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Deadwood volume assessment in Calabrian pine (Pinus brutia Ten.) peri-urban forests: Comparison between two sampling methods

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ABSTRACT
In the Sustainable Forest Management, deadwood is a fundamental substrate for numerous species, and a key factor in carbon and nutrient cycles. The main aim of the paper is to estimate the amount of deadwood in two Calabrian pine forests (Monte Morello in Italy; Xanthi in Greece) characterized by different stand conditions and management practices. The second aim is to compare two different sampling methods to estimate the volume of lying deadwood: the fixed-area sampling (FAS) method and the line intersect sampling (LIS) method. The results show that the Monte Morello peri-urban forest is characterized by a high quantity of deadwood (75.1 m$^3$ ha$^{-1}$) divided in 80% of lying deadwood, 18% of standing dead trees, and 2% of stumps. The Xanthi peri-urban forest is characterized by a total amount of deadwood of 9.21 m$^3$ ha$^{-1}$ divided in 34% of lying deadwood, 18% of standing dead trees and 48% of stumps. The mean volume of lying deadwood in Monte Morello estimated using the FAS is 59.91 m$^3$ ha$^{-1}$, while using the LIS the mean volume is 64.9 m$^3$ ha$^{-1}$. In the Xanthi, the mean volume of lying deadwood is 3.11 m$^3$ ha$^{-1}$ using FAS and 5.49 m$^3$ ha$^{-1}$ using LIS.

KEYWORDS
Deadwood volume; fixed-area sampling method; line intersect sampling method; lying deadwood; standing dead trees; stumps

Introduction
In the last decades, the role of deadwood in forest ecosystems has been widely recognized both by the scientific community and forest practitioners, and the strategies to manage the non-living woody biomass have been discussed in many forestry research studies (Merganičová, Merganič, Svoboda, Bače, & Šebeň, 2012; Paletto, De Meo, Cantiani, & Ferretti, 2014).

The term “deadwood” refers to all non-living woody biomass in a forest, either standing, lying on the ground or in the soil and not included in the litter (Harmon et al., 1986). According to this definition, deadwood includes three main components (Ligot, Lejeune, Rondeux, & Hébert, 2012; Paletto & Tosi, 2010): lying deadwood or logs, standing dead trees or snags, and stumps.

Considering size, deadwood can be classified in the following categories (Stokland, Tomter, & Söderberg, 2004): coarse woody debris (CWD) and fine woody debris (FWD). In the international literature, there are no universally accepted thresholds for...
distinguishing between CWD and FWD (Debeljak, 2006; du Cros & Lopez, 2009; Travaglini et al., 2007; Vandekerkhove, Keersmaeker, Menke, Meyer, & Verschelde, 2009). Frequently, CWD is defined as dead woody materials at various decay stages, including sound and rotting logs, and large branches with diameter more than 10 cm (Kraigher et al., 2002), while FWD includes dead woody materials on the ground (small branches and twigs) with diameter between 10 cm and 2.5 cm (Kruys, Fries, Jonsson, Lämås, & Ståhl, 1999). According to some authors, woody debris with diameter less than 2.5 cm can be considered as litter (Fridman & Walheim, 2000; Paletto & Tosi, 2010; Woldendorp, Spencer, Keenan, & Barry, 2002), while other authors classify it as very fine woody debris (Hegetschweiler, Van Loon, Ryser, Rusterholz, & Baur, 2009).

Deadwood in forests has had different connotations during time, due to the evolution of forest management approaches. In particular, the traditional forest management approach considers deadwood as a potential source of biotic and abiotic disturbances and an obstacle to silvicultural practices (Radu, 2006). Non-living woody biomass was traditionally perceived by forest managers as an indicator of “mismanagement, negligence and wastefulness” of the applied forest management practices (Pastorella et al., 2016). In the last decades, with the development of biodiversity-oriented forest management, perception of forest managers regarding deadwood in forests has changed. In biodiversity-oriented forestry, the goal is to increase the amount of deadwood, and one of the main purposes is to reduce the difference in deadwood volume between managed and unmanaged forests (Swanson & Franklin, 1992). The close-to-nature forest management approach even aims at maintaining a certain amount of deadwood in order to preserve the functionality of the forest ecosystem (Müller-Using & Bartsch, 2009).

The State of Europe’s Forests 2011 (Forest Europe, UNECE, FAO, 2011) indicates that deadwood in European forests increased over the past 20 years in accordance with the principles of biodiversity-oriented management. The main factors that influence deadwood in forests are the following: soil and climate conditions, vegetation zones, forest type, natural and/or anthropogenic disturbances, forest management regimes (Karahalil, Baskent, Sivrikaya, & Kiliç, 2017; Lombardi, Cherubini, Lasserre, Tognetti, & Marchetti, 2008; Rock, Badeck, & Harmon, 2008). Regarding the latter variable, the presence of deadwood in forests is influenced both by the forest system ( coppice or high forest) and the intensity of management (Fridman & Walheim, 2000; Green & Peterken, 1997). In fact in managed forests, potential deadwood volumes are reduced by timber extraction and use of biomass for energy (Andersson & Hytteborn, 1991; Verkerk, Lindner, Zanchi, & Zudin, 2011).

Currently, standing dead trees and lying deadwood are considered two important structural and functional components of forest ecosystems. These components provide important habitats for numerous insect species including flies and beetles, fungi and millipedes, moreover nurse log facilitating germination of conifers in mountain forest (Vallauri, André, & Blondel, 2003). The “habitat trees” (large trees with diameter greater than 30 cm) play an important ecological role with holes that provide shelter for wildlife (Humphrey et al., 2004). The bird species that are hosted by dead trees can be primary excavators of cavities (i.e., woodpeckers) or secondary cavity nesters (Hagan & Grove, 1999). In addition, lying deadwood improves slope stability in order to protect human activities from landslides and rockfalls and increases soil surface stability to prevent erosion (Enrong, Xihua, & Jianjun, 2006).

Deadwood is also an important carbon reservoir of forest ecosystems (Kalies, Haubensak, & Finkral, 2016), due to its slow decomposition rate. According to Brown (2002), 10–20% of
total carbon storage in forest ecosystems is in the deadwood carbon pool, while Woodall, Heath, and Smith (2008) estimated that in United States, 14% of the total forest carbon pool is stored in deadwood. Simultaneously, deadwood is a carbon source contributing up to 50% of soil surface CO₂ efflux (Bond-Lamberty, Wang, & Gower, 2002), even if the slow nature of the decay process and the significant pool size make the estimates difficult and rare (Forrester, Mladenoff, Gower, & Stoffel, 2012).

Besides, deadwood is a key factor in nutrient cycle of C, N and Mg (Holub, Spears, & Lajtha, 2001; Krankina & Harmon, 1994) and in natural regeneration (Vallauri et al., 2003), and a fundamental element in the geomorphological and soil hydrological processes (Bragg & Kershner, 1999).

Deadwood decay level is a very important variable because it affects deadwood-inhabiting fungi, bryophyte presence and diversity (Odor & Standovár, 2001) and the carbon released to the atmosphere (Rock et al., 2008). The snag longevity (duration of time from tree mortality to falling down) influences the succession of the species assemblages (Onodera & Tokuda, 2015).

In the National Forest Inventories (NFIs), many methods for estimating deadwood volume have been applied, such as (Bebber & Thomas, 2003; Larjavaara & Muller-Landau, 2011): fixed-area sampling (FAS), line intersect sampling (LIS), diameter relascope sampling, perpendicular distance sampling, and line intersect distance sampling. Generally, FAS and LIS are the two methods most widely used in the NFIs. These methods are characterized by practicability and operational advantages with respect to variable plot radius or diameter relascope sampling. FAS is the most widely used method in Europe to assess lying deadwood in NFIs, while LIS is used by the Swiss Forest Inventory and in the United States of America to assess log residues, firewood, and more recently deadwood for carbon accounting and biodiversity (Böhl & Brändli, 2007; Di Cosmo, Gasparini, Paletto, & Nocetti, 2013; Ligot et al., 2012; McRoberts et al., 2010). LIS has found many applications also in forest planning because this method is simple, rapid and non-destructive. Brown (1970) adapted the LIS method in order to sample the small fuel particles (conglomerate of vegetative particles less than 8 cm). Bell, Kerr, McNickle, and Woollons (1996) investigated the influence of different arrangements of transect lines and the length of sample line on the estimation of the lying deadwood volume in typical New Zealand stand of Monterey pine. Herrero, Krankina, Monleon, and Bravo (2013) investigated the amount and distribution of CWD in different pine ecosystems (north-western Spain, Russia and United States of America) using line intersect approach.

Starting from these considerations, the main objectives of the present paper are: (1) to assess the amount of deadwood (lying deadwood, standing dead trees and stumps) in peri-urban Calabrian pine (Pinus brutia Ten.) forests characterized by different stand conditions and forest management practices; (2) to estimate the volume of lying deadwood using both FAS method and LIS method in order to compare the results and the applicability of the two methods in the field measurements.

**Materials and methods**

**Study areas**

The research was developed in two study areas located respectively in Italy and in Greece (Figure 1). The study areas are both peri-urban forests characterized by a similar tree species composition but different forest management practices.
Monte Morello peri-urban forest

The study area in Italy is the peri-urban forest of Monte Morello (43°51′20″N; 11°14′23″E) located immediately North–West of the urban area of Florence (Tuscany Region). This forest is derived from reforestations realized from 1909 to 1980, and the current area is 1,035 ha. The purpose of these reforestations was to provide hydrogeological stability in mountainous areas depleted by the intensive use of natural resources, especially during World War I and II and to facilitate the natural succession toward mixed forests with a strong component of broadleaved species (Cantiani & Chiavetta, 2015). The Monte Morello area was characterized by difficult pedoclimatic conditions and interested by phenomena of hydrogeological hazards, in particular for the underlying plain (Cenni, Bussotti, & Galeotti, 1998). Like other reforestations in Italy, also in Monte Morello, several species of conifers were planted. Pinus nigra (Am.), with all its various subspecies, was widely used in reason of its characteristics of a pioneer species: fast juvenile growth, low mortality, low incidence of health issues, and the capability to improve both chemical and physical characteristics of the soil (Cantiani & Chiavetta, 2015). Moreover, other tree species used in the reforestation of Monte Morello were: Calabrian pine (Pinus brutia Ten. subsp. brutia), cypress (Cupressus spp.), flowering ash (Fraxinus ornus L.), Turkey oak (Quercus cerris L.) and Downey oak (Quercus pubescens L.).

Monte Morello reforestation was realized with a density of about 2,700 trees per hectare, but during the rotation period, the necessary silvicultural treatments have not been applied, and the stands have been largely abandoned with important consequences on tree stability, mortality and increase of fire risk. Currently, Monte Morello forest can be considered a degraded forest often characterized by poor regeneration, marked susceptibility to adversities, huge quantity of deadwood and a high degree of flammability (Cenni et al., 1998; Nocentini,
The lying deadwood and standing dead trees are not removed from the forest during silvicultural operations for economic and ecological reasons. The altitude of the area is between 55 m and 934 m a.s.l., and the climate is characterized by precipitations concentrated in the period from autumn to early spring and a dry summer in which July is the driest month, while October and November are the most rainy months. During the last decades (from the early 1980s), the total annual rainfall is 1,003 mm, and the average annual temperature is 13.9°C.

The basic stone is a calcareous flysch (turbidites) constituted by alternating limestones, marly limestones ("alberese") marls, claystones and, subordinately, sandstones. Soil is therefore mainly calcareous, with pH ranging between 7.0 and 8.2 and a depth between 20 and 100 cm.

**Xanthi peri-urban forest**

The second study area is the peri-urban forest of Xanthi (41°09′33″N; 24°54′80″E), in North-Eastern Greece (East Macedonia and Thrace Region). The forest covers an area of 2,366 ha and is a part of the Xanthi-Gerakas-Kimerion public forest. The Xanthi forest originated from a reforestation started in 1936 and completed, for the greatest part, in 1973. Planting activities took place periodically up to 2007. The main species used for the reforestation were: Calabrian pine (Pinus brutia Ten. subsp. brutia), Maritime pine (Pinus maritima Lam.), Stone pine (Pinus pinea L.), cypress (Cupressus spp.), black pine (Pinus nigra J.F.Arnold), black locust (Robinia pseudoacacia L.), oaks (Quercus spp.), and Oriental hornbeam (Carpinus orientalis Mill.). At the highest elevations, there are European beech (Fagus sylvatica L.) stands.

Silvicultural treatments (thinning, pruning) were applied scarcely, but generally the deadwood was removed in order to protect forests from fire. In 2006, the forest was declared protected area. Currently, many areas are characterized by an understory of broadleaves (Quercus spp., Carpinus orientalis Mill.); in some areas, broadleaves appear as individuals or create formations of mainly small dimensions. In sites characterized by better conditions, broadleaves are beginning to reoccupy the growing space; thus, a mixed forest is showing.

The altitude ranges between 100 m and up to 630 m a.s.l. The climate of the area is characterized by low temperature (mean temperature in December, January, February around 5°C) and high rainfall (mean precipitation 80 mm in November and 85 mm in December) in winter, and high temperature (mean temperature more than 25°C in July and August) and low rainfall (mean precipitation less than 20 mm in July and less than 10 mm in August) in summer.

The rock formations are Gneisses and Para-gneisses, fine to coarse grained gneisses with variation in color from light flesh to dark grey.

**Field measurements**

The field data were collected in 18 sampling plots randomly located both in the Monte Morello peri-urban forest and in the Xanthi peri-urban forest (Figure 1). The sampling plots have been located through a two-step sampling method. During the first step, the Monte Morello forest was divided in monitoring-areas (each one of 1 ha surface) on the basis of forest stand characteristics (i.e., stem density, basal area, tree species composition). During the second step, nine monitoring-areas have been selected in order to represent all
stand characteristics of the Monte Morello forest. In each monitoring-area were placed, with random criterion, two circular sampling plots.

In each sampling plot, the main dendrometric data—such as height and diameter at breast height (dbh) for all standing living trees, number of stems, canopy cover over-storey—were collected during the field measurements. The standing living (stem) volume was estimated using the model elaborated by second Italian National Forest Inventory (NFI) for black pine species. In this model, the diameter at breast height (d) and the total tree height (h) has been adopted as independent variables for the prediction equations.

In addition, all three deadwood components were considered and measured in the sampling plot: (1) lying deadwood or logs (sound and rotting pieces of wood located on the ground); (2) snag (standing dead trees with a height greater than 1.3 m); and (3) stumps (standing dead trees truncated or cut to a height of less than 1.3 m). Considering size of deadwood, in the present study, threshold diameter for distinguishing between deadwood and litter was set at 5 cm: all woody debris with a diameter greater than 5 cm were recorded and classified, while the woody debris with a diameter less than 5 cm was considered as litter. In each plot, lying deadwood was sampled using two sampling methods: fixed-area sampling (FAS) and line intersect sampling (LIS).

**Fixed-area sampling method**

All deadwood pieces lying on the soil (logs), standing dead trees (snags) and stumps were measured in a sampling plot of 13 m radius (531 m²).

For each lying deadwood piece, the following information was collected: (1) diameter in the minimum section (equal to or greater than 5 cm), (2) diameter in the end section, and (3) distance (length) between the minimum section and the end section. In each section, perpendicular diameters were measured using a forest caliper, while the length between minimum and maximum diameter was measured using a tape measure. In the case of deadwood pieces strongly decomposed and/or incorporated into the soil—for which it was not possible to measure the diameters with the forest caliper—a visual assessment of the diameters was made. In the sampling plot, only lying deadwood pieces with a diameter equal to or greater than 5 cm were measured, while lying deadwood pieces outside the sampling plot and those with a diameter less than 5 cm have not been measured (Figure 2).

**The volume of lying deadwood (Vl) was estimated using the Huber’s formula**

\[ V_l = \frac{\pi}{4} \cdot L_l \cdot \left( \frac{D_l + d_l}{2} \right)^2 \]

where \( L_l \) is the length of log (m), \( D_l \) is the maximum diameter of log (m), and \( d_l \) is the minimum diameter of logs (m).

Standing dead trees (whole or truncated) with a height more than 1.30 m were measured, and the following information was collected: (1) two perpendicular diameters measured at dbh (cm); (2) height of standing dead trees or broken height (cm). The volume of standing dead trees (Vs) was calculated with the following formula:

\[ V_s = f \cdot BA \cdot h_s \]
where $BA$ is basal area ($m^2$), $f$ the stem form factor as relationship between real stem volume and cylinder volume (0.5) and $h_s$ the height of standing dead tree (m).

Standing dead trees with a height less than 1.30 m were considered as stumps. For each stump, the following attributes were measured: (1) two perpendicular diameters measured on the cutting plane or broken height (cm); (2) minimum and maximum height of the stump on the cutting plane or broken height (m). The volume of stumps ($V_{st}$) was estimated using the Huber’s formula:

$$V_{st} = \frac{\pi}{4} \cdot \left( \frac{H_{st} + h_{st}}{2} \right) \cdot \left( \frac{D_{st} + d_{st}}{2} \right)^2$$

where $H_{st}$ is the maximum height of stump (m), $h_{st}$ is the minimum height of stump (m), $D_{st}$ is the maximum diameter (m), and $d_{st}$ is the minimum diameter (m).

In addition, for each deadwood piece of all three components, tree species—if not recognizable, the botanical category distinguishing between conifer and broadleaf—and decay class were recorded.

The decomposition of deadwood was visually assessed by forest experts using the five decay classes proposed by Næsset (1999): recently dead, weakly decayed, medium decayed, very decayed and almost decomposed. The visual assessment of rates of decay was executed considering some key variables and visible characteristics (Fridman & Walheim, 2000; Næsset, 1999; Paletto, Chincarini, & Tosi, 2008): (i) structure of bark; (ii) presence of small branches with a diameter less than 3 cm; (iii) softness of wood; (iv) other visible characteristics such as rot extension and development of fungus mycelium, mosses and lichens (Table 1).
Line intersect sampling method

Line intersect sampling (LIS) method is considered as an efficient and reliable method to estimate the volume of lying deadwood (Warren & Olsen, 1964). According to the line-intersect approach, all lying woody debris that intersect a transect are measured with a caliper at the point of intersection of the transect and the central axis of the log (Marshall, Davis, & LeMay, 2000). The assumption of this approach is that the cross sections of all logs are circular. The transect length \(L\) is the key variable affecting the precision of the estimate because the probability of sampling a woody debris piece is proportional to its length (Bell et al., 1996; Van Wagner, 1968).

In this study, in order to quantify the volume of lying woody debris (angle of inclination greater than 45°), two transects of 26 m for a total length of 52 m were employed. Transects were located within the sampling plot, passing through the central point of it: the first transect in direction North-South (N-S), while the second transect in direction East-West (E-W), perpendicular to the first (Figure 3).

For each lying deadwood piece intercepted by the transects, the following information was recorded: (1) two perpendicular diameters measured in the intersection point of the transect (cm); (2) tree species or, if not recognizable, botanical category distinguishing between conifer and broadleaf; (3) decay class considering five decay classes as described for FAS method.

The total volume of woody debris on the ground \(V_l\) was estimated using the following equation (Van Wagner, 1968; Warren & Olsen, 1964):

\[
V_l = \pi^2 \sum \left( \frac{d_i^2}{8L} \right)
\]

where \(V_l\) = volume of lying deadwood \((m^3 \text{ ha}^{-1})\), \(L\) = length of the transect in meter \((m)\) and \(d_i\) = diameter \((\text{mean of the two diameters})\) of the intersection point \((\text{cm})\).

Data analysis

The data collected in the field were elaborated to assess deadwood volume in the two study areas. Both in Monte Morello and in Xanthi peri-urban forest, the volume was estimated distinguishing by decay class and tree species. Besides, the volume of lying deadwood was estimated using the FAS and LIS method in order to compare the results obtained.

Results were compared from the statistical point of view using the Wilcoxon signed-rank test. The non-parametric test was used to compare two paired measurements (FAS and LIS

<table>
<thead>
<tr>
<th>Decay classes</th>
<th>Bark condition</th>
<th>Small branches</th>
<th>Wood consistency</th>
<th>Other characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Recently dead</td>
<td>Entire and attached</td>
<td>Present</td>
<td>Intact</td>
<td>Little rotten area under bark</td>
</tr>
<tr>
<td>2 Weakly decayed</td>
<td>Entire but not-attached</td>
<td>Partly present</td>
<td>Intact</td>
<td>Rotten areas &lt; 3 cm</td>
</tr>
<tr>
<td>3 Medium decayed</td>
<td>Fragments of bark only</td>
<td>Absent</td>
<td>Partly broken</td>
<td>Rotten area &gt; 3 cm</td>
</tr>
<tr>
<td>4 Very decayed</td>
<td>Absent</td>
<td>Absent</td>
<td>Broken</td>
<td>Large rotten area</td>
</tr>
<tr>
<td>5 Almost decomposed</td>
<td>Absent</td>
<td>Absent</td>
<td>Dust</td>
<td>Very large rotten area, musk and lichens</td>
</tr>
</tbody>
</table>

method) on a single sample (lying deadwood), to assess whether their population mean ranks differ (paired difference test). In addition, a Spearman correlation between the lying deadwood volume collected using the two different sampling methods was performed.

**Results**

**Deadwood volume by component, decay class and species**

In Table 2, the main dendrometric parameters of each sample plot (standing living volume, stand density, canopy cover overstorey, and deadwood volume by component) are reported to characterize the structure of the forest stands in the two study areas.

In Table 2 is evidenced a large variability among plots in the amount of deadwood, which varies from less than 3 m$^3$ ha$^{-1}$ to 190 m$^3$ ha$^{-1}$.

The peri-urban forest of Monte Morello has an average standing volume of 602 m$^3$ ha$^{-1}$ and an average number of stems of 1511 per hectare. The standing volume is between a minimum of 313 m$^3$ ha$^{-1}$ and 927 m$^3$ ha$^{-1}$, while the stems per hectare are comprised between 960 and 2185. The Xanthi peri-urban forest has an average standing volume of 396 m$^3$ ha$^{-1}$ (range between 268 m$^3$ ha$^{-1}$ and 545 m$^3$ ha$^{-1}$) with an average number of stems of 1303 (range between 621 stems per ha and 2496 stems per ha).

The total amount of deadwood (lying deadwood, standing dead trees and stumps) is quite high in the peri-urban forest of Monte Morello (12.6% of standing living volume with a range between 2.0% and 59.4%), while the total amount of deadwood in Xanthi peri-urban forest is 2.3% of living wood volume (range between a minimum of 0.6% and a maximum of 4.2%). The Spearman correlation ($\alpha = 0.01$) between standing living volume and deadwood shows that these two variables are positively correlated (p value = 0.010, r = 0.425).

*Figure 3. Arrangement of the two transects in the sampling plot.*
Regarding the deadwood volume, results show that the peri-urban forest of Monte Morello is characterized by a high quantity of deadwood (75.1 m$^3$ ha$^{-1}$), concentrated in the lying deadwood component with an average volume of 59.9 m$^3$ ha$^{-1}$ (estimated with FAS method). Considering the other two deadwood components, the volume is: 13.9 m$^3$ ha$^{-1}$ for standing dead trees and 1.25 m$^3$ ha$^{-1}$ for stumps. Conversely, the total amount of deadwood volume in the peri-urban forest of Xanthi is 9.21 m$^3$ ha$^{-1}$ divided among components as follows: 3.11 m$^3$ ha$^{-1}$ of lying deadwood (estimated with FAS method), 1.63 m$^3$ ha$^{-1}$ of standing dead trees and 4.48 m$^3$ ha$^{-1}$ of stumps.

Considering the distribution of deadwood volume by decay classes (Table 3), results show that in Monte Morello the lying deadwood volume is concentrated in the third decay class (54% of total volume) followed by second and fourth decay class (respectively with 25% and 14% of total volume). The standing dead trees volume is equally distributed among the first three decay classes (respectively with 32%, 35% and 32% of total volume of decay classes).

### Table 2. Dendrometric parameters per sampling plot in Xanthi and Monte Morello peri-urban forests.

<table>
<thead>
<tr>
<th>N° plot</th>
<th>Standing volume (m$^3$ ha$^{-1}$)</th>
<th>N° living stems per ha</th>
<th>Canopy cover overstorey (%)</th>
<th>Deadwood volume (m$^3$ ha$^{-1}$) estimated with FAS approach</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Logs</td>
<td>Snags</td>
<td>Stumps</td>
<td>Total</td>
</tr>
<tr>
<td>Monte Morello</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.1</td>
<td>832.72</td>
<td>1130</td>
<td>70</td>
<td>16.64</td>
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<tr>
<td>1.2</td>
<td>921.60</td>
<td>962</td>
<td>70</td>
<td>34.93</td>
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<tr>
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<td>1243</td>
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<td>172.96</td>
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<td>7.2</td>
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<td>8.1</td>
<td>421.01</td>
<td>1601</td>
<td>70</td>
<td>24.49</td>
</tr>
<tr>
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this component). The volume of stumps is concentrated in third and fourth classes of decay (respectively 56% and 32%).

In the peri-urban forest of Xanthi, the volume of lying deadwood presents the higher percentage in the first decay class (29%), while the other four classes include the remaining 52% of the total volume. Standing dead trees volume is concentrated in the second decay class (71% of the total volume), while the fourth and fifth classes of decay are not represented in this study area. Concerning stumps, the volume is concentrated in the fifth decay class (43% of total volume of this component) followed by first and third decay class (respectively with 20% and 18%).

With regard to the distribution of deadwood by species (Table 4), the results show that in Monte Morello forest, 75.5% of total deadwood is represented by Calabrian pine followed by Arizona cypress (22.3%), while broadleaved species represent only 2% of total deadwood. The distribution of deadwood by species and component is the following: 83% of lying deadwood is Calabrian pine and 16% Arizona cypress; 51% of standing dead trees is Calabrian pine and 42% Arizona cypress; 77% of stumps belong to Calabrian pine.

In the peri-urban forest of Xanthi, the results show that all three components are mostly represented by Calabrian pine: in particular, 98% of the volume of lying deadwood, 94% of the volume of standing dead trees and 98% of the volume of stumps.

| Table 3. Distribution of deadwood volume (m³ ha⁻¹) by decay class in Xanthi and Monte Morello peri-urban forests (mean values with standard deviation in brackets). |
|---------------------------------|-----------------|-----------------|-----------------|-----------------|
| Logs                           | Snags           | Stumps          | Total           |
| Monte Morello                  |                 |                 |                 |
| Decay class 1                  | 2.90 (6.38)     | 4.48 (5.38)     | 0.00 (0.00)     | 7.38            |
| Decay class 2                  | 15.05 (18.60)   | 4.82 (5.62)     | 0.07 (0.12)     | 19.94           |
| Decay class 3                  | 32.37 (28.56)   | 4.48 (8.06)     | 0.70 (0.71)     | 37.55           |
| Decay class 4                  | 8.51 (6.89)     | 0.12 (0.30)     | 0.40 (0.55)     | 9.03            |
| Decay class 5                  | 1.09 (1.63)     | 0.02 (0.05)     | 0.07 (0.15)     | 1.18            |
| Total                          | 59.91 (50.45)   | 13.92 (12.96)   | 1.25 (1.12)     | 75.08           |
| Xanthi                         |                 |                 |                 |
| Decay class 1                  | 0.91 (2.56)     | 0.21 (0.87)     | 0.89 (1.18)     | 2.01            |
| Decay class 2                  | 0.52 (0.75)     | 0.99 (2.47)     | 0.49 (0.48)     | 1.99            |
| Decay class 3                  | 0.69 (1.32)     | 0.43 (1.70)     | 0.79 (2.39)     | 1.91            |
| Decay class 4                  | 0.69 (0.79)     | 0.00 (0.00)     | 0.38 (0.40)     | 1.07            |
| Decay class 5                  | 0.30 (0.41)     | 0.00 (0.00)     | 1.94 (4.20)     | 2.23            |
| Total                          | 3.11 (4.45)     | 1.63 (2.89)     | 4.48 (5.01)     | 9.21            |

| Table 4. Distribution of deadwood volume (m³ ha⁻¹) by species in Monte Morello and Xanthi peri-urban forests (mean values with standard deviation in brackets). |
|---------------------------------|-----------------|-----------------|-----------------|-----------------|
| Species                         | Logs            | Snags           | Stumps          | Total           |
| Monte Morello                   |                 |                 |                 |                 |
| Calabrian pine                  | 49.85 (50.86)   | 5.82 (8.13)     | 0.98 (1.02)     | 56.65           |
| Arizona cypress                 | 9.45 (10.10)    | 7.09 (8.64)     | 0.23 (0.80)     | 16.77           |
| Other conifers species          | 0.17 (0.40)     | 0.00 (0.00)     | 0.03 (0.10)     | 0.20            |
| Broadleaved species             | 0.44 (0.76)     | 1.00 (4.01)     | 0.02 (0.05)     | 1.46            |
| Total                           | 59.91 (50.45)   | 13.91 (12.96)   | 1.26 (1.12)     | 75.08           |
| Xanthi                          |                 |                 |                 |                 |
| Calabrian pine                  | 3.06 (4.46)     | 1.53 (2.92)     | 4.45 (5.02)     | 9.05            |
| Broadleaved species             | 0.04 (0.091)    | 0.10 (0.36)     | 0.03 (0.064)    | 0.17            |
| Total                           | 3.11 (4.45)     | 1.63 (2.89)     | 4.48 (5.02)     | 9.21            |
Comparison between FAS and LIS method to estimate lying deadwood

The mean volume of lying deadwood in peri-urban forest of Monte Morello estimated using the FAS method is 59.91 m$^3$ ha$^{-1}$, while using the LIS method the mean volume is 64.9 m$^3$ ha$^{-1}$. In the peri-urban forest of Xanthi, the mean volume of lying deadwood is 3.11 m$^3$ ha$^{-1}$ using FAS method and 5.49 m$^3$ ha$^{-1}$ using the LIS method. In both case studies, the volume estimated through LIS is higher than the volume estimated with the traditional fixed-area plots (Figure 4). The non-parametric Wilcoxon signed-rank test shows that these differences are not statistically significant considering all 36 plots ($V = 224$, p value = 0.088, $\alpha = 0.01$). Also analyzing the data by study area, the differences are statistically not significant both for the 18 plots of the Xanthi peri-urban forest ($V = 56$, p value = 0.212, $\alpha = 0.01$) and for the 18 plots of Monte Morello peri-urban forest ($V = 60$, p-value = 0.284, $\alpha = 0.01$).

In terms of working time, the results of this study show that FAS is more time-consuming than LIS. The difference is between twice and four times taking into account the amount of lying deadwood. Conversely, the risk of omitting pieces is higher with FAS, especially when lying deadwood density is high.

In addition, the Spearman correlation ($\alpha = 0.01$) between the two methods is significant at $p < 0.0001$ ($r = 0.719$), with a slight overestimation of LIS method respect to FAS method, as showed by the slope >1 of the curve reported in the scatterplot (Figure 5). The largest variability is observed among the sample plots characterized by a medium-high amount of lying deadwood volume (20–50 m$^3$ ha$^{-1}$). In particular, the difference between the lying deadwood volume estimated by FAS method and by LIS method is between $-46.1$ m$^3$ ha$^{-1}$ and $+46.6$ m$^3$ ha$^{-1}$ for two sample plots in Monte Morello study area with a medium-high amount of lying deadwood.

Discussions

Results show that Monte Morello forest is characterized by a high presence of deadwood, and in particular, lying deadwood is the most abundant component. The amount of deadwood volume in Monte Morello peri-urban forest is about eight times more than that the volume in Xanthi peri-urban forest (respectively 75.1 m$^3$ ha$^{-1}$ and 9.21 m$^3$ ha$^{-1}$). These differences are due to two factors. First, in the Monte Morello reforestation, the silvicultural treatments have not been applied during the rotation period, the stands have been largely abandoned so that currently the forest can be considered a degraded forest.

Figure 4. Lying deadwood volume estimated with FAS and LIS method (box-plots).
Second, the fact that in Monte Morello the lying deadwood is generally not collected during the silvicultural treatments, while in the forest of Xanthi the lying deadwood is regularly collected by households for domestic use or by the Forest Service to prevent forest fires.

As confirmed by literature, deadwood stocking is related to a number of factors that are connected with stand and site characteristics (Siitonen, 2001; Tinker & Knight, 2000; Woodall & Westfall, 2009); also topography characteristics influence soil, climate conditions, dynamics and management and, consequently, the volume of deadwood.

Deadwood accumulation reflects the balance between deadwood accretion (through external disturbances, self-thinning, and senescence) and depletion (through harvesting and decomposition). From this point of view, the Monte Morello forest is in line with other studied areas where the absence of silvicultural interventions and of deadwood removal, and the site characteristics explain the high quantities of deadwood (Rouvinen, Kuuluvainen, & Karjalainen, 2002; Siitonen, 2001). The Xanthi forest is in line with managed forests characterized by direct removal of deadwood to obtain firewood and to reduce wildfire risk.

Results of the present study confirm that forest management is a key variable for the presence of deadwood in forest (Lombardi et al., 2008; Pedlar, Pearce, Venier, & McKenney, 2002). In this sense, some authors highlight that the ratio between the average volume of lying deadwood for managed and unmanaged stands is about 0.3 (Duvall & Grigal, 1999; Green & Peterken, 1997). In Swedish studies, this ratio has varied between 0.02 and 0.15 (Lämås &

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**Figure 5.** Spearman correlation between FAS and LIS method (correlation is significant at p < 0.0001).
Fries, 1995; Linder & Östlund, 1998) and in Finland between 0.10 and 0.39 (Siitonen, Martikainen, Puntila, & Rauh, 2000; Similä, Kouki, & Martikainen, 2003). In particular, a study in United Kingdom shows very large volumes of deadwood in unmanaged old growth woodlands (104.4 m$^3$ ha$^{-1}$), and 23.9 m$^3$ ha$^{-1}$ in managed semi-natural stands (Green & Peterken, 1997). In a coppice with standards actively managed in England, the authors estimated a volume of fallen wood of 11.9 m$^3$ ha$^{-1}$, while for a oak high forest under extensive management, the estimated volume of deadwood was 23.1 m$^3$ ha$^{-1}$ (Kirby, Reid, Thomas, & Goldsmith, 1998). For intensively managed forests in Scandinavian countries, Kruys et al. (1999) and Fridman and Walheim (2000) show a lying woody debris volume from 1.7 to 9.7 m$^3$ ha$^{-1}$. In Southern Italy, Paletto et al. (2014) highlight that the extensive managed oak forests have a significantly lower amount of deadwood than the intensive managed oak forests (respectively 8.5 m$^3$ ha$^{-1}$ and 3.1 m$^3$ ha$^{-1}$). With special regard to the standing dead trees volume,Marge and Lemperiere (2005) have estimated an average volume of 64.6 m$^3$ ha$^{-1}$ in the unmanaged forests and 15.8 m$^3$ ha$^{-1}$ in the managed forests of the Southern French Alps.

In addition, many studies have shown that protected areas—in which the deadwood is not removed for ecological reasons—have higher quantities of deadwood: in Izvoarele Nerei beech reserve in Romania, the deadwood volume is 87 m$^3$ ha$^{-1}$ (Tomescu, Tarziu, & Turcu, 2011); in Białowieża forest in Poland the volume of deadwood varies between 87 and 160 m$^3$ ha$^{-1}$ (Bobiec, 2002); in Fontainebleau forest reserve in France the volume of non-living component was estimated in a range between 142 and 256 m$^3$ ha$^{-1}$ (Mountford, 2002). Kraigher et al. (2002) have found a volume of deadwood of 100 m$^3$ ha$^{-1}$ for European beech and 192 m$^3$ ha$^{-1}$ for silver fir in the Rajhenavski Rog forest reserve (Slovenia), and a volume of deadwood equal to 57 m$^3$ ha$^{-1}$ for European beech and to 88 m$^3$ ha$^{-1}$ for silver fir in the Krokar forest reserve (Slovenia).

With regard to the Calabrian pine forests, in the international literature, there is a gap of knowledge about the amount of deadwood in this forest type. Solely, Karahalil et al. (2017) estimated a total deadwood volume of 3.8 m$^3$ ha$^{-1}$ (0.5 m$^3$ ha$^{-1}$ standing dead trees, 0.2 m$^3$ ha$^{-1}$ stumps, and 3.1 m$^3$ ha$^{-1}$ lying deadwood) in Calabrian pine forests in the Koprülü Canyon National Park (Southern Turkey).

As a result of these data reported in the international literature and of the findings of the present research, we can assert that unmanaged forests and protected forests areas have deadwood volumes between 3 and 10 times more than managed forests. In particular, the highest concentration of deadwood volume in unmanaged forests is in the lying deadwood component. It is also important to evidence that results of the present study, in particular Monte Morello findings, support data of other researches (Christensen et al., 2005; Lombardi et al., 2013) confirming that lying deadwood represents the most significant component in stands where natural mortality occurs due to endogenous processes, such as competition.

The quantity and quality of deadwood provide information on disturbances regime and mortality process (Castagneri, Garbarino, Berretti, & Motta, 2010). Concerning relations between disturbance regime and amount of deadwood, in the sampling plots of Monte Morello, there is a large variability of deadwood amount among plots. Particularly, deadwood distribution is related to single-tree mortality and small-scale disturbances and not related to large-scale disturbances. Since the forest type is the same in the study areas, the main factors that explain these variations in deadwood are the forest history, the development stage of the forest and exogenous disturbances as confirmed by other studies (Lombardi et al., 2013).
Considering the various components of deadwood, the number of stumps is strictly related to time of silvicultural interventions and the number of stumps indicates the intensity of cutting (Siitonen et al., 2000). In Monte Morello, forest stumps represent only 1.6% of total deadwood confirming that no silvicultural interventions have been realized in the forest, while in Xanthi forest, this component represents 48.6% of total deadwood.

The variation of deadwood volume in decay class distribution gives an indication of the temporal variation in tree felling and tree mortality and can be used as an indicator of the history of a forest (Rouvinen, Rautiainen, & Kouki, 2005).

In the two study areas, all the decay stages were found, but the most advanced classes (classes 4 and 5) were lower represented in Monte Morello forest. Similar results were observed by other studies (Christensen et al., 2005; Lombardi et al., 2013) confirming that the variability in deadwood decay classes guarantee habitats for saproxylic fauna (Mason, 2003; Siitonen, 2001).

It is essential to remember that both Monte Morello and Xanthi are peri-urban forests, with an important tourist flow during the year and where the presence of deadwood in forest can influence the recreational value of the area. Relations between deadwood in forest and recreation have been little investigated, with some studies in Northern Europe (Jankovska, Straupe, Brumelis, Donis, & Kupfere, 2014).

In general, deadwood is considered a potential danger for visitors, and especially in urban forests, deadwood on the soil is considered a potential cause of accidents (Weidinger, 2002).

Taking into account the above considerations, the total amount of deadwood in Calabrian pine forest of Monte Morello should be decreased from the current 75 m$^3$ ha$^{-1}$ to 10–15 m$^3$ ha$^{-1}$ corresponding to the 2–3% of the standing living volume. In particular, lying deadwood volume of third decay classes should be removed during the future silvicultural treatments. Conversely, the amount of deadwood in Xanthi peri-urban forest should be maintained around 9 m$^3$ ha$^{-1}$ for biodiversity conservation reasons.

**Conclusions**

In conclusion, the results of this study show that the volume of lying deadwood estimated using the LIS method is slightly higher than the volume of lying deadwood estimated using the FAS method. In this sense, Herrero, Monleon, Gómez, and Bravo (2016) highlighted that the lying deadwood estimated using the intersection diameter formula is greater than that estimated using the average-of-ends formula (respectively 10.89 m$^3$ ha$^{-1}$ and 9.66 m$^3$ ha$^{-1}$).

The LIS method is more appropriate in the forest areas characterized by a high amount of lying deadwood (e.g., protected areas, unmanaged and degraded forests) since it reduces the times of field measurements to a third (Ringvall & Ståhl, 1999). For LIS, the assessment time depends on the length of the transect and from the minimum diameter, but LIS is in general quicker, easy to set up and more regular in the assessment time (Du Cros & Lopez, 2009; Martin, 1976). Moreover with FAS, it is necessary to mark the measured pieces, to avoid missing some of them and re-measuring (Martin, 1976). But to have high accuracy a long transect, a low minimum diameter and a large number of plots are required (Bell et al., 1996; Ligot et al., 2012). The present study confirm that a good possibility is too choose LIS for lying deadwood.
and FAS for snags and stumps, especially when the volume of the lying components is very high (Bruciamacchie, 2005). In addition, the results of this study suggest to use two or more transects in the LIS method with a total length of transects from 50 to 80 m. Nevertheless, the choice of the sampling method depends on local conditions (quantity and size of lying deadwood), on applied thresholds and on inventory objectives. Moreover time, personnel and economic resources availability deeply influence the choice.

The present research confirms that human interventions have a clear impact on deadwood volume and that management strategies can deeply influence deadwood quantity and in consequence the effects produced on related ecosystem services (biodiversity, recreation activities, climate change mitigation).

The investigation of deadwood dynamics is crucial for supporting sustainable forest management strategies aimed at maintaining certain levels of deadwood in forest. In the present case, a solution is to integrate sampling campaign for deadwood into existing forest inventories, so that deadwood field measurements could be realized every 10–15 years. Field information can be integrated with data obtained using dendrochronological techniques, valuable for assessing deadwood decomposition rates and related processes. Being black pine reforestations widely spread in the Italian Apennine, also studies investigating forests in different successional stage could be informative on deadwood dynamics.

Deadwood in pine forests has not been deeply investigated, and field surveys can be used to enrich a systematic program of research whose results can implement the developments of guidelines concerning peri-urban forests management.

Since the type of management greatly influences the presence of deadwood in forests and the ecological role of deadwood (habitat for species, a key factor in the nutrient cycle and relevant carbon pool), silvicultural strategies can be implemented in order to regulate the volume of deadwood in the forests. Considering the role of deadwood for biodiversity, quantitative thresholds for the amount of deadwood in different size and decay classes have been established recently (Gossner et al., 2013), and results of the present research can be useful to schedule silvicultural interventions finalized at regulating deadwood quantity considering various ecosystem services.

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References


