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Ecological and Environmental Role of Deadwood in Managed and Unmanaged Forests

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1. Introduction

According to the Global Forest Resources Assessment 2005, forest deadwood encompasses all non-living woody biomass not contained in litter, either standing, lying on the ground, or in the soil (FAO, 2004). This definition considers the non-living biomass which remains in the forest regardless of the portion removed for production purposes (i.e. biomass-energy production). All different components of deadwood such as snags, standing dead trees (including high stumps), logs, lying dead trunks, fallen branches, fallen twigs and stumps are comprised in this account (Hagemann et al., 2009).

The role and importance of deadwood in forest ecosystem has been recognized by the international scientific community since the early 80's. The first scientific studies focused on the role of deadwood as a key factor for biodiversity conservation thanks to its ability in providing microhabitats for many species (Hunter, 1990; Raphael & White, 1984). Other issues were then discussed and analysed such as the protective role of coarse woody debris in stabilizing steep slopes and stream channels (Densmore et al., 2004), the contribution of deadwood to carbon, nitrogen and phosphorus cycles (Laiho & Prescott, 1999) and the influence on stand dynamics and regeneration of natural and semi-natural forests (Duvall & Grigal, 1999).

At the political level the recognition of its role was more recent, and raised in importance a decade after the scientific recognition. In particular, deadwood was included within the five carbon pool list (above-ground and below-ground biomass, litter, deadwood and soil) provided by Intergovernmental Panel on Climate Change (IPCC)-Good Practice Guidance for Land Use, Land Use Change and Forestry (IPCC-GPG) (2003). The change in C-stock in deadwood is required for reporting to the Kyoto Protocol (1997), Marrakesh Accords (7th Conference of the Parties, 2001) as well as to the United Nations Framework Convention on Climate Change (1992) (Tobin et al., 2007).

In Europe the importance of forest deadwood has been identified for the first time by the Ministerial Conference on the Protection of Forests in Europe (MCPFE) (2002) during the definitions of a set of Pan-European indicators for sustainable forest management. Deadwood is one of the indicators under the criterion "Maintenance, conservation and appropriate enhancement of biological diversity in forest ecosystems" and can be usefully considered in order to measure the level of biodiversity (Indicator 4.5: volume of standing deadwood and of lying dead-wood on forest and other wooded land classified by forest type).

The amount of deadwood in forest depends on a set of variables (Lombardi et al., 2008): forest type, stage of development, kind and frequency of natural or anthropogenic disturbances, local soil, local climatic characteristics and type of management. Regarding the latter, the qualitative and quantitative presence of deadwood in forest ecosystems is influenced by both forest system (either coppice or high forest) and the intensity of management (Green & Peterken, 1997; Fridman & Walheim, 2000). In managed forests, potential deadwood volumes are reduced by the extraction of timber and biomass. (Andersson & Hytteborn, 1991; Christensen et al., 2005; Green & Peterken 1997; Kirby et al., 1998; Verkerk et al., 2011)

Similarly, also the qualitative features are altered in comparison with those of natural dynamics. Furthermore, in traditional management practices, the accumulation of deadwood may not be desirable because of the increasing risk of either insect pests (such as bark beetles) or forest fires. In biodiversity oriented forest management one of the main purposes is to reduce the difference in deadwood volume between managed and unmanaged forests, while the close-to-nature forest management aims at maintaining a certain level of deadwood (Müller-Using & Bartsch, 2009).

For these reasons, in order to support technicians in developing suitable forest management plans and selecting the best silvicultural option, qualitative and quantitative data on deadwood should be collected. The silvicultural treatment can play a fairly significant role in balancing necromass volumes. Ad hoc solutions and well-designed planning of different silvicultural actions may increase, wherever is thought to be important, the presence of deadwood in the system. However, this achievement should be obtained without affecting costs and related management components (cost of harvesting, pest and fire hazard). With these premises, the authors provide a method to quantify stumps, standing and lying deadwood in forest with the aim at supporting multifunctional planning and management practices.

1.1 Functional and structural role of forest deadwood

Deadwood is an essential multifunctional and structural component of forest ecosystems (Harmon et al., 1986), being a key factor in the nutrient cycle (N, P, Ca and Mg) (Holub et al., 2001), a fundamental element in the ecological, geomorphological and soil hydrological processes (Bragg & Kershner, 1999), a relevant forest carbon pool (Krankina & Harmon, 1995), a potential resource for biomass-energy production and an important habitat for many species (mammals, birds, amphibians, insects, fungi, moss and lichen communities) (Nordén et al., 2004).

From the ecological and environmental point of view, deadwood increases the structural and biological diversity of the ecosystem since many organisms are adapted to utilise this resource. In particular, two types of organisms, which depend on its presence in the forest ecosystem, can be distinguished (Wolynski, 2001):

- directly dependent organisms: use the deadwood as substrate for germination, power source and nesting site;
- indirectly dependent organisms: find occasionally shelter in the coarse woody debris or in standing dead trees at either first or advanced level of decomposition.

Among the organisms of the first group, saproxylic insects occupy the most important position, being a major part of biodiversity in forest ecosystem (Schlaghamersky, 2003). The saproxylic organisms, either those classified as obligatory or facultative, depend, at some stage of its life cycle, on deadwood of senescent trees or fallen timber.

Considering the relationship between deadwood and bird species, a particularly important role is played by the "habitat trees". Normally, "habitat trees" are large size individuals, with a diameter greater than 30 cm, which contain hollows used by forest fauna (Humphrey et al., 2004). The bird species that are hosted by dead trees can be primary excavators of cavities (i.e. wood peckers) or secondary cavity nesters (Hagan & Grove, 1999). The importance of deadwood as an indicator of biodiversity is provided by the diameter of the tree which is closely related, in turn, to the size of the nest holes. Thus, some bird species, such as *Parus palustris, Parus caeruleus*, *Passer montanus*, and *Sitta europaea* require small cavities (hole diameter less than 5 cm), whereas some other species such as *Strix aluco*, *Upupa epops* (Longo, 2003), *Dryocopus martius*, *Picoides leucotos* and *Picoides major* need larger cavities (hole diameter more than 5 cm).

Moreover, several mammal species use hollows, cavities, roots, fallen branches and deadwood such as bear, lynx, fox, martens, squirrels, bats and many small rodents (Radu, 2006). In particular, many Mustelids use the deadwood as a shelter: the stone marten (*Martes foina*), marten (*Martes martes*) and wolverine (*Gulo gulo*). The tree holes are also used by common dormouse (*Muscardinus avellanarius*) and fat dormouse (*Myoxus glis*) as nesting site (Paolucci, 2003).

Deadwood plays also a role in soil stabilization, since the lying logs on the soil surface control the movements of soil and litter across the ground surface (Harmon et al., 1986). With special regard to the protective function of forests (indirect protection), the fallen logs may retain soil and water movement either on slopes or through the ground (Kraigher et al., 2002). Similarly, the fallen tree trunks provide good protection against avalanches and rockfalls (direct protection - Berretti et al., 2007). Considering the latter, lying deadwood has a positive effect in the short-medium term, whereas the decomposition of the wood can bring back the movement of stones accumulated over time.

Moreover, deadwood can act as a temporary storage site for carbon (C), because of its slow carbon dioxide release ability, thereby showing a potential in moderating global warming (Keller et al., 2004). Deadwood, as a carbon pool, can account for a substantial fraction of stored carbon, but only few studies have provided quantitative features and the length of the turnover in comparison with other C storing components of the forest ecosystem (above-ground biomass, below-ground biomass, litter and soil organic C) (Kueppers et al., 2004). The few efforts on this topic show that standing and lying deadwood accounts for about 6% of total carbon stock in forest (Ravindranath & Ostwald, 2008), but, according to a set of qualitative and quantitative features, it does so with a certain variability.

1.2 Quantitative and qualitative features of forest deadwood

The importance of deadwood in forest ecosystems can be analysed by considering some qualitative and quantitative features such as: volume and its distribution by component and size, origin (species or botanical group), decay class and spatial distribution.

The main variable to be considered, in order to evaluate and analyze the ecological importance in forests, and its influence on other ecosystem components, is volume. Volume was measured during the forest inventory by applying two main procedures (Morelli et al., 2006): the line transect method (Line Intersect Sampling - LIS), which was applied in order to quantify directly the amount of deadwood on the ground (Van Wagner, 1968) and the measurement of the metric attributes (length and diameter) in ordinary sample plots, in order to calculate both standing and lying deadwood volumes (Harmon & Sexton, 1996).

As indicated in literature, deadwood volumes vary greatly in forest: unmanaged natural or semi-natural forests show the highest values with more than 100 m^3 ha^{-1} (Green & Peterken, 1997), while intensively managed forests manifested the lowest outputs with 5-30 m^3 ha^{-1} (Kirby et al., 1998). This variability is influenced by the classification of components sizes as well as the diametric threshold used in the inventory and the different measurement methods. These data are confirmed by the results of the National Forest Inventories (NFIs). As explained in Table 1, the different management traditions existing in Europe have a direct consequence in the accumulation of deadwood. The highest values are recorded in central European forests (Austria, Germany and Switzerland), whereas the lowest values are found in France and Finland. In Italy the volume of all deadwood components (stump, standing and lying deadwood) amounts to 8.8 m^3 ha^{-1} (INFC, 2009).

At local level, different situations can be found since potential deadwood volumes are reduced in managed forests either by the extraction of timber and biomass (Verkerk et al., 2011) or by sanitation cuttings. Also the qualitative features are altered in comparison with those of natural dynamics (Hodge & Peterken, 1998). In the traditional forest management the presence of deadwood is considered negatively for several reasons. Historically, deadwood has been removed in order to decrease firewood risk as well as to protect timber from insect and fungal attacks (Radu, 2006). Nowadays, the newest paradigms in forest management have recognized the ecological role of deadwood and developed strategies to both maintain or increase the amount of deadwood in forest ecosystem (i.e. by increasing volume of lying deadwood in order to favour population of invertebrates).

Country	Volume (m^3 ha^{-1})	Note
Austria	13.9	NFI 2000-2002 Threshold considered 20 cm
Belgium	9.1	Standing and lying deadwood of Wallonia region
Finland	5.6	NFI 1996-2003. Threshold considered 10 cm
France	2.2	NFI 2002. Threshold considered 7.0 cm
Germany	11.5	NFI 2001-2002. Threshold considered 20 cm
Italy	8.8	NFI 2005. Threshold considered 10 cm
Norway	6.8	Threshold 10 cm
Sweden	6.1	NFI 1993-2002. Threshold considered 10 cm
Switzerland	11.9	NFI 1993-199. Threshold considered 7.0 cm

Source: Brassel & Brändli, 1999; Fridman & Walheim, 2000; INFC, 2009; Mehrani-Mylany & Hauk, 2004; Pignatti et al., 2009; Vallauri et al., 2003.

Table 1. Volume of deadwood in the main European Forest Inventories

Deadwood can be subdivided into three main components (Næsset, 1999): (1) snags or standing dead trees, (2) logs or lying deadwood and (3) stumps. All of them occupy a different ecological role in the forest ecosystem. Standing dead trees play an important role in increasing natural diversity and, in general, in the functioning of forest ecosystems, since a wide number of plants and animals has been strongly associated with their presence (Marage & Lemperiere, 2005). Lying deadwood provides important habitats for numerous insect species including flies, beetles and millipedes, while nurse logs facilitate the germination of conifers in mountain forests (Vallauri et al., 2003). Referring to the origin of deadwood, each piece can be classified on the basis of the species or by simply distinguishing between coniferous or deciduous. The tree species can be easily identified if the plant has recently died by observing the bark and the wood structure. When these parameters are no longer recognizable because of the advanced state of decomposition, a simple distinction conifer/broadleaved should be applied (Stokland et al., 2004).

Decomposition is the process through which the complex organic structure of biological material is reduced to its mineral form, and it is the result of the interactions between biotic and abiotic factors such as non-enzymatic chemical reactions, leaching, volatilisation, comminution and catabolism. Decay processes depend on species (hardwood or softwood species), site conditions (microclimate) and exposure; these characteristics can be quantified visually by using a decay class scale. The decay rate influences the dynamics of carbon release and sequestration, and it is measured with a decay class scale that takes into account species, microclimate and exposure. Moreover, the stage of decay is a very important parameter in order to analyse ecological dynamics and quantify carbon pools (Zell et al., 2009). Several ways to classify the level of decomposition can be found in literature. Normally the most widely accepted classification considers different (three, four or five) decay classes determined on the basis of the following variables (Montes et al., 2004): structure of bark, presence of small branches, softness of wood and other visible characteristics. The most common classification system is a 5-class system (Hunter, 1990) used in the American Forest Inventory (Waddell, 2002) and in the main European forest inventories (Paletto & Tosi, 2010; Sandström et al., 2007). The five decay classes used in the international standard are reported in Table 2.

Decay class	Bark condition	Small branches	Woody consistency	Other visual characteristics
1- Recently dead	Entire and attached	Present	Intact	Little rotten area under bark
2- Weakly decayed	Entire but not-attached	Partly present	Intact	Rotten areas < 3 cm
3- Medium decayed	Fragments of bark	Absent	Partly broken	Rotten area > 3 cm
4- Very decayed	Absent	Absent	Broken	Large rotten area
5- Almost decomposed	Absent	Absent	Dust	Very large rotten area, musk and lichens

Table 2. Decay classes of deadwood (five-class system)

Considering the size, lying deadwood is normally divided into two categories: coarse woody debris (CWD) which includes the logs with minimum diameter of 10 cm and fine woody debris (FWD) which refers to logs smaller than this threshold (Densmore et al., 2004). The same values are used to classify standing dead tree and stumps. Woldendorp et al. (2002) suggested to consider litter those small woody debris which have diameters below

2.5 cm, whereas other authors classify them as very fine woody debris (VFWD – Hegetschweiler et al., 2009). The distinction between these two (or three) categories of size is important when the habitat requirements of animal, fungi and plant species must be identified. Normally, FWD is relevant for diversity of wood-inhabiting fungi, especially ascomycetes in boreal forest whereas CWD favours many species of basidiomycetes. VFWD, in particular, may be associated to wood-inhabiting basidiomycetes, especially in managed forests where there is little availability of other substrates (Küffer & Senn-Irlet, 2005).

The spatial density, as a parameter, (Comiti et al., 2006) indicates how CWD and FWD are distributed on the ground. The spatial distribution is the result of human activities (i.e. cutting) or natural events (i.e. landslides). This variable can be qualitatively divided into three classes: (1) homogeneously concentrated, (2) concentrated in small groups, (3) scattered.

2. Materials and methods

The quantitative and qualitative features of snags, stumps and logs were estimated and analysed according to the forest types and forest systems (coppice and high forest) in three case studies. Hence, the authors examined the relationship between the presence of deadwood - species, size and decay class distribution - and the forest management practices.

The analysis of the influence of forest management on deadwood were investigated in a four-phases research:

- Classification of land uses/cover;
- Qualitative and quantitative description of forest formations;
- Dendrometric measures including the qualitative and quantitative information on forest deadwood;
- Analysis of the relationship between carbon storage and intensity of management.

The CORINE land cover (EC, 1993) European classification - level III - was adopted as a reference classification system for basic cartography. A specific classification was assembled for the forests that was based on the use of a homogeneous cultivation subcategory. This feature was ranked as an intermediate between the forest category and the forest type, and took into account both the forest system and the possible treatments of the wood. This classification was obtained according to the existing regional forest types and was coherent with higher superior reference systems (Italian National Forest Inventory-INFC, European Nature Information System - EUNIS, CORINE).

Regarding the qualitative and quantitative description of forest formations (woodlands and shrub lands), stratified samplings were conducted on the basis of homogeneous cultivation subcategory. The information was then entered in a Geographical Information System (GIS) built on the regional forest map.

The main dendrometric and management parameters were calculated in a sub-sample of woodlands using a circular area with a radius of 13 m measured onto a topographic map for a total surface of 531 m^2. The parameters measured were: number of trees, diameter at breast height (dbh), tree height of some sample trees, regeneration, deadwood, and qualitative attributes linked to the forest management and harvesting operations.

This method was tested on three study areas (forest districts) located in three different administrative regions of Southern Italy (Figure 1): (1) Arci-Grighine district in Sardinia region, (2) Alto Agri district in Basilicata region and (3) Matese district in Molise region.

The Arci-Grighine district (39°42′7′′ N; 8°42′4′′ E) is located in the Centre-East area of the Sardinia island. The district has a total surface of 55,183 ha and a population of 26,207 inhabitants (density of about 0.47 persons ha^{-1}) subdivided in 21 municipalities. The forests cover a surface area of 26,541 ha, comprising 48.1% of the Arci-Grighine territory. The forest categories, in order of prevalence, include: Mediterranean maquis (57.0%), Mediterranean Evergreen Oak forests (*Quercus ilex* L.) (14.7%), Cork Oak forests (*Quercus suber* L.) (9.9%), Eucalyptus forests (*Eucalyptus spp.*) (5.3%), Mediterranean pine forests (*Pinus spp.*) (3.1%), Downy oak forests (*Quercus pubescens* Willd.) (2.3%) and Monterey Pine (*Pinus radiata* Don) (1.7%)

The Alto Agri district (40°20′25′′ N; 15°53′52′′ E) is located in the Province of Potenza and characterized by a population of 33,739 people and a surface of 72,469 ha (density of about 0.47 persons ha^{-1}) divided into 12 municipalities. The forest areas cover 42,367 ha, comprising 58.4% of the Alto Agri territory. The forest categories, in order of prevalence, include: Downy oak forests (*Quercus pubescens* Willd.) (28.4%), followed by Turkey oak (*Quercus cerris* L.) forests (17.8%), shrub lands such as broom thicket, mixed thorny thicket and thermophile thicket with *Phillyrea sp.* and *Pistacia lentiscus*, (12.7%) and Beech (*Fagus sylvatica* L.) forests (9.6%).

The Matese district (41°29′12′′ N; 14°28′26′′ E) is located in the Province of Campobasso and characterized by a population of 21,022 people and a surface area of 36,539 ha (density of about 0.58 persons ha^{-1}) divided into 11 municipalities. The forest areas cover 15,712 ha, comprising 43.0% of the Matese territory. The forest categories, in order of prevalence, include: Turkey oak (*Quercus cerris* L.) forests (42.3%), followed by Beech (*Fagus sylvatica* L.) forests (30.5%), Hop hornbeam (*Ostrya carpinifolia* Scop.) forests (10.9%).

Fig. 1. Location of the case studies in Italy

The number of sub-plots were proportionally chosen according to the different forest surfaces: 218 sub-plots in Arci-Grighine, 235 sub-plots in Alto Agri and 117 sub-plots in Matese.

The quantitative presence of forest deadwood (volume) was investigated in each sub-sample plot taking into account four main integrative features: components, origin, decay class and size.

The volume of each log or snag included in the sub-sample was measured by applying a geometric system and, only for the snags, the stereometric equation of Italian National Forest Inventory 1985.

The forest operators registered lengths and diameters in three cross sections (minimum, maximum and medium) for lying dead wood while for the standing dead trees also the tree height and diameters at breast height (dbh) were considered.

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

$$V_s = f \cdot BA \cdot h \tag{1}$$

which includes a standard stem form factor (*f*) of 0.5.

Lying deadwood volume (V_l) and stump volume (V_{st}) was calculated using the following formula:

$$V = \frac{\pi}{4} \cdot h \cdot \frac{D+d}{2} \tag{2}$$

Where:
h = height or length measured (m)
D = maximum diameter (m)
d = minimum diameter (m)

The total volume of deadwood in forest (V_d) was the sum of three components:

$$V_d = V_s + V_l + V_{st} \tag{3}$$

3. Results and discussion

3.1 Volume by components and decay class

The quantitative data on deadwood (snags, logs and stumps) in the three districts showed interesting differences linked to the different traditions of management (Table 3 & Figure 2). The maximum value of deadwood was found in the Matese district with 47.1 m^3 ha^{-1} being stumps (30.4 m^3 ha^{-1}) and snags (9.9 m^3 ha^{-1}) the major contributors. In the Arci-Grighine district the total volume was 21.2 m^3 ha^{-1}, almost exclusively concentred in snags (19.2 m^3 ha^{-1}). The Alto Agri district showed the lowest volumes of deadwood (8.8 m^3 ha^{-1}), the majority (61%) comprised of snags (5.4 m^3 ha^{-1}).

The variable number of deadwood pieces and volume provided an average of 0.54 m^3 piece^{-1}, with a minimum value in the Alto Agri district (0.23 m^3 piece^{-1}) and a maximum value in the Matese district (0.90 m^3 piece^{-1}).

The results obtained were also compared with the Italian NFI. The volumes in the three districts were higher than those provided by NFI (INFC, 2009). In addition, the quantitative and qualitative differences were found to be comparable. A total of 1.7 m^3 ha^{-1} were recorded in Sardinia (0.8 m^3 ha^{-1} snag, 0.4 m^3 ha^{-1} stump and 0.5 m^3 ha^{-1} of log), 2.2 m^3 ha^{-1} in Basilicata (1.1 m^3 ha^{-1} snag, 0.5 m^3 ha^{-1} stump and 0.6 m^3 ha^{-1} log) and 4.3 m^3 ha^{-1} in Molise (2.7 m^3 ha^{-1} snag, 1.0 m^3 ha^{-1} stump and 0.6 m^3 ha^{-1} log). Other studies conducted in Italy show various values: 71.3 m^3 ha^{-1} were estimated in a site of Basilicata (Cozzo Ferriero) and in three sites of Molise of 95.6 m^3 ha^{-1} (Abeti Soprani), 17.4 m^3 ha^{-1} (Collemelluccio) and 26.5 m^3 ha^{-1} (Monte di Mezzo) (Lombardi et al., 2010). Moreover, in 21 study areas in North-West of Molise, Marchetti and Lombardi (2006) measured 15.1 m^3 ha^{-1}. These data show how the great variability in volumes is associated with specific site conditions and management practices.

District	Snag		Log		Stump		Total
	N ha^{-1}	Volume (m^3 ha^{-1})	N ha^{-1}	Volume (m^3 ha^{-1})	N ha^{-1}	Volume (m^3 ha^{-1})	Volume (m^3 ha^{-1})
Alto Agri	11.3	5.4	16.3	3.3	11.0	0.1	8.8
Arci-Grighine	17.1	19.2	7.3	1.2	17.9	0.9	21.3
Matese	16.2	9.9	20.4	6.8	15.8	30.4	47.1
Mean	*14.9*	*11.5*	*14.7*	*3.8*	*14.9*	*10.5*	*25.7*
St.dev.	*3.1*	*7.0*	*6.7*	*2.8*	*3.5*	*17.3*	*19.5*

Table 3. Volume and number of pieces for the different components of deadwood by district

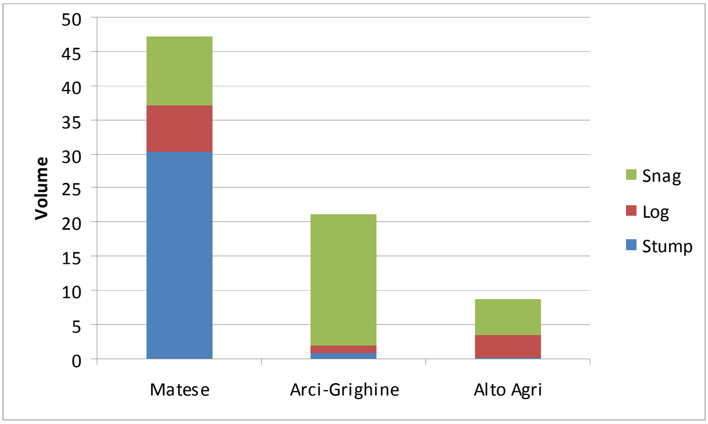

Fig. 2. Distribution of deadwood components volume (m^3 ha^{-1}) by district

The variation in decay class distribution provides an indication of the temporal variation in both tree mortality and tree felling and this variable can be used as an indicator of the history of a forest (Rouvinen et al., 2005). Generally, when fallen dead trees show all decay classes, the death of the plants have probably occurred evenly over a long time. *Vice versa,* when decay stages are concentrated in one or few classes, external events (naturally or human-induced) have concentrated the mortality in specific moments. Two different situations were observed in the case studies (Figure 3). In the Arci-Grighine district the volume of deadwood was concentrated in the first decay class (around 80% of total deadwood) and was composed almost exclusively of standing deadwood. Probably, the dead material might have been deliberately left in the forest for ecological or economic reasons after recent cuttings. Conversely, deadwood was regularly distributed along the five decay classes in the other two districts. The Matese scored higher values in the strongly decayed classes (fourth and fifth class) with around 67% of total volume, while the Alto Agri showed an opposite trend with 76% of the volume concentrated in the first two classes.

In general, the relatively scarce presence of highly decayed material in the Alto Agri and Arci-Grighine districts may be related to the effect of repeated clearing of the undercover vegetation which was carried out in order to prevent forest fires. Furthermore, heavy forest grazing in the Alto Agri caused the removal of dead material in the past.

The difference distribution of deadwood volume by decay classes in the three case studies were compared using the Kruskal-Wallis non-parametric test (Table 4). The results showed statistically significant differences only for stumps. In particular, the differences were related to the different distribution of deadwood in the Matese district compared with the other two districts.

	Observed K	Critical value	Degrees of freedom	p-value	α
Snag	0.081	5.991	2	0.961	0.05
Log	1.940	5.991	2	0.379	0.05
Stump	12.020	5.991	2	0.002	0.05

Table 4. Kruskal-Wallis non-parametric test: difference among the three districts concerning the three deadwood components

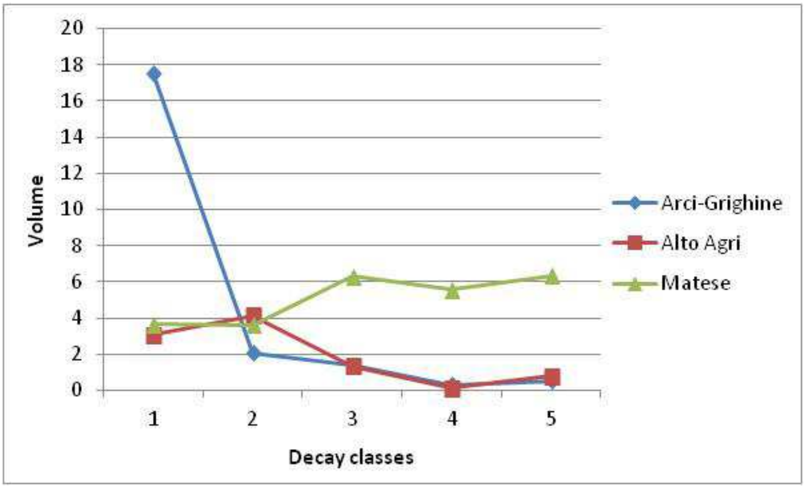

Fig. 3. Distribution of deadwood volume (m^3 ha^{-1}) by decay class in the three districts

3.2 Diametric and species distribution

The diametric distribution of deadwood (Figures 4, 5 & 6) provides important information on the presence of habitat trees and the differences among the three components of deadwood itself.

Regarding the tree habitat, a minimum number of 5-10 trees ha^{-1} is required for biodiversity conservation, especially for saproxylic organisms (Mason et al., 2005). The situation found in the three districts varied greatly since in the Arci-Grighine 31 dead trees ha^{-1} and 44 logs ha^{-1} with a minimum diameter of 30 cm were recorded, whereas both in Alto Agri and Matese habitat trees were only 1.7 per hectares.

In addition, the results on diametric distribution showed two different situations, being the Alto Agri more represented in small diameter classes and the Arci-Grighine and Matese in high diameter classes. In particular, in the Alto Agri district all three components were concentred in the first diametric class (40.4% of snags and 58.6% of logs). Instead, in the Arci-Grighine around 36% of snags and 41% of logs and stumps fell above the 30 cm diameter class. Similarly, in the Matese district 51% of logs and 69% of stumps were distributed in the highest diametrical class. Probably, the Alto Agri differed so significantly from the other two districts because almost 30% of its forests is constituted of young evergreen oak coppices, with high densities and a continuous mortality of thin dominated individuals.

The difference between the diametric distribution of the deadwood components in the three case studies were compared in pairs through the use of Kolmogorov-Smirnov non-parametric test. This test is based on the difference in the cumulative distributions of the two datasets. The results showed in all cases no statistically significant differences.

In order to test these differences by forest district, the Chi-square test (χ^2) was applied to the three deadwood components. The results obtained (Table 5) showed a statistical difference in sampling distribution of stumps and logs, while for the snag distribution the difference among the three districts was not significant.

	Observed chi-square value	Calculated chi-square value	Degrees of freedom	p-value	α
Snag	11.738	15.507	8	=0.163	0.05
Log	94.668	15.507	8	< 0.0001	0.05
Stump	51.274	15.507	8	< 0.0001	0.05

Table 5. Chi-square test (χ^2): difference among the three districts concerning the three deadwood components

Regarding the deadwood distribution per species in the Arci-Grighine district, a total of 60% of non-living biomass was concentrated in a single species (Monterey pine). Similarly, in the Matese district 64% and 9.7% of deadwood belonged to European beech and Turkey oak respectively. These results may be explained by the active firewood collection in oak forests and the substantial abandonment of beech forests. The species in the Alto Agri district were more evenly distributed: 34.4% of deadwood belonged to European black pine, 15.1% to chestnut and 12.2% to European beech.

In the Matese district, the beech deadwood consisted mainly of stumps (45.9%) and logs (48.7%), probably originated by old cuttings. In the Arci-Grighine instead, the presence of Monterey pine deadwood was almost exclusively composed by standing trees coming from abandoned old plantations.

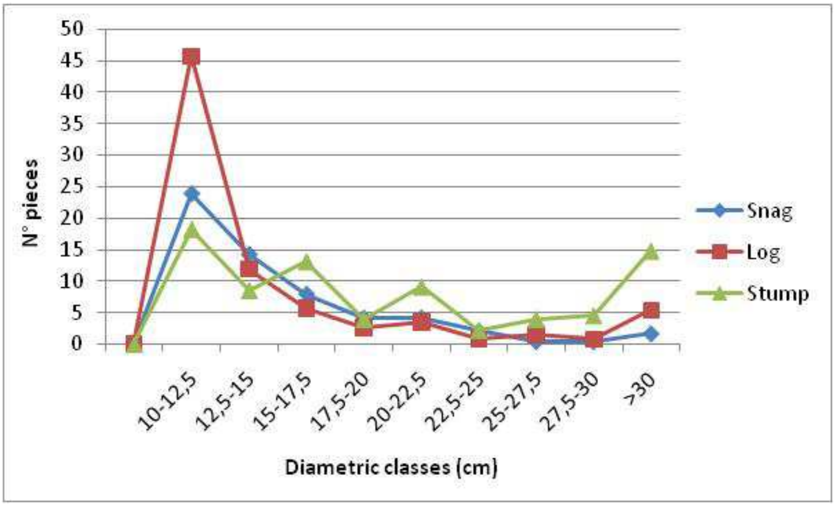

Fig. 4. Diametric distribution of deadwood in Alto Agri district

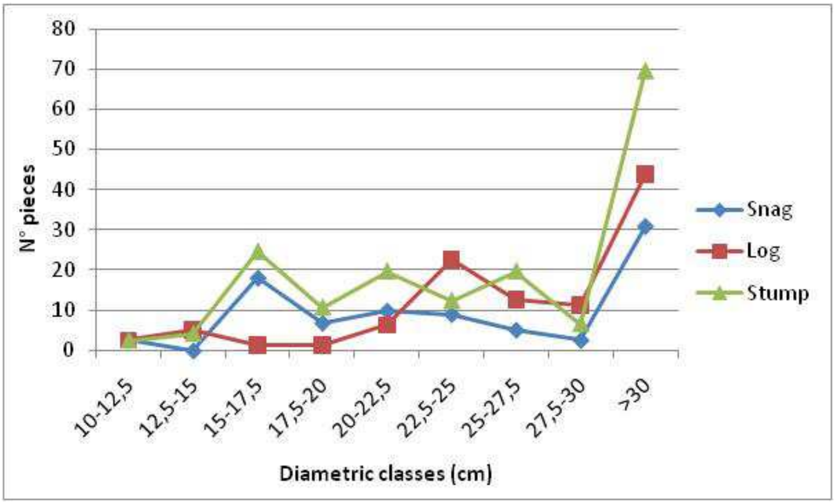

Fig. 5. Diametric distribution of deadwood in Arci-Grighine district

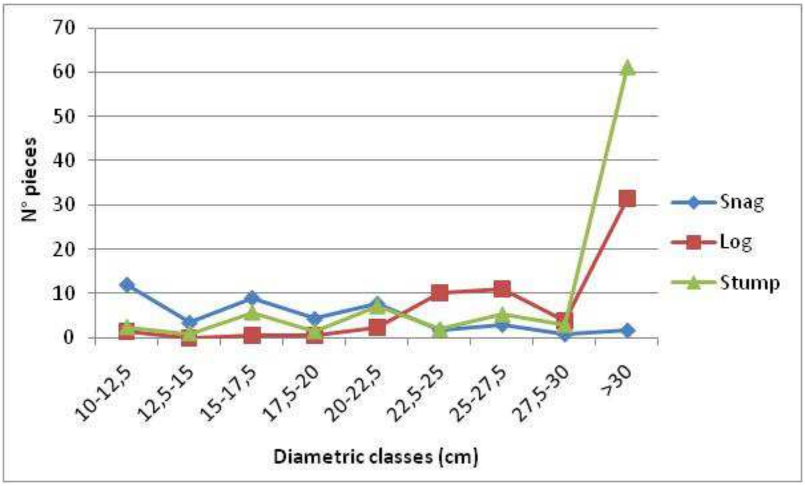

Fig. 6. Diametric distribution of deadwood in Matese district

3.3 Forest type and forest system

The type of forest system applied to the forest is a key factor to understand the impacts of forest management on deadwood and, consequently, on biodiversity conservation. The results showed that high forests had on the average higher volumes of deadwood for all three components in comparison with coppices (Table 6). In particular, the greatest differences were found for stumps in the Matese district (coppice: 7.4 m^3 ha^{-1}, high forest: 53.1 m^3 ha^{-1}) and for snags in the Arci-Grighine district (coppice: 3.8 m^3 ha^{-1}, high forest: 25.9 m^3 ha^{-1}). Only in the Matese district, snags scored higher values in coppices (11.1 m^3 ha^{-1}) rather than in high forests (8.7 m^3 ha^{-1}). This result was probably caused by a higher number of abandoned coppices in the area.

	Matese		Arci-Grighine		Alto Agri	
	Coppice	High forest	Coppice	High forest	Coppice	High forest
Stump	7.4	53.1	0.8	0.9	0.1	0.2
Log	4.4	9.1	0.2	1.6	1.6	5.9
Snag	11.1	8.7	3.8	25.9	3.9	7.6

Table 6. Volume (m^3 ha^{-1}) of deadwood components by forest system

Regarding the forest type, interesting differences were retrieved: in the Matese district *Fagus sylvatica* forests showed higher values than those of *Quercus cerris* forests, except for snags (Figure 7). In the Arci-Grighine district (Figure 8) very high volumes of snags were recorded in two forest type: *Pinus radiata* forests (93.5 m^3 ha^{-1}) and *Eucalyptus sp*. forests (54.1 m^3 ha^{-1}). In the Alto Agri district, instead, (Figure 9) Mediterranean pine forests (29.5 m^3 ha^{-1}) and, secondly, Mixed broadleaved forests (12.7 m^3 ha^{-1}) and *Castanea sativa* forests (12.8 m^3 ha^{-1}) showed the highest values of deadwood.

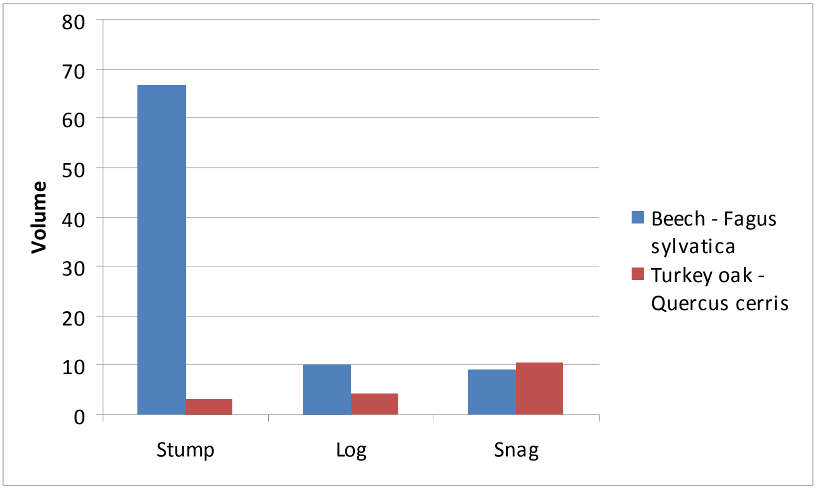

Fig. 7. Volume (m^3 ha^{-1}) distribution per forest type in the Matese district

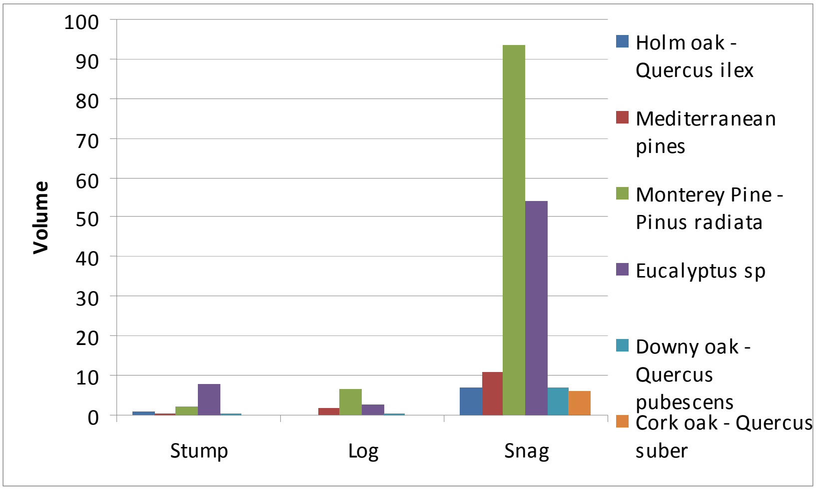

Fig. 8. Volume (m^3 ha^{-1}) distribution per forest type in the Arci-Grighine district

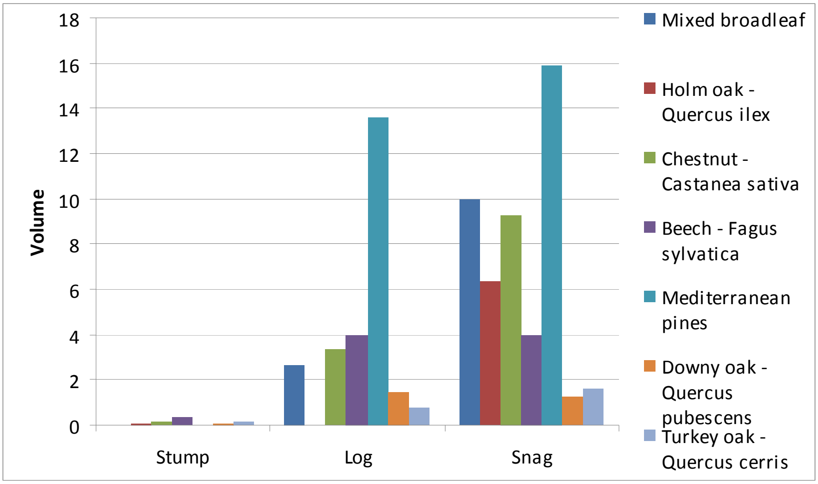

Fig. 9. Volume (m^3 ha^{-1}) distribution per forest type in the Alto Agri district

The higher number of stumps in the beech forests in comparison with those of the Turkey oak forests in the Matese district was a direct consequence of the different silvicultural treatments. As a matter of fact, these residues in the *Fagus sylvatica* forests, which belonged mainly to old standard trees, were originated by the conversion to high forests of abandoned coppices.

In addition, these types of forest had traditionally undergone to a less active management because of a minor economic interest on its main product (firewood) and a generally difficult accessibility. Similar considerations explain the high number of snags in the Arci Grighine *Pinus radiata* and *Eucaliptus spp.* forests. The abandonment, in the last decades, of these plantations increased the competitions among the individuals, thereby promoting high mortality rates and big sized deadwood material.

4. Conclusions

A method to collect quantitative and qualitative features of deadwood was a useful tool in order to define management strategies and silvicultural treatments aimed at optimizing the presence of deadwood in forest. In addition, its importance is remarked by the relevance of deadwood in carbon sequestration.

The expeditious method for the quantification of deadwood has an effective management relevance in supporting the choice of silvicultural treatments for the different forest type. The planners, with the analysis of the deadwood stock distinguished by type, specie and modality of active management, may acquire fundamental elements in order to define the sustainability of their technical proposals. Hence, appropriate interventions, aimed at valorising the specific functions of deadwood, can be defined case by case.

The different techniques may prescribe, wherever necessary, either the release of standing dead trees or other particular actions to increase deadwood. In coppices, for instance, a few standards may be left to indefinite ageing as well as some declining or dying individuals may be chosen as standards. In high forests instead, snags may be artificially increased by girdling some plants. The number of stumps and logs may be improved by releasing dominated plants without economic value that will rapidly die and fall down. However, the increase of deadwood should be carefully planned along with all the remaining management considerations such as production, protection etc, giving particular attention on fire hazard and pest control.

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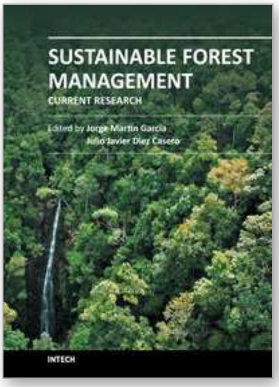

Sustainable Forest Management - Current Research
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Sustainable forest management (SFM) is not a new concept. However, its popularity has increased in the last few decades because of public concern about the dramatic decrease in forest resources. The implementation of SFM is generally achieved using criteria and indicators (C&I) and several countries have established their own sets of C&I. This book summarises some of the recent research carried out to test the current indicators, to search for new indicators and to develop new decision-making tools. The book collects original research studies on carbon and forest resources, forest health, biodiversity and productive, protective and socioeconomic functions. These studies should shed light on the current research carried out to provide forest managers with useful tools for choosing between different management strategies or improving indicators of SFM.

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