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Living and Dead Aboveground Biomass in Mediterranean Forests: Evidence of Old-Growth Traits in a *Quercus pubescens* Willd. s.l. Stand

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Abstract: For a long time, human impact has deeply simplified most of the forest ecosystems of the Mediterranean Basin. Here, forests have seldom had the chance to naturally develop a complex and multilayered structure, to host large and old trees and rich biological communities, approaching old-growth conditions. Also for this reason, limited information is currently available about Mediterranean old-growth forests, particularly with regard to deadwood. The main aim of this work is to help fill this critical knowledge gap. In Sicily (Italy), we identified a *Quercus pubescens* forest that seemed to show some typical old-growth features. Total living volume (360 m^3 ha^{-1}) and basal area (34 m^2 ha^{-1}) were, respectively, about 6 and 3 times higher than the averages recorded in the regional forest inventory for this forest type. Deadwood was particularly abundant, exceeding the threshold of 30 m^3 ha^{-1}, mainly represented by lying dead elements. Dead to live wood ratio reached 9%, a value close to the threshold of 10% considered for Mediterranean old-growth forests. As the investigated forest showed some typical old-growth traits, it deserves to be fully protected and could be a permanent monitoring area for studying deadwood and stand dynamics in mature Mediterranean stands.

Keywords: mature forests; deadwood; downy oak; *Quercus ilex*; *Acer campestre*

1. Introduction

Interest in and attention to old-growth forests have grown considerably in Europe in recent decades [1]. Compared to the remaining primary forests, which are estimated to occupy only 4% of the total European forest area, excluding the Russian Federation [2], old-growth forests show a physiognomy still affected by former anthropogenic management [3]. When a forest stand has had the chance to develop and mature for a sufficient period of time in the almost-total absence of human interference, it tends to reach physiognomic, structural, and compositional traits very different from those of similar forest types that are not sufficiently aged or are still managed and/or largely disturbed by humans [4]. Under certain circumstances, natural development may allow the establishment of structurally complex, biologically rich, resilient, and stable forest stands, while in other cases, some form of forest management seems to be required to facilitate the achievement of such conditions [5]. This is particularly the case of Mediterranean forests. However, it should be kept in mind that not all old-growth forests are species rich and complex, as also monospecific forest stands with only one dominant tree layer may originate old-growth stands.

Old-growth forests play a major and well-recognised role in conservation of biological diversity, soil protection, and mitigation of climate change by means of C sequestration in long-term pools, as well as watershed supply and water quality [6–8]. Many living organisms exclusively owe their survival to complex, mature, and relatively undisturbed (by humans) forest ecosystems, which are worthy to be fully preserved. However, to accomplish this, such forest stands need to be identified and characterised.

There is no universally-accepted definition of old-growth forest. Instead, some selected biological and structural parameters are commonly used as proxy indicators for old-growth conditions. For instance, in temperate ecosystems all around the world, despite large climatic and compositional differences, densities of large living trees, quadratic mean diameter, amount of living aboveground biomass, and coarse woody debris are found to be significantly higher in old-growth forest stands [9]. Accordingly, the occurrence of senescent and/or large trees, the amount of deadwood, and, consequently, the absence of significant and recent signs of human disturbance are considered the most reliable proxy of mature forest stands, tending toward old-growth conditions [3]. Particularly, deadwood is among the major diagnostic features that have to be taken into account for the identification and characterisation of an old-growth forest because it provides indirect information about forest ageing, human disturbance, as well as living organisms [10].

The formation of deadwood in a forest depends on the frequency, intensity, and scale of disturbances, such as wind, snow, drought, pests, and wildfires, which may determine the falling of branches or twigs and/or the death of whole trees [11]. Hence, natural disturbance represents the main input of deadwood in a forest ecosystem, and this seems to be a rather general pattern. However, in the Mediterranean basin, the chance of effective accumulation and maintenance in time of deadwood is largely a consequence of the abandonment of forest management, as deadwood removal was one the most common silvicultural practices. It has been therefore the cessation of logging the major driving factor allowing deadwood accumulation and diversification within Mediterranean forests. The amount of deadwood in a forest is influenced by many interacting factors; among them, the dominant tree species, aboveground living biomass, and the time elapsed since the last harvest seem to play a major role [2,12].

Deadwood plays an essential role in the functioning of forest ecosystems and the maintenance of biodiversity. It is at the base of the detrital food chain and the key site of many biological activities, allowing the differentiation of many potentially-available ecological niches [13]. Deadwood is the main and/or exclusive habitat for a broad range of living organisms that, in turn, may feed other important wild animal species, so that all ecosystem food chains are enriched. The more diversified and abundant the deadwood is, the higher the biodiversity of organisms that a forest stand can potentially host. Both the quantitative and qualitative aspects are of great importance for the conservation of a wide array of different taxonomic groups. Apart from a quantitative assessment, deadwood has to be characterised in qualitative terms, including the type, size and decay class of dead elements, the tree species, the cause of death of the plant, and spatialdistribution [14]. Standing dead trees are used by some birds as nesting sites, while cavities are directly made by woodpeckers such as *Dendrocopos major* Linnaeus 1758 for shelter and safe places to feed on larvae of saproxylic insects [15]. Lying deadwood is used as habitat by reptiles, amphibians, and small mammals, as a food source or shelter. Insects are particularly linked to deadwood, as they are, together with soil fungi, the main organisms responsible for the decomposition and mineralisation of organic matter on the forest floor, thus allowing the recirculation of mineral nutrients fixed in woody biomass [16]. In Europe, forest management generally exerted a negative effect on biodiversity of substrate-dependent taxonomic groups, such as mosses, lichens, and saproxylic beetles [17]. Even many bird species have been strongly affected by the alteration and the simplification of European forest ecosystems [18,19].

Last but not least, deadwood plays a key role in nutrient recycling, the enhancement of C stock, the improvement of soil fertility, protection, and biological activity [20], with clear positive effects on slope stability [21]. For these reasons and many others, deadwood has been included among the Pan-European indicators of Sustainable Forest Management (SFM), particularly under Criterion 4, concerning "*Maintenance, conservation and appropriate enhancement of biological diversity in* *forest ecosystems*" [2,22], and it is widely considered a key parameter to assess and monitor the overall status of a forest ecosystem, as it is strongly affected by forest ageing and human disturbance, as well as living organisms [10,23].

Despite the increasing attention of research to this topic, both at the national and European level, in the Mediterranean knowledge is still limited about the amount and the variation over time of deadwood within many forest types, especially those dominated by thermophilic *Quercus* spp. [24,25]. In contrast, extensive research and much more detailed information is available for the forests and tree species of Central and Northern Europe. Making up for this lack of knowledge is crucial if we are to ensure long-term protection of these valuable ecosystems, as has been emphasised in a recent report on the state of European forests [22], and further confirmed by Paletto et al. [25], who stated: "*Deadwood has not been extensively investigated in Mediterranean-oak ecosystems*...".

We aimed at filling this gap of knowledge about deadwood and old-growth forests in Mediterranean ecosystems. It is the necessary starting point if we are to ensure effective protection to so important forest stands. Our research has been carried out within a Mediterranean *Quercus pubescens* Willd s.l. (Downy oak) stand, suspected to hold old-growth traits [26]. Our main hypothesis is that aboveground traits of this forest, both living and dead, fall within the values reported in literature concerning Mediterranean old-growth forests. We hypothesize that deadwood amount could approach 30 m^3 ha^{-1}, the most commonly considered threshold, that deadwood lying on the ground is prevalent, and that dead to live wood ratio could be close to 10%, the reference value for Mediterranean old-growth forests. We have also assessed the contribution of coarse deadwood (diameter > 30 cm) to standing, lying and total deadwood for its recognized role to enhance biological diversity of forests. If these hypotheses were confirmed, similar forest stands could be relatively more frequent than expected in the Mediterranean. At last, the current research should be used for future development of specific guidelines for the identification and management of old-growth Mediterranean forests.

2. Materials and Methods

2.1. Study Area and Vegetation

The study area is located on the island of Sicily (Italy), within the Nature Reserve "*Bosco della Ficuzza, Rocca Busambra, Bosco del Cappelliere e Gorgo del Drago*", as classified according to the regional legislation about protected areas. It consists of a large protected area, covering more than 7000 ha. The experimental 1-ha plot is located within zone A of the Reserve, in Contrada Fanuso (Municipality of Godrano, Palermo Province; Figure 1). The plot lies at a mean altitude of 1000 m and falls within the mesomediterranean upper sub-humid bioclimatic belt [27]. Mean annual precipitation is 752 mm while mean annual temperature is 15.1 °C, with a mean maximum temperature of 20.5 °C and a mean minimum temperature of 9.8 °C [28]. Soils at the base of the northern slopes of Rocca Busambra are predominantly sandy loam; they are deep and developed enough to be well-suited to supporting tree vegetation [29].

The considerable climatic and altitude variability that characterises the whole Nature Reserve has played a major role in driving biodiversity patterns and structural traits of local forest ecosystems. The reserve consists of a mosaic of natural, seminatural, and synanthropic vegetation [30], due to the interpolation of afforestation interventions into the natural evolution of the forest, including continuous grazing, which is still one of the most critical aspects of forest management in Sicily and has to be particularly considered.

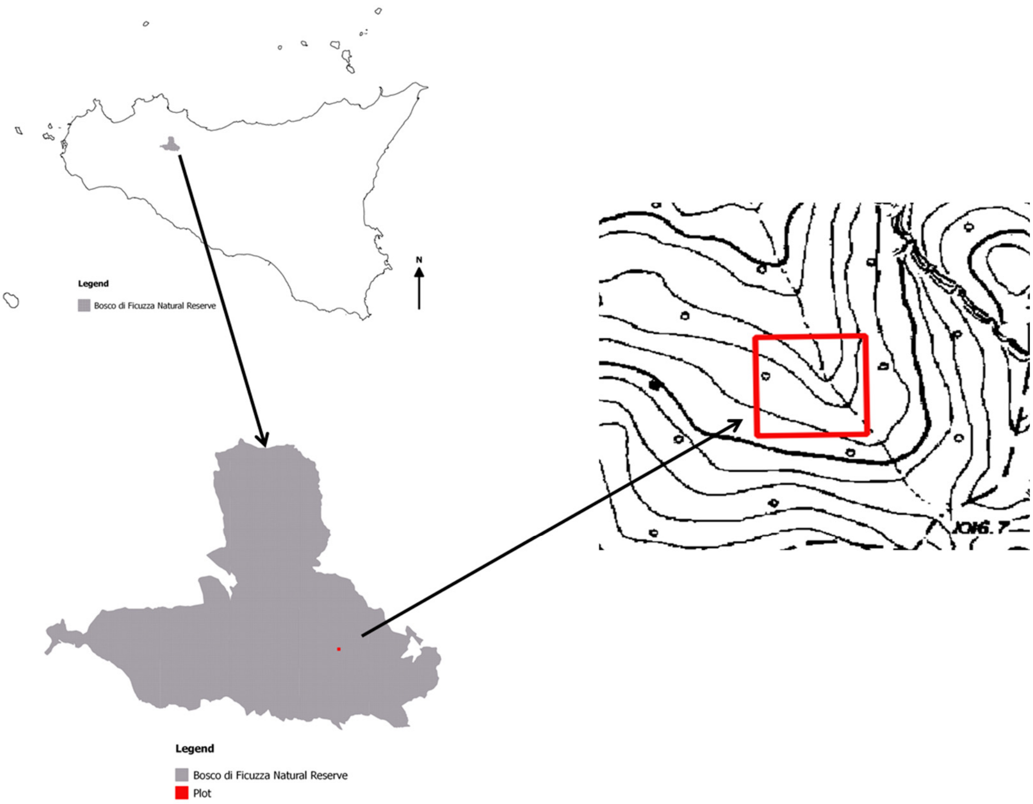

Figure 1. Location of the Reserve within which the experimental plot was established. On the right a detail of the Technical Map of Sicily in 1:10,000 scale.

The natural woody vegetation mainly consists of thermo-mesophilous deciduous oak forests, including species such as *Quercus pubescens* and *Quercus gussonei* (Borzi) Brullo [31,32] together with the evergreen thermophilous oaks *Quercus ilex* L. (Holm oak) and *Quercus suber* L. [33]. Other tree species present are *Fraxinus ornus* L. (Manna ash), *Acer campestre* L. (Field maple), *Sorbus torminalis* L. Crantz, *Mespilus germanica* L. (Common medlar), and *Malus sylvestris* Mill. [30], including two recently found and uncommon woody species such as *Ostrya carpinifolia* Scop. and *Quercus trojana* Webb subsp. *trojana* [34,35].

Our survey was carried out within a forest stand dominated by *Quercus pubescens*, *Quercus ilex*, and *Acer campestre*. The dominant trees generally reach full canopy cover but in some areas the forest cover is interrupted by several fallen trees. The presence of such gaps is a notable element for the structural diversification of the forest, which enhances its biological diversity and presents a chance for heliophilous tree species to regenerate [36]. The choice of this area to characterise deadwood was made taking into account the main attributes that are generally considered to be the most useful proxy indicators of old-growth conditions: the occurrence of large and/or old trees, a complex forest structure, a significant amount of deadwood either standing or lying on the ground, a very high overall level of biodiversity, and the absence of recent human disturbance especially in terms of harvest or wildfire [26].

2.2. Sampling Protocol

The sampling design used in the experimental area to detect forest attributes followed the standard procedure adopted under the project PRIN 2007, "*Innovative methods for the identification, characterization and management of old-growth forests in the Mediterranean environment*" (e.g., [37]). The experimental area constitutes a square plot of 100 × 100 m (total area of about 1 hectare), with sides perpendicularly oriented to the cardinal directions N–S and E–W (Figure 2).

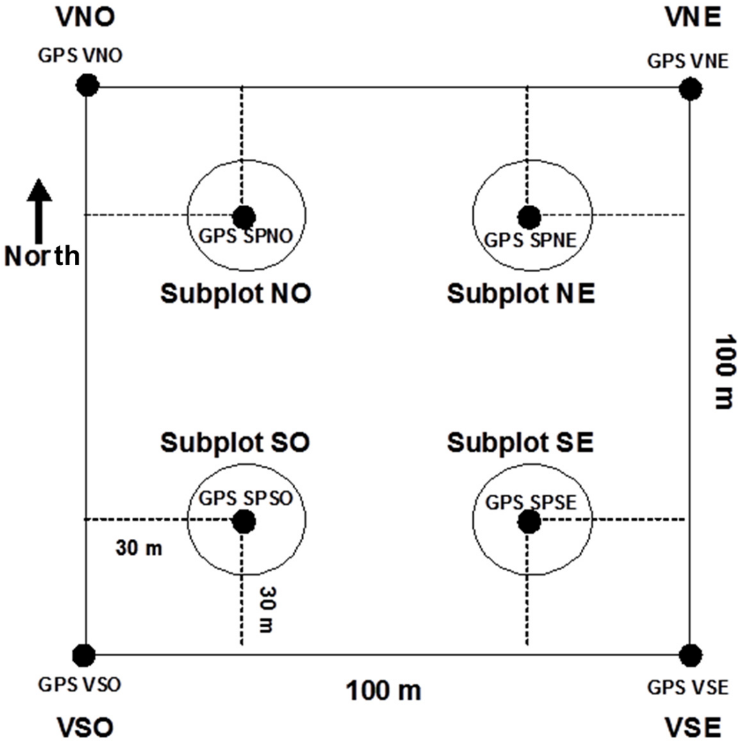

Figure 2. Sampling design of the experimental plot on the Nature Reserve.

After the preliminary phase of inspections and identification on the map, the experimental area needed to be materialised in the field. After the first vertex had been established, its coordinates were used to automatically get the coordinates of the other three vertices. Then, all the vertices were retraced in the field by means of GPS (Trimble® GeoXH 2008, Sunnyvale, CA, USA), and were materialised with *Castanea sativa* Mill. (Sweet chestnut) poles sprayed with red varnish to facilitate the subsequent recognition and monitoring activities. For each vertex, the geographical coordinates within the cartographic reference system UTM, zone 33N, datum WGS84, were acquired. To acquire positions with GPS, at least 200 positions per each point were taken. In addition to the four vertices (VNO, VNE, VSE and VSO), eight other points, including four intermediate with respect to the vertices (CF1, CF2, CF3 and CF4), were also identified and acquired. The other four georeferenced points (SPSE, SPNE, SPNO and SPSO), located at a distance of 30 m from each plot border, represented the centre of just as many circular sampling subplots (total area of about 150 m^2), where surveys on regeneration by tree species, shrub layer, and litter were also performed. For regeneration layer, seedlings and saplings of tree species with a height between 25 cm and 130 cm were considered, regardless of their DBH. In the shrub layer, we measured all the shrub individuals with a height $\geq$ 25 cm. Due to the peculiar morphological characteristics of the area (nature of the terrain, slope variations, etc.), the total plot area was 10,211 m^2—slightly higher than expected—and the shape slightly irregular rather than being a perfect circle.

2.3. Field Surveys

Deadwood was investigated before living biomass to avoid alteration of its size, shape, and natural distribution on the forest floor. However, it seems appropriate to first describe the parameters concerning the living biomass. Both living and dead elements were described in the field with following information: species identity (where possible for dead elements), diameter at breast height (DBH) (all the living trees with DBH > 2.5 cm and all the dead elements with DBH $\geq$ 5 cm), height or length (m), and topographic position in terms of distance to the nearest reference point (m) and azimuth (degrees). Although the legacy of past coppicing is still apparent, in most cases old stumps are no longer recognisable and coppice shoots are old enough to develop as single trees. Hence, individuals originating from seeds and shoots were analysed together, except where otherwise stated.

The distances and orientations were measured from the woody fragment of larger size (D_{max}) in the case of lying deadwood or from the base of the tree with respect to the other inventory categories. Then, the basal area (m^2 ha^{-1}), average diameter (D_m, calculated with the following formula: $\sqrt{\frac{4 \times G}{\pi \times N}}$), average height ($H_m$) (i.e., the height of the tree with average basal area as observed on a hypsometric curve, that put in relation DBH and height for each tree species), and volume (m^3 ha^{-1}) were calculated. The distribution diameter of each inventory category was also performed.

Total deadwood was distinguished into standing deadwood, including standing dead trees (SDT), snags (SN), stumps (ST) and dead coppice shoots on living stumps (DCS), and lying deadwood, including lying dead trees or logs (LDT) and coarse woody debris (CWD) (Table 1). SDT and SN were dead trees higher than 130 cm with an intact or broken stem, respectively, whereas ST were lower than 130 cm. We also assessed the contribution of coarse deadwood, including all dead elements larger than 30 cm, due to its recognised ecological importance for biological diversity [38].

Table 1. Size thresholds and collected attributes of the deadwood categories.

Deadwood Category	Size Threshold (cm)	Collected Attribute
Standing Deadwood		
Standing Dead Trees (SDT)	$H \geq 130$	$D_{1.30m}$
Snags (SN)	$H \geq 130$	D_{base}, D_{top}
Dead Coppice Shoots (DCS)	$H \geq 100$	$D_{1.30m}$
Stumps (ST)	$H < 130$	D_{base}, D_{top}, origin (natural or artificial)
Lying Deadwood		
Lying Dead Trees (LDT)	$L \geq 130$	$D_{1.30m}$, length
Coarse Woody Debris (CWD)	$L \geq 100$	D_{min}, D_{max}

H: height; L: length. Orientation and position were considered for all the elements.

The volume of snags, coarse woody debris, and stumps was calculated with the following formula (adopted in the protocol of the PRIN 2007 project):

$$V = \pi \times h/3 \times [R^2 + r^2 + (R \times r)] \quad (1)$$

where V is the volume (m^3 ha^{-1}), h is the height/length (m), R is the major radius (m) and r is the minor radius (m).

The volume of whole trees, living or dead, was calculated using the double-entry tree volume tables as developed by Tabacchi et al. [39], and built within the National Inventory of Forests and Carbon Sinks [40]. For the other tree species, for which specific formulas have not developed yet, the formulas developed on *Ulmus minor* Mill. (Field elm) were considered. Decay stage was visually assessed for each dead element following the classification proposed by Hunter [41], which is based on wood surface aspect and bark structure as well as on the presence of evident wood alterations (e.g., wood cavities, hollows, broken branches, etc.) and microorganisms (e.g., fungal mycelium).

3. Results

3.1. Living Biomass (Dendrometric and Structure Data)

As regards the whole forest stand, living stem density reached 402.4 per hectare; total living volume, including coppice shoots, reached 363.8 m^3 ha^{-1}, whereas total basal area was 34.4 m^2 ha^{-1} (Table 2). Stand density of living and dead elements was 631.5 stems per hectare. Among living elements, 33.3 living stumps per hectare (a total of 96.9 living shoots, 2.9 shoot per stump) were also found, corresponding to about one quarter of the total stems, mostly belonging to *Quercus ilex* (47.5%) and *Acer campestre* (35.4%). Overall, living tree density was 338.7 per hectare. In terms of living stem density, the most common woody species was *Quercus pubescens* (44.3%), followed by *Quercus ilex* (28.2%), and *Acer campestre* (19.5%). Some *Castanea sativa* individuals also occurred (1.9%). Some other woody species of particular scientific and/or ecological interest were also present, such as *Pyrus pyraster* (L.) Burgsd. (European wild pear), *Crataegus monogyna* Jacq. (Common hawthorn), *Mespilus germanica*, *Malus sylvestris* (L.) Mill. (European wild apple), *Fraxinus ornus*, *Prunus spinosa* L. (Blackthorn), and *Ulmus minor*. All together they accounted for 6.1% of the total number of living stems, corresponding to less than 1% and 2% of volume and basal area, respectively. *Quercus pubescens* was by far the dominant tree species, both in terms of stem density, basal area, and volume, representing about 44%, and more than 80% and 70% of the whole stand values, respectively (Table 2). Accordingly, both mean diameter and height were also clearly higher in *Quercus pubescens* than in the other tree species, reaching, for instance, almost double values than *Quercus ilex* individuals. *Quercus ilex* stem density was higher than *Acer campestre*, but being that this species was represented by smaller individuals, it reached lower values of basal area and volume, with the latter being approximately half of the *Acer campestre* value. *Castanea sativa* individuals represented only about 3% of total volume and basal area.

Table 2. Density, diameter, height, volume and basal area of the woody species surveyed.

Species	Tree Density		Mean Diameter	Mean Height	Volume		Basal Area	
	N ha^{-1}	%	cm	m	m^3 ha^{-1}	%	m^2 ha^{-1}	%
Quercus pubescens	178.2	44.3	42.0 ± 13.1	19.9 ± 5.9	297.38	81.7	24.75	71.9
Quercus ilex	113.6	28.2	18.6 ± 7.8	10.2 ± 3.9	18.98	5.2	3.08	9.0
Acer campestre	78.3	19.5	28.0 ± 15.2	12.9 ± 4.2	35.07	9.6	4.84	14.1
Castanea sativa	7.8	1.9	43.3 ± 8.6	18.7 ± 5.1	10.59	2.9	1.19	3.5
Other woody species	24.5	6.1	15.0 ± 7.7	6.0 ± 2.2	1.79	0.5	0.54	1.6
Total	402.4				363.8		34.4	

Means are followed by ± standard deviation (St. Dev.)

Diameter frequency distribution of the forest stand fitted well with a fourth-degree polynomial distribution with a typical rotated-sigmoid shape (Figure 3). Both are considered characteristic trends of diameter distribution of mature or old-growth forests [42,43].

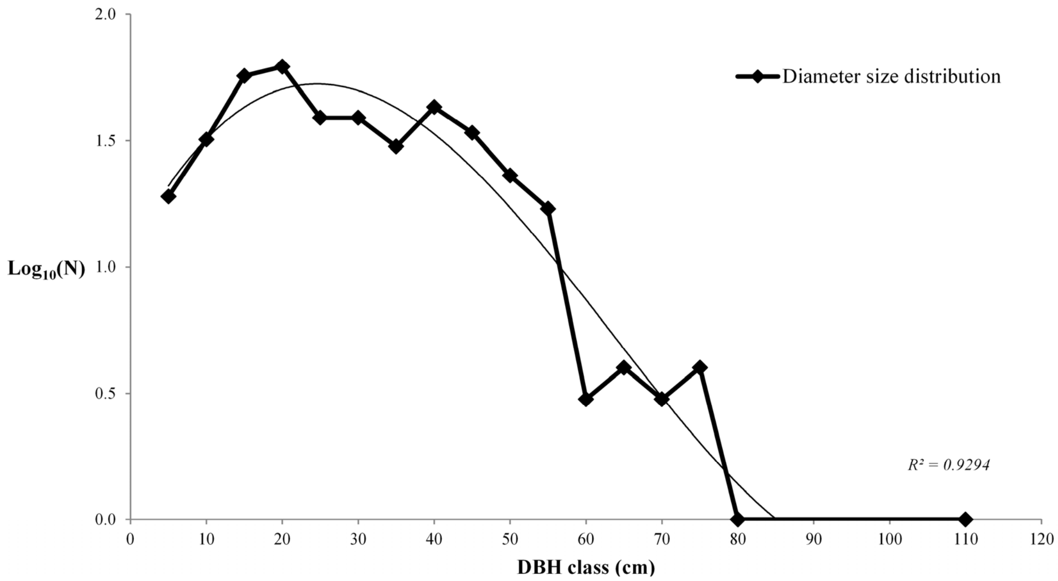

Figure 3. Diameter frequency distribution of all the living stems.

More than 50% of total volume and basal area was among 40 and 55 cm DBH classes (Figure 4). About 4% and 8% of volume and basal area, respectively, fell in the DBH classes lower than 20 cm. Interestingly, almost one quarter of the total volume fell within DBH classes higher than 60 cm, including the largest trees. Overall, volume was slightly shifted towards the highest DBH classes with respect to basal area, and vice versa.

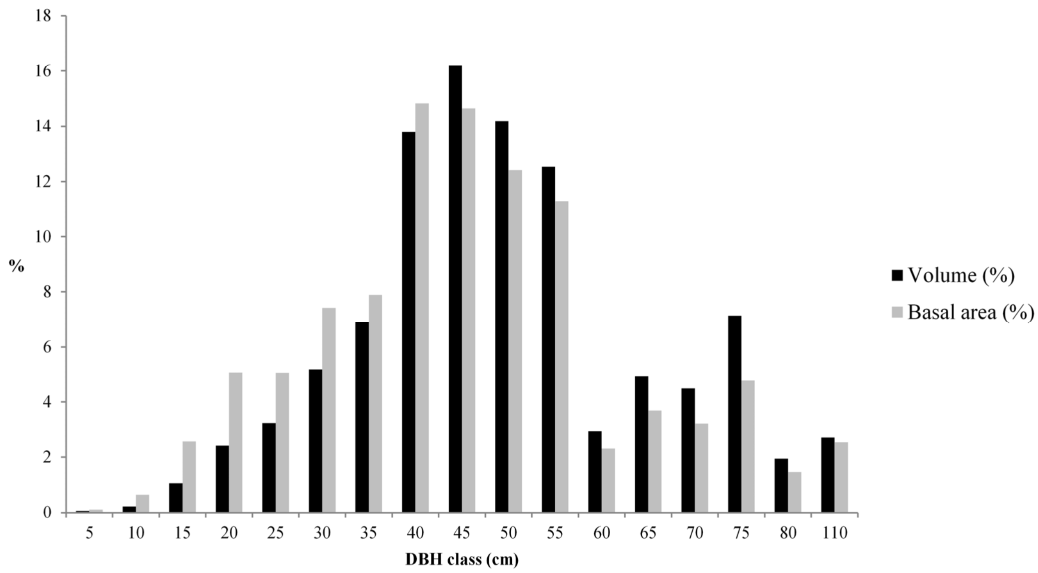

Figure 4. Volume and basal area percentage distribution in DBH classes of all the living stems.

Considerable differences in the relative contribution to volume and basal area of largest stems by each tree species were found. *Quercus pubescens* made a major contribution, whereas *Quercus ilex* played a quite minor role in that respect (Figure 5). Almost 80% and 50% of total *Quercus pubescens* volume came from stems with DBH higher than 40 cm, and higher than 50 cm, respectively. Also, more than 40% of *Quercus pubescens* and more than 50% of *Acer campestre* total volumes were represented by stem diameters larger than 50 cm.

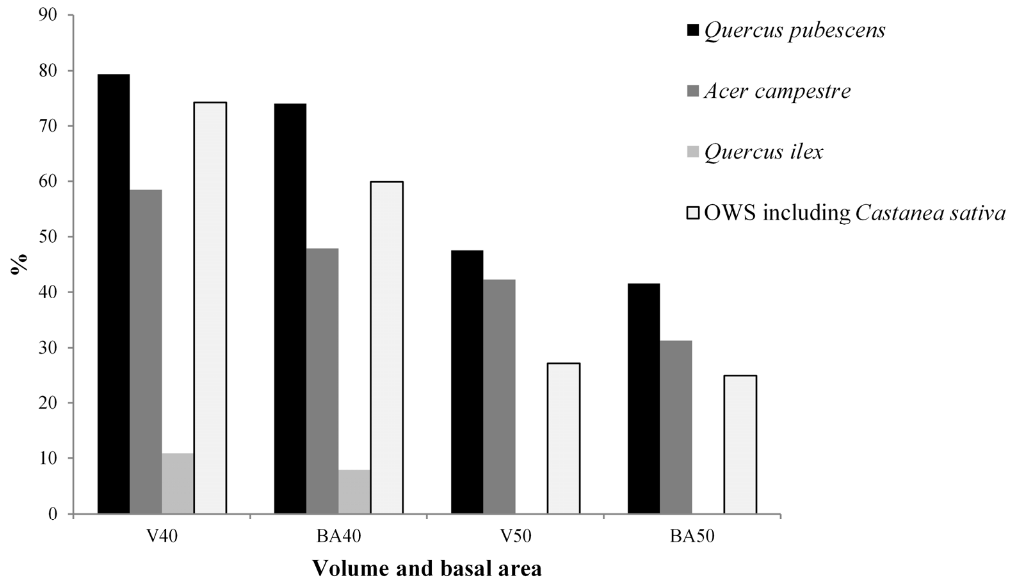

Figure 5. Percentage allocation (%) of volume (V) and basal area (BA) in the largest trees sorted by tree species. The numbers 40 and 50 after V and BA refer to stems with DBH equal to or larger than 40 and 50 cm, respectively.

The highest stem mortality was found in the 10 and 15 cm DBH classes (Figure 6). This parameter displayed fluctuating values among DBH classes, but mortality occurred only in the DBH classes lower than 50 cm. On average, stem mortality was about 8% of the total living stems.

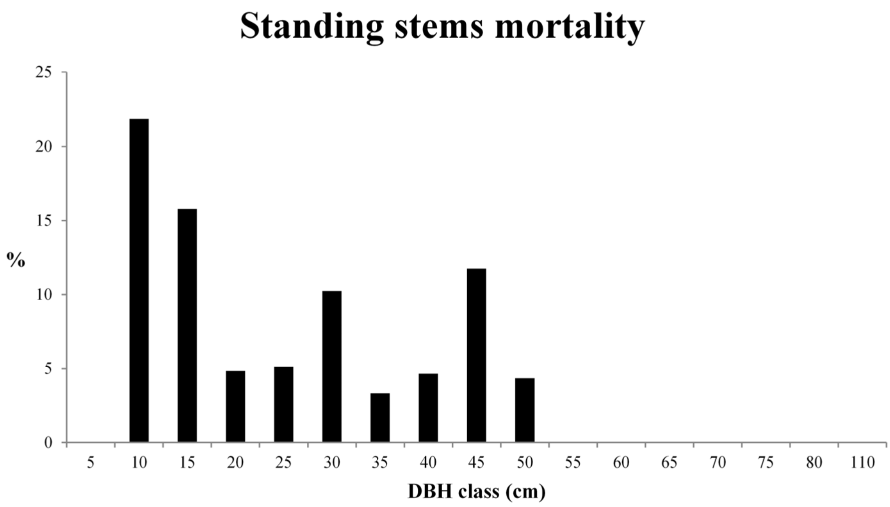

Figure 6. Stem mortality sorted by diameter class.

3.2. Deadwood Characterisation

Overall, total deadwood was equal to 32.9 $m^3\ ha^{-1}$ and was formed by some 229 elements per hectare (Table 3). As living volume is 363.9 $m^3\ ha^{-1}$, dead to live wood ratio is 9%. More than 80% of deadwood was lying on the ground, predominantly composed by CWD in terms of density and by LDT in terms of volume (Table 3).

Table 3. Total number and volume of deadwood categories.

Deadwood Category	Density		Volume	
	$N\ ha^{-1}$	%	$m^3\ ha^{-1}$	%
Standing deadwood				
Standing Dead Trees (SDT)	14.7	45.5 (6.4)	4.3	79.6 (13.1)
Snags (SN)	7.8	24.1 (3.4)	0.6	11.1 (1.8)
Dead Coppice Shoots (DCS)	3.9	12.1 (1.7)	0.3	5.6 (0.9)
Stumps (ST)	5.9	18.3 (2.6)	0.2	3.7 (0.6)
Total	32.3	100 (14.1)	5.4	100 (16.4)
Lying deadwood				
Lying Dead Trees (LDT)	66.6	33.8 (29.1)	22.4	81.5 (68.1)
Coarse Woody Debris (CWD)	130.2	66.2 (56.8)	5.1	18.5 (15.5)
Total	196.8	100 (85.9)	27.5	100 (83.6)
Total deadwood	229.1		32.9	

Within round brackets is the percentage with respect to total deadwood.

Standing deadwood, accounting for about 16% of total deadwood volume, was largely composed by SDT, approaching 80% of the volume. More than half of the SDT volume belonged to trees with a DBH larger than 40 cm. LDT represented the prevailing type of deadwood, accounting for just under 70% of the total deadwood volume (Figure 7). Slightly more than half of the LDT volume belonged to the medium diameter classes, ranging from 25 to 35 cm. However, about one-third of the volume was from dead trees larger than 40 cm, and more than 11% from lower diameter classes. Coarse deadwood volume was slightly more than half of the total deadwood volume, whereas large dead elements were about 10% of the total deadwood (Table 4). CWD was the dominant form of deadwood in the lowest diameter classes, and CWD and LDT were almost equally represented in the diameter class of

15 cm. Conversely, LDT were dominant in the larger diameter classes and represented the only type of deadwood for elements larger than 30 cm. Overall, LDT_{30} were dominant, whereas global SD_{30} was higher than 20% of the total coarse deadwood volume.

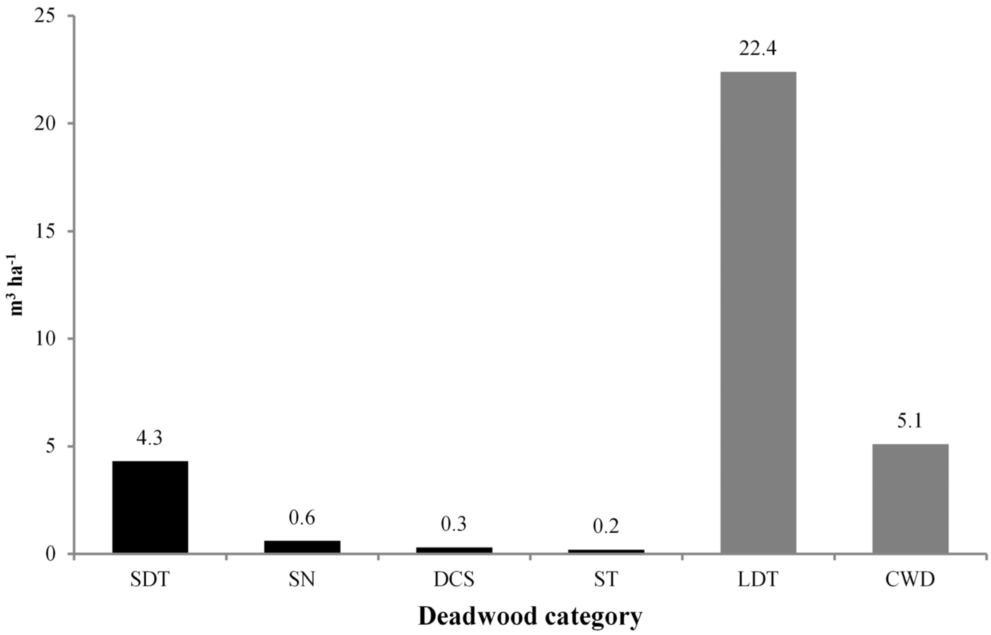

Figure 7. Relative contribution of each deadwood category to total deadwood volume (m^3 ha^{-1}).

Table 4. Total number and volume of deadwood categories of coarse deadwood (DBH ≥ 30 cm from Lombardi et al. [38]).

Deadwood Category	Density		Volume	
	N ha^{-1}	%	m^3 ha^{-1}	%
Standing deadwood				
Standing Dead Trees (SDT_{30})	3.9	26.7	3.2	18.4 # (74.4 §)
Snags (SN_{30})	2.0	25.0	0.5	2.9 # (83.3 §)
Dead Coppice Shoots (DCS_{30})	-	-	-	-
Stumps (ST_{30})	2.9	50.0	0.17	1.1 # (77.3 §)
Total	8.8	27.3	3.9	22.4 # (72.2 §)
Lying deadwood				
Lying Dead Trees (LDT_{30})	16.6	25.0	13.5	77.6 # (60.3)
Coarse Woody Debris (CWD_{30})	-	-	-	-
Total	16.6	8.5	13.5	100 (77.6)
Total coarse deadwood	25.4	11.1 *	17.4	52.9 *

#: with respect to total coarse deadwood; §: with respect to total deadwood volume per category; *: with respect to total deadwood.

Diameter frequency distribution of all dead elements of the forest stand, either standing or lying (Figure 8), fitted well with a fourth-degree polynomial distribution with a typical rotated-sigmoid shape.

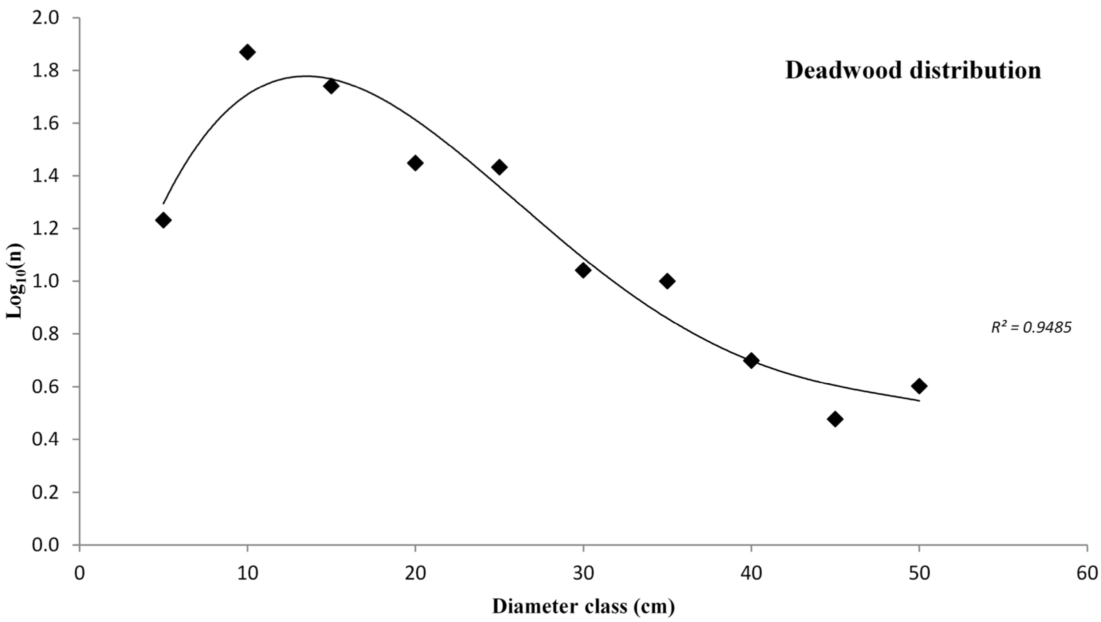

Figure 8. Total deadwood distribution according to mean diameter.

Deadwood was represented in all the diameter classes from 5 cm to 50 cm, but its volume was not equally distributed among them. Almost half of dead elements were found in the medium diameter classes, between 25 and 35 cm (Figure 9). Fine (DBH $\leq$ 20 cm) and coarse (DBH $\geq$ 40 cm) dead elements were also well-represented, accounting for about one quarter and more than one-third of the total deadwood volume, respectively.

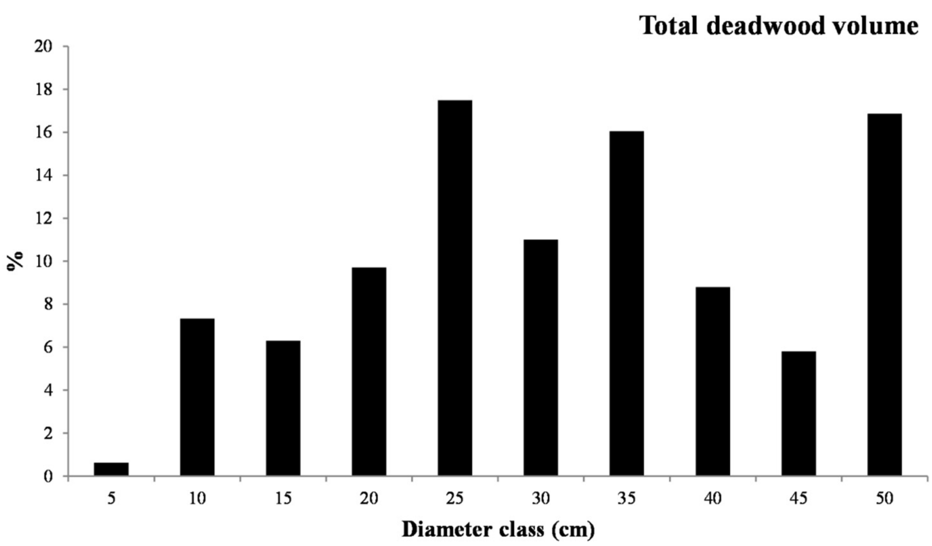

Figure 9. Total deadwood volume percentage distribution according to mean diameter.

Wood decay classes 3 and 4 had the largest share of both standing and lying deadwood (Figure 10). However, standing deadwood was more common than lying deadwood in the first two decay classes, whereas lying was prevalent in the highest three. It is worth highlighting that highly decayed dead elements had the largest share of total and lying deadwood volume.

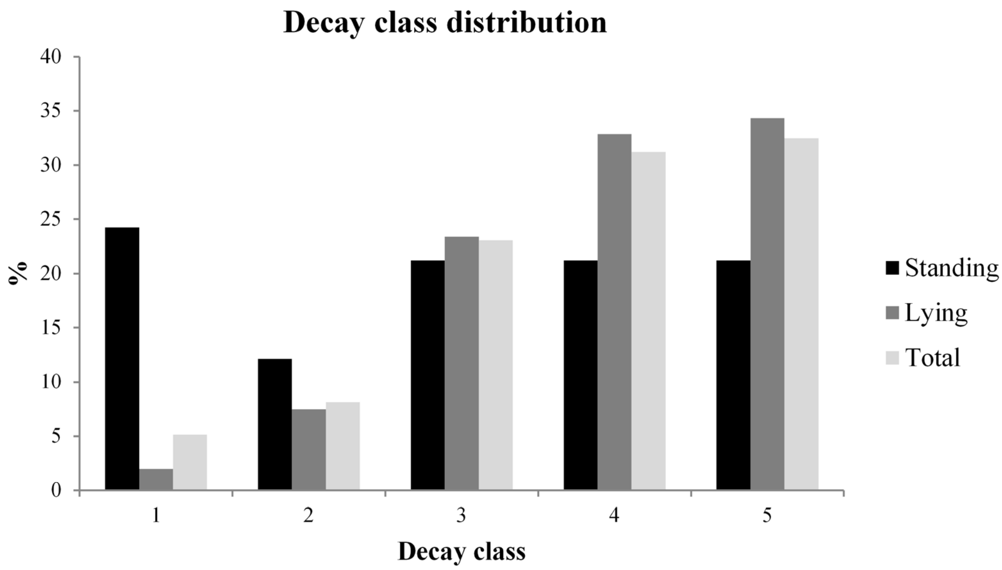

Figure 10. Wood decay classes percentage distribution.

4. Discussion

Forests possessing old-growth traits in the Mediterranean Basin are considered to be quite rare and localised, occurring only in restricted areas and under particular environmental and management conditions [44]. However, due to the lack of a shared definition, it is difficult to effectively assess how large is the area covered by such peculiar forest stands. Their expected limited extension is largely a consequence of the historical and widespread alteration processes on a large scale to which forest ecosystems of this biogeographical region have been subject for thousands of years [45,46]. However, it is also true that current knowledge, especially for some regions and forest types, is still quite limited and fragmented. This is the case of ageing or old-growth forests dominated by thermophilic oaks such as *Quercus ilex* and, above all, *Quercus pubescens*, to which only a handful of studies have been devoted [47,48]. It must be stressed that specific information on deadwood amount in mature and/or old-growth *Quercus pubescens* Mediterranean forests, to the best of our knowledge, is currently not available [49,50]; hence this could be the first experimental study carried out in such stands.

Our research allowed us to identify a Mediterranean *Quercus pubescens* stand (The Fanuso wood) showing a number of old-growth traits, both in living and dead aboveground biomass. In particular, deadwood displayed a number of features that are commonly associated with old-growth Mediterranean forest stands. Total deadwood amount, exceeding 30 m^3 ha^{-1}, is particularly relevant. It is higher than the most common threshold considered for the preservation of forest biodiversity, especially the survival of organisms exclusively linked to mature and with low human impact forest habitats [16], such as saproxylic beetles [51]. Such amount is also about 10 times higher than the average for *Quercus pubescens* and *Quercus petraea* (Matt.) Liebl. woods of Sicily [52], it is far higher than that of regularly managed forests, and it falls within the mean values found in unmanaged Mediterranean forests [25]. In 21 sites representative of different forest types of Molise region (Italy), deadwood amount ranged from 3.2 to 15.8 m^3 ha^{-1} in regularly managed forests, and from 5.8 to 56.3 m^3 ha^{-1} in forests withdrawn from regular management for about 50 years [53].

Compared to similar Mediterranean deciduous oak forests, deadwood amount is also notably higher than that of *Quercus petraea* (1–20 m^3 ha^{-1} in Bagnato et al. [54]), *Quercus frainetto* Ten. (9.3 m^3 ha^{-1} in Barreca et al. [55]), and *Quercus cerris* stands (15 m^3 ha^{-1} in Marchetti and Lombardi [11]). Conversely, it is within the observed range of another *Quercus cerris* stand in Tuscany, left unmanaged for about 50 years (22–40 m^3 ha^{-1} in Bertini et al. [24]). Compared to *Quercus ilex* forest stands, a deadwood amount higher than 30 m^3 ha^{-1} is very close to that recorded in the Gargano wood [49], and it is far higher than that recorded in similar stands in Tuscany, Sardinia, and Lazio

(Bertini and Fabbio in Bertini et al. [50]). However, *Quercus ilex* stands may reach much higher values, ranging from 44 to 46 m^3 ha^{-1} ([50,56], Bertini and Fabbio in Bertini et al. [50]), so that 45 m^3 ha^{-1} could be considered a benchmark for thermophilous Mediterranean old-growth forests. By contrast, it is currently quite difficult to define a similar threshold value for *Quercus pubescens* old-growth forests, due to the lack of reliable data. Italian *Fagus sylvatica* old-growth forests generally contain a higher deadwood amount than the Fanuso wood, but not in all cases [23,44]. Four of these forest stands have a lower amount, and about 60% of them show a much lower dead to live wood ratio.

An important feature is the relationship between standing and lying components of deadwood, which both play specific and different ecological roles [57]. In Mediterranean oak forests, subject to different forms of management, only 35–44% of the total deadwood volume is found lying on the forest floor [25,58]. As long as the abandonment of management proceeds, this share tends to progressively increase, until lying deadwood becomes prevalent. A similar trend has been observed both in mesic oaks [24,25] and *Fagus sylvatica* forests [12,59]. In Europe, this trend seems to be more pronounced in oaks rather than in *Fagus sylvatica* forests, where, on the contrary, this ratio tends to remain rather constant and lying deadwood always prevalent [60]. It is noteworthy that a multilayered 70-year-old *Quercus cerris* stand showed a similar value of lying deadwood (84.6%, [11]) compared to what was found in the present study (i.e., 83.6%). Furthermore, trees with the smallest diameters (DBH < 20 cm), are much more common on the ground than in the standing component (77% vs. 57%). On the contrary, trees with DBH > 40 cm are more represented in standing than in lying deadwood (18% vs. 3%, respectively), as expected in old-growth forests [1].

Compared to other similar Mediterranean forests, the Fanuso wood hosts a relatively high number of standing dead elements, more than 25 per hectare, of which slightly more than half are whole standing trees [5,25,58]. However, standing elements with a DBH > 30 cm are less than four, just close to the lower limit of 5–10 trees per hectare, considered as a reference value for the survival of most saproxylic organisms [61]. Large old trees are a major source of deadwood in the medium- to long-term, firstly as snags when standing and then as logs, thus strongly affecting deadwood dynamics, as well as its availability and supply over time in the ecosystem. This current lack of large standing trees is, however, reasonably expected to be filled in the next decades (i.e., 40–50 years). This should occur as consequence of the progressive natural death of large and old living trees, especially if some natural disturbance event will affect the forest stand. Conversely, a considerable number and volume of lying dead elements was observed, reaching more than 65 elements and more than 20 m^3 per hectare, respectively. The first one is higher than the lower limit proposed for deciduous British forests undisturbed by humans by at least 80 years [62]. The number and volume of dead stumps (0.2 m^3 ha^{-1}), both very low, indicate the lack of forest utilizations in a long time and they are in line with those of Mediterranean forests left to natural development or unmanaged for decades [49,58].

The distribution of deadwood volume into decay classes provides valuable information on the stage of development reached by the forest stand, and it allows to evaluate indirectly the time elapsed since the last timber harvesting or intense human pressure. In the investigated stand, the co-occurrence of all decay classes, and in particular of the most advanced stage, suggests the availability of many ecological niches and a certain degree of heterogeneity in deadwood. Several saproxylic beetle species are closely related to the more advanced stages of wood degradation [51] and a higher species richness is associated to large-diameter dead fragments, especially in an advanced stage of decay, with respect to smaller ones [63]. Large dead elements, or coarse woody debris, play a key role in the conservation of specific substrate-dependent living organisms and they are one of the more frequently lacking traits in the European forests, as a result of the widespread and intensive utilization to which traditionally-managed forest systems were subject. Accordingly, the saproxylic beetles closely linked to larger dead elements are among the species with a higher extinction risk within European forests [64].

We found decay classes 3 and 4 as dominant. In other unmanaged Mediterranean forests, a lower level of decomposition was detected, with decay classes 2 and 3 being prevalent [24,49,50]. In Mediterranean oak forests of the Basilicata region, previously managed and now left to natural development [25], the same predominance of classes 3 and 4 was found but they accounted for 39% of the total deadwood, while in the Fanuso wood they exceeded 60%. The stand has an average tree mortality of standing individuals of 8%, equal to that of Pomieri woods [54] and, close to the threshold of 10% identified as a reference value in temperate old-growth forests [1]. About 75% of the standing dead elements belonged to the diameter classes from 10 to 30 cm, while about 15% were individuals with a DBH > 40 cm. In other Mediterranean oak forests, mortality was almost exclusively concentrated in the diameter classes lower than 10 cm [49,54]. In the Fanuso wood, within the lowest diameter classes, ranging from 2.5 to 7.5 cm, dead trees are totally absent.

For what concerns living biomass traits, tree density was quite low, slightly higher than 400 stems per hectare. This value falls within the range of an ageing *Quercus petraea* stand [54] and, more importantly, it is very close to that reported in comparable Mediterranean *Quercus ilex* and *Quercus pubescens* forests occurring in Corsica [47] and Sardinia [65], respectively. This parameter is clearly linked to the average size of the plants constituting the dominant forest layer, that is particularly high. *Quercus pubescens* is the main tree element of the forest stand, having a mean DBH higher than 40 cm, a mean height close to 20 m, and a dominant height higher than 21 meters. A relict *Quercus pubescens* stand in Gennargentu (Sardinia, Italy) reached dominant heights ranging from 7 to 11 m [65]. Trees with DBH larger than 50 cm were 38.2 per hectare (87% of which were *Quercus pubescens* individuals) within the Fanuso wood, a value which is notably higher than the most frequently considered minimum threshold for European and Mediterranean forests, corresponding to at least 30 stems per hectare [38,66]. Such value exceeded the benchmark for temperate European old-growth forests [9], it is almost equal to that of other Mediterranean old-growth forests [66], and it is considerably higher than the average recorded in many forest reserves of France, including many oak species [67]. As expected, this value is far lower than the average recorded in Italian old-growth *Fagus sylvatica* forests, where more than 80 living trees per hectare with DBH larger than 50 cm are found [38]. However, it is noteworthy that a large proportion of the total living biomass and basal area is concentrated in the highest DBH classes, a typical trait of old-growth forests [1], as large living trees play a key role in the biological and structural diversity of forests. Many birds and insects strongly depend on the presence of a minimum number of large trees for their survival and/or reproduction. In the investigated stand, stems with DBH > 50 cm accounted for more than 40% and 35% of the total volume and basal area, respectively. Also, about 25% of the total volume is represented by individuals belonging to the DBH classes > 60 cm, a considerably high value in the context of Mediterranean forests [5]. According to Nilsson et al. [1], in temperate and boreal old-growth forests, trees with DBH > 40 cm should constitute most of the total volume and basal area of the stand. The Fanuso wood entirely falls within this threshold, as this group of trees accounted for more than 70% of total volume and more than 60% of basal area. The abundance of large trees translates into quite high values of volume and basal area. The total living volume, amounting to 363.9 m^3 ha^{-1}, is much higher than that of old-growth oak stands from different Italian regions [49,50,68], where it did not exceed 300 m^3 ha^{-1}. It is also higher than what was recorded in more mesic Mediterranean forests, characterised by *Quercus petraea* in Sicily [54] and by *Quercus cerris* L. (Turkey oak) in Tuscany [24], and in oak stands not managed in more than 170 years [56]. The total basal area, equal to 34.4 m^2 ha^{-1}, is almost equal to that of a *Quercus ilex* stand in Tuscany, withdrawn from forest utilization since about 50 years [68]. Some comparable forest stands exhibited higher values, even higher than 50 m^2 ha^{-1} [49,50]. However, a relict *Quercus pubescens* stand of Sardinia showed just half the basal area of the Fanuso wood, while having very similar values of tree density [65]. The frequency distribution of DBH classes is considered another important diagnostic feature to identify old-growth forests. The distribution of the investigated stand fits well to a polynomial fourth-degree curve and it shows a typical J-reversed shape on a semi-logarithmic scale, indicating a great contribution of large trees [42,43].

Woody species richness recorded in our experimental plot was high compared to other Mediterranean forests [5]. This result significantly enhances the ecological value and the conservation interest of the Fanuso wood, and it highlights the need to ensure adequate long-term protection.

Eleven different tree species were inventoried during field surveys and other important woody species, such as *Sorbus torminalis*, were present in the regeneration layer. Although they represent only a small share of the total living biomass, such species play an important ecological role, enriching the trophic chains and providing food to birdlife or small mammals, structurally and biologically diversifying the forest stand. Among them, species such as *Ulmus minor* and *Mespilus germanica* are considered of particular interest in Sicily [69]. Such a biological richness may be partly explained by the co-occurrence of two different Mediterranean oak forests, dominated by evergreen *Quercus ilex* and deciduous *Quercus pubescens*, and by the absence of forest management since about 50 years.

Deadwood may play an effective role for ecosystem functioning and for biodiversity conservation only if it represents a non-negligible share of the overall aboveground biomass. Thus, it is important to know the relationship between living and dead elements. Despite its high variability, the dead to live wood ratio tends to increase as soon as human pressure on the forest is reduced and it is therefore an important indicator of the maturation of a forest system under the prevailing drive of natural factors. For instance, in mature *Quercus cerris* stands left to natural development for about 50 years [24], a gradual increase of the dead to live wood ratio, reaching the critical threshold of 10% [59], was observed.

Based on the results of our field survey, we think that the Fanuso wood should be considered at least as a potentially old-growth Mediterranean forest stand. As far as deadwood traits are concerned, Lombardi et al. [59] have proposed to consider three main aspects for the identification of Mediterranean old-growth forests:

- Dead to live wood ratio should approach 10%;
- Lying deadwood should be prevalent;
- There should be a good diversification of deadwood both in terms of size and decay classes.

The Fanuso wood appears to meet all three criteria. To further corroborate our statement, comparing our field data with a recent review about old-growth temperate forests ([9]; Table 5), it can be observed that only the total amount of deadwood currently does not fall within the range of the considered values.

Table 5. Comparison between the mean values recorded in a recent review about old-growth temperate forests and the values of the investigated forest stand.

Parameter	Range [1]	The Fanuso Wood
Dead to live wood ratio (%)	9–89	**9**
Basal area (m^2 ha^{-1})	24–57	**34.4**
Stem density (N ha^{-1})	124–1835	**402.4**
Large living trees * (N ha^{-1})	36.5–122	**38.2**
Living aboveground biomass (m^3 ha^{-1})	255.5–510	**363.9**
Quadratic mean diameter (cm)	14.6–64.3	**33.0**
Coarse woody debris (m^3 ha^{-1})	45–469	32.9

[1]: Burrascano et al. [9]; *: with DBH > 50 cm. In bold the values falling within the range reported.

5. Conclusions

The near 50-year absence of regular forest utilizations has allowed the Fanuso wood to develop structures and traits typical of Mediterranean old-growth forests, especially concerning dead elements. Deadwood amount, exceeding the threshold of 30 m^3 ha^{-1}, is particularly high in the context of Mediterranean oak forests, and it is one of the highest values so far recorded in Sicilian forests. Also, dead to live wood ratio (9%) is close to the reference value for Mediterranean old-growth forests (10%) and lying deadwood was found to be prevalent. There is still a limited contribution of large standing dead trees, but they are expected to increase in the next 40–50 years. The total living volume is also quite high (>360 m^3 ha^{-1}) as it is higher than that of old-growth Italian oak stands. Furthermore, almost 25% of the total volume is found in DBH classes higher than 60 cm, including the largest trees.

However, it is quite difficult to predict how such a forest stand will really change over time. The main future drivers of stand dynamics, that will also affect deadwood components, are the protection regime to which this forest will be subject, and the occurrence of natural and/or anthropogenic disturbance events, including logging.

In the light of the results of our field survey, we recommend the adoption of specific protection measures and management options aimed at maintaining deadwood level, and favoring its increase, and addressed to preserve biodiversity and the peculiar traits of the investigated forest stand. To ensure the long-term preservation of this peculiar Mediterranean *Quercus pubescens* forest, the following management options are proposed:

- Completely fence off the study area, at least the inner and more preserved area, in order to protect it from livestock grazing, enhancing the chance of seedling establishment by native tree species and also reducing soil erosion processes. Such a restriction measure appears to be urgently needed because abusive grazing still occurs in the Nature Reserve [70];
- Preserve the remnant nuclei of other woody species, different from the dominant tree species, which significantly contribute to the biological and structural diversification of the forest stand;
- Deepen the overall knowledge of the forest ecosystem, including ad hoc investigations of all the biological communities (animals, plants, insects, and fungi) and their competitive and symbiotic relationships, including the role of seed dispersers, mycorrhizae, phytopathogens, etc. [71];
- Establish a permanent monitoring area in which to assess the natural dynamics of deadwood and woody vegetation in a Mediterranean forest stand left unmanaged for about 50 years. It could be known, for instance, the average annual accumulation rate of deadwood [60], the average time needed for the transition from standing to lying on the ground deadwood [72], or the mean degradation time of *Quercus* spp. wood in similar Mediterranean ecological contexts [73].

The increased and deepened knowledge about Mediterranean old-growth oak forests should help develop specific guidelines regarding the identification and characterisation of such forest ecosystems, which have particular ecological and conservation value. This paper provides a small contribution to that desirable goal.

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