

Analyzing deadwood volume of Calabrian pine (*Pinus brutia* Ten.) in relation to stand and site parameters: a case study in Köprülü Canyon National Park

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Abstract The importance of deadwood (DW) in forest ecosystems is widely recognized today. Deadwood is used as a proxy indicator for biodiversity conservation and sustainable management of forests. This research aims to determine the amount and spatial distribution of DW (standing dead trees, stumps, and coarse woody debris) and characterize the changes with few selected parameters in an unmanaged forest reserve of Köprülü Canyon National Park (NP). The data were collected from 387 temporary sample plots with different stand characteristics such as stand age, crown closure, site index, and density, and site parameters like elevation, aspect, slope, and distance to settlement areas of Calabrian pine (*Pinus brutia* Ten.)-dominated forests. The mean volume of DW was 3.8 m³/ha which was 2.4% of the total standing living volume. The volume of standing DW was 0.5 m³/ha (13.2%), that of stumps was 0.2 m³/ha (5.3%), and that of down DW was 3.1 m³/ha (81.5%). Statistically, positive

correlation was found between the volume of DW and that of living trees, crown closure, altitude ($p < 0.01$), and stand age ($p < 0.05$). However, negative correlation was found between the number of understory trees ($p < 0.01$) and DW. The results obtained from Calabrian pine (*P. brutia* Ten.) can be used as reference values for managed forests and can contribute to set the rules in deciding the appropriate level of DW in particularly biodiversity integrated forest management planning.

Keywords Forest management · Deadwood reference values · Geographic information systems · Physiographic parameters · Mediterranean region

Introduction

Deadwood (DW) is an important component of natural forests, generally defined as all non-living tree biomass, including woody debris representing standing or lying trees alone with stumps except for duff and litter (FAO 2006). Standing dead trees and lying DW provide critical habitat for numerous flora and fauna, assuring food sources and proper places for nesting, mating, loafing, and food storage for a large variety of animal species from amphibians and reptiles to birds and mammals (Rahman et al. 2008). Deadwood also influences the forest microclimate, acting as an important water-storing element during dry periods and providing nurse logs for regeneration in cool temperatures especially in sub-mountain forest types. Additionally, DW provides important benefits in reducing erosion, maintaining slope and soil surface stability, and

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acting as seedbed for plants in forest regeneration (Maser and Trappe 1984; Harmon et al. 1986; McComb and Lindenmayer 1999; Takahashi et al. 2000). Besides, the carbon content of DW adds significant values to the overall carbon storage of forest ecosystems (Harmon 2001) and contributes to the humification process that secures a continuous supply of organic material to the soil (Schaeztl et al. 1989). Therefore, the awareness of DW by the key stakeholders having certain interests in the management of forest ecosystems has gradually changed and efforts have been made to carefully manage DW dynamics in managed forests, as it is accepted as an important indicator especially for sustainable forestry and biodiversity conservation (Hodge and Peterken 1998; Harmon 2001; MCPFE 2007).

Deadwood inventories have expanded extremely, particularly focusing on the quantities and qualities in managed forests, near-natural forests, or forest reserves (Kirby et al. 1998; Fridman and Walheim 2000; Saniga and Schütz 2001; Mountford 2002; Christensen et al. 2005; Von Oheimb et al. 2007; Rahman et al. 2008; Çolak et al. 2009; Löhmus and Liira 2013). The recent studies showed large variability of DW accumulation in forest ecosystems. Differences in tree species composition, site productivity, and climate and disturbance regime in natural forest ecosystems have certain impacts on the amount of DW. Although some guidelines and recommendations for individual forest types exist, there are no standards throughout the world because of the large variations of DW values. Detailed information is still needed for different forest types and for better understanding of DW dynamics at local or regional levels. The related studies in the literature generally investigate the amount, type, temporal changes, or a number of certain stand parameters of DW. Nevertheless, other factors that may influence the dynamics of DW remain unidentified. The effects of crown closure, slope, aspect, understory canopy, or distance to settlements on DW dynamics have not been studied except latitudinal gradients (Woodall and Liknes 2008) and developmental stages (Harmon et al. 1986; Sturtevant et al. 1997; Saniga and Schütz 2002; Montes and Canellas 2006). Therefore, the changes of DW according to other parameters need to be analyzed for the sustainable management of forest ecosystems for multiple values.

Researches in forest reserves are important as they can provide reference values for DW and valuable information about the related biodiversity that can later be used in sustainable management of other forests. Such information is of great interest for conservationists, forest managers, and policymakers. In Turkey, for instance,

there are several protected areas that are less influenced by anthropogenic disturbances. For this reason, Köprülü Canyon National Park (NP) was selected to investigate the relationships between the level and dynamics of DW and stand parameters. Moreover, no study is available concerning the amount of DW in Calabrian pine stands. Therefore, the aims of this study are to analyze the quantity and types of DW in a protected Calabrian pine (*Pinus brutia* Ten.) forest, compare the amount of DW in managed and unmanaged forest ecosystems that can help to develop appropriate management prescriptions and display the changes and relationships of DW according to selected stand and site parameters.

Methods

Study area

The case study area is located in the Köprülü Canyon National Park (NP), surrounding the cities of Antalya and Isparta located in the southern Mediterranean Region of Turkey, one of the 41 national parks in Turkey (Fig. 1). The study area covers a total area of 7926.6 ha within the NP (22.2% of the total NP area), having 5863.6 ha (73.9%) of forested lands and 2063.0 ha (26.1%) of open lands including settlements and agriculture areas. The case study area is characterized by dominantly steep and rough terrain conditions with an average slope of 40.3% and an altitude from 110 to 870 m a.s.l. The area includes only fully stocked and loose canopy stands of Calabrian pine, providing many services to the public, such as water, soil protection, carbon sequestration, biodiversity, and especially recreation. Forest lands in the study area even in the park are state-owned and there is no private forest owner.

Since the establishment of Köprülü Canyon NP in 1973, national and local authorities have been quite slow to take necessary management actions. Upon the declaration of a master plan, a forest management plan was prepared, for the period of 2008–2017, allowing moderate timber production without endangering ecological integrity. However, the management plan was unable to reach the target as it was not put in practice as desired. Besides, the prescribed management activities such as regeneration and thinning have not been undertaken since 1996. After the announcement of NP, tourism activities were developed rapidly. Since then, there has been an intensive use of the park over the summer

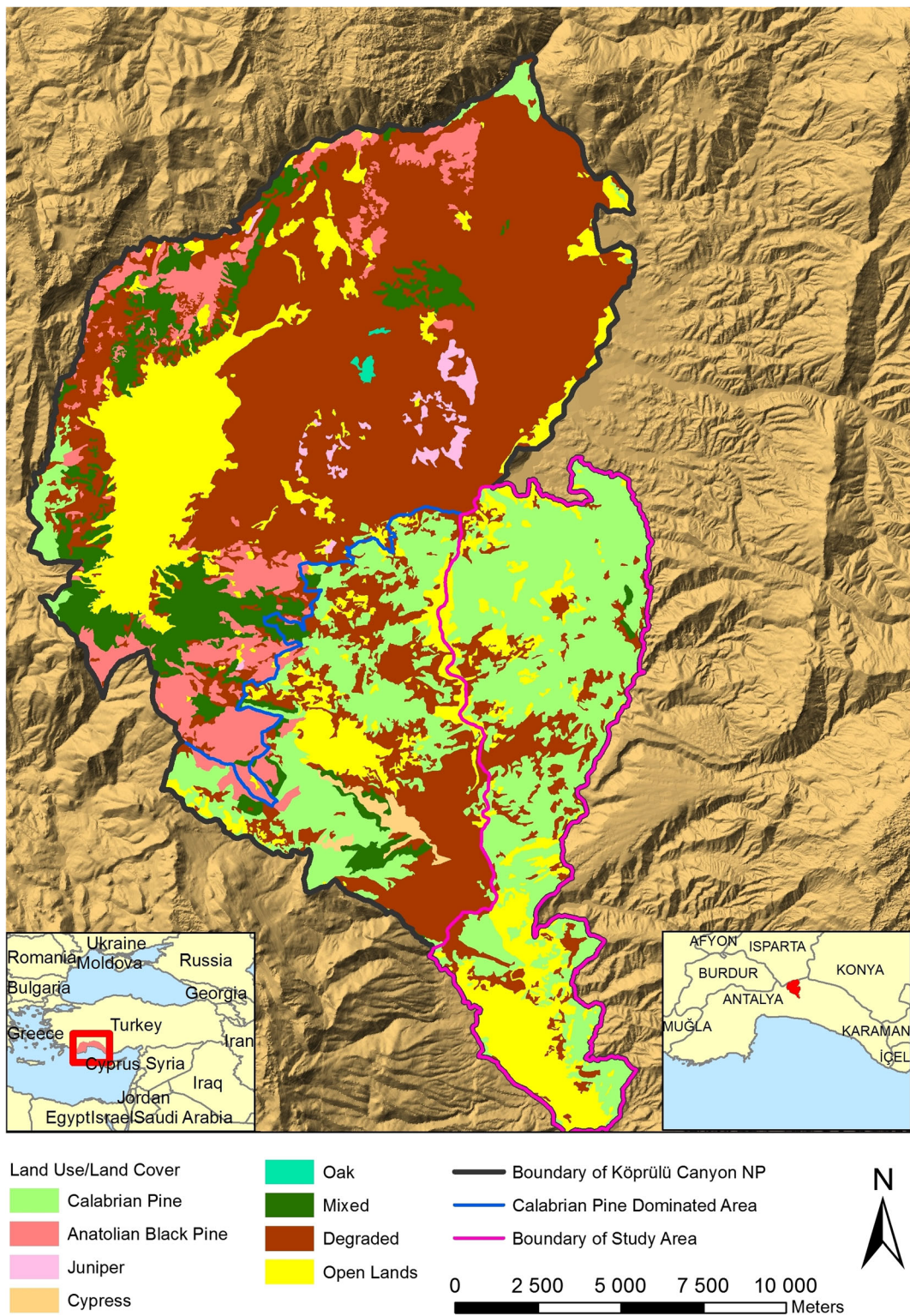


Fig. 1 Location and land cover of Köprülü Canyon National Park

months. Although visitors' records are not kept regularly in the park, it is estimated that nearly 360,000 people visit the NP each year. Sometimes, however, 8000 people with an average of 3000 people visit the park in a day. Therefore, local people have gradually begun to work in the service works such as rafting boat captaincy or waitresses in the park. Meanwhile, agriculture and stockbreeding were gradually diminished, leading to a reduction in the public pressure on forests. As the visitors use certain parts of the NP and tourist activities take place within a limited area now, the forested areas have begun to improve in that period (Karahalil et al. 2009; Karahalil et al. 2015).

The conceptual framework of the approach

While there are some attempts to set up some standards as presented in COST Action E272, the definition of DW components varies around the world and there are no accepted standards for the definitions and inventory format for sampling (Fridman and Walheim 2000; Schuck et al. 2004; Debeljak 2006; Rondeux and Sanchez 2009). Some authors (Fridman and Walheim 2000; Christensen et al. 2005; Atıcı et al. 2008) distinguish only two types of DW, standing and lying deadwood; other researchers use a more detailed classification with four or five components such as standing dead trees, snags, stumps, downed dead trees, and lying fine and coarse pieces (Kirby et al. 1998; Schuck et al. 2004; Travaglini et al. 2007). Since coarse DW persists in the ecosystem over a substantial time, it is regarded to be a more significant component of DW than fine woody debris. Hence, most inventories do not account for fine woody debris and deal only with the components of coarse woody debris. In this study, three kinds of DW were considered: standing dead trees, stumps, and coarse woody debris (Table 1).

A discrepancy in the understanding of snags and stumps exists among some researchers. For example, Harmon and Sexton (1996) consider a snag to be any vertical piece irrespective of its height resulting from natural processes only, while Travaglini et al. (2007) require a snag to have a height equal to or greater than 1.3 m (Merganicova et al. 2012). In this study, a snag according to Harmon and Sexton (1996) was considered within the definition of standing dead trees. A stump is also defined according to Harmon and Sexton (1996) as a short vertical piece resulting from cutting. However, we caution that stumps originated from illegal cutting

Table 1 Definitions of the selected deadwood types

Deadwood type	Characteristics
Standing dead trees	Standing dead trees with or without boles over 8 cm of diameter at breast height, includes snags by Harmon and Sexton (1996)
Stumps	Ground parts of illegally cut trees over 8 cm in diameter at 10 cm height (interventions not allowed since 1996)
Coarse woody debris (down deadwood)	Fallen trees or coarse woody debris over middle diameter ≥ 8 cm and length ≥ 15 cm

because commercial harvesting has not been allowed for the last 20 years within the park. Similarly, the variability of minimum threshold diameter between coarse and fine woody debris is large. While some authors such as Green and Peterken (1997), Debeljak (2006), Travaglini et al. (2007), and Vandekerkhove et al. (2009) use a minimum threshold of 5 cm, other authors prefer the diameter limit of 7 cm as Woodall and Liknes (2008) stated. On the other hand, Harmon et al. (1986), Çolak (2002), Fridman and Walheim (2000), Norden et al. (2004), Atıcı et al. (2008), and Sefidi et al. (2013) use a higher diameter limit of 10 cm as suggested by IPCC (2003). Harmon and Sexton (1996) found that, below this diameter, the decay rate increases exponentially, while above this diameter the decay rate decreases quite slowly. However, Vandekerkhove et al. (2009) showed that the differences in diameter thresholds do not significantly affect the results, and DW volume is less affected by size thresholds (Merganicova et al. 2012). Similarly, Çolak (2002) argued that smaller material is considered of lesser importance. The decay rate increases exponentially below 10 cm, generally accepted as threshold value for coarse woody debris. On the other hand, above this diameter, the decay rate decreases only slowly (Harmon and Sexton 1996). Due to this fact, the decomposition process of coarse woody debris can sometimes take up to 1000 years depending on wood characteristics, climate regime, and the position on the ground (Feller 2003). Since coarse woody debris persists a substantial time in the ecosystem, it is regarded as a more significant component of DW than fine woody debris. Hence, most inventories do not account for fine woody debris and deal only with the components of

coarse woody debris (Merganicova et al. 2012), as we considered in this study.

After determining DW types and their threshold values, stand and site parameters were selected to determine the amount of DW. A conceptual framework for achieving the purpose of this study was developed and presented below (Fig. 2). Stand characteristics such as stand age, developmental stage and crown closure were obtained from the national forest inventory data. However, site factors like altitude, slope, aspect and distance to settlement were calculated using the appropriate GIS functions. Belowground DW was not considered in the context of this study. After calculating the amount of DW, we also tried to display the dependence of DW to selected factors using statistical analyses.

Deadwood inventory and data analyses

Although, there is no harmonized methodology for DW inventory, standing DW is usually inventoried with the same methodology as living trees. The common approach is the plot based sampling, while the plots can either be of fixed or variable sizes (Rondeux and Sanchez 2009). In this study, variable area sample plots were used for the inventory to include certain number of trees. The size of circular plots was determined as 400, 600, and 800 m² depending on crown closure with <40%, 40–70%, and >70% respectively, according to the national forest inventory guidelines (GDF 2014a). In this study, the data were obtained from 387 temporary sample plots, systematically distributed over the study area with 300 m × 300 m intervals to cover variability in the selected stands and site parameters (Fig. 3).

The diameters at breast height of all living trees and standing dead trees larger than 8 cm and height of three to five individuals at different diameter categories were measured in each sample plot. Besides, age and height of dominant, free-growing trees in the upper forest canopy were also measured to determine the relationship between the amount of DW and stand age and site index. The site index was determined on a 50-year base age according to Alemdağ (1962) for further analyses. Stand age was determined by taking increment bores at breast height from at least two individuals using increment borer. To determine the actual stand age, 6 to 10 years were added to the age obtained from the increment core to account for the years it took for the tree to grow to the breast height. For the stumps and

lying coarse DW pieces, middle diameter and length values were measured.

During the inventory, only DW inside a plot was considered and the part outside the plot was not accounted. The volume of both living and standing dead trees was estimated using the tree volume tables of the Köprülü Canyon NP forest management plan (GDF 2008). The volume of snags, stumps, and coarse woody debris was estimated using the formula for a cylinder (Kramer and Akça 1995; Roibu 2010). After calculating the volume of different types of DW, all of them were summed up and converted to per-hectare values. Subsequently, we tried to investigate the changes of DW in relation to the following selected parameters: altitude, tree species, age, crown closure, developmental stage, and distance to settlement. Developmental stages were determined as seedling, (the diameters between 0 and 8 cm), pole (8–20 cm), small wood (20–36 cm), and mature (>36 cm) in this study.

Site factors such as slope, altitude, and aspect were calculated using Triangular Irregular Network (TIN) data for each sample plot with ArcGIS 10.2™ GIS. Distance to settlement and distance to road values were also computed using the spatial analysis functions of ArcGIS. The data were then stored as attribute data for each sample plot, and the spatial database was established for the study area for further analyses. We then displayed the outputs related to DW volume and its change according to the selected parameters using GIS functions as well as DW volume map. In order to design DW map, first of all, the sample plot layer with DW volumes was intersected with the stand type layer, then the mean DW volume was computed for each stand. The relationships between DW and the selected parameters were investigated using Pearson correlation through SPSS 16.0™ software.

Results

The volumes of stands and DW as well as the ratios are given in Table 2. Here, the changes of average living volume of stands in relation to given parameters were quite logical and noteworthy. For instance, the volume increased with the developmental stage, crown closure, age, or site index. The mean live volume was 160.1 m³/ha. DW volume ranged between 0 and 72.2 m³/ha with an average of 3.8 m³/ha calculated from all sample plots (Table 2).

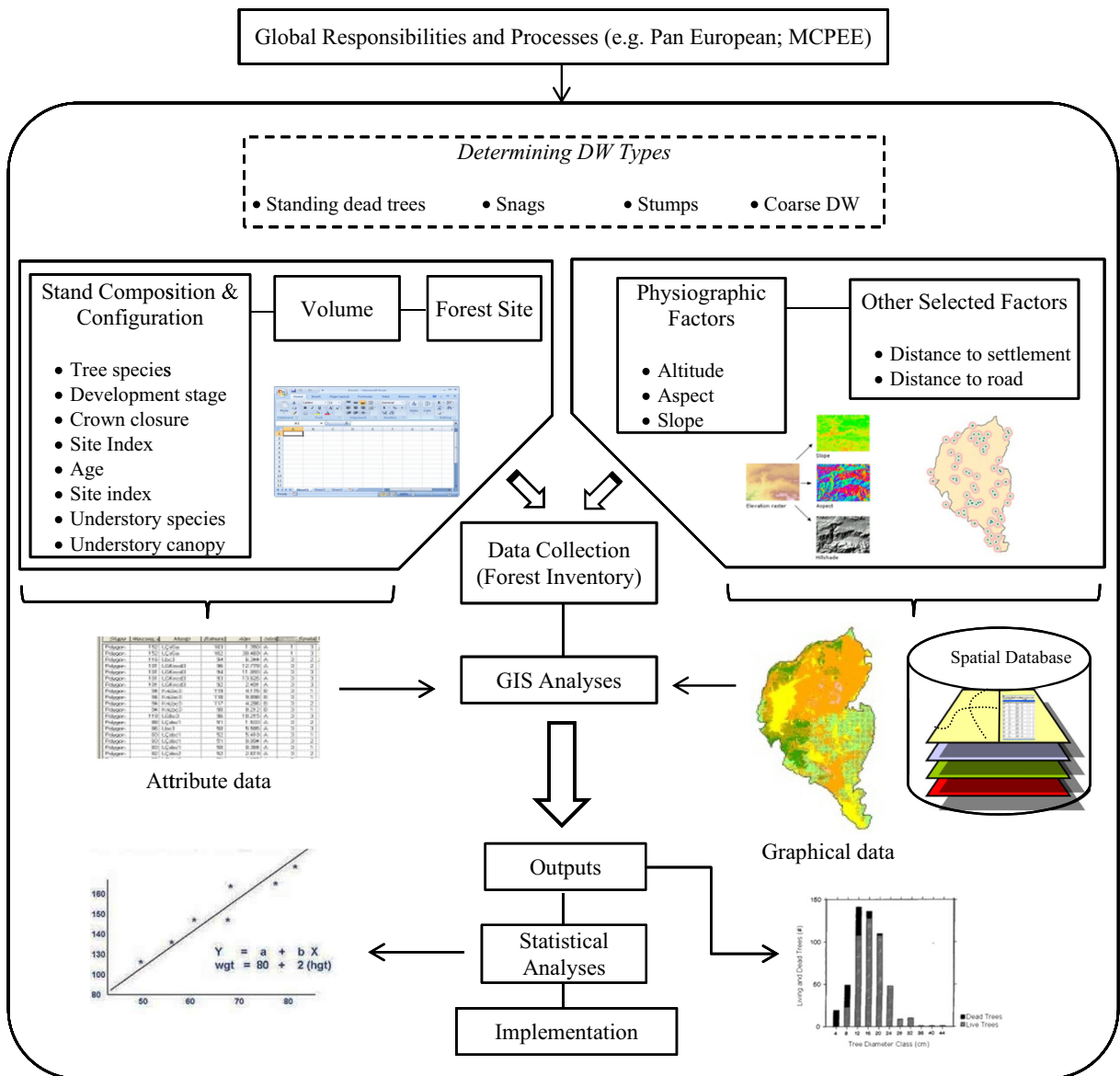


Fig. 2 Conceptual framework of this study

As expected, the amount of DW was the highest under closed canopies, gradually increasing from 1.6 to 6.2 m³/ha as the stands became progressively closed. Similarly, the amount of DW at good sites was also the highest. When the number of understory species increased, the amount of DW decreased from 8.2 to 1.5 m³/ha, but the amount of DW fluctuates when understory canopy increased. Stands seemed to have more DW from 1.9 to 4.7 m³/ha as the developmental stage changes to older stages except for the mature developmental stage. However, these differences were

not statistically significant. On the other hand, age was a significant factor on the amount of DW which was found to increase with age from 1.6 m³, between 0 and 20 years, to 6.2 m³ over 100 years. It is understood that the highest stump DW was in the regenerated developmental stage (0–8 cm) and young stands (0–20 years). Similar results were observed with the site index. It seems that, as the site index decreases, the amount of DW reduces from 4.2 to 2.4 m³/ha, without any statistically significant differences between the amount of DW and site index.

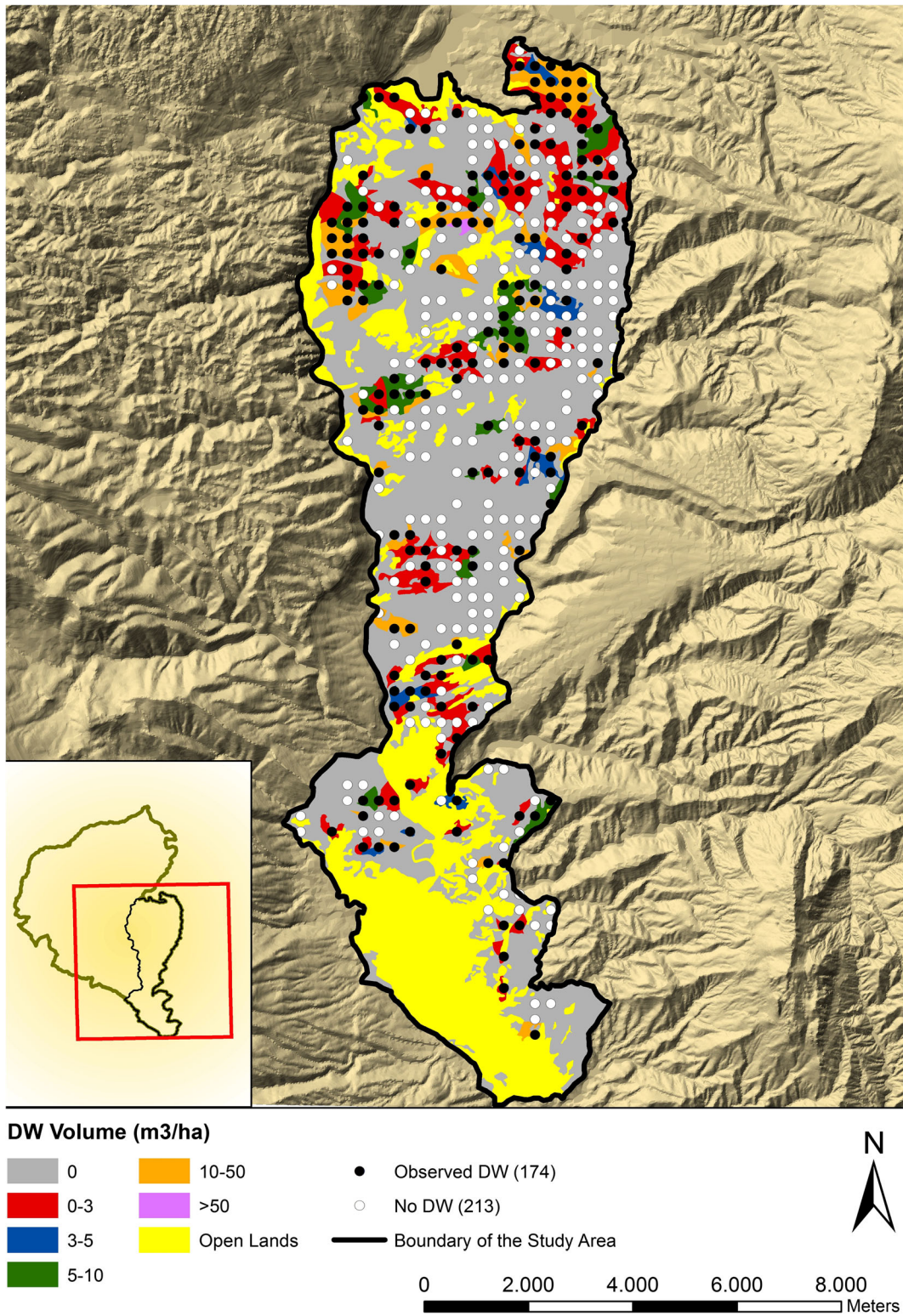


Fig. 3 Spatial distribution of sample plots and deadwood volume map of the study area

Table 2 The amount of DW according to selected stand parameters

	SP	Living V (m ³ /ha)	Standing DW (m ³ /ha)	Stump (m ³ /ha)	Down DW (m ³ /ha)	Total DW (m ³ /ha)	DW to live wood (%)
Developmental stage (cm)							
Degraded	3	29.0	–	–	–	–	–
0–8	12	47.6	–	1.9	–	1.9	4.0
8–20	112	116.5	0.4	0.1	2.4	2.9	2.5
20–36	125	176.1	0.4	0.2	4.1	4.7	1.9
>36	135	194.6	0.7	0.1	2.9	3.7	1.9
Crown closure (%)							
0–10 (degraded)	3	29.0	–	–	–	–	–
10–40	102	133.5	0.1	0.1	2.6	2.8	2.1
40–70	168	176.5	0.6	0.1	2.1	2.8	1.6
>70	114	163.2	0.8	0.3	4.9	6.0	3.7
Age							
0–20	14	70.1	–	1.6	–	1.6	2.3
20–50	111	113.7	0.3	0.1	2.0	2.4	2.1
50–100	194	169.5	0.5	0.1	3.2	3.8	2.2
>100	68	227.6	1.2	0.2	4.8	6.2	2.7
Site index (m)							
21.25–25.75	62	198.3	0.6	0.3	3.3	4.2	2.1
16.75–21.25	264	156.6	0.6	0.2	3.2	4.0	2.6
12.25–16.75	61	136.2	0.2	–	2.2	2.4	1.8
U. canopy (%)							
0–20	173	169.3	0.8	0.4	2.7	3.9	2.3
20–50	106	156.8	0.2	0.0	4.1	4.3	2.7
>50	108	148.6	0.3	0.1	2.5	2.9	2.0
Number of U. species							
0	55	200.9	0.9	0.6	6.7	8.2	4.1
1–3	171	162.4	0.8	0.2	2.5	3.5	2.1
4–6	151	144.3	0.1	0.0	2.4	2.5	1.7
>6	10	134.5	–	0.1	1.4	1.5	1.1
Overall means		160.1	0.5	0.2	3.1	3.8	2.4

U understory, SP number of sample plot, V volume, DW deadwood

The analysis of site parameters revealed that the amount of DW increased from 2.6 to 5.0 m³/ha with the increase of elevation. On the other hand, the remaining site factors were not statistically significant. For instance, DW dropped gradually from 4.3 to 2.9 m³/ha as the slope increased except for the slope values between 60% and 80%. The sites with northern and eastern aspects had more DW as 4.3 m³/ha in the north and 3.9 m³/ha, respectively. On the other hand, western and southern aspects had lower values as 3.7 and 3.1 m³/ha, respectively. The total amount of DW increased from

1.0 to 5.6 m³/ha with the increasing distance from settlements. Stump DW was not markedly high in areas closer than 500 m distance from settlements and did not decrease significantly based on the distance as expected. Similarly, the total amount of DW and the stump fluctuated when distance to road increased (Table 3).

The results of the statistical analysis showed that there is a significant positive correlation between DW and volume of living trees, crown closure, altitude ($p < 0.01$), and stand age ($p < 0.05$). Significant negative correlation was observed between DW and the number

Table 3 The amount of DW in relation to site parameters

	SP	Living vol. (m ³ /ha)	Standing DW (m ³ /ha)	Stump (m ³ /ha)	Down DW (m ³ /ha)	Total DW (m ³ /ha)	DW to live wood (%)
Altitude (m)							
180–300	79	141.9	0.2	0.1	2.3	2.6	1.8
300–600	158	145.6	0.5	0.1	2.6	3.2	2.2
600–850	150	185.0	0.8	0.3	3.9	5.0	2.7
Slope (%)							
0–20	66	176.6	0.5	0.2	3.6	4.3	2.4
20–40	182	157.6	0.6	0.1	2.9	3.6	2.3
40–60	111	155.9	0.3	0.4	2.7	3.4	2.2
60–80	24	149.0	0.8	0.1	4.2	5.1	3.4
>80	4	92.2	–	–	2.9	2.9	3.1
Aspect							
North	108	167.5	1.0	0.3	3.0	4.3	2.6
East	92	152.2	0.5	0.1	3.3	3.9	2.6
South	89	154.2	0.4	0.1	2.6	3.1	2.0
West	96	166.0	0.2	0.3	3.2	3.7	2.2
Flat	2						
Dist. to settlement(m)							
0–500	44	142.8	0.1	0.2	0.7	1.0	0.7
500–3000	329	161.8	0.6	0.2	3.2	4.0	2.5
>3000	14	174.0	–	0.1	5.5	5.6	3.2
Distance to road (m)							
0–100	57	148.9	0.1	0.1	1.9	2.1	1.4
100–500	197	157.9	0.6	0.3	3.3	4.2	2.7
>500	133	168.1	0.6	0.2	3.0	3.8	2.3
Overall mean		160.1	0.5	0.2	3.1	3.8	2.4

of understory species ($p < 0.01$) (Table 4). Although different regression models were tested to estimate the amount of DW, the selected parameters explained relatively lower total variations in DW volume. Thus, living stem volume, altitude, or number of understory species did not contribute to the DW volume. The models provided around 0.10 to 0.15 coefficient of determination due to the other effecting factors.

The results indicated that the mean volume of standing dead trees was 0.5 m³/ha (13.2%), that of stumps was 0.2 m³/ha (5.3%), and that of down dead trees (coarse wood debris) was 3.1 m³/ha (81.5%). Therefore, the majority of DW originated from down DW. These results indicate that illegal cutting was not a major problem within the NP and constituted an average of only 0.2 m³/ha of DW and 0.1% of total living volume.

Furthermore, the study showed that 835.2 ha (14.2%) of the forested land had the volume of DW between 0 and 3 m³/ha, while DW accumulated between 3 and 5 m³/ha in 129.3 ha (2.2%) of forests. The stands having DW between 5 and 10 m³/ha covered only 291.2 ha (5.0%) of area, and 348.1 ha (5.9%) of stands had DW volume between 10 and 50 m³/ha. Finally, the stands with more than 50 m³/ha covered only 9.1 ha (0.2%) of area. On the other hand, 4250.7 ha (72.4%) of the forested stands had no DW. These results showed that a total of 11,296.2 m³ DW was accumulated in the study area (Fig. 3).

Discussion

Our results indicated that the accumulated DW volume increased with elevation. While the amount of DW was

Table 4 The statistical results of Pearson correlation between total DW (m^3/ha) and selected parameters

Factor	Pearson correlation	Sig. (2-tailed)
Living volume (m^3/ha)	0.198**	0.000
Stand density (N/ha)	0.051	0.315
Developmental stage	0.067	0.187
Crown closure (%)	0.136**	0.008
Age (years)	0.131*	0.010
Site index (m)	0.053	0.298
Understory canopy (%)	-0.028	0.578
Number of under sp. (N)	-0.163**	0.001
Altitude (m)	0.161**	0.001
Slope (%)	-0.004	0.938
Aspect (degree)	-0.027	0.600
Distance to settlement (m)	-0.049	0.339
Distance to road (m)	0.015	0.770

$2.6 \text{ m}^3/\text{ha}$ between 180 and 300 m a.s.l, the average value reached to $5.0 \text{ m}^3/\text{ha}$ between 650 and 880 m a.s.l. Similarly, Kühnel (1999) reported that the amount of DW in mountain forests is three times higher than that in lowlands. Merganic et al. (2011) reported DW volume as $10 \text{ m}^3/\text{ha}$ at lower elevations and around $100 \text{ m}^3/\text{ha}$ under the timberline. On the other hand, Merganicova and Merganic (2010) found that DW volume declines with increasing elevation from 1260 to 1460 m. However, the reason for this reduction was the decreasing dimensions of trees with increasing elevation. In upper elevations, climate characteristics are less favorable, which negatively affects the forest productivity, and hence also the amount of DW accumulated in the forest. Tomescu et al. (2011) showed that the amount of DW from the uneven aged natural beech forests varies by altitude between 50 and $223 \text{ m}^3/\text{ha}$, with an average of $87 \text{ m}^3/\text{ha}$. The largest values were recorded at 1000 m altitude, where the vegetation conditions are near optimal conditions for the beech forests, and the lowest values were found at 1350 m altitude (Table 5). Calabrian pine stands are generally dominant between 200 and 1300 m followed by *Pinus nigra* subsp. *pallasina* (Austrian pine)-dominated stands. Timberline reaches as far as 1800 m a.s.l. in the study area. Therefore, the amount of DW increases as the altitude rises depending on the increase in the live volume of forests in this study.

According to the literature, the highest amount of DW generally occurs in over mature or breakdown developmental stages, while the lowest amount happens to be in the stage of maturity (Merganicova and

Merganic 2010). Sturtevant et al. (1997) presented that DW volume principally develops like the general “U-shaped” temporal trend. On the other hand, Herrero et al. (2016) displayed like inverse “j” pattern, as the amount of DW was $17.14 \text{ m}^3/\text{ha}$ in seedling stage, $34.09 \text{ m}^3/\text{ha}$ in pole stage, $22.54 \text{ m}^3/\text{ha}$ in mature stage, and $24.27 \text{ m}^3/\text{ha}$ in regeneration stage. The early presence of DW volume originates from residuals already left by the final harvesting operations, and the highest occurs generally in older developmental stages. Saniga and Shütz (2002) confirmed that virgin forests, consisting of stable tree species with approximately the same physical age, showed small differences between maximal increase and decrease in DW during a succession cycle. Our results indicated similar findings with gradual increase of DW volume over time except for young stands. Although the immature stands hold relatively more DW volume as indicated in previous studies, our results provided less amount of DW since young stands were almost 20 years old in the case study area and the expected residuals from harvesting activities had already diminished.

Sturtevant et al. (1997) stated that DW is influenced by site quality due to larger log sizes on the forest floor generated by the larger standing trees. Although our results seem to be similar to the mentioned study with $4.2 \text{ m}^3/\text{ha}$ in good site, $4.0 \text{ m}^3/\text{ha}$ in medium site and $2.4 \text{ m}^3/\text{ha}$ in poor site, it was not quite significant according to the statistical analyses. Furthermore, increasing DW volume with the full crown closure could be explained with the increase of live volume. Additionally, we detected more DW in distant areas from the settlements in accordance with Pasierbek et al. (2007).

In protected areas such as forest reserves and old growth forests, there are significant differences in the amount of DW due mainly to different ecosystem conditions and compositions. For instance, DW varied between 87 and $160 \text{ m}^3/\text{ha}$ in Bialowieza forest, protected since the 1300s (Bobiec 2002). In another study, Tomescu et al. (2011) found DW amount with an average of $87 \text{ m}^3/\text{ha}$ in Izvoarele Nerei beech reserve. Von Oheimb et al. (2007) found the mean volume of DW nearly $94 \text{ m}^3/\text{ha}$, amounting to 14% of the total volume of all trees in a near-natural beech forest in Serrahn located in northeastern Germany. In Poloniny National Park beech forest, an average of $121 \text{ m}^3/\text{ha}$ of DW was observed (Saniga and Schütz 2001). Tomescu et al. (2011) found that $129.2 \text{ m}^3/\text{ha}$ was the volume of fallen wood and standing dead trees in Slatioara forest reserve. According to Mountford (2002),

Table 5 The summary of DW results from the previously conducted studies in relation to stands and site characteristics

Authors	Year	Country (region)	Management type	Explanatory variables	DW volume characteristics
Kühnel	1999	Germany	Managed	Altitude	3 times higher than lowlands
Pasierbek et al.	2007	Poland (West Beskides)	Nature reserve	Altitude	Increases with the altitude. Small amount of DW was recorded (under 10 m ³ /ha) at 300 m, and over 100 m ³ /ha at nearly 1000 m.
Merganicova and Merganic	2010	Slovakia (Babia hora)	Nature reserve	Altitude	Declines with increasing elevation from 1260 to 1460 m.
Tomescu et al.	2011	Romania (Izvoarele Nerei)	Nature reserve	Altitude	Varies between 50 m ³ /ha at 1000 m and 223 m ³ /ha at 1350 m
<i>This Study</i>	2016	Köprülü Canyon	Protected area	Altitude	Increased from 2.6 m ³ /ha (180–300 m) to 5.0 m ³ /ha (650–800 m)
Sturtevant et al.	1997	Canada (Newfoundland)	Unmanaged	Dev. stage	DW volume principally develops like the general “U-shaped” temporal trend (32.3 m ³ /ha in a 36-year-old stand, lowest in a 58-year-old stand (15.2 m ³ /ha), and highest in an 80-year-old stand (78.1 m ³ /ha)
Pasierbek et al.	2007	Poland (West Beskides)	Nature reserve	Dev. stage	Strong and positive relationship between the year a reserve was founded and the DW. Increased from below 10 m ³ /ha in 1950 to over 100 m ³ /ha in 1970.
Merganicova and Merganic	2010	Slovakia (Babia hora)	Nature reserve	Dev. stage	More DW in over mature or breakdown stages, while the lowest amount is in the maturity stage
Herrero et al.	2016	Spain (Navarra)	Managed	Dev. stage	DW changed with stand development stage as 17.14 m ³ /ha in seedling stage, 34.09 m ³ /ha in pole stage, 22.54 m ³ /ha in mature stage, and 24.27 m ³ /ha in regeneration stage
<i>This study</i>	2016	Köprülü Canyon	Protected area	Dev. stage	Increased from 1.9 m ³ /ha (0–8 cm) to 3.7 m ³ /ha (>36 cm)
Sturtevant et al.	1997	Canada (Newfoundland)	Unmanaged	Site	DW is influenced by site quality due to log sizes on the forest floor generated by standing trees
<i>This Study</i>	2016	Köprülü Canyon	Protected area	Site	Increased from 2.4 m ³ /ha at poor site to 4.2 m ³ /ha at good site
Pasierbek et al.	2007	Poland (West Beskides)	Nature reserve	Distance to settlements	The amount of DW was greater in reserves situated high in the mountains, away from settlements.
<i>This study</i>	2016	Köprülü Canyon	Protected area	Distance to settlements	Increased from 1.0 to 5.6 m ³ /ha away from settlements of 0–500 and >3000 m respectively.

the DW volume ranged between 142 and 256 m³/ha in the Fontainebleau forest reserve, protected from logging since

1853. Christensen et al. (2003) found 273 m³/ha of DW in Ridge Hanger beech forest reserve. Exceptionally larger

values, more than 400 m³/ha of DW, were found in virgin forests of Central Europe (Saniga and Schütz 2001; Bobiec 2002; Debeljak 2006). The amount of DW in less intensively managed and more natural forests of Central and Eastern Europe generally ranges from 40 to 220 m³/ha (Vallauri et al. 2003; Christensen et al. 2005).

In general, our study documented low DW values as compared to the previous studies. The studies conducted in conifer Mediterranean forest resulted lower DW volumes. However there was no study dealing with the DW in Calabrian pine, which is a shade-intolerant and fast-growing species closely adapted to the Mediterranean-type climate. While Lombardi et al. (2010) found an average of 60 m³/ha DW volume ranging between 2 and 143 m³/ha for 11 different study areas under Mediterranean conditions in the Italian peninsula, INFC (2005) found an average of 5 m³/ha between 2.3 and 10.2 m³/ha for the same regions. The average DW volume was 24 m³/ha in beech stands in northern Iberian Peninsula (Herrero et al. 2016). Paletto et al. (2014) estimated the total volume of DW as 11.2 m³/ha in the stands under multifunctional management in Basilicata region located in southern Italy. Forests under extensive management had 8.5 m³/ha of DW volume, constituted by 2.7 m³/ha of lying deadwood, 4.3 m³/ha snags, and 1.5 m³/ha stumps. On the other hand, intensively managed forests had lower DW volumes as 3.1 m³/ha in the same study. On the other hand, Hernando et al. (2013) showed a DW volume lower than 5 m³/ha in Eastern Spain.

Compared to those similar studies conducted in the Mediterranean region using the percentage values, our results were still low except for two studies. While some other factors may cause a lower value and be investigated further, we tried to explain the possible reasons based on some prevailing characteristics of the case study area. For example, Calabrian pine forests grow abundantly in semi-arid and sub-humid zones (Boydak 2004). Mean stand volume in good sites does not reach 300 m³/ha in 150 years, which is a relatively maximum (breakdown) age according to yield tables developed for natural forests in Turkey (Alemdağ 1962). The average stand volume is about 160.1 m³/ha in our case study area. Therefore, the amount of DW could not be expected to reach the higher levels found in other studies conducted in different ecosystems.

Another factor causing less amount of DW volume in the study area is the frequent forest fires, having a pervasive influence on the DW quantities. The park is

sensitive to forest fires as it is located in the Mediterranean region. Forests in and around the park have been subjected to substantial levels of fire disturbances over the past. Historically, forest fires caused by lightning or anthropogenic activities have shaped forest landscape patterns in this ecoregion. The surrounding landscape has clear indications of many fire damages in and around the park. Those fires generally occur as ground or surface fires in the park. For instance, this park is located adjacent to the acute Serik-Taşağıl (Antalya) forest fire, which broke out in August 2008 and destroyed about 24,000 ha land with 16,000 ha forests. Moreover, 111 different forest fires occurred (nearly all of them ground fires) over 34 years from 1979 to 2013, with an average annual 3 fires (GDF 2016). Therefore, fire had negative effect on the accumulation of DW in the park.

There are 11 villages and many sporadic settlements within the boundaries of the Köprülü Canyon NP. The total population of the park's communities is 6814 according to the 2010 census data acquired from State Institute Statistics (SIS 2016). The management concept was mainly preventing the locals from further utilizing the resources without proving any alternatives. Unfortunately, the top-down and strict regulatory management principles inevitably let the local communities meet their timber and fire wood needs in the surrounding forests. The local people used to cut only the unhealthy, dead and dried trees for their fire-wood needs. Although wood collecting is prohibited in the park, it is a big challenge to control the collection because it is usually performed in small amounts at a time and it is always too late when it was spotted. Specifically, wood residues and lying coarse woody debris have been frequently removed and used as fuelwood by local populations. Besides, the villagers inside the park have relatively low income levels and socioeconomic status (Coşgun and Uzun 2007), triggering the increasing probability of DW to be collected from the park. Furthermore, a Mediterranean-type climate probably influences decay rates, with its specific precipitation regime and temperature pattern, which are more erratic than the regions. Therefore, decomposition might be generally more rapid due to higher average temperatures in the Mediterranean region (Hahn and Christensen 2004). Although the factors such as forest fires or wood collection would be integrated to this study, however, there is no reliable data about collecting the amount of wood material and the exact boundaries of the burnt areas by ground fires.

Studies related to DW in the Mediterranean region are quite scarce because forests have been heavily exploited since ancient times. For that reason, old growth forests are very rare in the Mediterranean region and usually are found only inside the strict forest reserves or in the remote and impervious mountain areas. As mentioned earlier, since the establishment of Köprülü Canyon NP in 1973, authorities have been quite slow to implement the necessary forest management activities including harvesting. Although a 10-year forest management plan was prepared in 1984, allowing moderate timber production without damaging ecological integrity, this plan has not put in practice to carry out regeneration or thinning activities since 1996. One might think that the time from 1973 to date may not be enough for DW accumulation and that would not be considered as a reference for other managed forest ecosystems. However, Calabrian pine reaches its greatest distribution in southern Turkey. Among the 41 national parks, only 12 of them contain Calabrian pine-dominated stands in the country and Köprülü Canyon NP covers the largest Calabrian pine stands with the longest protection history. Here, it should be noted that all parts of DW in the study area are not the results of the accelerated breakdown of forest stands due to the natural disturbances, because a large amount of DW does not always indicate the high level of naturalness of forest ecosystems (Pasierbek et al. 2007; Laarmann et al. 2009). Therefore, considering the spatial distribution of Calabrian pine in the world and its potential protection history, the study area is not affected by the historical management activities, providing a good opportunity to examine the Calabrian pine DW accumulation although some forest fires and wood collection have taken place in the park.

Great number of researches discuss the appropriate amount of DW to be left in a forest. However, recommended values vary greatly. Older studies suggest at least 3 m³/ha (Utschick 1991), 1–5 m³/ha (Albrecht 1991; Schmitt 1992), or 5–10 m³/ha (Ammer 1991), which is 1–2% of the total volume of a stand. In more recent studies, however, the suggested values are higher and fluctuate between 15 and 30 m³/ha (Çolak 2002; Butler and Schlaepfer 2004; Jankovsky et al. 2004), or 5–10% of the total stand volume (Butler and Schlaepfer 2004; Vandekerckhove et al. 2009). Some authors argued that the quantity of DW in unmanaged forests is a third higher than that in managed forests on average (Green and Peterken 1997; Duvall and Grigal 1999). On the other hand, Commarmot et al. (2005) showed that, on average, the quantity of DW in managed forest stands could be 14

times lower than that in unmanaged forest. In another study, Lombardi et al. (2008) found that the ratio of DW volume to the living stand volume varies between 3.3% and 10.9% in different unmanaged forest types in Central Apennines of Italy. However, for the managed stands, the same ratio is suggested to be between 1.4% and 4.2% for similar forest types in the same region. The ratio of DW to live wood ranges between 0.7% and 4.1% with an average of 2.4% in this study in relation to different parameters. Although recommendations differ depending on ecosystem conditions, our results indicate that 2–3% of the total living volume seems quite reasonable and could be suggested for managed Calabrian pine forests. For instance, national silvicultural guidelines require some stand level targets towards DW management on the field in Turkey (GDF 2014b). It is stated that in economically designated areas for wood production, 1–3 DW trees per hectare is to be retained in all managed areas. However, the stated value must be updated according to the stand and site characteristics. When looking at the previous studies, comparing the managed and unmanaged forest types in the Mediterranean region, our suggestion for DW levels seems logical and offers proportional value in a specified range in relation to existing stand and site characteristics. Additionally, nearly 15% (0.5 m³/ha out of 3.6 m³/ha) of the total amount of DW was found as standing dead trees, while the rest (80%) is lying dead trees as far as the types of DW are considered, except the stumps. Therefore, such findings could also help the forest managers better determine the appropriate level of DW types.

Furthermore, Reineke's stand density index could also help the managers to determine the amount of DW with different densities. Stand density index is defined as the equivalent number of trees per hectare at a quadratic mean diameter of 25 cm (Reineke 1933). The desired density of forest stands depends on management objectives, site productivity, species composition, development stages, and frequency of treatments. While tree mortality caused by inter-tree competition, increases with density, tree size, and vigor increase as competition or stand density decreases. Moreover, wood yield is relatively constant beyond a certain density. Therefore, the decrease in trees per hectare over time considering Reineke's stand density index, could give reference values for the potential amount of DW. For instance, decrease ratio in trees per hectare initiated with 1-m planting intervals would be different from 2-m intervals for a stand between the 60 and 80 ages, even on the same site. Using the decrease values in trees per

hectare, meaning potential DW, would help in the calculation of DW levels in different densities at certain ages.

Conclusions

The traditional or historical approach that a clean forest without DW is healthier and DW brings fire and disease to forests has almost diminished as we gradually appreciate the function of DW in a forest ecosystem. In fact, the role of DW in maintaining the proper functioning, stability and biodiversity of forest ecosystems is widely recognized. While the importance of DW has been well received by researchers, less information is available about the relationship between DW and other factors. There is a lack of information regarding the most appropriate volume thresholds in relation to different parameters such as age, crown closure, living volume, or altitude. The lack of information may be completed with such studies conducted especially in protected areas or reserves proposing acceptable DW values for managed forests.

This study showed that DW volume in Calabrian pine-dominated forests ranged between 0 and 72.2 m³/ha with an average of 3.8 m³/ha primarily for conservation-oriented forest management areas. The values are based on 387 temporary sample plots with different stand characteristics (stand age, crown closure, site index, and density) and site parameters (elevation, aspect, slope). The mean volume of DW constituted 2.4% of the total living volume (160.1 m³/ha). In terms of DW types, the volume of standing DW was 0.5 m³/ha (13.2%), that of stumps was 0.2 m³/ha (5.3%), and that of down DW was 3.1 m³/ha (81.5%). The statistical analysis indicated that DW volume is significantly dependent on the volume of living trees, crown closure, number of understory species, altitude, and stand age. Therefore, the increase in the volume of living trees, crown closure, age, and altitude will have a positive impact on the total DW volume. However, DW volume decreased when the number of understory species increased in a stand. Although the amount of DW differs depending on the stand and site parameters, 2–3% of the total living volume could be suggested as the appropriate level of DW needed in managed Calabrian pine forests, primarily for conservation-oriented forest management areas.

There are a number of related studies displaying the changes of DW volume over time in forest reserves. Although some rationales are provided about the

possible reasons for relatively low amount of DW in the NP, there are still some gaps remained as “other factors” in this study. Therefore, similar work may have to be repeated for every 10- or 20-year interval to eliminate the conceivable adverse effects such as wood collection or fires. This kind of study could also help to reveal the potential causes of the amount of DW. In this way, the spatiotemporal dynamics of DW accumulation could well be displayed and understood. In this study, variable area circular sample plots were used in the inventory process of DW as well as living trees. On the other hand, different sampling methods such as line intersect sampling may be considered for more efficiency and less time consumed to estimate the volume of downed logs. Additionally, different equations with high precision and low errors may have to be tried in the calculation of DW volume.

The results obtained from the Calabrian pine forests can contribute to better understanding of DW dynamics and the factors affecting the amount of DW for Mediterranean forests. Our study provides great potential to set up initial understanding about the appropriate or natural levels of DW in a Calabrian pine forest reserve in the Mediterranean region. Nonetheless, further work is needed in forest reserves as well as in managed forests outside the study area. Similar studies integrating different climatic, physiographic, and edaphic conditions need to be carried out.

References

- Albrecht, L. (1991). The importance of deadwood material in forests. *Forstwissenschaftliches Centralblatt*, 110(2), 106–113.
- Alemdağ, Ş. (1962). *The growth, yield and management principles of Pinus brutia (Ten.) in Turkey*. Ankara: Forestry Research Institute, Technical Bulletin Series No: 11.
- Ammer, U. (1991). Konsequenzen aus den Ergebnissen der Tothholzforschung für die forstliche praxis. *Forstwissenschaftliches Centralblatt*, 110, 149–157.
- Atıcı, E., Çolak, A. H., & Rotherham, I. D. (2008). Coarse dead wood volume of managed oriental beech (*Fagus orientalis* Lipsky) stands in Turkey. *Investigación Agraria, Sistemas y Recursos Forestales*, 17(3), 216–227.
- Bobieć, A. (2002). Living stands and dead wood in the Białowieża forest: suggestions for restoration management. *Forest Ecology and Management*, 165(1), 125–140.
- Boydak, M. (2004). Silvicultural characteristics and natural regeneration of *Pinus brutia* Ten. : A review. *Plant Ecology*, 171, 153–161.
- Butler, R., & Schlaepfer, R. (2004). Dead wood in managed forests: how much is enough? *Schweizerische Zeitschrift für Forstwesen*, 155(2), 31–37.

- Christensen, M., Hahn, K., Mountford, E. P., Wijdeven, S. M. J., Manning, D. B., Standovar, T., Odor, P., & Rozenbergar, D. (2003). A study on dead wood in European beech forest reserves. NatMan Working report no 9.
- Christensen, M., Hahn, K., Mountford, E. P., Odor, P., Standovar, T., Rozenbergar, D., Diaci, J., Wijdeven, S., Meyer, P., Winter, S., & Vrska, T. (2005). Dead wood in European beech (*Fagus sylvatica*) forest reserves. *Forest Ecology and Management*, 210, 267–282.
- Çolak, A. H. (2002). Dead wood and its role in nature conservation and forestry: a Turkish perspective. *The Journal of Practical Ecology and Conservation*, 5(1), 37–49.
- Çolak, A. H., Kirca, S., Rotherham, I. D., & Atıcı, E. (2009). The amount of coarse dead wood and associated decay rates in forest reserves and managed forests, Northwest Turkey. *Investigation Agraria: Sistemas y Recursos Forestales*, 18(3), 350–359.
- Commarmot, B., Bachofen, H., Bundziak, Y., Burgi, A., Ramp, B., Shparyk, Y., Sukhariuk, D., Viter, R., & Zingg, A. (2005). Structure of virgin and managed beech forests in Uholka (Ukraine) and Sihlwald (Switzerland): a comparative study. *ForSnow Landscape Res*, 79, 45–56.
- Coşgun, U., & Uzun, E. (2007). *Determination of socioeconomic infrastructure of forest villages in Köprülü Canyon National Park and constitution of the rural development action plan*. Antalya: Southwest Anatolia Forest Research Institute, Technical Bulletin no 7.
- Debeljak, M. (2006). Coarse woody debris in virgin and managed forest. *Ecological Indicators*, 6(4), 733–742.
- Duvall, M. D., & Grigal, D. F. (1999). Effects of timber harvesting on coarse woody debris in red pine forests across the Great Lakes states, U.S.A. *Canadian Journal of Forest Research*, 29, 1926–1934.
- FAO. (2006). *Global forest resources assessment, 2005. Forestry paper*. Rome: Food and Agricultural Organization of the United Nations.
- Feller, M. C. (2003). Coarse woody debris in the old-growth forests of British Columbia. *Environmental Review*, 11, 135–157.
- Fridman, J., & Walheim, M. (2000). Amount, structure, and dynamics of dead wood on managed forestland in Sweden. *Forest Ecology and Management*, 131, 23–26.
- GDF. (2008). *Köprülü Canyon National Park forest management plan*. Ankara: General Directorate of Forestry 389 pp.
- GDF. (2014a). *Procedures and principles of implementing ecosystem based multi-objective forest management plans, Guidelines no: 299*. Ankara: General Directorate of Forestry.
- GDF. (2014b). *Silvicultural guidelines: technical principles of silvicultural applications, Guidelines no: 298*. Ankara: General Directorate of Forestry.
- GDF. (2016). *Fire registers of the Köprülü Canyon National Park. Different forest fire register reaches to 111 from 1979 to 2013*. Ankara: Department of Forest Fire Combating.
- Green, P., & Peterken, G. F. (1997). Variation in the amount of dead wood in the woodlands of the Lower Wye Valley, UK in the relation to the intensity of management. *Forest Ecology and Management*, 98, 229–238.
- Hahn, K., & Christensen, M. (2004). Dynamics of deadwood in European beech forests in relation to natural disturbances. *Iceland Forest Research Bulletin*, 22, 5–8.
- Harmon, M. E. (2001). Carbon sequestration in forests: addressing the scale question. *Journal of Forestry*, 99, 24–29.
- Harmon, M. E., & Sexton, J. (1996). *Guidelines for measurements of woody detritus in forest ecosystems*. Seattle: University of Washington.
- Harmon, M. E., Franklin, J. F., Swanson, F. J., Sollins, P., Gregory, S. V., Lattin, J. D., Anderson, N. H., Cline, S. P., Aumen, N. G., Sedell, J. R., Lienkaemper, G. W., Cromack, K., & Cummins, K. W. (1986). Ecology of coarse woody debris in temperate ecosystems. *Advances Ecological Research*, 15, 133–276.
- Hernando, A., Rosario, R., Garcia, A., Perez, A., & Arrechea, E. (2013). La madera muerta como indicador del estado de conservación de los habitats de la Red Natura. VI Congreso Forestal Espanol. Gazteiz. 6CFE01–045.
- Herrero, C., Monleon, V. J., Gomez, N., & Bravo, F. (2016). Distribution of dead wood volume and mass in mediterranean *Fagus sylvatica* L. forests in Northern Iberian Peninsula. Implications for field sampling inventory. *Forest Systems*, 25(3). doi:10.5424/fs/2016252-09009.
- Hodge, S. J., & Peterken, G. F. (1998). Dead wood in British forests: priorities and a strategy. *Forestry*, 71(2), 99–112.
- INFC (2005). *Inventario Nazionale delle Foreste e dei Serbatoi Forestali di Carbonio*. Ispettorato Generale- Corpo Forestale dello Stato. Ministero delle Politiche Agricole Alimentari e Forestali. CRA - Unità di ricerca per il Monitoraggio e la Pianificazione forestale. <http://www.ifni.it>. Accessed 25 February 2016.
- IPCC. (2003). Good practice guidance for land use, land-use change and forestry. In J. Penman, M. Gytarsky, T. Hiraishi, T. Krug, D. Kruger, R. Pipatti, L. Buendia, K. Miwa, T. Ngara, K. Tanabe, & F. Wagner (Eds.), *Intergovernmental panel on climate change*. Kanagawa: Institute for Global Environmental Strategies.
- Jankovsky, L., Licka, D., & Jezek, K. (2004). Inventory of dead wood in the Knehyne-Certuv mlyn National Nature Reserve, the Moravian-Silesian Beskids. *Journal of Forest Science*, 50(4), 171–180.
- Karahalil, U., Kadioğulları, A. İ., Başkent, E. Z., & Köse, S. (2009). The spatiotemporal forest cover changes in Köprülü Canyon National Park (1965–2008) in Turkey. *African Journal of Biotechnology*, 8(18), 4495–4507.
- Karahalil, U., Başkent, E. Z., & Köse, S. (2015). Integrating visitor characteristics and preferences into forest management plans in protected areas: a case study in Köprülü Canyon National Park. *Journal on Protected Mountain Areas Research and Management*, 7(2), 5–17.
- Kirby, K. J., Reid, C. M., Thomas, R. C., & Goldsmith, F. B. (1998). Preliminary estimates of fallen dead wood and standing dead trees in managed and unmanaged forests in Britain. *Journal of Applied Ecology*, 35, 148–155.
- Kramer, H., & Akça, A. (1995). *Leitfaden zur Waldmeßlehre*. Frankfurt: Sauerländer's Verlag.
- Kühnel, S. (1999). Totholz im Bayerischen Staatswald-Ergebnisse der Totholzinventur. *LWF aktuell*, 18, 6–12.
- Laarmann, D., Korjus, H., Sims, A., Stanturf, J. A., Kiviste, A., & Koester, K. (2009). Analysis of forest naturalness and tree mortality patterns in Estonia. *Forest Ecology and Management*, 258, 5187–5195.
- Löhmus, K., & Liira, J. (2013). Old rural parks support higher biodiversity than forest remnants. *Basic and Applied Ecology*, 14, 165–173.

- Lombardi, F., Lasserre, B., Tognetti, R., & Marchetti, M. (2008). Deadwood in relation to stand management and forest type in central Apennines (Molise, Italy). *Ecosystems*, *11*(6), 882–894.
- Lombardi, F., Chirici, G., Marchetti, M., Tognetti, R., Lasserre, B., Corona, P., Barbati, A., Ferrari, B., Di Paolo, S., Giuliarelli, D., Mason, F., Iovino, F., Nicolaci, A., Bianchi, L., Maltoni, A., & Travaglini, D. (2010). Deadwood in forest stands close to old-growthness under Mediterranean conditions in the Italian peninsula. *Italian Journal of Forest and Mountain Environments*, *65*(5), 481–504.
- Maser, C., & Trappe, J. M. (1984). *The seen and unseen world of the fallen tree*. Department of Agriculture, Portland: Forest Service, Pacific Northwest Forest and Range Experiment Station, Technical Report PNW-164.
- McComb, W., & Lindenmayer, D. (1999). Dying, dead, and down trees. In M. L. Hunter (Ed.), *Maintaining biodiversity in forest ecosystems* (pp. 335–372). Cambridge: Cambridge University Press.
- MCPFE. (2007). *State of Europe's forests 2007. The MCPFE report on sustainable forest management in Europe*. Warsaw: Liaison Unit.
- Merganic, J., Seben, V., & Merganicova, K. (2011). Zásoba odumretého dreva v 1. až 8. lesnom vegetačnom stupni a na azonálnych stanovištiach. In J. Vladovic (Ed.), *Research of the classification methods and structural models of forest ecosystems favorable state—assessment of the state and development with help of RS*. NLC: Zvolen.
- Merganicova, K., & Merganic, J. (2010). Coarse woody debris carbon stocks in natural spruce forests of Babia hora. *Journal of Forest Science*, *56*(9), 397–405.
- Merganicova, K., Merganic, J., Svoboda, M., Bace, R., & Seben, V. (2012). Deadwood in Forest Ecosystems, In J. A. Blanco (Ed.), *Forest ecosystems—more than just trees*, <http://www.intechopen.com/books/forest-ecosystems-more-than-just-trees/deadwood>. Accessed 10 April 2016.
- Montes, F., & Canellas, I. (2006). Modelling coarse woody debris dynamics in even-aged Scots pine forests. *Forest Ecology and Management*, *221*, 220–232.
- Mountford, E. P. (2002). Fallen dead wood levels in the near-natural beech forest at La Tillaie reserve, Fontainebleau, France. *Forestry*, *75*, 203–208.
- Norden, B., Ryberg, M., Gotmark, F., & Olausson, B. (2004). Relative importance of coarse and fine woody debris for the diversity of wood-inhabiting fungi in temperate broadleaf forests. *Biological Conservation*, *117*, 1–10.
- Paletto, A., De Meo, I., Cantiani, P., & Ferretti, F. (2014). Effects of forest management on the amount of deadwood in Mediterranean oak ecosystems. *Annals of Forest Science*, *71*, 791–800.
- Pasierbek, T., Holeska, J., Wilczek, Z., & Zywiec, M. (2007). Why the amount of dead wood in Polish forest reserves is so small? *Nature Conservation*, *64*, 65–71.
- Rahman, M., Frank, G., Ruprecht, H., & Vacik, H. (2008). Structure of coarse woody debris in Lange-Leitn Natural Forest Reserve, Austria. *Journal of Forest Science*, *54*(4), 161–169.
- Reineke, L. H. (1933). Perfecting a stand-density index for even-aged stands. *Journal of Agricultural Research*, *46*, 627–638.
- Roibu, C. (2010). *Cercetări dendrometrice, auxologice și dendrocronologice în șgete din Podișul Sucevei aflate la limita estică a arealului*. Suceava: Ștefan cel Mare University.
- Rondeux, J., & Sanchez, C. (2009). Review of indicators and field methods for monitoring biodiversity within national forest inventories. Core variable: deadwood. *Environmental Monitoring and Assessment*, *164*(1–4), 617–630.
- Saniga, M., & Schütz, J. P. (2001). Dynamics of changes in dead wood share in selected beech virgin forests in Slovakia within their development cycle. *Journal of Forest Science*, *47*(12), 557–565.
- Saniga, M., & Schütz, J. P. (2002). Relation of dead wood course within the development cycle of selected virgin forests in Slovakia. *Journal of Forest Science*, *482*(12), 513–528.
- Schaetzl, R. J., Burns, S. F., Johnson, D. L., & All, T. W. (1989). Tree uprooting: Review on impacts on forest ecology. *Vegetation*, *79*, 165–176.
- Schmitt, M. (1992). Buchen-Totholz als Lebensraum für Xylobionte Käfer-Untersuchungen im Naturwaldreservat “Waldhaus” und zwei Vergleichsflächen im Wirtschaftswald (Forstamt Ebrach, Steigerwald). *Waldhygiene*, *19*, 97–191.
- Schuck, A., Meyer, P., Menke, N., Lier, M., & Lindner, M. (2004). Forest biodiversity indicator: dead wood—a proposed approach towards operationalising the MCPFE indicator. *EFI-Proceedings*, Vol. 51, pp. 49–77.
- Sefidi, K., Mohadjer, M. R. M., Mosandl, R., & Copenheaver, C. A. (2013). Coarse and fine woody debris in mature oriental beech (*Fagus orientalis* Lipsky) forests of Northern Iran. *Natural Areas Journal*, *33*(3), 248–255.
- SIS. (2016). *Demographic data query*. Ankara: State Institute Statistics http://www.tuik.gov.tr/VeriBilgi.do?alt_id=39. Accessed 21 April 2016.
- Sturtevant, B. R., Biossonette, J. A., Long, J. N., & Roberts, D. W. (1997). Coarse woody debris as a function of age, stand structure and disturbance in boreal Newfoundland. *Ecological Applications*, *7*(2), 702–712.
- Takahashi, M., Sakai, Y., Ootomo, R., & Shiozaki, M. (2000). Establishment of tree seedlings and water-soluble nutrients in coarse woody debris in an old-growth Picea–Abies forest in Hokkaido, northern Japan. *Canadian Journal of Forest Research*, *30*, 1148–1155.
- Tomescu, R., Tarziu, D. R., & Turcu, D. O. (2011). The importance of dead wood in the forest. *ProEnvironment*, *4*, 10–19.
- Travaglini, D., Barbati, A., Chirici, G., Lombardi, F., Marchetti, M., & Corona, P. (2007). ForestBIOTA data on deadwood monitoring in Europe. *Plant Biosystems*, *141*(2), 222–230.
- Utschick, H. (1991). Beziehungen zwischen Totholzreichtum und Vogelwelt in Wirtschaftswäldern. *Forstwissenschaftliches Centralblatt*, *110*(2), 135–148.
- Vallauri, D., Andre, J., & Blondel, J. (2003). Dead wood—a typical shortcoming of managed forests. *Revue Forestiere Francaise*, *55*(2), 99–112.
- Vandekerckhove, K., Keersmaecker de, L., Menke, N., Meyer, P., & Verschelde, P. (2009). When nature takes over from man: dead wood accumulation in previously managed oak and beech woodlands in north-western and Central Europe. *Forest Ecology and Management*, *258*, 425–435.
- Von Oheimb, G., Westphal, C., & Hardtle, W. (2007). Diversity and spatio-temporal dynamics of dead wood in a temperate near-natural beech forest (*Fagus sylvatica*). *European Journal of Forest Research*, *126*, 359–370.
- Woodall, C. W., & Liknes, G. C. (2008). Relationships between forest fine and coarse woody debris carbon stocks across latitudinal gradients in the United States as an indicator of climate change effects. *Ecological Indicators*, *8*, 686–690.