FABIO LOMBARDI (*) (°) - GHERARDO CHIRICI (*) - MARCO MARCHETTI (*)
ROBERTO TOGNETTI (*) - BRUNO LASSERRE (*) - PIERMARIA CORONA (**)
ANNA BARBATI (**) - BARBARA FERRARI (**) - SILVIA DI PAOLO (**)
DIEGO GIULIARELLI (**) - FRANCO MASON (***)
FRANCESCO IOVINO (****) - ANTONINO NICOLACI (****)
LIVIO BIANCHI (*****) - ALBERTO MALTONI (*****)
DAVIDE TRAVAGLINI (*****)

DEADWOOD IN FOREST STANDS CLOSE TO OLD-GROWTHNESS UNDER MEDITERRANEAN CONDITIONS IN THE ITALIAN PENINSULA

Considering that indicators of old-growth features can vary across the European ecoregions, this paper provides some results to identify the distinctive traits of old-growth forests in the Mediterranean ecoregion. Deadwood occurrence as indicator of naturalness is investigated in some remote forest areas that have developed in absence of anthropogenic disturbance over the past few decades. Eleven study sites across the Italian peninsula were selected and records of deadwood were carried out in 1-ha size plots. Deadwood volume, deadwood types and decay stages were inventoried in the selected sites. The amounts of deadwood indicate a large variability among the investigated forest stands: the total volume ranged between 2 and 143 m^3ha^{-1}, with an average of 60 m^3ha^{-1}. Lying deadwood is the most abundant component of deadwood in the investigated forests, due to the natural mortality occurring in the stands in relation to the processes established in the last decades. On the contrary, stumps are the less represented type of deadwood in almost all the study areas. All the decay classes are present in each study site. The amount of deadwood in Southern Europe, even if lower than that reported for North and Central European countries, could have a different meaning due to the faster decay occurring in Mediterranean forest ecosystems. For this reason, old-growth features and the characteristics of each indicator should be framed and referred to well-defined climatic and

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(*) Dipartimento di Scienze e Tecnologie per l'Ambiente ed il Territorio, Università degli Studi del Molise; c.da Fonte Lappone, 86090 Pesche (IS), Italy.
(**) Dipartimento di Scienze dell'Ambiente Forestale e delle sue Risorse, Università degli Studi della Tuscia; via San Camillo de Lellis, 01100 Viterbo, Italy.
(***) Centro Nazionale per lo Studio e la Conservazione della Biodiversità Forestale "Bosco della Fontana" - Corpo Forestale dello Stato - Verona; strada Mantova 29, 46045 Marmirolo (MN), Italy.
(****) Dipartimento di Difesa del Suolo Vincenzo Marone, Università della Calabria; via P. Bucci ed. 41B, 87036 Arcavacata di Rende (CS), Italy.
(*****) Dipartimento Economia, Ingegneria, Scienze e Tecnologie Agrarie e Forestali, Università degli Studi di Firenze; via S. Bonaventura 13, 50145 Firenze, Italy.
(°) Corresponding Author; fabio.lombardi@unimol.it

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biogeographic contexts. Distinctively, under the conditions here investigated, three main deadwood features prove to characterize forest stands close to old-growthness: a ratio of dead to living wood not lower than 10%; lying deadwood much more abundant than the standing one; large range of deadwood size and decay classes across all the deadwood components.

Key words: unharvested Mediterranean forests; sustainable forest management; forest inventory; Italy.
Parole chiave: foreste mediterranee non gestite; inventari forestali; gestione forestale sostenibile; Italia.

1. INTRODUCTION

In ecological studies, the occurrence of persistent woodlands represents an unique chance: the absence of silvicultural activities for decades lets forest dynamics to take successional pathways mainly driven by site potential and natural disturbances. Under these conditions, forests can develop diversified stand structures and biodiversity may increase over the time, slowly approaching the level of a native forest (FRELICH and REICH, 2003; SPIES, 2004). These circumstances rarely occur in Mediterranean environments, and particularly in the Italian peninsula, where forestland has been affected by human activities since long through wood and non-wood good harvesting (MOTTA and EDOUARD, 2005).

In Italy, forests have been exploited since Roman time and no intact primeval stands occur in the country (MOTTA, 2002). Moreover, in recent times, wood harvesting practices have routinely removed trees before they reach large sizes. Wood residues and lying coarse woody debris have been frequently removed and used as fuelwood by local populations. In the fear of the spread of diseases and insect damages, diseased, senescent, unwanted and deformed trees are frequently removed (PIUSSI, 1983). As a result, Italian forests are extremely poor in deadwood, with an average of 8.8 m^3ha^{-1} estimated by the last National Forest Inventory (INFC, 2005).

In the last decades silvicultural activities were reduced, especially in less accessible mountain forests: as a result, many forests have developed more natural processes over the past few decades, even if their composition and structure still reflect past human activity (MOTTA *et al.*, 2006; BURRASCANO *et al.*, 2008). These forests could be defined as persistent woodlands (MARCHETTI *et al.*, 2010). The characterization and conservation of old-growth forests and persistent woodlands are key issues for nature conservation. The study of these forest stands may give precious indications on forests natural dynamics (MASON, 2004) and their bio-geo-chemical cycles (LUYSSAERT *et al.*, 2008).

The study of old-growth forests is fundamental for the effective conservation measures and for the implementation of ecological networks. However, there are many ways for a forest to grow old, and that it is probably a futile task to aim at providing a unique standard definition of old-growth forests and persistent woodlands (WIRTH *et al.*, 2009).

For this reason, in literature, a general and unambiguous definition of old-growth forests has not been reached (SPIES, 2004): such definition should be supported by indicators that can be easily used for the identification of old-growth conditions, also in terms of structural and functional complexity (PETERKEN, 1996). A typical criterion to identify old-growth conditions is the presence of large amounts of standing and downed deadwood in all stages of decay, considering that large standing dead trees and woody detritus on the forest floor are indirect evidence of canopy mortality and gap phase dynamics (SPETICH *et al.*, 1999; JONSSON, 2000; SIITONEN *et al.*, 2000; PEDLAR *et al.*, 2002; FORESTBIOTA, 2004; WIRTH *et al.,* 2009).

Deadwood always occurs in natural conditions, considering that recurring natural disturbances continuously replenish and create new deadwood (HANSEN *et al.*, 1991). It plays significant roles in several ecological processes: it creates the basis for cycling of photosynthetic energy, carbon, and nutrients stored in woody material; it contributes to soil formation and development and has functions such as erosion control (HARMON *et al.*, 1986; HYVÖNEN and ÅGREN, 2001). Deadwood is also a major component of ecosystem carbon storage and cycling (JANISCH and HARMON, 2002; CORNWELL *et al.*, 2009). Currently, the importance of deadwood is emphasized for its function in the maintenance of biodiversity (BRADSHAW *et al.*, 2009; BRASSARD and CHEN, 2008; BOBIEC *et al.*, 2005), providing habitats for a plenty of organisms (MASON, 2003). Saproxylic species, notably, are associated to deadwood habitats and include vertebrates (VAILLANCOURT *et al.*, 2008; ECKE *et al.,* 2001), invertebrates (MASON *et al.* 2002; VANDERWEL *et al.*, 2006), fungi (RENVALL, 2003; SIITONEN, 2001), lichens and bryophytes (CRITES and DALE, 1998), as well as vascular plants. Important deadwood microhabitats for biodiversity conservation are those found on live, senescent trees, such as dendrothelmic cavities, sap runs, and loose bark (MASON, 2003; WINTER and MOLLER, 2008; MICHEL and WINTER, 2009); unfortunately, these are among the most complicated microhabitats to quantify in that they are difficult to find, and future research should focus on this aspect.

Unexpected changes in deadwood and stand dynamics can arise from changes in the disturbance regimes. It is evident that climatic warming may alter the frequency and severity of episodic tree mortality events, including those caused by prolonged and high-severity insect outbreaks (SOJA *et al.*, 2007; GRAY, 2008).

In Europe, many studies were conducted on old-growth forests (WIRTH *et al.*, 2009), focusing on forest structure and composition (e.g. KUULUVAINEN *et al.*, 1998; EMBORG *et al.*, 2000; TABAKU, 2000), dynamics and natural regeneration (e.g. KORPEL, 1982; KOOP and HILGEN, 1987; BJÖRKMAN and BRADSHAW, 1996; LINDNER *et al.,* 1997; LINDER, 1998; BOBIEC *et al.*, 2000; DIACI *et al.*, 2003; NAGEL *et al.*, 2006), age structure (e.g. ROZAS, 2003) and deadwood occurrence (e.g. JONSSON, 2000; SIITONEN *et al.*, 2000; SANIGA and SCHUTZ, 2002). Research attention has been mainly directed towards boreal and temperate old-growth forests, where several remnants of "virgin" forests have been protected in forest reserves since a long time and were less influenced by human activities (CHRISTENSEN *et al.*, 2005).

In the Mediterranean region, deadwood studies are much more scarce because forests have been heavily exploited since ancient times. For these reasons, in the Mediterranean contest, old-growth forests are very rare and usually are found only inside strict forest reserves (PACI and SALBITANO, 1998) or in remote and impervious mountain areas (MOTTA and EDOUARD, 2005; PIOVESAN *et al.*, 2005; MOTTA *et al.*, 2006). The isolation of these forests has left few stands relatively undisturbed by human activities, in contrast to neighboring less protected forest systems. These areas offer an opportunity to examine deadwood accumulation within a minimally disturbed Mediterranean mountainous zone, where the stand dynamics will be comparatively more similar to a primary forest, with successional stages reaching high levels of naturalness (LOMBARDI *et al.,* 2008a).

The definition of old-growth must be supported by indicators that can be easily used for the identification of old-growth tracts in different forests types, considering that they can vary across the European ecoregions. The major limitation of structural indicators is that they have been developed to characterize old-growth phases in a very limited set of forest types (SPIES, 2004); particularly, BERGERON and HARPER (2009) demonstrate the limited validity of typical old-growth indicators using a number of boreal types as examples.

In order to characterize the level of naturalness and the role of deadwood for identifying old-growthness under Mediterranean conditions, eleven study sites, located in undisturbed forest stands, were selected across the Italian peninsula on the basis of literature references (Figure 1). A survey of deadwood occurrence on a 1-ha sample plot for each site was carried out. The characterization of study areas in terms of deadwood volume, types and decay stages are here presented.

Figure 1 – Location of the study sites. Numbers refer to the first column of Table 1.

2. Material and methods

2.1. Study sites

Forest type, altitude and climatic data of the study sites are reported in Table 1. The stage of development varies locally but all the sites have not been logged since decades. Two different developmental stages were distinguished: "large-sized tree" (stands with dbh_{100}, i.e. mean diameter at breast height of the hundred largest trees per hectare, ≥ 50 cm) and "middle-sized tree" ($20 \leq dbh_{100} < 50$ cm). A description of each study area is reported below, referring to the characteristics of the area and not only to the 1ha plot surveyed (numbers refers to the map in Figure 1 and to the *Id* column in Table 1).

1) "*Cozzo Ferriero*" site is located nearby the village of Rotonda (PZ), in the Pollino National Park. The study area is west facing, located on a plateau defining the watershed between Basilicata and Calabria districts. Bedrock consists of Cretaceous limestone where dolomitic limestone is prevalent, with moderately deep greensands and clay soils that can be

Table 1 – Main characteristics of the study sites.
(*) 1: Apennine-Corsican montane beech forest; 2: Mediterranean and Anatolian black pine forest; 3: Mediterranean and Anatolian fir forest (EEA, 2006).
(**) LTT: large-sized treed stand ($dbh_{100} > 50$ cm); MTT: middle-sized treed stand (dbh_{100} = 20-50 cm).

Id	*Site*	*Forest type (*)*	*Altitude (m a.s.l.)*	*Mean annual T (°C)*	*Mean annual P (mm)*	*Plot area (ha)*	*Years since last harvesting*	*Development stage (**)*
1	Cozzo Ferriero	1	1700-1750	7.3	1350	0.16	80	MTT
2	Fosso Cecita	2	1140-1200	9.9	1180	0.45	110	MTT
3	Monte Sacro	1	1330-1550	7.1	1600	0.20	60	MTT
4	Val Cervara	1	1730-1830	7.2	1211	0.97	no reference	LTT
5	Abeti Soprani	3	1250-1450	8.4	1124	1.00	30	MTT
6	Collemelluccio	3	900-1000	9.2	960	0.99	50	MTT
7	Monte di Mezzo	1	950-1150	8.6	1022	0.98	55	MTT
8	Monti Cimini	1	925-1053	14.3	1300	1.00	61	MTT
9	Fonte Novello	1	1340	10.0	1071	1.00	310	LTT
10	Sasso Fratino	1	950-1050	9.0	1689	0.92	51	LTT
11	Gargano Pavari	1	720-800	11.6	1041	1.00	56	MTT

referred to the Typic Hapludolls (REGIONE BASILICATA, 2004). The forest is an almost pure *Fagus sylvatica* high forest, with presence of *Acer pseudoplatanus* in the more humid microsites.

2) The Mediterranean and Anatolian black pine forest of "*Fosso Cecita*" is managed by the Italian State Forest Corp, located in the Sila National Park, nearby the village of Longobucco (CS). The study site is south-southwest facing, characterized by metamorphic and igneous rocks, with acid moderately deep soils (ARSSA, 2003). The forest is dominated by *Pinus laricio*, with presence of *Quercus cerris*. The actual forest structure is clearly influenced by the past human activities that delayed the natural evolution of pine forest towards more complex structures (IOVINO and MENGUZZATO, 1996).
3) "*Monte Sacro*" is located in the Cilento and Vallo di Diano National Park, in the municipality of Novi Velia (SA), Campania District. The study site is south-west facing and characterized by Cretacic limestone, with greensands and clay deep soils (ISPRA, 2008). The selected stand is a pure *Fagus sylvatica* high forest, unharvested for more than one century due to its difficult accessibility.
4) The forest of "*Val Cervara*" is located nearby the village of Villavallelonga "AQ", within the Abruzzo, Lazio and Molise National Park. The forest is located in an east- west oriented amphitheatre shaped valley, with Cretaceous limestone bedrock and soils that can be referred to the brown group. The upper part of the valley, where the surveyed area is located, escaped logging because of its difficult access. Summer grazing

in higher elevation pastures may have been for centuries the main disturbance in this site. The forest is an almost pure *Fagus sylvatica* high forest.

5) The "*Abeti Soprani*" site is located near Pescopennataro, a small village close to Isernia (Molise districts), 160 km east of Rome. In the study area, the slope is north facing and the pedology is dominated by miocenic-clay soils and cretacic white limestone. Rendzina soils are also locally prevalent. The forest is a relict stand dominated by *Abies alba*, typical of the fir forests currently widespread in the Mediterranean and Anatolian regions. Its structure and composition were frequent in the past throughout the Apennines (CIANCIO *et al.*, 1985). The forest is an almost pure *Abies alba* stand, sometimes mixed with *Fagus sylvatica* and *Quercus cerris*. Other species, such as *Acer pseudoplatanus*, *Acer campestre*, *Acer obtusatum*, *Tilia platyphyllos and Taxus baccata* occur.
6) "*Collemeluccio*" is located close to Pescolanciano, a small village in the Isernia province. The site is part of the MAB UNESCO Reserve of "Collemeluccio-Montedimezzo", a forest area unharvested since 1960. The slope is south-west facing and the geology is characterized by the presence of a single Miocene formation, constituted by micaceous sandstones, shaly clays and marly limestones. The forest, similarly to "*Abeti Soprani*" site, is a relict stand of the last post-glacial period. The forest is dominated by *Abies alba*, mixed with *Quercus cerris*, *Fagus sylvatica*, *Carpinus betulus* and *Ilex aquifolium*.
7) The European beech site of "*Montedimezzo*" is located close to Vastogirardi, a small village in the Isernia province. The site is part of the MAB UNESCO Reserve of "Collemeluccio-Montedimezzo", a forest area that has been unharvested since 1950. The slope is north facing, and the geology is dominated by Cretacic limestone, with greensands and clay soils prevalent.
   The forest is a *Fagus sylvatica* stand associated with *Quercus cerris* and mixed with other species (e.g. *Acer pseudoplatanus*, *Acer obtusatum*, *Taxus baccata*, *Tilia platyphyllos*). Even if *Quercus cerris* is quite dominant in the selected site, the vegetation unit is the *Polistycho aculeati-Fagetum sylvaticae aceretosum pseudoplatani* (CARRANZA *et al.*, 2006).
8) The study area of "*Monti Cimini*" is a beech forest of nearly 60 ha, growing on Cimini mountains, an isolated relief of volcanic origin located in Central Italy (Viterbo province, 100 km north from Rome). The site has a temperate oceanic semicontinental bioclimate and a very fertile soil with a mull horizon. Maples (*Acer pseudoplatanus* and *Acer obtusatum*) and chestnut (*Castanea sativa*) are additional tree species. The beech forest has been unharvested for the past sixty years.

9) The "*Fonte Novello*" site is located in Venacquaro valley, in the Gran Sasso - Laga National Park (Teramo province). The study area is north facing and the soils are classified as Lithic Rendolls, derived from alteration of the calcareous rock. The area of the Gran Sasso massif has a temperate continental climate. The vegetation of the Venacquaro Valley is dominated by beech forests. The study area was not cut during the last centuries due to legal debates concerning the position of the administrative boundaries between Pietracamela and Fano Adriano municipalities.
10) *"Sasso Fratino"* is located in Emilia-Romagna Region (Forlì province) within the Foreste Casentinesi, Monte Falterona and Campigna National Park. It is a Strict Nature Reserve established in 1959 and has an area of 764 ha. The forest stand where the study area was placed was been left to natural evolution for more than seventy years. The mountain side has an east aspect and the terrain is slightly leaning (30%). *Fagus sylvatica* is the prevailing tree species in the upper storey with an average dominant height of about 40 m. Small groups (12-15 m tall) and singles trees (2-5 m tall) of *Abies alba* locally occur (BIANCHI *et al*., 2009).
11) The site of "*Gargano - Pavari*" is located in Puglia Region (Foggia province), within the "Foresta Umbra" of Gargano National Park. It is part of an old forest research network established in 1952 by the Experimental Station of Silviculture of the former Italian Ministry of Agriculture (PAVARI and MORANDINI, unpublished data) and this forest is nowadays a Strict Nature Reserve (5,35 ha) unharvested since 1954. The site is north facing and the geology is dominated by Cretacic limestone, with greensands and clay soils prevalent. The forest is an almost pure *Fagus sylvatica* stand, with *Ilex aquifolium* in the understorey (GUIDI and MANETTI, 1999).

2.2. Survey protocol

Fieldwork was carried out in 2009. In each study site, deadwood was assessed within one plot by a standard protocol. In eight sites, a square plot around 1-ha wide was established. In three sites, the size of the plot was reduced to 0.16-0.45 ha because of the very steep slopes (Table 1). The coordinates of the plots corners were acquired by submetric precision GPS averaging at least 200 positions, then the plot area was computed with a GIS. The surveyed deadwood components and attributes are detailed in Table 2.

Standing dead trees, downed dead trees, snags and stumps were measured when more than half base of their trunk lied within the plot. Coarse woody pieces were measured when more than half base of their thicker end lied within the plot. A threshold height of 1.3 m was used to

Table 2 – Deadwood components surveyed in the study sites (Dbh: diameter at breast height; H: height; L: length; D_{min}: minimum diameter; D_{max}: maximum diameter; D_{base}: diameter at the base of the trunk; D_{top}: diameter at the top of the trunk; Origin: natural or artificial).

Deadwood component	*Dimensional thresholds*	*Assessed attributes*
Standing dead trees	Dbh ≥ 5 cm; H ≥ 130 cm	Species, dbh, H, crown height, crown projection on soil, decay class, position
Snags	Dbh ≥ 5 cm; H ≥ 130 cm	Species, D_{base}, D_{top}, height, decay class, position
Downed dead trees	Dbh ≥ 5 cm; H ≥ 130 cm	Species, dbh, L, crown insertion distance, decay class, position, stem direction
Coarse woody debris	D_{min} ≥ 5 cm; L ≥ 100 cm	Species, D_{min}, D_{max}, L, decay class, position, stem direction
Stumps	D_{top} ≥ 5 cm; H < 130 cm	Species, D_{base}, D_{top}, height, decay class, origin, position

distinguish stumps (less than 1.3 m) from snags (higher than 1.3 m). The position of each deadwood piece was obtained by measuring horizontal distances and azimuth from GPS points. The volume of standing and downed dead trees was computed by double-entry volume equations (CASTELLANI *et al.*, 1984). The volume of snags, stumps and coarse lying deadwood was computed by equation [1]:

$$V = \pi * h/3 * [(D/2)^2 + (d/2)^2 + (D/2)*(d/2)] \quad [1]$$

where: V = volume (m^3); h = height or length (m); D = maximum diameter (m); d = minimum diameter (m).

Decay level classification of each deadwood piece was carried out visually by the system proposed by HUNTER (1990). Such classification system is based on decay levels with a five-grade scale, in which morphological features of deadwood, presence of bark, integrity of wood structure, and wood color are considered. Considering how the stage of decay could vary in different parts of the deadwood components, when more than one class of decay was present on the same sample, with the most widespread decay class was assigned.

3. RESULTS

3.1. Deadwood volume

Deadwood volume shows a large variability among the study sites (Table 3), ranging between 2 m^3ha^{-1} in "*Fosso Cecita*" forest and 143 m^3ha^{-1} in "*Val Cervara*" forest. In "*Abeti Soprani*", "*Fonte Novello*" and "*Gargano Pavari*" sites a volume of around 90 m^3ha^{-1} occurred. On average, 60 m^3ha^{-1} of deadwood was found in the study sites.

Table 3 – Living wood volume and deadwood volume among the study sites. The average estimates by the National Forest Inventory (www.sian.it/inventarioforestale/jsp/home.jsp) for the corresponding forest type and administrative region are reported in the brackets.

Id	*Site*	*Living wood volume* *(m^3ha^{-1})*	*Deadwood volume* *(m^3ha^{-1})*
1	Cozzo Ferriero (PZ)	1383.3 (271.5)	71.3 (2.3)
2	Fosso Cecita (CS)	583.9 (322.7)	2.0 (10.2)
3	Monte Sacro (SA)	469.3 (294.3)	70.7 (2.8)
4	Val Cervara (AQ)	363.6 (230.9)	143.0 (5.2)
5	Abeti Soprani (IS)	569.8 (260.8)	95.6 (3.9)
6	Collemelluccio (IS)	557.8 (260.8)	17.4 (3.9)
7	Monte di Mezzo (IS)	702.5 (264.4)	26.5 (5.6)
8	Monti Cimini (VT)	783.8 (247.3)	32.3 (3.5)
9	Fonte Novello (TE)	1030.3 (230.9)	88.9 (5.2)
10	Sasso Fratino (FC)	1189.1 (210.9)	65.3 (8.3)
11	Gargano Pavari (FG)	666.3 (285.7)	89.5 (5.5)

In order to make the data comparable across the investigated areas, the proportion of deadwood volume with respect to living volume is reported on Figure 2. "*Val Cervara*" forest is characterized by a large relative amount of deadwood (39% of living wood volume), while all the other sites show a deadwood proportion less than 10%, with the exception of "*Abeti Soprani*", "*Monte Sacro*" and "*Gargano Pavari*" sites, where the proportion is about 15%.

3.2. Deadwood components

Figure 3 shows the proportion of deadwood volume by components in each study site.

Lying deadwood (i.e., downed dead trees plus coarse woody debris) is well represented in all the study sites: on average, 58% of total amount of deadwood; values greater than 70% were observed in "*Monte Sacro*" (75%), "*Val Cervara*" (85%), "*Monte di Mezzo*" (71%), "*Monti Cimini*" (86%) and "*Sasso Fratino*" (75%).

Standing deadwood (i.e., standing dead trees plus snags) is abundant in the two silver fir forests ("*Abeti Soprani*" and "*Collemeluccio*"), where more than 60% of the total volume of deadwood refers to this component.

Stumps are the less represented deadwood component in almost all the sites (less than 5%), with the exception of the black pine forest of "*Fosso Cecita*" and the silver fir forest of "*Abeti Soprani*", where more than 10% of the volume of deadwood refers to stumps. The very most part of stumps was of natural origin.

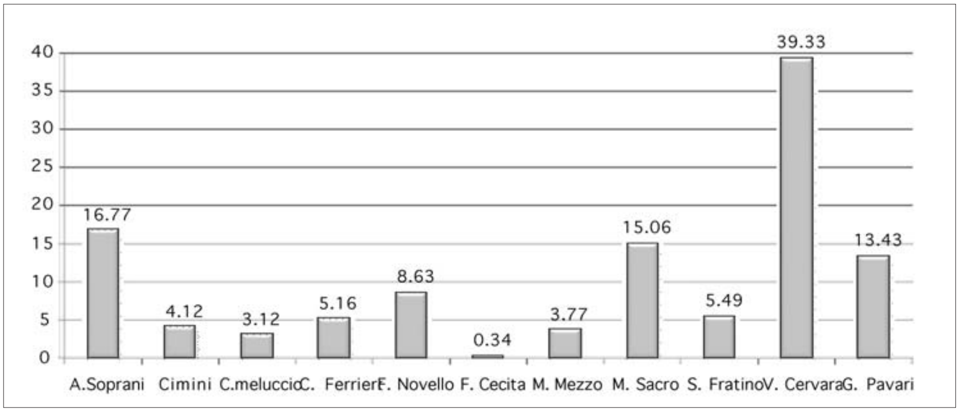

Figure 2 – Proportion of deadwood volume with respect to living wood volume in the study sites.

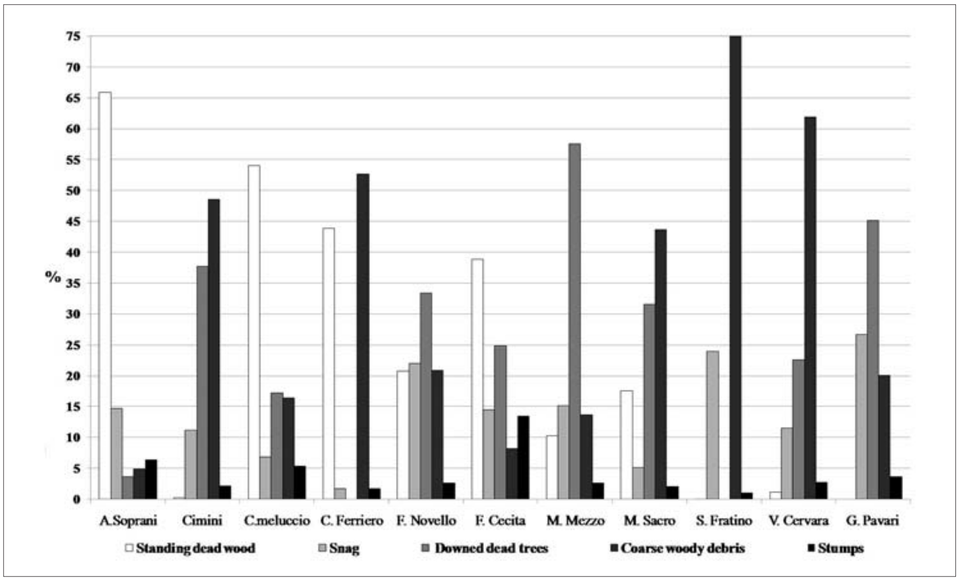

Figure 3 – Proportion of deadwood components in the study sites.

3.3. Deadwood decay-class distribution

The distribution of decay classes across deadwood components is reported in Table 4.

All the decay classes are present in each study site, with the exception of "*Fosso Cecita*" and "*Monti Cimini*" where only two classes occur. However, decay class 5 is poorly represented in all the sites.

Coarse woody debris is the component usually characterized by all the

Table 4 – Decay class (according to HUNTER, 1990) distribution across deadwood components in each study site. Values are reported as percentages with respect to the overall deadwood volume in each study site (class 1 = bark intact, presence of twigs <3 cm, texture intact, round shape, original color of wood, log elevated on support points; class 2 = bark intact, absence of twigs <3 cm, texture from intact to partly soft, round shape, original color of wood, log elevated but sagging slightly; class 3 = traces of bark, absence of twigs <3 cm, texture hard in large pieces, round shape, color of wood from original to faded, log is sagging near ground; class 4 = bark absent, absence of twigs <3 cm, texture small and soft in blocky pieces, shape from round to oval, color of wood from light to faded brown or yellow, all of log on ground; class 5 = bark absent, absence of twigs <3 cm, texture soft and powdery, oval shape, color of wood from faded to light yellow or grey, all of log on ground).

Id	*Site*	*Standing dead trees*					*Snag*					*Downed dead trees*					*Coarse woody debris*					*Stumps*				
		1	*2*	*3*	*4*	*5*	*1*	*2*	*3*	*4*	*5*	*1*	*2*	*3*	*4*	*5*	*1*	*2*	*3*	*4*	*5*	*1*	*2*	*3*	*4*	*5*
1	Cozzo Ferriero		32	12					2											30	22				1	1
2	Fosso Cecita		32	7				6	9					12	13				6	2				3	10	
3	Monte Sacro		15	2				4	1			16	5	8	3		11	11	8	12	2				1	1
4	Val Cervara	1					6	6				16	5	1		1	30	23	8				2	1		
5	Abeti Soprani	5	61				4	10				3					2	1		2		1	1	1	3	6
6	Collemelluccio	47	7				6	1				15	2				5	9	2	1				4	1	
7	Monte di Mezzo	7	3				11		3			30	26		2		1	4	8	1				3	1	
8	Monti Cimini	1						11				38					48					2				
9	Fonte Novello			10	6	5			11	6	5	8	17	3	5			4	11	6						3
10	Sasso Fratino							16	4	4								13	16	30	16					1
11	Gargano Pavari							5	22	1			5	38	4			3	11	7				3	1	

decay stages. Distinctively, in the sites of "*Collemeluccio*" and "*Monte Sacro*", logs are characterized by all the decay stages, while, on the contrary, in the "*Monti Cimini*" logs in decay class 1 represent almost the 50% of the total deadwood. Stumps are mainly in decay classes 3 and 5. Crosswise the studied forests, standing dead trees are more abundant in class 2, with the exception of "*Collemeluccio*" site, where standing dead trees in decay class 1 are the majority (47% of the total deadwood). Snags are mainly characterized by decay classes 2 and 3, while downed dead trees by classes 1 and 2.

4. Discussion

For generations, people have looked on deadwood as something to be removed from forests, as a necessary part of "*correct*" forest management (Kirby, 1992; Green and Peterken, 1997; WWF, 2004). For this reasons, the presence of large amounts of deadwood in forest ecosystems is often connected with low anthropic disturbances (Hansen *et al.*, 1991; Lombardi *et al.*, 2008a). Where human activities in forests are reduced, it is expected that naturalness progressively increases in time and space.

The main question addressed by this study is to use deadwood occurrence as indicator of naturalness in Mediterranean montane-forest, with a special focus on Apennines woodland that might evolve to old-growth traits in the next decades. Distinctively, the focal aim of this research is to contribute to fill the knowledge gap on deadwood components in old-growth forests in the Mediterranean forest areas, considering that most of the available information refers to Central and North European forests (Peterken, 1996; Spetich *et al.*, 1999; Siitonen *et al.*, 2000; Pedlar *et al.*, 2002; Wirth *et al.,* 2009).

Results obtained indicate a large variability in the amount and quality of deadwood occurred in the investigated sites (from less than 5 m^3ha^{-1} to almost 150 m^3ha^{-1}). Since the forest type was the same for the study areas, with the exception of three sites ("*Abeti Soprani*", "*Collemeluccio*" and "*Fosso Cecita*"), the successional stage of each stand, the forest history and exogenic disturbances can be considered as the main factors explaining the variation in deadwood.

We have found that deadwood volumes tend to be higher in forest stands characterized by steep slopes and located quite far from rural villages, with high living wood volume and in forests unharvested since a long time. The only exception is represented by the "*Abeti Soprani*" site, where the deadwood is abundant even if past logging activities are relatively recent (Table 1), probably due to the strong competition established in few decades among silver fir regeneration.

In literature, many studies reports very high amounts of deadwood occurring in European old-growth forests. For example, in Austria, MAYER and NEUMANN (1981) found 256 m^3ha^{-1} of deadwood in the *Rothwald* forest reserve. BRETZ GUBY and DOBBERTIN (1996) estimates that deadwood volumes are often in the range of 14-222 m^3ha^{-1} in natural and semi-natural temperate forests. In Slovenia, DEBELJAK (1999) observed more than 500 m^3ha^{-1} of deadwood in the *Pecka* old-growth forests. In Poland, JAWORSKI *et al*. (1999) found 300 m^3ha^{-1} of deadwood in the *Swietokrzyski* forest.

Data on deadwood occurrence across European beech forest reserves are provided by CHRISTENSEN *et al*. (2005). These authors found a mean value of deadwood volume equal to 130 m^3ha^{-1}, ranging from almost nothing to 550 m^3ha^{-1}. In addition, they observed that the total deadwood volume and dead to live wood ratio was highest for long-established montane reserves (220 m^3ha^{-1}, 37%), followed by long-established lowland/submontane reserves (131 m^3ha^{-1}, 30%), then by recently-established montane reserves (116 m^3ha^{-1}, 23%) and finally by recently-established lowland/submontane reserves (100 m^3ha^{-1}, 13%). Our results in Mediterranean montane beech forests seems to be similar to recently-established-reserves, with the exception of "*Val Cervara*" site, where deadwood volume and dead to live wood ratio are equal to 140 m^3ha^{-1} and 40%, respectively. "*Val Cervara*", which is the only examined site where past logging information are totally absent (PIOVESAN *et al*., 2005), it looks like a long-established reserve.

In Italy, results obtained in unharvested forests from decades (PACI and SALBITANO, 1998; PIOVESAN *et al*., 2005; MOTTA and EDOUARD, 2005; MOTTA *et al*., 2006; MARCHETTI *et al*., 2010), revealed a high variability of deadwood occurrence, with values similar to those here reported. On the contrary, the volume of deadwood generally occurring in Italian forests (mainly managed forest) is markedly lower: the National forest Inventory (INFC, 2005; PIGNATTI *et al*., 2009) estimates deadwood occurrence in Italy on average equal to 8.8 m^3ha^{-1}.

The ratio of dead to live wood varied greatly between the investigated sites. This contrasted with the ratios reported for several old-growth forests in North America and North Europe, which were more constant, for example at 23-28% (STEWART *et al*., 2003). This aspect could be explained considering that Mediterranean forests have a recent history of silvicultural management and wood harvesting, with deadwood input so far being limited and of small, rapidly-decaying material (e.g. MOUNTFORD, 2003). Also in this case, "*Val Cervara*" site represents an exception, where almost 40% ratio of dead to live wood was assessed.

A higher incidence of windstorm-damages, natural disturbances, such as wind and ice storms, at sites in North Europe (PETERKEN, 1996), might explain the higher amount and ratio of deadwood generally reported in literature with respect to those here assessed.

In addition, a Mediterranean-type climate probably influences decay rates, with its specific precipitation regime and temperature pattern, which are more erratic than those in northern Europe (FALINSKI, 1978). Consequently, decomposition might be generally more rapid due to higher average temperatures (HAHN and CHRISTENSEN, 2004). For examples, deadwood could decay five times faster in Mediterranean ecosystems than in that located at higher latitudes (LOMBARDI *et al.*, 2011, in press). For this reason, in Mediterranean forests, the smallest deadwood volumes do not necessarily indicate that these forests are disturbed or threatened more than temperate or boreal forests; on the contrary, old-growth features and the characteristics of each indicator should be framed and referred to a particular climatic and biogeographic context.

These results support the data from CHRISTENSEN *et al.* (2005), confirming that, also under Mediterranean conditions, lying deadwood constitutes, from a quantitative standpoint, the most significant deadwood component in the developmental phases close to old-growthness. Coarse woody debris and downed dead trees are the consequence of natural mortality occurring in the stands, due to the natural processes established in the studied forests in the last decades. Current mortality is mainly due to endogenous processes, such as competition. However, in some sites, like in "*Val Cervara*", "*Gargano Pavari*" and "*Fonte Novello*", exogenous factors, such as windthrow (GUIDI and MANETTI, 1999), can induce mortality with a subsequent gap formation (OLIVER and LARSON, 1996). The "*Abeti Soprani*" site represents an exception: standing dead trees, particularly of silver fir, are prevalent; this aspect might be related to the autoecology of silver fir (MAZZINI and PACI, 1991), considering its limited regeneration due to the high density of the canopy.

Stumps were found as a limited fraction of total deadwood volume. They often originated from natural tree fall, and had irregular surfaces in various states of decay, as also reported by LOMBARDI *et al.* (2008b).

All the decay stages were found in the study areas, but the most advanced stages (classes 4 and 5) were relatively unfrequent (Table 4). Similar results were found by CHRISTENSEN *et al.* (2003). The diversity in deadwood decay stages guarantee habitats for saproxylic fauna (SIITONEN, 2001; MASON *et al.*, 2002; MASON, 2003). On the other hand, the decay rate of deadwood depends on tree species and size. For instance, small dead stems generally decay faster than large ones, and cut stumps probably decay faster than snags (MACMILLAN, 1988; VANDERWEL *et al.*, 2006).

Even if the investigated forests were unmanaged for decades, signs of past removal of deadwood are sometimes still evident, and this is probably the reason why deadwood in most advanced decay classes is not frequent. However, decay classes may not reflect directly the time elapsed since dead, and deadwood in early stages of decay is not always constituted by wood recently dead (LOMBARDI *et al.*, 2008b).

The presence of different decay stages in the examined stands let us hypothesize that many saproxylics species could occur in these forests (SIITONEN, 2001; MASON *et al.*, 2002; MASON, 2003). Also the large range of diametrical distribution (FALINSKI,1978; BRETZ GUBY and DOBBERTIN, 1996; HOTTOLA *et al.*, 2009) across all the deadwood components and decay classes suggests that these traits could be functional to integrate and identify common indicators of old-growth conditions in Mediterranean forests.

The relative species composition of deadwood and growing stock volumes may help in understanding future dynamics of forest stands. For example, both the investigated sites of "*Abeti Soprani*" and "*Collemeluccio*" are silver fir dominated. In "*Abeti Soprani*", almost all deadwood volume (99.5%) is constituted by silver fir while the broadleaves component (mainly beech) is almost negligible. This suggest a probable diversification of the stand composition that is plausibly evolving in a mixed forest with silver fir and beech. In "*Collemeluccio*" the trend seems to be the opposite. The silver fir deadwood volume is just the 17.5% of the total and the other is from Turkey oak and beech: this means that the forest is probably evolving from a mixed forest to an almost pure silver fir stand.

5. CONCLUDING REMARKS

Considering that indicators of old-growth features can vary across the European ecoregions, this paper provides some results to identify the traits of potential old-growth forests under Mediterranean conditions.

The amounts of deadwood in Southern Europe, even if lower than that reported for North European countries (TRAVAGLINI *et al.*, 2007), could have a different meaning due to the faster wood decay occurring in Mediterranean forest ecosystems. Distinctively, under the conditions here investigated, three main deadwood features prove to characterize forest stands close to old-growthness: a ratio of dead to living wood not less than 10%; lying deadwood much more abundant than the standing one; large range of deadwood size and decay classes across all the deadwood components, which can guarantee microhabitats in time and space for the saproxylic fauna, fostering the stand naturalness.

One of the questions still open is how long does it takes the development of old-growth conditions from managed stands and, in addition, how long they could be in relation to forest types, climate and orographic traits. For example, NILSSON *et al.* (2002) showed that 100 years without management may be enough to hide the traces of past cutting, even though the structure of the forest may still be influenced by past disturbances.

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RIASSUNTO

Caratterizzazione del legno morto in popolamenti forestali prossimi alla vetustà in ambiente mediterraneo nella penisola italiana

Considerando quanto gli indicatori di vetustà possano variare in relazione alle regioni biogeografiche in Europa, in questo lavoro sono riportati alcuni risultati utili ad identificare le caratteristiche tipiche delle foreste vetuste in ambiente mediterraneo.

Sono stati selezionati alcuni popolamenti forestali che si sono evoluti, negli ultimi

decenni, in assenza di disturbi di origine antropica, valutando e caratterizzando quindi l'occorrenza del legno morto quale indicatore di naturalità. Tale approccio è stato applicato in undici siti localizzati lungo la penisola Italiana, dove è stato effettuato un censimento totale del legno morto su una superficie di un ettaro per sito, considerando i volumi occorrenti, le tipologie di necromassa presenti ed il grado di decomposizione.

I risultati hanno evidenziato come i quantitativi di legno morto differiscono sensibilmente tra i siti oggetto di studio: il volume di necromassa ottenuto varia tra 2 e 143 m^3ha^{-1}, con un valore medio di 60 m^3ha^{-1} .

Il legno morto a terra è la componente di necromassa più abbondante nei siti censiti, aspetto probabilmente indotto dall'elevata mortalità presente nei popolamenti in relazione ai processi evolutivi che si sono innescati negli ultimi decenni. La componente meno presente in quasi tutti i siti è invece quella rappresentata dalle ceppaie. Inoltre, sono state riscontrate tutte le classi di decomposizione.

I quantitativi di legno morto occorrenti nell'Europa meridionale, anche se inferiori rispetto a quelli riportati in letteratura per le foreste vetuste dell'Europa centrale e settentrionale, possono avere un significato differente in relazione al più elevato tasso di decomposizione rilevato nelle aree forestali con clima più tipicamente mediterraneo.

Per questo motivo, i parametri di vetustà e le caratteristiche di ogni singolo indicatore dovrebbero essere sempre riferiti e calati in un preciso contesto biogeografico e climatico. In particolare, nelle condizioni presenti nei siti oggetto del presente studio, sono tre i parametri relativi al legno morto che possono caratterizzare un popolamento prossimo alla vetustà: un rapporto tra volume del legno morto e la biomassa vivente non inferiore al 10%; presenza di abbondante legno morto a terra quale componente prevalente della necromassa; ampio range dimensionale tra tutte le componenti del legno morto, afferenti a numerosi stadi decompositivi.

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