DC3, DC3, DC3 and DC3 decay classes, respectively, in Karagöl-Sahara National Park. Behjou et al. (2018) determined the order of the deadwood volume in the hardwood stands as DC5 > DC4 > DC3 > DC2 > DC1 in medium road class and DC3 > DC5 > DC4 > DC1 > DC2 in tough road classes in terms of access to the deadwood volume. On the other hand, they determined that the amount of deadwood volume in each decay class was higher in the tough road conditions. In the study conducted by Bayraktar et al. (2020) on oak–beech stands in Istanbul Belgrade forest, the highest amount of deadwood volume was found to be 3.74, 7.04, 4.79 and 5.17 m^3/ha in DC1 decay class by four age classes (< 60, 60–120, 120–180 and > 180 years, respectively). They have also determined that the volume of deadwood in the early decay stages is the highest in both easy and tough road classes on the basis of access classes to the deadwood.

The volume of deadwood in forests depends on the deadwood accretion factors (e.g., disturbance, self-thinning and senescence) and depletion factors (e.g., decay, harvest and stagnation) (Woodall and Westfall 2009). The large variability in deadwood volume revealed in our study is consistent with the other studies. This variability is related to the stand characteristics such as stand type (tree species combination), stand age, site index, stand density, development stages and crown closure; the topographic parameters such as slope, aspect and elevation and the social pressure variables such as distance from the road and settlement, the process and duration of decomposition of deadwood, the history of natural destruction disasters and the management approach of the forests (Senhofa et al. 2020).

Conclusions

In this study, it was assessed how much deadwood was present in pure and mixed Oriental spruce stands (spruce + pine and spruce + fir), both in the managed forests of Şavşat-Veliköy FMU and the protected areas of Karagöl-Sahara National Park. In the Veliköy FMU, the deadwood volume and the proportion of total deadwood volume to the growing stock were calculated to be 10.1 m^3/ha and 2.6%, and 22.5 m^3/ha and 4.2% in the Karagöl-Sahara NP, respectively. The high stump volume in the Veliköy FMU is caused by a significant amount of unplanned harvesting, as well as the illegal removal of standing deadwood and leaning deadwood from the forest. Nonetheless, the maximum standing deadwood volume (10.8 m^3/ha and 47.8%) found in Karagöl-Sahara NP suggests that unlawful harvesting is not as problematic there as it is in protected forest stands. It was determined that the deadwood volume was mostly in the DC2 (3.56 m^3/ha and 35%) decay class in the Veliköy FMU and in the DC3 (9.81 m^3/ha and 44%) decay class in the Karagöl-Sahara NP. The majority of the deadwood volume in the Veliköy FMU is in the DC2 (3.56 m^3/ha and 35%) decay class, which suggests that the managed forests are under more social pressure due to their distance from the road and populated areas. However, the deadwood volume in the Karagöl-Sahara NP is primarily in the DC3 (9.81 m^3/ha and 44%) decay class, which suggests that there is less societal pressure in the protected forests.

The findings from both pure and mixed eastern spruce forest stands can serve as a guide for managed and protected forest regions. When creating forest management plans that take into account multiple ecosystem services, these values acquired with the deadwood volumes and decay classes can be utilized to estimate carbon storage. The findings of the study are significant because they provide information for future decisions on how to manage deadwood in pure and mixed Oriental spruce stands. Indicators of the naturalness of the forests under research, such as the amount of deadwood collected in this study based upon deadwood types and decay classes, are important for ensuring the long-term viability of forest ecosystems.

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Authors' contributions Conceptualization was contributed by all; methodology was contributed by all; investigation was contributed by AK; data curation was contributed by SÖ and AK; formal analysis was contributed by AK; visualization was contributed by SÖ and AK; writing—original draft was contributed by SÖ and AK; writing, review and editing were contributed by all; project administration was contributed by AK and supervision was contributed by MY and AK. All authors have read and agreed to the published version of the manuscript.

Data availability The data presented in this study are available from the corresponding author on request. The data are not publicly available due to the ongoing analyses.

Declarations

Conflict of interest The authors declare no competing interests.

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