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

Selim Bayraktar (Bayraktar, S.) 1, Alessandro Paletto (Paletto, A.) 2, Antonio Floris (Floris, A.) 2
1 Department of Landscape Architecture, Faculty of Forestry, Istanbul University – Cerrahpasa, Istanbul (Turkey). Valide Sultan Cad. No: 2 34473 Bahçeköy, Istanbul, Turkey. 2 Consiglio per la ricerca in agricoltura e l’analisi dell’economia agraria (CREA), Forestry and Wood Research Centre. Piazza Nicolini 6, 38123, Trento, Italy.

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 m³ 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 m³ ha⁻¹, followed by forests with 61-120 years with 15.77 m³ ha⁻¹. Concerning forest management objectives, the results show that average deadwood volume is 13.66 m³ ha⁻¹ in the forest section managed for water resource conservation and 21.14 m³ 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.

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 (Hooggaard, 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 ecosystems, 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 m³ ha⁻¹ (average value of 15.8 m³ 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 (Debejlik, 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; Banaš 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 (Banaš 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 & Arnbager, 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 (Castanea 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 Castaneum-Fagetum transition zone characterized by a vegetation period of approximately 230 days (7.5 months) (Çoban et al., 2016).
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 Kurtkemerı 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 m²). 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...
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    |
Deadwood amount in the Belgrade forest in Turkey

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):

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

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 \( j \) intersection point (cm).

Standing dead tree volume \( V_s \) per hectare was estimated using maximum diameter measured at the point of intersection and the total length of transect. Under the assumption that the cross-sections of all standing dead trees are circular (Larjavaara & Muller-Landau, 2011), the total volume \( V_s \) of standing dead trees per unit area (m\(^3\) ha\(^{-1}\)), was estimated using the algorithm by van Wagner (1968):

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

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:

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

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; \( \alpha =0.05 \)) was used to highlight the differences related to stand ages, while the non-parametric Mann-Whitney test (U; \( \alpha =0.05 \)) 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, 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%).

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 of age.

Figure 3. Boxplot charts (Min, Q1, Median, Q3, Max) of deadwood volume (m\(^3\) ha\(^{-1}\)) by forest type and component.
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 class, and 12.7% in fourth class.
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
Deadwood amount in the Belgrade forest in Turkey

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 concentration 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 m³ ha⁻¹, while for the unmanaged young-growth forests of 38.0 m³ 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 m³ ha⁻¹ in seedling stage; 34.09 m³ ha⁻¹ in pole stage; 22.54 m³ ha⁻¹ in mature stage and 24.27 m³ 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 m³ ha⁻¹ for Mesophytic deciduous forests and of 23.8 m³ ha⁻¹ for beech forests. In Turkey, Atici et al. (2008) estimated an average deadwood volume of 22.87 m³ ha⁻¹ (13.24 m³ ha⁻¹ in snags, 9.63 m³ ha⁻¹ in logs) in the Oriental beech dominated forests. These values are comparable with those found in the present study: 17.22 m³ ha⁻¹ for Oriental beech dominated forests and 16.09 m³ 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 Hycranian forests of northern Iran the following average deadwood volume in plots characterized by different accessibility: 14.87 m³ ha⁻¹ in difficult accessibility classes, 8.84 m³ ha⁻¹ in medium accessibility classes, and 4.03 m³ 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 m³ ha⁻¹ versus 14.84 m³ 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.

References

Arslan N, 2011. Bentler Orman İşletme Şefliği (Belgrad Ormanı)nde öli olû ağaç miktarı üzerine araştırmalar. MSc Thesis, Istanbul University, Institute of Science, Istanbul, Turkey.

Arslangündoğdu Z, Yılmaz E, 2011. The Effects of Tree stand layers on Resident Bird Species in Belgrade Forest, Istanbul, Turkey. Alg Forst- u J-Ztg 182: 25-29.

Atici E, Colak AH, Rotherham ID 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. https://doi.org/10.5424/srf/2008173-01036

Banaş J, Bujoczek L, Zięba S, Drozd M, 2014. The effects of different types of management, functions, and characteristics of stands in Polish forests on the amount of coarse woody debris. Eur J Forest Res 133: 1095-1107. https://doi.org/10.1016/S1018-1437(03)00106-0

Bauhus J, Puettmann K, Messier C, 2009. Silviculture for old-growth attributes. Forest Ecol Manag 258: 525-537. https://doi.org/10.1016/j.foreco.2009.01.053

Bell G, Kerr A, McNickle D, Woollons R, 1996. Accuracy of the line intersect method of post-logging sampling under orientation bias. Forest Ecol Manag 84: 23-28. https://doi.org/10.1016/0378-1127(96)03773-5

Beskardes V, Keten A, Kumbasli M, Pekin B, Yilmaz E, Makineci E, Ozdemir E, Zengin H, 2018. Bird composition and diversity in oak stands under variable coppice management in Northwestern Turkey. iForest 11: 58-63. https://doi.org/10.3832/ifo2489-010

BFMP, 2012. Bentler Forest Management Plan. Republic of Turkey General Directorate of Forestry, Istanbul, Turkey.

Brown S, 2002. Measuring carbon in forests: Current status and future challenges. Environ Pollut 116: 363-372. https://doi.org/10.1016/S0269-7491(01)00212-3

Çaglayan AY, 1999. Belgrad ormanında rekreasyonel talep özelliklerinin saptanması. MSc Thesis, Istanbul University, Institute of Science, Istanbul, Turkey.

Çakir M, Makineci E, Kumbasli M, 2010. Comparative study on soil properties in a picnic and undisturbed area of Belgrad forest. Istanbul. J Environ Biol 31(1): 125

Cannell MGR, 1984. Woody biomass of forest stands. Forest Ecol Manag 8: 299-312. https://doi.org/10.1016/0378-1127(84)90062-8

Castagneri D, Garbarino M, Berretti R, Motta R, 2010. Site and stand effects on coarse woody debris in montane mixed forests of Eastern Italian Alps. Forest Ecol Manag 260: 1592-1598. https://doi.org/10.1016/j.foreco.2010.08.008

Çoban S, Bayraktar S, Akgül M, 2016. Forest vegetation maps and its development in Turkey: a case from Istanbul Belgrade forest. Forest Rev 47(1): 7-16.

De Meo I, Angelli EA, Graziani A, Kitikidou K, Lagomarsino A, Milios E, Radoglou K, Paletto A, 2017. Deadwood volume assessment in Calabrian pine (Pinus brutia Ten.) peri-urban forests: Comparison between two sampling methods. J Sustain Forest 36(7): 666-686. https://doi.org/10.1007/s11515-005-0019-y

De Meo I, Lagomarsino A, Agnelli AE, Paletto A, 2018. Direct and Indirect Assessment of Carbon Stock in Deadwood: Comparison in Calabrian Pine (Pinus brutia Ten. subsp. brutia) Forests in Italy. Forest Sci 65(4): 460-468. https://doi.org/10.1093/forestsci/fxy051

Debeljak M, 2006. Coarse woody debris in virgin and managed forest. Ecol Ind 6: 733-742. https://doi.org/10.1016/j.ecolind.2005.08.031

Ebenberger M, Anbermer A, 2019. Exploring visual preferences for structural attributes of urban forest stands for restoration and heat relief. Urban For Urban Green 41: 272-282. https://doi.org/10.1016/j.ufug.2019.04.011

Eker Ö, 2007. An Economic Analysis of Multiple Use of Forests: Belgrade Forest Example. J Appl Sci Res 3(11): 1472-1475.

Eker Ö, 2008. Recreational Carrying Capacity of Belgrade Forest: A Case Study. KSU J Sci Eng 11(2): 77-80.

Enrong Y, Xihua W, Jianjun H, 2006. Concept and Classification of Coarse Woody Debris in Forest Ecosystems. Front Biol China 1: 76-84. https://doi.org/10.1007/s11515-005-0019-y

Green P, Peterken GF, 1997. Variation in the amount of dead wood in the woodlands of the Lower Wye Valley, UK in relation to the intensity of management. Forest Ecol Manag 98: 229-238. https://doi.org/10.1016/S0378-1127(97)00106-0

Herrero C, Monleon VJ, Gómez 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 Syst 25(3): e069. https://doi.org/10.5424/fs/2016253-09009

Hofgaard A, 2000. Structure and regeneration pattern in a virgin *Picea abies* forest in northern Sweden. J Veg Sci 4: 601-608. https://doi.org/10.2307/3236125

IPCC, 2003. Good practice guidance for land use, land-use change and forestry. The Intergovernmental Panel on Climate Change (IPCC) National Greenhouse Gas Inventories Programme, Kanagawa.

Jankovska I, Straupe I, Brumelis G, Donis J, Kupfere L, 2014. Urban forests of Riga, Latvia - Pressures, Naturalness, Attitudes and Management. Baltic For 20: 342-351.

Jonsson MT, Jonsson BG, 2007. Assessing coarse woody debris in Swedish woodland key habitats, implications for conservation and management. Forest Ecol Manag 242: 363-373. https://doi.org/10.1016/j.foreco.2007.01.054

Karahalil U, Başkent EZ, Sivrikaya F, Kılıç B, 2017. Analyzing deadwood volume of Calabrian pine (*Pinus brutia* Ten.) in relation to stand and site parameters: a case study in Köprülü Canyon National Park. Environ Monit Assess 189: 112. https://doi.org/10.1007/s10661-017-5828-3

Lang M, Liljeleht A, Neumann M, Bronisz K, Rolim SG, Seedre M, Uri V, Kiviste A, 2016. Estimation of above-ground biomass in forest stands from regression on their basal area and height. Forestry Studies 64: 70-92. https://doi.org/10.1515/fsmu-2016-0005

Larfavaara M, Muller-Landau HC, 2011. Cross-Section Mass: An Improved Basis for Woody Debris Necromass Inventory. Silva Fenn 45(2): 291-298. https://doi.org/10.14214/sf.119

Marshall P, Davis G, LeMay V, 2000. Using Line Intercept Sampling for Coarse Woody Debris. Forest Research Technical Report, Vancouver.

Maser C, Trappe JM, 1984. The seen and unseen world of the fallen tree. Gen. Tech. Rep. PNW-164. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland. https://doi.org/10.2737/PNW-GTR-164

Mountford EP, 2002. Fallen dead wood levels in the near-natural beech forest at La Tillaire reserve, Fontainebleau, France. Forestry 75: 203-208. https://doi.org/10.1093/forestry/75.2.203

Nieset E, 1999. Relationship between relative wood density of *Picea abies* logs and simple classification systems of decayed coarse woody debris. Can J Forest Res 14: 454-461. https://doi.org/10.1080/02827589905154159

Notaro S, Paletto A, Raffaelli R, 2009. Economic impact of forest damage in an Alpine environment. Acta Silva & Lignaria Hungarica 5: 131-143.

Özcan M, Gökbülat F, Hızal A, 2013. Exclosure effects on recovery of selected soil properties in a mixed broadleaf forest recreation site. Land Degrad Dev 24(3): 266-276. https://doi.org/10.1002/ldr.1123

Ożhan S, Gökbülat F, Serengil Y, Özcan M, 2010. Evapotranspiration from a Mixed Deciduous Forest Ecosystem. Water Resour Manage 24: 2353-2363. https://doi.org/10.1007/s11269-009-9555-6

Paletto A, Agnelli AE, De Meo I, 2020. Carbon stock in deadwood: the mountain birch (*Betula pubescens* subsp. czerepanovii) forests in the Khibiny Mountains (Russia). J Sustain Forest (in press). https://doi.org/10.1080/10549811.2020.1767144

Paletto A, De Meo I, Cantiani P, Ferretti F, 2014. Effects of forest management on the amount of deadwood in Mediterranean oak ecosystems. Ann Forest Sci 71: 791-800. https://doi.org/10.1007/s13595-014-0377-1

Paletto A, Tosì V, 2010. Deadwood density variation with decay class in seven tree species of the Italian Alps. Scand J Forest Res 25: 164-173. https://doi.org/10.1080/02827581003730773

Pastorella F, Avdagić A, Čabaravdić A, Mraković A, Osmanović M, Paletto A, 2016. Tourists’ perception of deadwood in mountain forests. Ann Forest Res 59: 311-326. https://doi.org/10.15287/afri.2016.482

Pastorelli R, Paletto A, Agnelli AE, Lagomarsino A, De Meo I, 2020. Microbial communities associated with decomposing deadwood of downy birch in a natural forest in Khibiny Mountains (Kola Peninsula, Russian Federation). Forest Ecol Manag 455: (in press). https://doi.org/10.1016/j.foreco.2019.117643

Pelyukh O, Paletto A, Zahvoyska L, 2019. People’s attitudes towards deadwood in forest: evidence from the Ukrainian Carpathians. J For Sci 65: 171-182. https://doi.org/10.17221/144/2018-JFS

Piętka S, Sotnik A, Damszel M, Sierota Z, 2019. Coarse woody debris and wood-colonizing fungi differences between a reserve stand and a managed forest in the Taborz region of Poland. J Forest Res 30(3): 1081-1091. https://doi.org/10.1007/s11676-018-0612-y

Prasad AE, 2009. Tree community change in a tropical dry forest: the role of roads and exotic plant invasion. Environ Conserv 36: 201-207. https://doi.org/10.1017/S0376892909900257

Puletti N, Canullo R, Mattioli W, Gawryś R, Corona P, Czerpeko J, 2019. A dataset of forest volume deadwood estimates for Europe. Ann Forest Sci 76: 68. https://doi.org/10.1007/s13595-019-0832-0

QGIS Development Team 2017. QGIS Geographic Information System. Open Source Geospatial Foundation Project. http://qgis.osgeo.org".
Radu S, 2006. The ecological role of deadwood in natural forests. J Environ Sci Eng 3: 137-141. https://doi.org/10.1007/978-3-540-47229-2_16

Rahman M, Frank G, Ruprecht H, Vacik H, 2008. Structure of coarse woody debris in Lange-Leitn Natural Forest Reserve, Austria. J Forest Sci 54(4): 161-169. https://doi.org/10.17221/3102-JFS

Russell MB, Fraver S, Aakala T, Woodall CW, D’Amato AW, Ducey MJ, 2015. Quantifying carbon stores and decomposition in dead wood: A review. Forest Ecol Manag 350: 107-128. https://doi.org/10.1016/j.foreco.2015.04.033

Sefidi K, Etemad V, 2016. Dead wood characteristics influencing macrofungi species abundance and diversity in Caspian natural beech (Fagus orientalis Lipsky) forests. Forest Syst 24(2): eSC03. https://doi.org/10.5424/fs2015242-06039

Simkin J, Ojala A, Tyrväinen L, 2020. Restorative effects of mature and young commercial forests, pristine oldgrowth forest and urban recreation forest - A field experiment. Urban For Urban Green 48: 126567. https://doi.org/10.1016/j.ufug.2019.126567

Skwarek K, Bijak S, 2015. Resources of dead wood in the municipal forests in Warsaw. For Res Paper 76: 322-330. https://doi.org/10.1515/frp-2015-0031

Tobin B, Black K, McGurdy L, Nieuwenhuis M, 2007. Estimates of decay rates of components of coarse woody debris in thinned Sitka spruce forests. Forestry 80(4): 455-469. https://doi.org/10.1093/forestry/cpm024

Tomescu R, Tarziu DR, Turcu DO, 2011. The Importance of Dead Wood in the Forest. ProEnvironment 4: 10-19.

Topaçoğlu O, Kara F, Yer EN, Savci M, 2017. Determination of deadwood volume and the affecting factors in Trojan fir forests. Austrian J Forest Sci 3: 245-260.

Tyrväinen L, Silvennoinen H, Kolehmainen O, 2003. Can ecological and aesthetic values be combined in urban forest management? Urban For Urban Green 1: 135-149. https://doi.org/10.1078/1618-8667-00014

van Wagner CE, 1968. The line intersect method for forest fuel sampling. Forest Sci 14: 20-26.

Warren WG, Olsen PF, 1964. A line-intersect technique for assessing logging waste. Forest Sci 10: 267-276.