Forest Systems
29 (2), e008, 13 pages (2020)
eISSN: 2171-9845
https://doi.org/10.5424/fs/2020292-16560
Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria (INIA)

RESEARCH ARTICLE

OPEN ACCESS

Deadwood volume and quality in recreational forests: the case study of the Belgrade forest (Turkey)

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Abstract

Aim of study: The aim of this study is to understand quantitative and qualitative characteristics of deadwood in recreational forests.

Area of study: Belgrade forest in the North of Istanbul city (Turkey).

Material and methods: The data has been collected through a stratified sampling scheme that has randomly located 50 clusters formed by 3 sample plots each (150 sample plots).

Main results: The results show an average deadwood volume of 16.49 m^3 ha^{-1} (81.5% in logs, 16.4% in snags, 2.1% in stumps). The highest volume of deadwood is in oldest forests (age over 180 years) with an average value of 20.39 m^3 ha^{-1}, followed by forests with 61-120 years with 15.77 m^3 ha^{-1}. Concerning forest management objectives, the results show that average deadwood volume is 13.66 m^3 ha^{-1} in the forest section managed for water resource conservation and 21.14 m^3 ha^{-1} in the forest section managed for recreational purposes.

Research highlights: Deadwood management in the recreational forests must consider both biodiversity conservation and recreational attractiveness of an area.

Keywords: forest management; forest types; forest accessibility; stand age; wood decomposition rate.

Authors' contributions: SB contributed to manuscript writing, collecting data and supervising the work. AP contributed to manuscript defining research framework and writing. AF contributed to manuscript developing statistical analysis.

Citation: Bayraktar, S., Paletto, A., Floris, A. (2020). Deadwood volume and quality in recreational forests: the case study of the Belgrade forest (Turkey). Forest Systems, Volume 29, Issue 2, e008. https://doi.org/10.5424/fs/2020292-16560.

Received: 18 Feb 2020 **Accepted:** 23 Jul 2020

Funding: The authors received no specific funding for this work.

Competing interests: The authors have declared that no competing interests exist.

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Introduction

In natural and semi-natural forests, deadwood (non-living woody biomass not contained in the litter) is considered an indispensable part of properly functioning forest ecosystems and an important indicator of naturalness and biodiversity (Jönsson & Jonsson, 2007; Skwarek & Bijak, 2015). As emphasized by the second and third Ministerial Conferences for the Protection of Forests in Europe (MCPFE), deadwood is strictly related to the level of biodiversity of a forest ecosystem as many species of invertebrates, fungi, bryophytes, lichens, amphibians, small mammals, and birds are directly or indirectly dependent on deadwood (Rahman *et al.*, 2008; Sefidi & Etemad, 2016). In addition, deadwood in forest ecosystem plays an important role in influencing microclimate heterogeneity on the forest floor retaining moisture during dry periods (Maser & Trappe, 1984), to reduce soil erosion and landslide phenomena (Enrong *et al.*, 2006), to increase soil organic matter and fertility (Bauhus *et al.*, 2009), and to provide nurse logs for tree regeneration and seeds germination (Hofgaard, 2000). Recently, scientific community and policy makers have recognized the role of deadwood in the global carbon cycle (Tobin *et al.*, 2007). The Intergovernmental Panel on Climate Change (IPCC, 2003) included deadwood in the five carbon pools (above-ground and below-ground biomass, litter, deadwood and soil) and the change in deadwood C-stock is required for reporting to the Kyoto Protocol (1997), Marrakesh Accords (7th Conference of the Parties, 2001). The Paris Climate Agreement (2015) emphasized the improvement of degraded forests – where deadwood is a key component – as potential Natural Climate Solution (NCS) to increase climate change mitigation (Paletto *et al.*, 2020).

Brown (2002) estimated that deadwood is an important store of carbon accounting for 10-20% of the above-ground biomass in mature forests, while De Meo *et al.* (2018) highlighted that the carbon stored in deadwood is between 2-13% of carbon stored in above-ground biomass in Mediterranean degraded forests. Conversely, deadwood in forest ecosystems can have negative consequences related to increased risk of forest fires (Radu, 2006) and biotic disturbances such as insects and pathogens (Notaro *et al.*, 2009). A high amount of lying deadwood reduces recreational accessibility and opportunities (Pastorella *et al.*, 2016). Some studies highlighted that dead trees and lying deadwood are perceived in a negative way by visitors for two main reasons (Tyrväinen *et al.*, 2003; Jankovska *et al.*, 2014): reduced accessibility of the area and decreased aesthetic value. In many cases, visitors consider deadwood an indicator of mismanagement and neglect with special regard in the recreational forests (Pastorella *et al.*, 2016; Simkin *et al.*, 2020).

To enhance the positive functions provided by deadwood in forest ecosystem, the key aspect to consider in forest management is the amount of deadwood by component (lying deadwood, standing dead trees and stumps), decomposition rate and size (coarse and fine woody debris). The deadwood volume in forests is characterized by a wide range of values as recently emphasized by Puletti *et al.* (2019). Those authors pointed out that the amount of deadwood for European forests ranges from 5.6 to 33.1 m^3 ha^{-1} (average value of 15.8 m^3 ha^{-1}) and average values are higher in Central European forests than in Northern and Mediterranean forests (Puletti *et al.*, 2019). The wide range of deadwood volumes is mainly related to several natural factors (*e.g.* forest types and stand age) and man-made factors (*e.g.* forest roads network, forest planning objectives, silvicultural treatments).

In the international literature, some studies focused on site and stand factors that influence the amount and quality of deadwood in forests to provide useful information to decision makers (Debeljak, 2006; Karahalil *et al.*, 2017). Data on deadwood volume can be considered an indicator of past natural disturbances and human interventions (Castagneri *et al.*, 2010). In this context, some authors investigated the relationship between forest management practices and characteristics of deadwood highlighting a decrease of volume in intensive managed forests compared to the extensive managed forests (Green & Peterken, 1997; Banaś *et al.*, 2014; Paletto *et al.*, 2014). Other authors focused on the comparison between amount of deadwood volume in forests managed for timber production and forest areas located in protected areas (*e.g.* national and regional parks, natural reserves) emphasizing the potential impact on biodiversity conservation (Piętka *et al.*, 2019). These studies showed that deadwood volume is from 5 to 20 times higher in protected areas compared to productive managed forests (Mountford, 2002; Tomescu *et al.*, 2011). Besides, stand age has a direct influence on the amount of deadwood (Banaś *et al.*, 2014; Herrero *et al.*, 2016; Topacoğlu *et al.*, 2017): generally, old-growth forests are characterized by high deadwood volume distributed in all decay classes, while young stands are characterized by low deadwood volume concentrated in fine woody debris of first decay classes. However, few studies have investigated the deadwood volume and quality in recreational forests close to urban areas (Skwarek & Bijak, 2015; De Meo *et al.*, 2017; Ebenberger & Arnberger, 2019). To overcome this knowledge gap, the aim of the present study is to assess quantity and quality of deadwood in a recreational forest taking into account natural and man-made factors. The hypothesis of the study is that in the recreational forests the deadwood distribution is mainly influenced by man-made factors (forest roads network and recreational pressure). The study was conducted in the Belgrade forest located near the Istanbul city in northwestern Turkey. This study area has been selected because it is characterized by a wide range of environmental situations related to age stands, forest types, and recreational pressure.

Material and methods

Study area

The study area is the Belgrade forest (Fig. 1) located near to Istanbul city (between 28°53'25" 29°00'55" eastern longitude and between 41°09'44" 41°14'40" northern latitude). In the 1950, Belgrade forest was designated as "Protection Forest" to protect water resources and landscape (BFMP, 2012). The Belgrade forest covers an area of 5,237 ha corresponding to 0.03% of total forested area in Turkey. The main forest types are (Çoban *et al.*, 2016): sessile oak (*Quercus petraea* (Matt.) Liebl.) and Hungarian oak (*Quercus frainetto* Ten.) dominated forest with 3,391 ha, and Oriental beech (*Fagus orientalis* Lipsky) dominated forest with hornbeam (*Carpinus orientalis* Mill.) and maple (*Acer campestre* L.) with 1,461 ha. In addition, there is a reforestation area with introduced species such as black pine (*Pinus nigra* J.F.Arnold) and Scots pine (*Pinus sylvestris* L.) (Arslangündoğdu & Yılmaz, 2011), and the Atatürk Arboretum characterized by stands with both oaks and oriental beech dominated forests.

From a climatic point of view, Belgrade forest has a humid, mesothermal, and maritime climate with a moderate water deficit in summer months; mean annual precipitation is 1,091 mm, and the mean annual temperature is 12.8 °C (Özhan *et al.*, 2010). In terms of Mayr's climate zone classification, the Belgrade forest is in the *Castanetum-Fagetum* transition zone characterized by a vegetation period of approximately 230 days (7.5 months) (Çoban *et al.*, 2016).

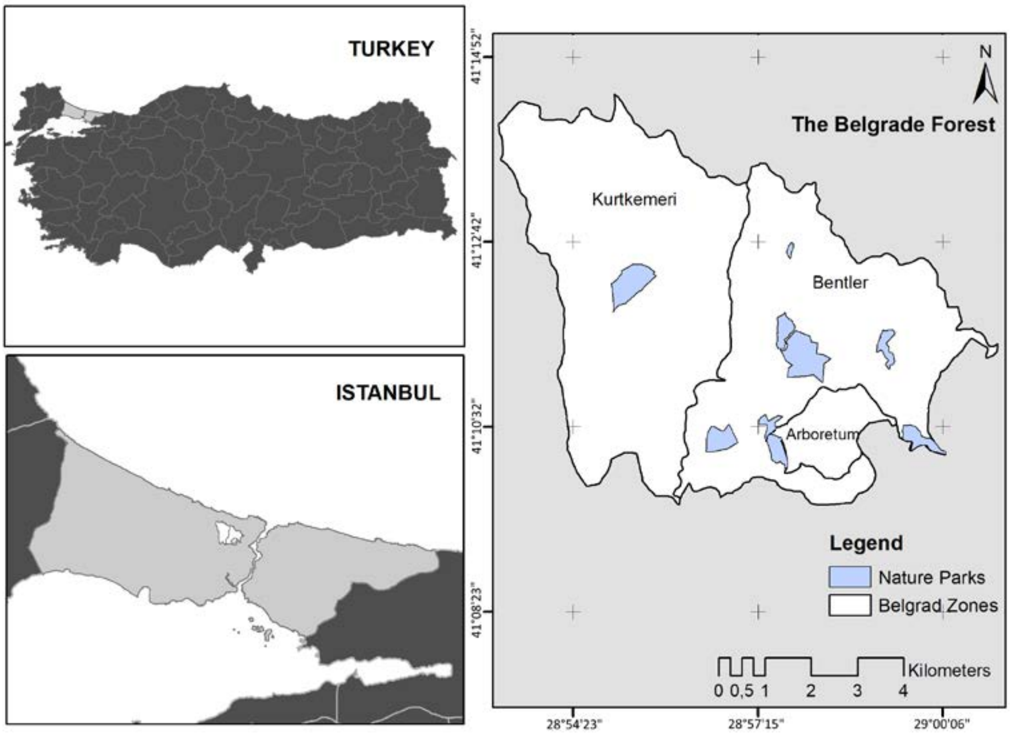

Figure 1. Location of study area (Belgrade forest). Geographic coordinates are in WGS84 datum.

Regarding forest management, the main aims of the Belgrade forest are protection and recreation achieved following close-to-nature approach to improve the multifunctionality and sustainability of forest ecosystem (Çoban *et al.*, 2016; Beskardes *et al.*, 2018). The Belgrade forest is divided in two sections with different priority functions: in the Kurtkemeri area, water resource conservation is considered the main function, while in the Bentler area also recreational activities (*e.g.* picnicking, hiking, running, relaxing) play a priority role. Within the Belgrade forest there are nine natural parks for recreational activities. Eight of these natural parks are located in Bentler area corresponding to 7.75% of this section. The Bentler area is subjected to intense recreational pressure (Eker, 2008) mainly from late spring to early autumn. For this reason, Belgrade forest is one of the most important recreational areas in Istanbul available to the public with approximately 800,000 registered annual visitors (Çaglayan, 1999). According to the Recreation Master Plan of Istanbul (1988-2010), 18.6% of the total area has great recreational supply capability due to the weather conditions, space requirements, presence of water bodies, slope tolerances (Eker, 2007).

Sampling scheme

A stratified sampling scheme was adopted to estimate deadwood volume in the Belgrade forest, using the two main forest types as strata. The data on deadwood were collected in 50 clusters (primary sampling units) distributed proportionally on the forest area for each forest type: 34 clusters in Sessile and Hungarian oaks dominated forest; 16 clusters in Oriental beech dominated forest (Fig. 2). The central points of the clusters were randomly generated using the Random points inside polygons routine of QGIS 2.18.7 (QGIS DT 2017), establishing a representative number of points per forest type (Table 1) and imposing a minimum distance of 100 m between points to avoid overlaps.

Each cluster is representative of a forest area of 100 ha on average. The 50 clusters have been stratified by forest type with the aim of highlighting differences in the deadwood distribution.

Field measurements

The field survey began in summer 2018 and ended in summer 2019. Each cluster was formed by three circular plots of 13 m radius (531 m^2). The first one (SP1) located 50 m in North direction starting from the center of the cluster, the second one (SP2) located 50 m in South-West direction, and the third one (SP3) located 50 m in South-East direction (Fig. 2).

During the field survey, deadwood was classified using the method proposed by De Meo *et al.* (2017). Thus, all dead trees inclined less than 45° from the vertical line, even those uprooted and crashed, were considered as standing dead trees, whereas those inclined more than

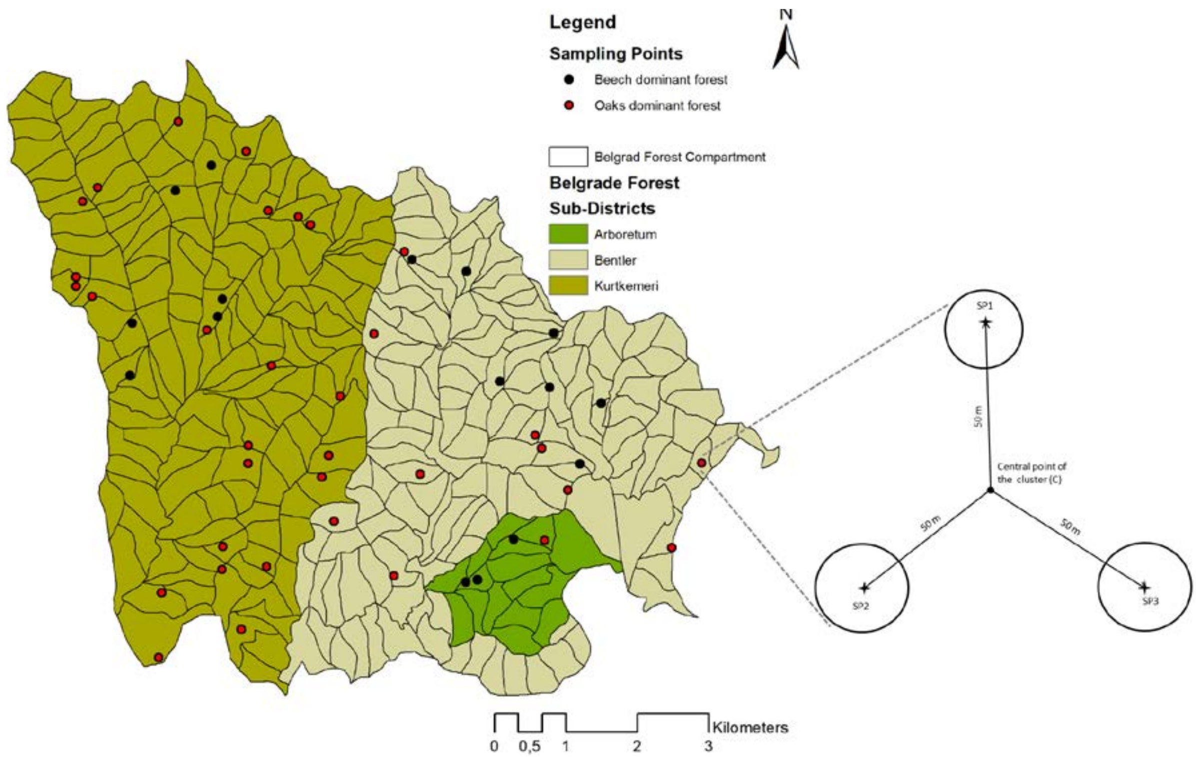

Figure 2. Location of 50 clusters stratified by forest type in the Belgrade forest.

45° were included in lying deadwood. Trees broken to a height of less than 1.30 m were classified as stump (including also stumps after logging). In each sample plot, the three deadwood components (standing dead trees, lying deadwood, stumps) were measured and estimated using two sampling methods (Russell *et al.*, 2015): Fixed-Area Sampling (FAS) and Line Intersect Sampling (LIS).

FAS method was used to measure standing dead trees and stumps with a diameter greater than 4.5 cm. For each standing dead tree and stump located in the three circular plots of the cluster were collected the following data: species, two perpendicular diameters measured at breast height (dbh) for snags and at cutting plane or broken height for stumps (cm); height (cm); decay class using a 5-class decay classification system.

LIS method was used to measure lying deadwood with a diameter greater than 4.5 cm. This sampling method based on the solution of the Buffon's needle problem is an efficient and reliable method to estimate the lying deadwood volume (Warren & Olsen, 1964). According to the line-intersect approach, all lying woody debris that intersect a transect are measured at the point of intersection of the transect and the central axis of the log (Marshall *et al.*, 2000). The assumption of the line-intersect approach is that the cross-sections of all logs are circular. In the present study, two transects arranged crosswise and passing through the center of the sampling plot were adopted to improve the quality estimation of lying deadwood volume on the ground (Bell *et al.*, 1996). In particular, two transects of 26 m (total length of 52 m in each sample plot) were located within the sample plot (SP1, SP2 and SP3): the first transect in the direction North-South (N-S), while the second transect in the direction East-West (E-W), perpendicular to the first one. For each lying woody debris intercepted by any of the two transects were collected the following data: species; two perpendicular diameters measured in the intersection point of the transect; decay class using a 5-class decay classification system.

Table 1. Distribution of number of clusters per forest type and age class in the Belgrade forest

Forest type/Age class	< 60 years old	60-120 years old	121-180 years old	>120 years old	Total
Hungarian oaks dominated forest	5	11	8	10	34
Oriental beech dominated forest	0	3	6	7	16
Total	5	14	14	17	50

The decay class was assigned using the 5-decay class classification system proposed by Næsset (1999) considering bark condition, presence of small branches, wood consistency, percentage of initial dry density, and other visual characteristics (Table 2). A 5-decay class classification system was adopted with the aim to compare the results of present study with those of other studies. The decay class was assigned through a visual assessment performed by two experienced trained assessors.

Data processing

The data collected during field measurements were processed in order to estimate total and average deadwood volume by component and decay class in the Belgrade forest.

Lying deadwood (logs) volume was estimated using average diameter measured at the point of intersection and the total length of transect. Under the assumption that the cross-sections of all logs are circular (Larjavaara & Muller-Landau, 2011), the total volume (V_l) of lying deadwood per unit area (m^3 ha^{-1}), was estimated using the algorithm by van Wagner (1968):

$$V_l = \left(\frac{\pi^2}{8L} \sum_{i=1}^{N} d_i^2 \right) \quad [1]$$

Where: L is length of the two transects in meters (52 m), and d_i is average diameter (mean of the two orthogonal diameters) of the i intersection point (cm).

Standing dead tree volume (V_s) per hectare was estimated from stand basal area (BA) whereas tree height (h) was obtained from the hypsometric curve by using the standard biometric equation (Cannell, 1984):

$$V_s = (\sum_{i=1}^{N} f \cdot BA \cdot h) \cdot \frac{10000}{S} \quad [2]$$

Where V_s is the volume of standing dead tree (m^3 ha^{-1}); BA is basal area (m^2); f is stem form factor as relationship between real stem volume and cylinder volume (0.5); S is the area of sampling plots (m^2); and h is height obtained from the hypsometric curve (m). A stem form factor (f) of 0.5 was used because it is considered suitable for broad-leaved species with 5–10% of branches (Cannell, 1984; Lang *et al.*, 2016).

Stumps volume (V_{st}) was estimated using maximum and minimum height of the stump and diameter of cutting or slating plan as shown in the following formula:

$$V_{st} = \left[\frac{\pi}{4} \sum_{i=1}^{N} \left(\frac{H_{st} + h_{st}}{2} \right) \cdot \left(\frac{D_{st} + d_{st}}{2} \right)^2 \right] \cdot \frac{10000}{S} \quad [3]$$

Where H_{st} and h_{st} are maximum and minimum height of stump (m), D_{st} and d_{st} are maximum and minimum diameter at cutting or slating plan (m), while S is the area of sampling plots (m^2).

The deadwood volume estimated for each component was distinguished by decay class to highlight the volume distribution based on decomposition rates because this is a key information to evaluate the microbial and entomological biodiversity (Pastorelli *et al.*, 2020).

Finally, the collected data were used to understand the influence of four main variables – forest management objectives, human accessibility, stand age, forest types – on deadwood volume by component and decay class. Human accessibility to different areas of the Belgrade forest was evaluated using a forest roads buffer zone of 50 m on each side to distinguish more easily accessible areas and less easily accessible areas. The forest roads buffer was identified using forest roads network map (.shp file).

To point out statistically significant differences between groups of sampling plots aggregated by cluster with different characteristics the non-parametric tests of Kruskal-Wallis (K) and Mann-Whitney (U) were applied.

Table 2. Description of the five decay classes of deadwood

	Decay classes	Bark condition	Small branches	Wood consistency	Dry density	Other visual characteristics
1	Recently dead	Entire and attached	Present	Intact	95-100% initial dry density	Little rotten area under bark
2	Weakly decayed	Entire but not-attached	Partly present	Intact	75-95%	Rotten areas < 3 cm
3	Medium decayed	Fragments of bark only	Absent	Partly broken	50-75%	Rotten area > 3 cm
4	Very decayed	Absent	Absent	Broken	25-50%	Large rotten area
5	Almost decomposed	Absent	Absent	Dust	5-25%	Very large rotten area, musk and lichens

Source: modified by Næsset (1999) and Paletto & Tosi (2010).

The non-parametric Kruskal-Wallis and Mann-Whitney tests were applied rather than using the one-way analysis of variance (ANOVA) for the following main reasons: the sample size is not large enough; the assumption of normality and homogeneity is violated. The non-normal distribution of data was confirmed by the Shapiro-Wilk test (W=0.632; p-value<0.0001) and Lilliefors test (D=0.278; p-value<0.0001). The homogeneity of data was tested using the Breusch-Pagan test (LM=6.366; p-value=0.012) and the Levene test (F=9.900; p-value=0.003).

The non-parametric Kruskal-Wallis test (K; α =0.05) was used to highlight the differences related to stand ages, while the non-parametric Mann-Whitney test (U; α=0.05) was applied to test differences for forest types, forest management objectives, and human accessibility.

All collected data were processed and the non-parametric Kruskal-Wallis and Mann-Whitney tests were performed using the XLStat 2017 software.

Results

The results of the study show that the average deadwood volume of Belgrade forest is 16.49 m^3 ha^{-1} so divided into three components: 81.5% in lying deadwood, 16.4% in standing dead trees, and 2.1% in stumps. Observing the data by decay class, the results highlight a higher concentration of deadwood volume in the first decay class (32.9% of total volume), while the other four decay classes have comparable volume. It is interesting to highlight that the highest amount of stumps volume is in the last decay class with 58.4% of total stumps volume, while the standing dead trees volume is almost completely concentrated in the first two decay classes with 73.0% and 20.0% respectively. Conversely, the lying deadwood volume is distributed equally in all five decay classes (25.7% in first decay class, 16.1% in second decay class, 15.3% in third decay class, 23.1% in forth decay class, and 20.2% in the last decay class).

Forest type

Observing the data by forest type, 68.0% of clusters are located in sessile and Hungarian oak dominated forests, 32.0% in Oriental beech dominated forests. The results show that Oriental beech dominated forests are characterized by an average deadwood volume of 17.22 m^3 ha^{-1}, while sessile and Hungarian oak dominated forests are characterized by an average volume of 16.09 m^3 ha^{-1} (Fig. 3). However, the non-parametric Mann-Whitney test show no statistically significant differences between forest types: lying deadwood (U=290; p-value=0.716); standing dead trees (U=308; p-value=0.459); stumps (U=227; p-value=0.359).

Observing the data by decay class (Table 3), the results show that in the sessile and Hungarian oak dominated forest deadwood volume is more concentrated in the first and last decay class with 37.0% and 20.2% respectively. Conversely, it is interesting to highlight that in the Oriental beech dominated forest there is a high deadwood volume not only in the first decay classes but also in the last two decay classes with the following values: 4.21 m^3 ha^{-1} in forth decay class (24.4%) and 2.13 m^3 ha^{-1} in the fifth decay class (12.4%).

Age class

Observing the data by age class, 13% of clusters are located in forest stands less than 60 years, 27% in forest stands 61-120 years and 121-180 years respectively, and the remaining 33% in forest stands over 180 years. The results show that the highest volume of deadwood is in oldest forests (age over 180 years) with an average value of 20.39 m^3 ha^{-1}, followed by forests with 61-120 years

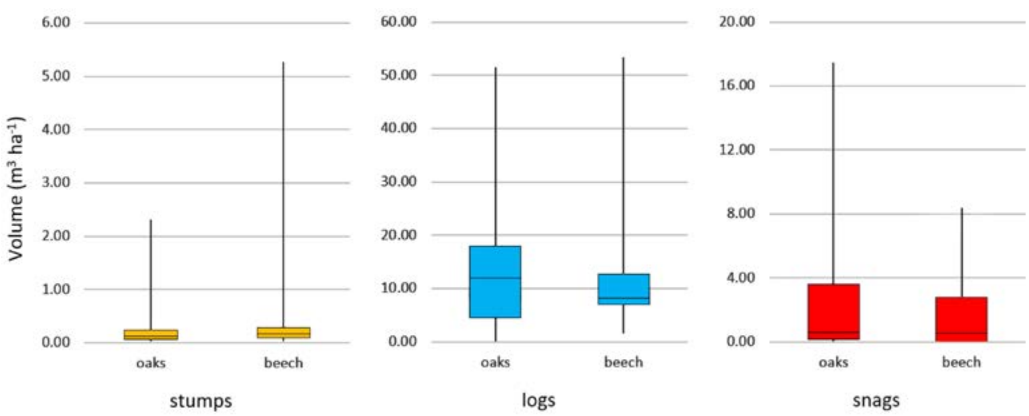

Figure 3. Boxplot charts (Min, Q1, Median, Q3, Max) of deadwood volume (m^3 ha^{-1}) by forest type and component.

Table 3. Distribution of deadwood volume (m^3 ha^{-1}) by decay class in the Belgrade forest

Decay classes	Recently dead	Weakly decayed	Medium decayed	Very decayed	Almost decomposed
Forest type					
Sessile and Hungarian oak dominated forest (*n*=34)	5.96	2.08	2.11	2.69	3.25
Oriental beech dominated forest (*n*=16)	4.22	4.22	2.44	4.21	2.13
Age classes					
< 60 years (*n*=6)	3.74	0.49	1.71	2.34	0.62
60-120 years (*n*=13)	7.04	1.96	1.69	2.56	2.52
121-180 years (*n*=14)	4.79	1.94	2.14	2.64	3.83
>180 years (*n*=17)	5.17	4.83	2.77	4.49	3.10
Human accessibility					
More easily accessible areas (*n*=39)	4.23	2.82	2.44	2.91	2.44
Less easily accessible areas (*n*=11)	9.13	2.47	1.34	3.84	4.22
Forest management					
Kurtkemeri area (*n*=33)	3.00	1.97	1.81	3.67	2.41
Bentler area (*n*=17)	8.35	4.07	2.83	2.28	3.62

with an average value of 15.77 m^3 ha^{-1}. Oldest forests are characterized by a slightly higher volume of lying deadwood than younger forests (Fig. 4). However, the non-parametric test of Kruskal-Wallis shows no statistically significant differences among age classes: lying deadwood (K=5.771; *p*-value=0.123); standing dead trees (K=1.815; *p*-value=0.612); stumps (K=1.554; *p*-value=0.670).

The results concerning the distribution of deadwood volume by decay class (Table 3) show that in forest stands less than 60 years 42.0% of volume is in the first decay class, while for other age classes the first decay class covers 44.6% (forest stands 61-120 years), 31.2% (121-180 years), and 25.4% (more than 180 years) of total deadwood volume respectively. However, the results evidence a balanced distribution of deadwood volume among all five decay classes.

Human accessibility

Observing the data by human accessibility show that 76% of clusters are located in more easily accessible areas of the Belgrade forest and 24% of them are located in less easily accessible areas. The results show that the average deadwood volume is 21.0 m^3 ha^{-1} in forest areas within buffer zone (17.43 m^3 ha^{-1} of lying deadwood, 3.25 m^3 ha^{-1} of standing dead trees, 0.32 m^3 ha^{-1} of stumps) and 14.84 m^3 ha^{-1} in forest areas out of buffer zone (11.92 m^3 ha^{-1} of lying deadwood, 2.54 m^3 ha^{-1} of standing dead trees, 0.38 m^3 ha^{-1} of stumps) (Fig. 5). However, the non-parametric Mann-Whitney test show no statistically significant differences between two groups for lying deadwood (*p*-value=0.756) and standing dead trees (*p*-value=0.321), and a slightly significant difference (*p*-value=0.060) for stumps.

The distribution of deadwood volume by decay class (Table 3) shows negligible differences between two groups of forest areas with the exception of a greater concentration of volumes in the first and last decay class in forest areas within buffer (43.5% of volume is in the first decay class and 20.1% in the fifth decay class). In the less accessible forest areas, the deadwood volume distribution by decay class is more balanced than in more easily accessible forest areas: 28.5% of volume is in first decay class, 19.0% in second decay class, 16.4% in third

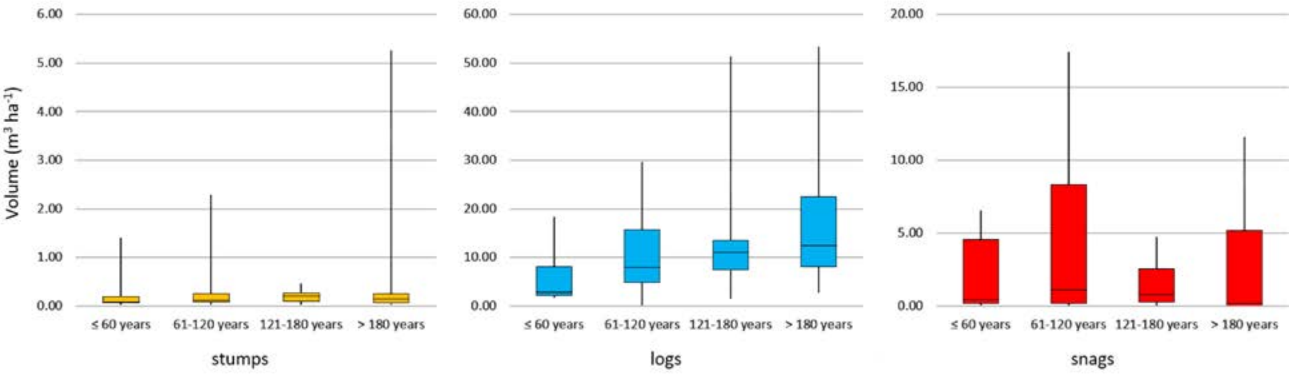

Figure 4. Boxplot charts (Min, Q1, Median, Q3, Max) of deadwood volume (m^3 ha^{-1}) by age class and component.

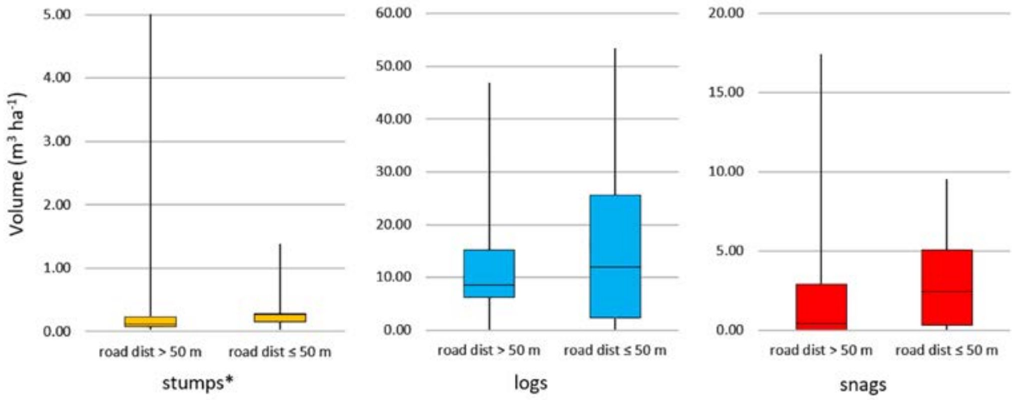

Figure 5. Boxplot charts (Min, Q1, Median, Q3, Max) of deadwood volume (m^3 ha^{-1}) by human accessibility (road dist=road distance buffer of 50 m) and component.

decay class; 19.6% in fourth decay class, and 16.5% in last decay class.

Forest management practices

Considering the two sections of Belgrade forest managed with different objectives (Kurtkemeri and Bentler), interesting differences are shown (Fig. 6). The Bentler area is characterized by higher average deadwood volume for all three components compared with Kurtkemeri area. The average volume in the Kurtkemeri area is 13.66 m^3 ha^{-1}, while the average volume in the Bentler area is 21.14 m^3 ha^{-1}.

Observing the data by decay class (Table 3), the results show that in the Kurtkemeri area deadwood volume is more concentrated in the last two decay classes (44.4% of total volume) rather than in the Bentler area where the last two decay classes cover only 27.9% of total volume. Conversely, in the Bentler area the deadwood volume of first decay class is 39.5% of total volume.

The non-parametric Mann-Whitney test shows statistically significant differences for the total standing dead trees volume (U=156.5; *p*-value=0.004). Considering the decay classes of snags, statistically significant differences can be found in the second decay class (U=204.5; *p*-value=0.034), and in the third decay (U=204; *p*-value=0.024), whereas the first and the fourth decay class show no significant differences (U=193.5; *p*-value=0.205, and U=263.5; *p*-value=0.183, respectively). In addition, the non-parametric Mann-Whitney test shows statistically significant differences for stumps (U=188; *p*-value=0.023), but not for lying deadwood (U=262.5; *p*-value=0.408).

Discussion

The results of this study show an average deadwood volume of 16.49 m^3 ha^{-1} corresponding to a non-living and living volume ratio of 5.65% considering the growing stock (291.78 m^3 ha^{-1}) estimated by national inventory report (BFMP, 2012).

The deadwood volume of the Belgrade forest is mainly influenced by forest management objectives and recreational pressure. The old-growth stands in the Bentler

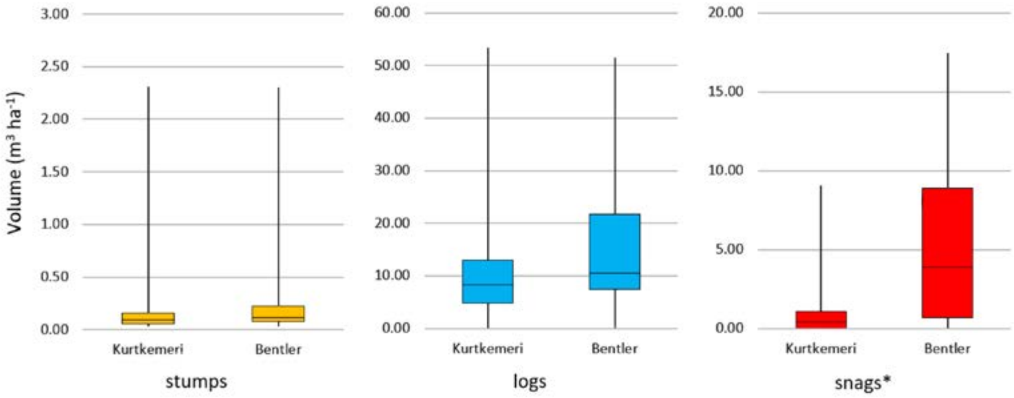

Figure 6. Boxplot charts (Min, Q1, Median, Q3, Max) of deadwood volume (m^3 ha^{-1}) by managed area (section) and component.

section are those with a greater amount of deadwood, while for stands located in Kurtkemeri section deadwood volume is of older origin being in the last two decay classes. This difference is due to the management of Bentler section more focused on improvement of recreational infrastructures rather than the removal of the deadwood to increase its accessibility and usability. The effect of recreational uses in forest stands is also emphasized on Forest Management Plan for period 2012-2021 (BFMP, 2012), as an increase of soil compaction, tree damages, die backing of trees. Similarly, some studies in the Bentler section have shown that recreational activities have negative influences on soil properties and compaction (Cakir *et al.*, 2010; Özcan *et al.*, 2013). In this study, an average deadwood volume of 21.14 m^3 ha^{-1} was estimated in the Bentler section, while about ten years ago Arslan (2011) estimated in the Bentler section an average deadwood volume of 4.24 m^3 ha^{-1} thus distributed: 63.3% in standing dead wood, 35.9% in recently fallen dead wood, and the remaining 0.8% in rotten fallen dead wood. The differences between these two studies are due to the methods adopted to estimate deadwood volume. Arslan (2011) quantified standing dead trees and lying deadwood volume using FAS method based on 33 square sampling plots (50m × 50m), while in our study lying deadwood volume was estimated using LIS method and standing dead trees volume using 150 circular sampling plots (13 m radius). Besides, Arslan (2011) included only coarse woody debris with a diameter greater than 10 cm, while in our study a diameter threshold of 4.5 cm was used to include both coarse and fine woody debris.

Summarizing the results of the present study, the highest deadwood volume is in the old sessile and Hungarian oak forest stands located in Bentler section, conversely the lowest deadwood volume is in the young Oriental beech forest stands located in Kurtkemeri section. The deadwood volume distribution in all decay classes suggests that the Belgrade forest has not been affected by natural events that caused an increase in mortality concentrated in certain years or periods. However, low stumps volume confirms that the main forest function is not timber production, but protective function associated with recreational activities and water resource conservation.

The results of this study are comparable with those of other studies conducted in Europe with the aim to highlight the differences in deadwood volume related to natural and man-made factors. Observing the average deadwood volume estimated in other European studies, Skwarek & Bijak (2015) estimated higher amounts of deadwood in the old-growth stands (on average 37.0 m^3 ha^{-1}) rather than in the young-growth stands (on average 9.0 m^3 ha^{-1}) in the Warsaw Municipal. The results of our study confirm that young-growth stands (with less than 60 years) are characterized by a low amount of deadwood than old-growth stands with special regard to the last decay class (6.9% of total volume). The deadwood volume distribution by decay class in young stands is related to the mortality rate and a faster decomposition rate of smaller deadwood fraction. Another study conducted in two recreational forests near urban areas (Florence city in Italy; Xanthi city in Greece) confirms that human interventions have a clear impact on deadwood volume and that management strategies can deeply influence deadwood quantity (De Meo *et al.*, 2017). Regarding the visitors' preferences towards deadwood in forests, Ebenberger and Arnberger (2019) assessed that for the Austrian visitors the preferred deadwood volume should be between 20 and 33 m^3 ha^{-1} in the recreational forests.

Generally, the managed forests, such as recreational forests, are characterized by a low amount of deadwood compared to the protected areas. In the protected areas, deadwood volume can assume very high values estimated between 80 and 250 m^3 ha^{-1}, while in the managed forests the values are five-ten times less (Mountford, 2002; Tomescu *et al.*, 2011; Paletto *et al.*, 2014).

Other studies carried out in managed forests evidenced that there is a trend of increasing deadwood volume with increasing stand age (Herrero *et al.*, 2016; Karahalil *et* *al.*, 2017). In the temperate deciduous forest of the United Kingdom, Green & Peterken (1997) estimated an average deadwood volume of unmanaged old-growth forests of 104 m^3 ha^{-1}, while for the unmanaged young-growth forests of 38.0 m^3 ha^{-1}. In a managed beech (*Fagus sylvatica* L.) forests in northern Iberian Peninsula, Herrero *et al.* (2016) show an average deadwood volume of 17.14 m^3 $ha^{–1}$ in seedling stage; 34.09 m^3 $ha^{–1}$ in pole stage; 22.54 m^3 $ha^{–1}$ in mature stage and 24.27 m^3 $ha^{–1}$ in regular stand in regeneration stage. Karahalil *et al.* (2017) found a positive correlation between deadwood volume and stand age in a Calabrian pine (*Pinus brutia* Ten.) dominated forest in the southern Turkey. Similarly, in the present study a trend of increasing deadwood volume with increasing stand age was found corresponding to +75% of deadwood volume from stands with less than 60 years to stands with 61-180 years, and to +31% from stands with 61-180 years to stands with more than 180 years.

Concerning deadwood volume by forest type, Puletti *et al.* (2019) estimated an average deadwood value of 23.9 m^3 ha^{-1} for Mesophytic deciduous forests and of 23.8 m^3 ha^{-1} for beech forests. In Turkey, Atici *et al.* (2008) estimated an average deadwood volume of 22.87 m^3 ha^{-1} (13.24 m^3 ha^{-1} in snags, 9.63 m^3 ha^{-1} in logs) in the Oriental beech dominated forests. These values are comparable with those found in the present study: 17.22 m^3 ha^{-1} for Oriental beech dominated forests and 16.09 m^3 ha^{-1} for sessile and Hungarian oak dominated forests. However, in both forest types the amount of deadwood is slightly lower than the values estimated by other studies because the study area is a recreational forest located near a city of over 15 million inhabitants. In this context, a large amount of lying deadwood can be considered an obstacle to the accessibility of the area, while standing dead trees a visitor safety risk (Pelyukh *et al.*, 2019).

With regard to the human accessibility, other studies emphasized that deadwood volume decreased with an increase in human accessibility class. Behjou *et al.* (2018) estimated in the Hyrcanian forests of northern Iran the following average deadwood volume in plots characterized by different accessibility: 14.87 m^3 ha^{-1} in difficult accessibility classes, 8.84 m^3 ha^{-1} in medium accessibility classes, and 4.03 m^3 ha^{-1} in easy accessibility classes. On the contrary, in the present study an opposite trend was shown: deadwood volume decreases in less accessible forest areas compared to areas close to forest roads (21.0 m^3 ha^{-1} versus 14.84 m^3 ha^{-1}). This difference is presumably due to the fact that deadwood of the Belgrade forest is not used for energy purposes by households. Generally, in easily accessible areas near forest roads the amount of deadwood decreases when it is an important energy source (firewood) for local population (Prasad, 2009). In addition, considering the location of Belgrade forest, silvicultural activities are likely less intensive in forest areas with very high daily pressure by citizens.

From the methodological point of view, the main advantage of the proposed method is the ease of data collection in the field focusing on three deadwood components. Particularly, the LIS approach to collect data on lying deadwood is a suitable method to reduce field measurements time without compromising the quality of the volume estimation compared to the traditional fixed-area sampling method. The main disadvantage of the proposed method is to investigate only deadwood without collecting data on living trees. Therefore, it was not possible to investigate in depth the relationship between non-living and living volume in the sampling plots. Information on deadwood attributes can guide decision makers towards sustainable management of recreational forests aimed to integrate biodiversity conservation and site attractiveness. However, additional data on living tree volume and stem density would provide a more comprehensive understanding of ecological and structural characteristics of the Belgrade forest.

The future steps of the study will monitor deadwood volume changes over time both in Kurtkemeri and Bentler sections of Belgrade forest and analyze the relationship between deadwood volume and additional stand characteristics (living tree volume, stem density, and canopy closure).

Conclusions

The present study estimated the qualitative and quantitative characteristics of deadwood in a recreational forest. The Belgrade forest is a recreational forest located near the city of Istanbul and characterized by a high recreational use. Forest planners and managers must take into consideration amount and spatial distribution of deadwood in recreational forests to increase the positive aspects of deadwood (*e.g.* biodiversity conservation, water resource protection, climate change mitigation, soil fertility and productivity) and to minimize the negative ones (*e.g.* highest risk of forest fires and biotic disturbances). A better knowledge of dynamics of deadwood changes is a fundamental starting point to improve sustainable management of recreational forests. In this context, the main outcome of this study was to provide data on volume and qualitative characteristics of deadwood in the Belgrade forest. This data can be used by forest planners and managers to define a strategy for the sustainable management of deadwood according to the Forest Management Plan (period 2012-2021). In the Belgrade forest, as well as in recreational forests close to metropolitan cities, lying deadwood with a diameter greater than 10 cm (coarse woody debris) must be removed or minimized from the most frequented areas and along paths to facilitate visitor access. The removal of the coarse woody debris in the most frequented areas has a positive aesthetic effect since deadwood is perceived negatively by visitors. Conversely, in areas with lower recreational attendance coarse woody debris should not be removed to maintain saproxylic fungi and beetles' community. Fine woody debris should be almost totally removed to reduce forest fires risk, as-well-as standing dead trees should be cut down and removed except from "habitat" trees (standing dead trees with a diameter greater than 30 cm) that provide ecological niches (microhabitats) to many species. Stumps should preferably be left to increase soil organic matter and fertility. Finally, we can assert that deadwood management in recreational forests should be the compromise between recreational attractiveness and biodiversity conservation.

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