Comparison of guidelines for deadwood management in selected Natura 2000 forests types

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“*Là, sul più alto pennone del Veliero Fantasma s’era levato un segnale di fiamma. Le sue vele rupestri si tinsero di rosa, di rosso. L’antico miracolo s’era degnato ancora una volta di ripetersi.*

È giorno, mortali, è giorno!”

Felice Benuzzi, *Fuga sul Kenya*

The forest is turned into a diagram; animals become mere mechanisms; nature’s workings become clever graphs. Today’s conviviality of squirrels seems a refutation of such narrowness. Nature is not a machine.

D. G Haskell, *The forest unseen*

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E poi... Eravamo fuori a chiacchierare una sera di fine primavera, quando saltò fuori la domanda “Ma tu come vorresti essere ricordato?”. La mia risposta, forse un po’impulsiva ammetto, è stata: “Come un buon padre”. E che ci posso fare, se i miei genitori, che ora posso dirlo senza paura di essere nel torto, sono i migliori genitori che mai potessi desiderare? La loro figura mi circonda così tanto che spero di essere in futuro una figura importante e splendida almeno la metà di quanto lo siano loro per me. Sempre a lasciarmi guidare la mia vita, ma senza mai distogliere lo sguardo dalla mia strada. Non gliel’ho detto mai, e adesso dopo due anni all’estero mi sembra così sciocco non averlo fatto, e spero non si offendano se lo scrivo, perché per parlare di queste cose non sono ancora forte abbastanza.

Passiamo oltre. Il Bandro. Va beh, manco a parlarne. Mi è mancato più di tutti in questi mesi lontano da casa, sì, come solo un fratello può mancare. Cacchio, l’avevo letto nei libri, o visto nei film, ma non l’avevo capito che un fratello vale così tanto. Solo tu me l’hai insegnato.

Diverso è per gli amici, tutti lo sanno che gli amici mancano. Me lo aspettavo, via. Ma fa male lo stesso. Quante volte ho pensato che ormai una parte di me è di Giulio, punto. Per sempre. Ti voglio bene, mayn.

Elisa. Mi hai dato tantissimo, mi sento come se avessi cavalcato l'arcobaleno insieme a te, e vorrei dedicarti una strana frase che ho letto in un libro: "C'era un aeroplano lassù: lasciava una scia di vapore come una lumaca celeste. Anche questa è una cosa comune, pensò, non c'è nulla di magico, tranne che è meraviglioso. Non tutti i miracoli sono magia". Vedere i miracoli, ecco, anche questo mi hai insegnato, non l'ho mai dimenticato e non lo dimenticherò.

Dicono che l'importanza delle cose si capisce solo quando le si perde. Io l'importanza del Bergio l'ho capita quando l'ho ritrovato, quando ho capito che mi mancava nella vita una voce sincera perfino più della mia, averti ritrovato mayn è stata una deliziosa scoperta che non mi aspettavo. Ti meriti più di quanto hai, e non vedo l'ora di scoprire dove ci porterà la vita, a tutti e due.

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“It’s like having a big white sheet of paper to draw on! A day full of possibilities. It’s a magical world, Hobbes, ol’buddy. Let’s go explore it!”

Come disse Calvin un’ultima volta, guarda caso, in una foresta.

Federico

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Abstract

Natura 2000 is the European network designated to ensure the long-term survival of Europe's most valuable and threatened habitats and species. Forests cover a major part of the Europe’s surface and play a main role in hosting its biodiversity; as a consequence, despite there are 9 main habitats categories protected by Natura 2000, forests cover approximately 50% of the network. Nowadays, deadwood is considered a key element for forest biodiversity, and its presence is important for the conservation of European habitats and the dependent fungi, animal and plant species.

Nevertheless, there are few indications regarding the minimum amounts of deadwood to be considered when managing Natura 2000 sites. Member states define different goals and apply different thresholds, hence making it difficult to provide a comprehensive framework for the management of Natura 2000 forests.

Therefore this thesis collects and compares data and information from scientific literature, management guidelines and reports of the member states of the European Union about the current conditions, assessment methodologies, guidelines and suggested thresholds about the deadwood amounts of selected habitats from the Habitats Directive. A framework is designed to assist decision-making about deadwood management in the case of absence of specific guidelines. This framework consists of a decision tree and four associated tables, which include suggestions for deadwood amounts to be considered in selected forest habitats.

The main problems encountered in designing the framework are discussed. They include the comparison of different deadwood assessment techniques and descriptors, and the differences in available guidelines and thresholds.

Recommendations are provided to improve the current deadwood management and to conduct further research to fill the gaps in knowledge.

Keywords

Deadwood, Natura 2000, Europe, biodiversity, threshold, habitat tree

Zusammenfassung

Das europäische Netzwerk Natura 2000 ermöglicht den langfristigen Erhalt der wertvollen und bedrohten Lebensräume und Arten in Europa. Wälder haben einen großen Anteil an der Landoberfläche Europas und haben eine wichtige Aufgabe bei der Sicherung der Artenvielfalt; von den 9 Kategorien der Hauptlebensräume nimmt Wald ca. 50% des Natura 2000 Netzwerks ein. Totholz wird als Schlüsselelement zur Sicherung der Biodiversität in Waldökosystemen betrachtet, und seine Präsenz ist eng mit der Erhaltung der bedrohten Lebensräume und den vorkommenden Pilzen, Tier- und Pflanzenarten verbunden.

Es gibt nur wenige Hinweise hinsichtlich der Mindestmengen an Totholz, die bei der Bewirtschaftung von Natura-2000-Gebieten zu berücksichtigen sind. Die Mitgliedstaaten legen unterschiedliche Ziele fest und wenden unterschiedliche Schwellenwerte an, wodurch es schwierig wird, einen umfassenden Rahmen für das Management von Natura-2000-Wäldern zu schaffen. Daher sammelt und vergleicht diese Arbeit Daten und Informationen aus der wissenschaftlichen Literatur, Berichten und Richtlinien der europäischen Mitgliedsstaaten über die aktuelle Situation, Bewertungsmethoden und vorgeschlagene Schwellenwerte, die in Bezug auf die Totholzmengen in Habitaten der Richtlinie vorgeschlagen wurden. Ein Rahmen zur Unterstützung der Entscheidungsfindung in Bezug auf das Totholzmanagement im Falle des Fehlens spezifischer Richtlinien ist entwickelt worden. Dabei werden ein Entscheidungsbaum und vier zugehörige Tabellen, die Vorschläge für Totholzmengen in ausgewählten Waldlebensräumen enthalten, verknüpft.

Die Probleme bei der Gestaltung der Entscheidungshilfe werden diskutiert. Sie umfassen den Vergleich verschiedener Techniken und Deskriptoren zur Erfassung von Totholz sowie die Unterschiede in den verfügbaren Empfehlungen und den zugehörigen Schwellenwerten. Vorschläge zur Verbesserung des Totholzmanagements sowie die notwendigen Forschungsaktivitäten zur Schließung der Wissenslücken werden gegeben.

Schlagwörter

Totholz, Natura 2000, Europa, Biodiversität, Grenzwert, Habitatbaum

1. Introduction

1.1. Natura 2000

Natura 2000 is a network of some rare natural habitat types, both on land and sea, as well of core breeding and resting sites for rare and threatened species, which must be protected by all the 28 member states of the European Union (EU) (European Commission, 2018a).

The aim of the Natura 2000 network is to ensure the long-term survival of Europe's most valuable and threatened habitats and species, listed either under the Birds Directive or under the Habitats Directive (see List of terms in chapter 6).

1.1.1. Brief History

On 2 April 1979, the EU adopted its Birds Directive (Council Directive 79/409/EEC), aiming at protecting all European wild birds and the habitats of listed species, in particular through the designation of Special Protection Areas (SPAs).

On 21 May 1992, the Birds Directive was complemented by the Habitats Directive, more formally known as Council Directive 92/43/EEC on the *Conservation of natural habitats and of wild fauna and flora*. The Habitats Directive requires national governments to specify areas that are expected to ensure the conservation of endangered native animals and plants. Particularly, it aims at protecting 220 habitat types and approximately 1,000 species listed in the directive's Annexes. These are species and habitats which are considered to be of European interest, following criteria given in the Directive which also directs member states to take measures to maintain the "favourable conservation status" of protected habitats and species and, particularly, to set up a network of Special Areas of Conservation (SACs).

Altogether, the areas designated under either the Birds Directive or the Habitats Directive form the network of protected sites across the European Union called Natura 2000.

Article 17 of the Habitats Directive requires EU member states to report on the state of their protected areas every six years, and the first complete set of Country data was reported in 2007.

In 2009, a new Birds Directive was adopted (Council Directive 2009/147/EC on the conservation of wild birds) to replace the old one which had been modified several times and had become unclear.

The establishment of the Natura 2000 network was not without opposition and had (and still has) to face criticism from several stakeholders (including landowners, farmers, hunters and other affected societal groups) who fear that the conservation of habitats and species places a brake on development (Sotirov *et al.*, 2017).

According to the last available information (Natura 2000 Barometer, available online at European Commission, 2018b), at the end of 2015 the Natura 2000 network includes 27.312 sites with 787.606 km^2 of terrestrial areas (18,1% of land of the EU countries) and 360,350 km^2 of marine areas.

The Natura 2000 network is considered almost complete in the EU terrestrial environment. However, while designation of sites may be near complete, the management and enforcement of protection on sites is less advanced and many sites lack management plans.

On the contrary, the network in marine areas is not considered complete and it is acknowledged as a key challenge for EU biodiversity policy in the coming years.

1.1.2. Basic rules

The designation of SPAs under the Birds Directive is straightforward: member states designate them according to scientific criteria such as “1% of the population of listed vulnerable species” or “wetlands of international importance for migratory waterfowl”. While member states may choose the most appropriate criteria, they must ensure that all the “most suitable territories”, both in number and surface area, are designated.

The designation of SACs under the Habitats Directive is more complex. Member states first carry out comprehensive assessments of each of the habitat types and species present on their territory. They then submit lists of proposed Sites of Community Importance (SCIs) including information such as the size and location of the site, and the species and/or habitat found on this site: all this information about the SCIs, and about SPAs as well, must be collected in a Standard Data Form (SDF), a unique form for all the sites.

Based on the proposals provided by the member states, scientific seminars are held; with the support of the European Environment Agency, these expert seminars aim to determine whether sufficient high-quality sites have been proposed by each member state.

Once the lists of Sites of Community Importance have been adopted, member states must designate them as Special Areas of Conservation (SACs), as soon as possible and within six years at most; it is also highlighted the importance of management or restoration measures to ensure the favourable conservation status of the sites.

Natura 2000 sites can vary considerably in character: many sites are heavily affected by human activities, some are farmed, or include managed forests, or are even in urban areas; *ca.* 4% of the Network is under strict regime (European Commission, 2013).

1.1.3. About forests

In the 28 countries of EU, around 42% of the surface is covered by forests, for a total of 1,8 million square kilometres; of these areas, around 87% is somehow managed with different degrees of intervention. More than 21% (383,000 km^2) of this surface is included in Natura 2000 network, and both managed and unmanaged forests are contemplated (Kremer *et al.*, 2015).

Of the network surface, 50% is described as forest, and this high percentage reflects the important distribution of forests across Europe, and their overall importance for biodiversity (Kremer *et al.*, 2015): indeed, among the main 9 habitats' categories envisaged by the Habitats Directive, forests are the more diverse, with 81 Flora and Fauna Habitat (FFH) types that need *conservation* intended as "a series of measures required to maintain or restore the natural habitats and the populations of species of wild fauna and flora at a favourable status" (Council of the European Union, 1992).

The distribution of forests on the Europe's surface though is not well balanced, with very high coverage in boreal regions such as Sweden and Finland, where forests occupy 75% of the landscapes, and lower coverage in Mediterranean countries: Table 1 provides both absolute figures and percentage of the forests included in Natura 2000 for every member state (Kremer *et al.*, 2015).

It should be remarked that, regarding conservation of deadwood, already in 1988, even before the Habitats Directive emanation, a Recommendation of Council of Europe discouraged the removal of dead trees in the forests, a clear sign that its importance is not new to the European decision-makers (Sibille, personal communication).

Table 1: Natura 2000 and forests in Europe

Member State	Total Natura 2000 on land (km^2)	Total Natura 2000 Forest Area (km^2)	% Natura 2000 which is Forest	Forest & other wooded land (km^2)	Total Forest within Natura 2000 (%)
Austria	12.559	4.790	38	40.060	12
Belgium	3.883	2.130	55	7.060	30
Bulgaria	38.066	22.220	58	39.270	57
Cyprus	1.628	880	54	3.870	23
Czech Republic	11.062	7.510	68	26.570	28
Germany	55.142	26.550	48	110.760	24
Denmark	3.584	760	21	5.910	13
Estonia	8.076	4.670	58	23.500	20
Spain	137.365	79.780	58	277.470	29
Finland	48.851	28.910	59	232.690	12
France	69.127	30.090	44	175.720	17
Greece	35.761	15.550	43	65.390	24
Croatia	20.675	9.172	44	24.740	37
Hungary	19.950	8.080	41	20.290	40
Ireland	9.222	410	4	7.890	5
Italy	57.137	29.300	51	109.160	27
Lithuania	7.890	4.910	62	22.400	22
Luxembourg	469	280	60	880	32
Latvia	7.449	4.030	54	34.670	12
Malta	41	20	49	0	-
Nederlands	5.563	1.210	22	3.650	33
Polonia	61.059	33.470	55	93.370	36
Portugal	19.010	7.460	39	36.110	21
Romania	53.788	22.390	42	67.330	33
Sweden	57.410	23.530	41	312.470	8
Slovenia	7.673	4.990	65	12.740	39
Slovakia	14.442	9.460	66	19.330	49
United Kingdom	20.884	1.290	6	29.010	4
Total	787.766	383.842	49	1.802.310	21

1.2. The importance of deadwood for forest management

Deadwood is a complex term referring to dead and dying wood, both standing and laying on the forest ground, and, together with living trees, it constitutes the main structural compound of any forest (Seidling *et al.*, 2014).

Historically, deadwood in managed forests has always been almost absent, since it has generally been removed to avoid diffusion of fire or of diseases spread by fungi and insects, as well as to be used as fuel wood. Deadwood removal is still considered the best solution to avoid the spread of diseases ("sanitation" or "inoculum reduction"), especially for vascular wilt diseases, such as Dutch elm disease and oak wilt, cankers and root diseases (Gonthier and Nicolotti, 2013), that may reduce the production of a desired ecosystem service in managed forests, and salvage logging is highly recommended after heavy disturbances, for example to avoid the spread of *Ips typographus* after heavy wind storms (Kiristis, 2017).

Today however, deadwood is increasingly being accepted as a key indicator of naturalness in forest ecosystems. It has been even acknowledged as one of the Pan-European Indicators for Sustainable Forest Management according to European Environmental Agency (EEA), specifically inserted in the "*Criterion 4: Maintenance, Conservation and Appropriate Enhancement of Biological Diversity in Forest Ecosystems*" (EEA, 2015).

Its occurrence, in an appropriate proportion according to the goal of forest's management, is fundamental for the maintenance of biological diversity, since deadwood represents a suitable habitat for hundreds of species of lichens, bryophytes, fungi, invertebrates, amphibians, birds and small mammals (Travaglini and Chirici, 2006).

North American researchers were the first to realize that decaying logs represent a habitat suitable for many species (see *e.g.* Graham, 1925), also depending on the state of decay: these first results, achieved in the first half of the twentieth century, led to a small current of articles relating deadwood to fauna in the 1970's (see *e.g.* Miller and Halls, 1969, Maser *et al.*, 1978). Later, in the last years of the century, articles about the ecological role of deadwood became more and more numerous (Thomas, 2002) until nowadays, when deadwood functions are largely acknowledged and its amounts and quality in European forests is improving.

Particularly, Natura 2000 was also helping in this process of acknowledgment, since several iconic species, either of invertebrates (*Lucanus cervus*) or vertebrates (woodpeckers, owls, bats, *etc.*) are associated with decaying wood habitat, cavities and fissures in old trees, and Natura 2000 explicitly list them among the species requiring the designation of Special Area Conservation (Council of the European Union, 1992).

1.2.1. Definitions of deadwood

The quantity of deadwood occurring in forests in the different European regions depends on many factors, and its correct estimation must consider forest type (species' composition and structure), development stage, local disturbance regime, type of management, but also soil and climatic characteristics, which together contribute to complete the formation and decomposition cycle of deadwood. Hence, if deadwood exploitation is a management goal, the factors influencing its quantity, quality and dynamics need to be identified (Christensen *et al.*, 2005).

In literature, deadwood is a term whose definition mainly depends on the aim of the studies. In almost all of the retrieved articles, however, deadwood is above ground: woody roots and buried wood are not considered, due to the difficulties in the quantification (Merganičová *et al.*, 2012). According to Kirby, the above ground deadwood may be grouped into fallen material, standing dead trees, stumps and deadwood on or in living trees (Figure 1) (Kirby *et al.*, 1998). Stumps are very seldom considered, and also dead parts of living trees are mostly neglected, with a higher focus on dead trees (both standing and lying) and fallen branches. The amount of deadwood which is part of the litter, the so called Fine Woody Debris (FWD, see List of terms), is considered very rarely too, due to the efforts necessary to its inventorying, but it is still a prolific habitat for its own invertebrate fauna (Kirby *et al.*, 1998).

Another reason for most inventories not to consider FWD is because Coarse Woody Debris (CWD, see List of terms) and Large Woody Debris (LWD, see list of terms) persist for a longer time in the ecosystem, hence they are regarded as more significant components than fine debris (Merganičová *et al.*, 2012).

The persistence of deadwood in the forests is driven by many abiotic factors such as climate, moisture and temperature: higher temperatures may drive faster decomposition, so that both latitude and altitude can play a major role (Lombardi *et al.*, 2010).

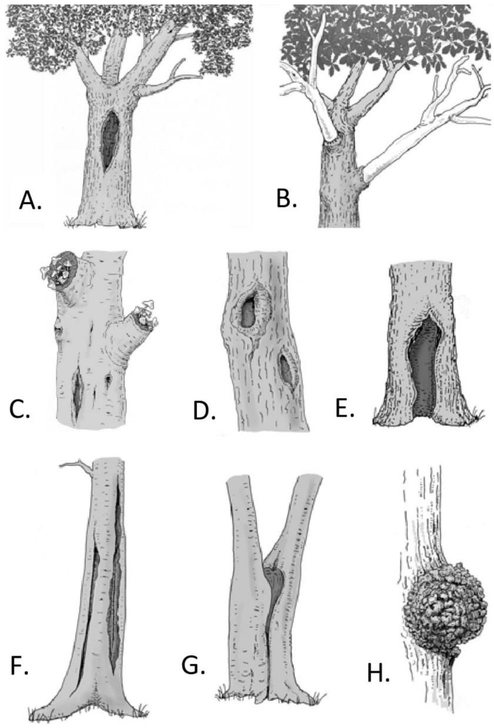


Figure 1: Especially when talking about habitat trees, deadwood may offer suitable microhabitats (see List of terms) for different organisms also on live trees, in several forms: A. non-woodpecker cavity, B. canopy deadwood, C. fruit-bodies of saproxylic fungi, D. cavities with mould, E. root-buttress cavity, F. cracks, G. fork split, H. burr. Image: Kraus and Krumm, 2013

Also the species influences its resistance: trees with high content of extractives (polyphenols, waxes, oils, resins, gums, tannins *etc.*) in the heartwood such as oaks or pines are slower to decompose, because of the toxicity for most decay fungi and some insects. Also, the diameter is positively correlated with decomposition time (higher diameter means longer time), as well as the position: snags (see List of terms) usually persists more than downed logs, which are more affected by higher wood moisture (Merganičová *et al.*, 2012).

1.2.2. Taxa *benefitting from deadwood*

As already mentioned, the importance of deadwood is connected to the conservation of biodiversity, a goal well recognized by Natura 2000.

A higher amount of deadwood increases number and density of species, and consequently species richness, since higher amounts correspond to higher surfaces and availability for potential users (Müller and Bütler, 2010). Not only the amounts though are important, because different saproxylic species depend on different decay stages of dead wood, and different spatial scales trigger different responds to habitat density (Ranius and Fahrig, 2006).

It is also important to note how standing and lying deadwood are relevant to different species, since birds and lichens are almost entirely associated to the first type, while fungi and mosses species are more associated to downed logs. To favour a broader range of species, it is also essential to balance proportions of deadwood typologies and decay stages (Merganičová *et al.*, 2012). Other differences are relevant when going into details, e.g. some insects and lichens require deadwood exposed to sun, or, on downed logs, fungi have the higher diversity in the intermediate decay stage, while mosses prefer late decay stages and high humidity (Christensen *et al.*, 2005).

The targets of conservation purposes are most usually groups, families, or even orders rather than single species and, in some cases, the target is general biodiversity, without confining the actions to any single taxon. Particularly, in the papers strictly related to Natura 2000, the goals are usually rather vague since they must be pursued on vast territories, while in unrelated publications the authors could focus on specific matters and single species, enhancing results' accuracy and threshold calculations. *E.g.*, Müller and Bütler (2010) provided an important contribution to the determination of suggested values for deadwood thresholds collecting values from many different experiences, all disconnected from Natura 2000 network, considering single species (*e.g.* three-toed woodpecker), families (*Clausilidae*) or orders (*Coleoptera*).

Insects are the most numerous *taxon* related with deadwood: only in France there are about 1900 species of deadwood-dependent beetles (Thauront and Stallegger, 2008), considered to be a crucial part of forest biodiversity, and almost all of these species are strongly threatened. Many deadwood-dependant insects are included in various Red Lists, and some (*Osmoderma eremita*, *Cucujus cinnaberinus*, *Rhysodes sulcatus*, *Limoniscus violaceus*) also in the Habitats Directive Annexes emanated for Natura 2000 (Council of the European Union, 1992).

A peculiar case, among other invertebrates, is represented by the wildlife who lives below the forest environment: for instance, deadwood fragments are transported, *e.g*. by water, even into karst caves, where a number of small animals feed on them. Among these specialized invertebrates, it can be found the *Alpioniscus feneriensis* (Parona, 1880) a xilobiontic *Isopoda* crustacean firstly described from the caves of Italian Pennine Alps.

Figure 2: *Alpioniscus feneriensis* feeding on deadwood in a cave of Italian Pennine Alps. Length: 7-8 mm. The body is fully depigmented: the black stripe is just deadwood in the animal's gut.
Photo: courtesy of Enrico Lana

Among vertebrates, birds have the strongest relations with deadwood: in beech forests for example, several species are found included in the Annex I of the Birds Directive (*Aegolius funereus*, Tengmalm's Owl; *Glaucidium passerinum,* Pigmy Owl; *Dryocopus martius*, Black Woodpecker; *Picus canus*, Grey-headed Woodpecker; *Dendrocopus medius*, Middle Spotted Woodpecker; *D. leucotos*, White-backed Woodpecker) (Thauront and Stallegger, 2008).

Deadwood however is a suitable habitat for many other organisms such as carnivores (large deadwood has been associated with bears for food and shelter (Dudley and Vallauri, 2004)), smaller mammals, bats, rodents (magazines for seeds, hiding and reproduction places), reptiles and amphibians (place for hiding, hibernation in winter, resting, feeding or reproduction).

Besides animals, plants also benefit from deadwood as habitat, *e.g.* bryophytes and, last but not least, fungi are typically the most visible element on decaying wood (Pawlaczyk and Kotulak, 2013).

Finally, one more species could be linked to deadwood: humans. Improving the quality of the landscape, attracting tourism and education as well as providing intangible values such as a general closeness to nature, deadwood may affect human fruition of forests, although some authors in the past underlined how excessive deadwood produces negative psychological impacts such as insecurity and fear (Nosswitz, 1998).

1.2.3. Others functions of deadwood

The importance of deadwood is mostly related to the maintenance of biodiversity (Dudley and Vallauri, 2004), but it is also associated with the forest microclimate and can act as an important water-storing element during drought. It also helps water retention by slowing down water flow on the surface and in the ground. The same happens on steep slopes vulnerable to soil erosion: deadwood may prevent rockfall and erosion (Merganičová *et al.*, 2012, Pawlaczyk and Kotulak, 2013). Furthermore, deadwood plays a role also in natural regeneration: large dead trees are often associated with patches in the forest where competition, light and moisture conditions are favourable for the establishment of seedlings, and also the availability of nutrients may increase depending on the decay stage; hence in some forests, woody debris is strongly connected to natural regeneration (Motta *et al*., 2016).

Finally, deadwood is also an important long-term nutrient storage: the carbon content adds significantly to the overall carbon storage of forest ecosystems, and the humification process secures a continuous supply of organic material to the soil (Woodall *et al.*, 2006).

1.3. Statement of the problem and aims of the thesis

Within the Natura 2000 framework, remarkable attention has been paid to forests, because of the amount of biodiversity that they ward and the long list of ecosystem services that they provide. Thus, it is particularly important to define a set of descriptors allowing to assess the quality of a forest ecosystem and, in this respect, the amount of deadwood in the forest environment has been recognized as a most significant one.

Nevertheless, the EU directives do not provide a common regulation or quantitative points of reference about the minimum or the recommended deadwood amounts to be left in a healthy forest, preferring to leave to the member states the task to define their own guidelines which, not surprisingly, are rather different among different countries and sometimes even among different regions of the same country.

One possible reason for these differences could be the different factors that drive member states into define priorities, factors that often remain tacit and implicit.

Thus, the aims of the thesis are:

- to compare different procedures for deadwood assessments;
- to screen the given definitions to identify the functions of deadwood;
- to collect and compare regional guidelines and thresholds for deadwood from two biogeographical regions and 17 member states;
- to provide suggestions for their harmonisation (when appropriate) or for the management of sites for which suitable guidelines have not been yet established;
- to define a framework for decision-makers facing the problem of deadwood management regarding amount and availability.

2. Materials and methods

The different steps undertaken to collect information and to elaborate it into the final outputs are graphically shown in Figure 3. The process involved two main phases: a first one, gathering information mainly from literature, and then a second one, the elaboration of the collected information to answer the thesis' aims. Every task illustrated in Figure 3 is further explained.

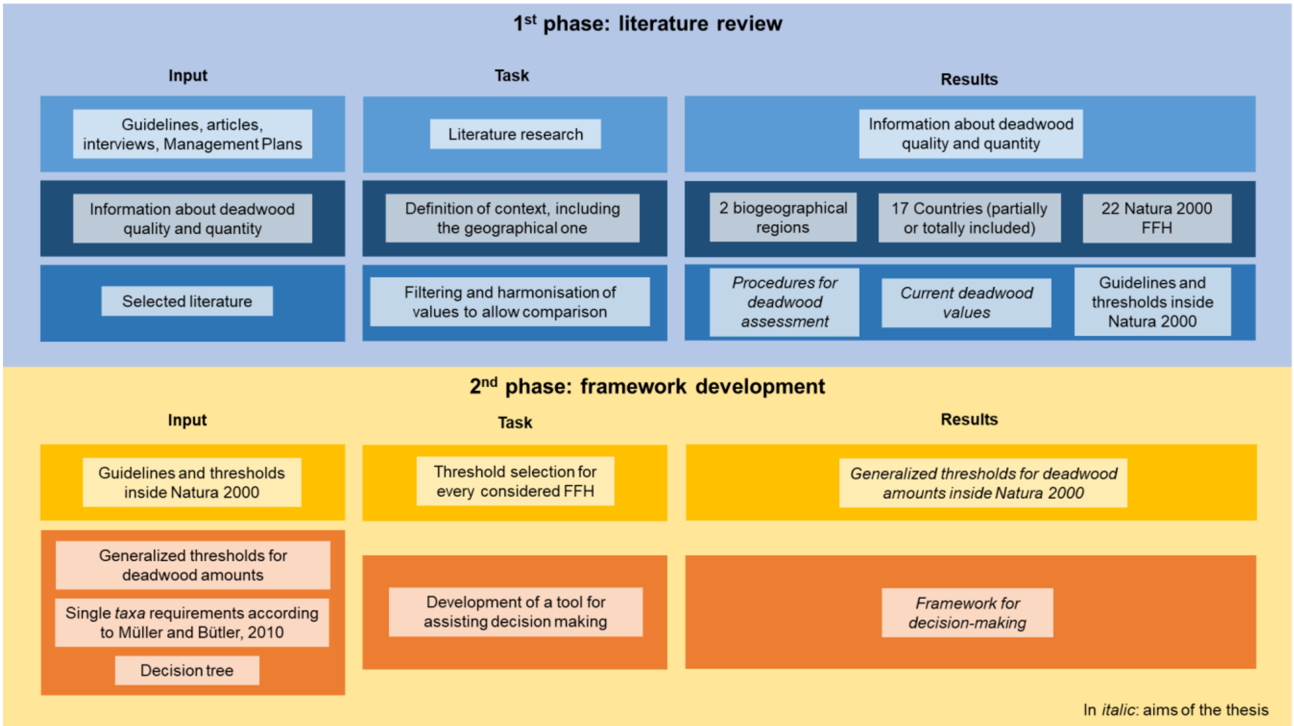


Figure 3: graphic representation of the material and methods utilised for this thesis

2.1. Literature review

2.1.1. Literature research

Much valuable information has been found in Internet sites regarding the Natura 2000 framework either by the EU or by its single member states. Other relevant information has been gained through searches in scientific literature databases, such as Scopus, Google Scholar or ResearchGate. The searches included the keywords "Natura 2000", "deadwood", "management", and "guidelines", in combination with several other terms related to the goal of the thesis. Furthermore, the reference lists of these papers were inspected for additional relevant material. The studies analysed are mainly published in international peer reviewed journals; papers published in local or national journals in languages different from English were usually not considered, with few exceptions for German and

Italian papers. The literature research about deadwood has been driven in two directions: one for the current amounts of deadwood that are present nowadays in European forests, and the other for the thresholds, suggested levels of deadwood amount to reach or maintain to preserve healthy forests.

A further source of valuable information has been represented by interviews, mainly by correspondence, with experts, to collect information on how deadwood is managed inside existing Natura 2000 sites. The managers of three specific Natura 2000 sites in Northern Italy have been addressed, plus two more interviews regarding European and Austrian general situations. Furthermore, 6 management plans from Italian Natura 2000 sites have been consulted to retrieve information regarding deadwood management; visiting two of these sites also allowed the author to observe both the theory and the practice of the management.

2.1.2. Definition of context

Even within the limits of the EU and of its Natura 2000 network, forests and deadwood management is such a vast and spread issue that this thesis had to focus on part of the forest types described in the Habitats Directive. Particularly, the thesis focuses on forests of two of the biogeographical regions defined by the European Commission (Figure 4): the Continental and the Alpine regions (European Commission, 2018c), selected according to their representativity within Natura 2000 network (the Continental region itself occupies 25% of Europe's surface).

These regions include, partially or totally, 17 out of the 28 members states and the main European mountain ranges (Table 2). Regarding the current amounts of deadwood, all of the 17 European countries mentioned before have been analysed; furthermore, a non-EU country, Switzerland, was also taken into account due to its relevance for the Alpine environment (Figure 5).

Information about deadwood management has been retrieved from literature for 22 Natura 2000 FFH types, among the 81 forest habitats listed in the Annex I of the Habitats Directive: they are listed in Table 3.

Table 2: Countries and main mountain ranges considered for the threshold analysis

Country	Partially/ Totally	Continental biogeographical region	Alpine biogeographical region	Main mountain ranges
Austria	T	•	•	Alps
Belgium	P	•		
Bulgaria	P	•	•	Balkans
Croatia	P	•	•	Dinaric Alps
Czech Republic	P	•		
Denmark	P	•		
Finland	P		•	Scandes
France	P	•	•	Pyrenees, Alps
Germany	P	•	•	Alps
Italy	P	•	•	Alps, Appennines
Luxembourg	T	•		
Poland	T	•	•	Carpathians
Romania	P	•	•	Carpathians
Slovakia	P		•	Carpathians
Slovenia	T	•	•	Alps, Dinaric Alps
Spain	P		•	Pyrenees
Sweden	P	•	•	Scandes

Table 3: Habitat taken into account in the thesis and their codes

Habitat code	Habitat description
9110	*Luzulo-Fagetum* beech forests
9130	*Asperulo-Fagetum* beech forests
9140	Medio-European subalpine beech woods with *Acer* and *Rumex arifolius*
9150	Medio-European limestone beech forests of the *Cephalanthero-Fagion*
9160	Sub-Atlantic and medio-European oak or oak-hornbeam forests of the *Carpinion betuli*
9170	*Galio-Carpinetum* oak-hornbeam forests
9180	*Tilio-Acerion* forests of slopes, screes and ravines
9190	Old acidophilous oak woods with *Quercus robur* on sandy plains
91E0	Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior* (*Alno- Padion, Alnion incanae, Salicion albae*)
91F0	Riparian mixed forests of *Quercus robur, Ulmus laevis* and *Ulmus minor, Fraxinus excelsior* or *Fraxinus angustifolia*, along the great rivers (*Ulmenion minoris*)
91G0	Pannonic woods with *Quercus petraea* and *Carpinus betulus*
91H0	Pannonian woods with *Quercus pubescens*
91I0	Euro-Siberian steppic woods with *Quercus* spp.
91M0	Pannonian-Balkanic turkey oak — sessile oak forests
91W0	Moesian beech forests
91Z0	Moesian silver lime woods
91AA	Eastern white oak woods
92A0	*Salix alba* and *Populus alba* galleries
9410	Acidophilous *Picea* forests of the montane to alpine levels (*Vaccinio- Piceetea*)
9420	Alpine *Larix decidua* and/or *Pinus cembra* forests
9430	Subalpine and montane *Pinus uncinata* forests
9530	(Sub-) Mediterranean pine forests with endemic black pines

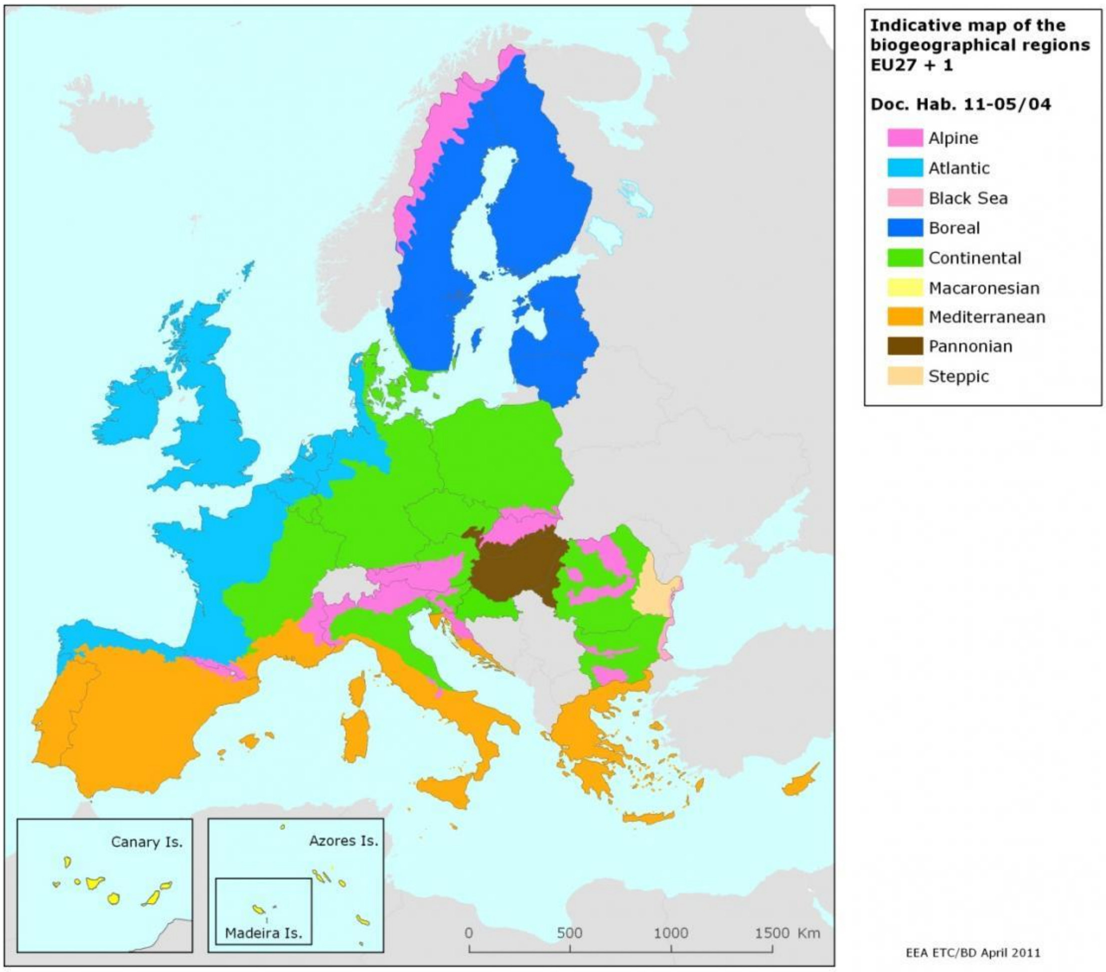
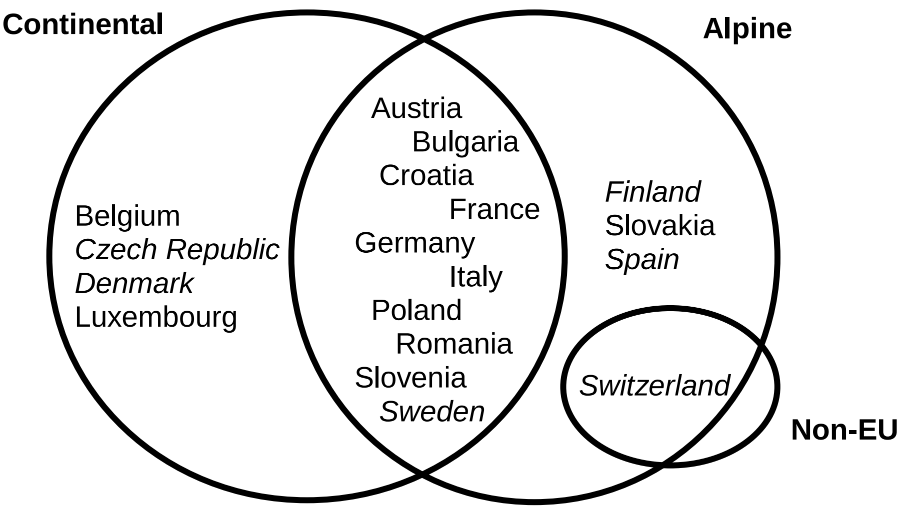


Figure 4: Indicative map of the biogeographical regions of Europe (European Commission, 2018d)



In italic: countries only considered for current deadwood amounts

Figure 5: Countries taken into account

2.2. Filtering and harmonisation of values to allow comparison

The retrieved literature was filtered to obtain information about the most common procedures for deadwood assessment, about the current values of deadwood inside the defined geographical context and about available guidelines.

To allow meaningful comparison, some harmonisation was needed, intended as the clustering of the results according to deadwood assessment methodologies. Five main descriptors were identified to cluster the several techniques and definitions encountered; once this classification was completed, comparison among guidelines was possible, since at least one of the three main deadwood descriptors (*total deadwood amount*, *large size deadwood* and *habitat trees*) was present in all of them.

The five identified deadwood descriptors are:

- *Deadwood amount*
- *Habitat trees*
- *Large size deadwood*
- *Extraction of deadwood*
- *Retention trees*

2.3. Framework development

2.3.1. Threshold selection for every considered FFH type

Among the different possibilities offered by literature, one or more thresholds were selected per habitat type and per descriptor, so to have at least one suggested threshold for each of the 22 FFH types. The selection was mainly based upon scientific literature regarding the minimum amounts of deadwood to maintain, comparison among available guidelines, and consideration of the geographical context of each habitat type.

2.3.2. Development of a tool for assisting decision-making

The retrieved and harmonised values were then used to develop a tool for assisting forests managers in decision regarding deadwood amounts, should they lack specific guidelines. To this end, the values were collected inside a framework in the form of four tables, with values obtained from the previous step and from a paper by Müller and Bütler (2010) for *taxa*-dependant management actions, together with a decision tree designed to allow the users to identify meaningful suggestions for the deadwood amount in the forests they are managing.

The decision tree has been designed favouring simplicity in both its design and use. Developed in the 1960's, decision trees are widely used in informatics for many purposes such as machine learning, data mining, calculating probabilities *etc*. (Huang *et al.*, 2010). More recently, they have been used also in ecology because they represent information in an intuitive, easy to visualize way. Variables can be of any type (numeric, binary, *etc.*), and they have a hierarchical structure, so that interactions between the different steps are automatically modelled. Their main disadvantage is their limits in their predictive performance, since the structure depends on the sample of data: small changes in data collection can result in very different series of splits (Elith *et al.*, 2008).

In this framework, the decision tree consists in a series of questions that should be answered, addressing relevant issues such as goal of the conservation action (improving general biodiversity, or just the status of one or few *taxa*) and availability of information. Questions are answered in a simple "yes/no" way: according to their answers to any specific question, the users are directed to which question must be answered next. At the end of this process, the users will be addressed to one entry of one of the four tables of the framework, which should provide meaningful suggestions for the deadwood amount to be left in the forest they are managing, having already taken into account any ecosystem service they wish to obtain.

3. Results

Guidelines and thresholds have been collected from 10 countries. They cover 22 Natura 2000 forest habitats and are mostly in English except those for Austria (mostly in German) and Italy (few texts in Italian). Basically, every guideline was ideated and written independently from the others, and different aspects of deadwood were taken into account, with different limits and definitions.

3.1. Descriptors

The five selected descriptors allow a comparison between the guidelines of the 10 countries. Table 4 summarises which descriptors are used in the 10 countries.

3.1.1. Deadwood amount

Deadwood amount is the most common measure, widely used in many articles. It is normally measured in m^3/ha, however in Bulgaria's guidelines, and according to some Austrian publications too, it is expressed as a percentage of the living wood stock in the stand.

This criterium to assess deadwood quantity is found in literature from Austria, Belgium, Bulgaria, Germany, Italy, Poland and Romania.

3.1.2. Habitat trees

Habitat trees are defined as standing live or dead trees providing ecological niches such as cavities, bark pockets, dead branches, cracks, sap runs, or trunk rot. Depending on their characteristics, habitat trees may have different names (*e.g.* veteran trees, mature trees, sometimes snags enter this descriptor), but they are always of prime concern for forest biodiversity. They are measured in individuals per hectare.

This criterium is found in literature from Austria, Belgium, Bulgaria, France, Germany, Italy, Luxembourg, Romania and Slovakia.

3.1.3. Large size deadwood

Large size deadwood is widely used by many researchers in different countries and forest habitats, since its measure, again in individuals per hectare, is quite easy. Its importance is due to the fact that in most forest ecosystems there is a shortage of large-dimension deadwood, and the xylobiotic species connected to it belong to the most endangered species; therefore, thick decomposing wood is evaluated by many countries as a separate indicator (Baran *et al.*, 2017). However, comparison among different guidelines is difficult, due to the large range of minimum diameters (10-60 centimetres) chosen by the authors to include a stem or a branch in this indicator. Inside this descriptor there are also considered the *coarse dead trees* (whole trees laying on the forest ground, either uprooted or broken), a feature that underlines the importance of thick large decaying wood parts.

This criterium is found in literature from Austria, Belgium, Bulgaria, France, Germany, Italy, Luxembourg, Poland and Slovakia.

3.1.4. Extraction of deadwood

Extraction of deadwood is something different from the previous descriptors but can be found sometimes as a relevant feature to consider. It is used either as yes/no indicator or expressed as an area percent in which extraction is allowed.

This criterium is found in literature from Austria and Bulgaria.

3.1.5. Retention trees

A common and mandatory feature in Scandinavian forestry (Gustafsson *et al*., 2010), but much less common in the area of study, retention trees are single trees or small stands exceeding the optimal economic criteria for the exploitation and going up to the double economical optimum age; also called *aging and decaying clumps*, trees are going toward the last death stage with no intervention. It is expressed as an area percent in which this kind of operation is expected (Thauront and Stallegger, 2008). Their importance is connected both to natural regeneration and biodiversity conservation. This criterium is found in literature from France.

Table 4: Summary of descriptors and utilizing countries

	Deadwood amount	Habitat trees	Large size deadwood	Extraction of deadwood	Retention trees
Austria	•	•	•	•	
Belgium	•	•	•		
Bulgaria	•	•	•	•	
France		•	•		•
Germany	•	•	•		
Italy	•	•	•		
Luxembourg		•	•		
Poland	•		•		
Romania	•	•			
Slovakia		•	•		
Number of countries utilizing the descriptor	**7**	**9**	**9**	**2**	**1**

3.2. Data investigation and inventory methodologies

Inventorying of deadwood could be considered relevant for several reasons: the most prominent are biodiversity conservation, carbon sequestration and estimation of fuel for fires, but also forest certification and sustainable forest management can drive countries to monitor deadwood (Merganičová *et al.*, 2012).

Nowadays, a small but increasing number of countries all around the world is inventorying the deadwood amounts in forests, and a publication by Woodall *et al.* (2006) collected information about these procedures.

According to this paper, only 30 countries inventory deadwood amounts, representing only 13% of the world's 229 countries. Though, most of these 30 countries are located in the forested regions of Europe, Russia and North America, so that deadwood is actually measured in more than 40% of the World's forests. In Europe, deadwood inventorying is a relatively recent phenomenon for some countries, which started their surveys around the year 2000 (Woodall *et al.*, 2006).

Almost all countries use fixed-area plots for inventorying standing deadwood, but for CWD more sampling methods were observed: 63% of countries uses fixed-area plots, 19% uses line-intersect sampling, while others use variable-radius plots or ocular estimation (where experts are required);

the Bitterlich relascope method can be used with some limitation and only for standing deadwood (Vacik *et al.*, 2009).

All of these techniques require in-field research, but recently remote sensing technologies has been tested mostly for counting dead standing trees, while for laying wood it is required such a high resolution that is still not feasible in many contexts (Merganičová *et al.*, 2012).

There is no established or accepted protocol on how to inventory deadwood, and each institution choses the method it prefers, considering costs, accuracy and goals: the reason for the preference of fixed-radius techniques is due to their being efficient and logical extensions of fixed-radius techniques commonly used to inventory standing live trees (Woodall *et al.*, 2006), but the line-intersect sampling, developed in the 60's, is fast, accurate, easy to use, more time efficient and more economical than other methods (Merganičová *et al.*, 2012).

These two most common methods, fixed area plot and line-intersect sampling, have both advantages and disadvantages: starting from the idea that an inventory is always a compromise between precision and costs of measurements, a French study showed how France should choose line-intersect sampling for lying deadwood and fixed-area samples for standing deadwood (snags and also stumps, usually neglected in deadwood measurements); it also shows though how on 29 samples a statistical comparison reveals that the results with the two methods are not significantly different (Teissier Du Cros and Lopez, 2009).

Regarding the ocular estimation, it is an expert-based method: it provides first-hand information, mostly updated and elaborated by experts who spent years or even decades in the field, who then possess efficient mental models to estimate deadwood. These methods do not require high costs, and experts are usually familiar with scientific method, that enables them to provide the most suitable information and at the same time confer validity to the whole process. Since only experts are involved, the first outcomes are already advanced results. Of course, the method is not always successful, and the biggest critiques are that it is not objective, since it's based on single individuals' experience, and it doesn't follow a fixed procedure, hence is not repeatable (Bogliani *et al.*, 2017). Also the scale plays a major role: applying expert-based methods to stand level may be feasible, while collecting such information on a national or regional level appears unrealistic.

It has to be mentioned that some countries recognize their lack of instructions: Bulgaria for example explicitly underlines the absence of an official methodology for deadwood assessment, and also that the previous data were not enough to formulate an accurate assessment (Dimitrov and Petrova, 2014a).

As already mentioned, all inventories apply to deadwood with different dimensions, so even using the same inventory methodology doesn't imply that results are comparable: this aspect will be further discussed.

3.3. Current availability in different European countries/regions

In natural conditions, the most relevant sources of dead and dying wood are mortality, diseases, fire, water stress and natural thinning. These events happen in any forest ecosystem all over Europe, but with different intensities depending upon climate, latitude, wind systems, microsites' conditions, disturbance regimes, management, *etc*. For this reason, values found in European forests significantly differ among countries and regions: selected deadwood amounts are collected in Table 5, while Table 6 collects few examples of unmanaged forests to showcase the effects of forest management on the availability of deadwood.

National averages range between 2 and 20 m^3/hectare (with the exception of Slovakia, which reported more than 40 m^3/ha). Data suggest that deadwood has been slightly increasing over the past 20 years in most of the members states and indicate that the increase of deadwood in forests is furthered by policies that support a shift towards more nature-oriented management, and by forest management trying to spare costs by reducing harvesting operations. On the other hand, national averages have to be interpreted carefully, since the figures about the volume of deadwood per hectare are referred to the total forest area, while the area on which deadwood actually occurs may be smaller, so that part of the forests does not have any deadwood (Forest Europe *et al*., 2011).

Table 5: Selected amounts of deadwood found in European forests; countries are listed in alphabetical order

Country	Region	Biogeographical region	Deadwood amount, m^3/ha	Notes	Reference
Austria	National average		13,9	2002	Pignatti *et al.* , 2009
Austria	National average		20,3	2010	FOREST EUROPE, 2011
Belgium	National average	Continental	7,3		FOREST EUROPE, 2011
Belgium	Wallonie	Continental	3,3		Vallauri *et al.* , 2003
Bulgaria			N/A		
Croatia	National average		13,9		FOREST EUROPE, 2011
Czech Republic	National average	Continental	11,7		FOREST EUROPE, 2011
Denmark	National average	Continental	5,1		FOREST EUROPE, 2011
European beech forests	Range		0-550	Range	Lombardi *et al.* , 2010
European beech forests	Average		130	Average	Lombardi *et al.* , 2010
Finland	National average		5,6	Average	Pignatti *et al.* , 2009
Finland	Production forests		2-10		Vallauri *et al.* , 2003
France	National average		2,2	Average	Vallauri *et al.* , 2003
France	Savoie	Alpine	6,7	Maximum departemental	Vallauri *et al.* , 2003
Germany	National average	Continental	11,5	2002	Pignatti *et al.* , 2009
Germany	National average	Continental	15	2010	FOREST EUROPE, 2011
Germany	Bavaria	Continental	1-3		Vallauri *et al.* , 2003
Italy	National average		8,8		Lombardi *et al.* , 2010
Italy	North		13,4		Pignatti *et al.* , 2009
Italy	Centre		6,6		Pignatti *et al.* , 2009
Italy	South		3,5		Pignatti *et al.* , 2009
Luxembourg	National average	Continental	11,6		Dudley, Vallauri, 2004
Poland	National average	Continental	5,6		FOREST EUROPE, 2011
Romania			N/A		
Slovakia	National average	Alpine	40,6		FOREST EUROPE, 2011
Slovenia	National average		19,1		FOREST EUROPE, 2011
Spain	Navarra	Alpine	8,8		Alberdi *et al.* , 2017
Spain	Navarra	Alpine	24,4	Beech forests	Herrero *et al.* , 2016
Sweden	National average		6,1		Vallauri *et al.* , 2003
Sweden	North	Alpine	12,8		Vallauri *et al.* , 2003
Switzerland	National average	Alpine	12	1999	Vallauri *et al.* , 2003
Switzerland	National average	Alpine	20,8	2010	FOREST EUROPE, 2011
Switzerland	Alps	Alpine	19,5		Vallauri *et al.* , 2003
Switzerland	Plateau	Alpine	4,9		Vallauri *et al.* , 2003
Switzerland	Prèalpes	Alpine	12,2		Vallauri *et al.* , 2003
Switzerland	Sud des Alpes	Alpine	11,6		Vallauri *et al.* , 2003

Table 6: Selected amounts of deadwood found in European unmanaged forests

Country	Region	Biogeographical region	Deadwood amount, m^3/ha	Notes	Reference
Austria	Goldeck	Alpine	69,3	Natural reserve	Ruprecht *et al.* , 2012
Austria	Kronawettgrube	Alpine	70,2	Natural reserve	Ruprecht *et al.* , 2012
Austria	Rothwald	Alpine	256	Old-growth forest	Lombardi *et al.* , 2010
Czech Republic	Knéhyné	Continental	128-206	Natural reserve	Ruprecht *et al.* , 2012
Czech Republic	Trojmezna	Continental	156-311	National Park	Ruprecht *et al.* , 2012
Italy	Foreste casentinesi	Continental	60	National Park	Lombardi *et al.* , 2010
Italy	Molise	Continental	30,1	Fluvial forests (*S. alba*)	Lombardi *et al.* , 2008
Italy	Molise	Continental	56,3	Fluvial forests (*Q. robur*)	Lombardi *et al.* , 2008
Poland	Bialowieza Forest	Continental	94	National Park	Kirby *et al.* 1998
Poland	Swietokrzyski Forest	Continental	300	National Park	Lombardi *et al.* , 2010
Poland	Babia Hora	Alpine	131-191	National Park	Ruprecht *et al.* , 2012
Slovakia	Babia Hora	Alpine	241	Natural reserve	Ruprecht *et al.* , 2012
Slovakia	Kosodrevina	Alpine	200	National Park	Ruprecht *et al.* , 2012

3.4. Current guidelines for deadwood amount and management

In 2018, 28 countries with 24 different languages adhere to Natura 2000: this makes the network somehow slow be implemented: concepts, definitions, indicators and data collection are diverse and even governments have different objectives and priorities.

This general problem, common to the whole network's organization and implementation, also affects deadwood management.

To manage deadwood in an effective way, general frameworks should be applied, but data are scarce, and the methodologies to collect them are too variegated and incomplete to represent a valid standard for international purposes. Particularly, no threshold has been unanimously accepted, nor even proposed, because deadwood may even represent a threat to an ecosystem, since it may spread fires or pathogens (Kiristis, 2017).

Guidelines were retrieved from 10 countries: Germany is present with one national and three regional guidelines; for Austria, Bulgaria and France one national and two regional guidelines were found. For Luxembourg, Poland, Romania and Slovakia only national guidelines were found, while Belgium and Italy appear with only regional guidelines.

Europe provides a standard ranking system, with the subdivision in *a*, *b* and *c* in order to define different levels of conservation. The three conservation status are defined as follows:

- *a*: favourable
- *b*: unfavourable inadequate
- *c*: unfavourable bad

This separation though is not widely utilised, only some countries define such levels, and when looking at the meaning of the values, it’s impossible to define a procedure to establish them (see discussion). For example, the Romanian guidelines formally follow this division, but they consider *b* and *c* as both “unfavourable bad”, in order to use a more radical approach and avoid, according to the authors, to draw a rather positive picture of the conservation status, like other authors did in the past (BeNatur, 2013).

Current national or subnational guidelines are collected in the following Tables 7 to 11. The guidelines have been clustered according to the five descriptors already discussed in paragraph *3.1*.

Table 7: amount of deadwood proposed for the conservation status assessment of forests in countries or regions involved in Natura 2000

Country	Habitat types	Deadwood amount				Reference
		Favourable	Unfavourable inadequate	Unfavourable bad	Criteria and Notes	
Austria	9110, 9130, 9140, 9150, 9180, 91E0, 91F0	6-12% of wood stock			Minimum 2-5 m^3/ha	Gimpl *et al.*, 2018
Austria	9160, 9170, 91G0, 91H0, 91I0	6-12% of wood stock				Gimpl *et al.*, 2018
Austria	9410	6-12% of wood stock			ø ≥ 20 cm, minimum 5-9 m^3/ha	Gimpl *et al.*, 2018
Austria	9420	6-12% of wood stock			ø ≥ 10 cm, minimum 5-10 m^3/ha	Gimpl *et al.*, 2018
Austria	9130, 91E0, 91F0, 91H0, 91I0	> 5 m^3/ha	2-5 m^3/ha	< 2 m^3/ha	ø ≥ 20 cm	Schroiff, 2014
Belgium (Wallonia)	9110	> 20 m^3/ha	7-20 m^3/ha	< 7 m^3/ha	Standing and laying	Thauront and Stallegger, 2008
Bulgaria	91M0	> 8% of wood stock			> 60% of the area	Zingstra *et al.*, 2009
Bulgaria (South)	91AA, 91M0, 91Z0	> 8% of wood stock				Dimitrov and Petrova, 2014a
Bulgaria (West)	9110, 9130, 9150, 9170, 9180, 91E0, 91H0, 91M0, 91W0	> 8% of wood stock				Dimitrov and Petrova, 2014b
Germany (Brandeburg)	9130	> 40 m^3/ha	21-40 m^3/ha	< 20 m^3/ha	ø ≥ 35cm	Schroiff, 2011
Italy (Ticino)	9160, 9190, 91E0, 91F0	> 33-35 m^3/ha			For conservation purposes	Casale *et al.*, 2016
Italy (Ticino)	9160, 9190, 91E0, 91F0	> 15 m^3/ha			For production purposes	Casale *et al.*, 2016
Poland	91E0	> 20 m^3/ha	10-20 m^3/ha	< 10 m^3/ha		Baran *et al.*, 2017
Romania	91E0, 92A0	> 30 m^3/ha	4-30 m^3/ha	< 4 m^3/ha		BeNatur, 2013

Table 8: density of habitat trees proposed for the conservation status assessment of forests in countries or regions involved in Natura 2000

Country	Habitat types	Habitat trees: Favourable	Habitat trees: Unfavourable inadequate	Habitat trees: Unfavourable bad	Habitat trees: Criteria and Notes	Reference
Austria (Upper Austria)	9130	woodpeckers trees and aerie trees have to be left				Winter *et al.*, 2014
Austria	9110, 9130, 9140, 9150, 9180, 91E0, 91F0	5-10 pcs/ha			preferably different species	Gimpl *et al.*, 2018
Austria	9410	5-10 pcs/ha			preferably different species	Gimpl *et al.*, 2018
Austria	9420	5-10 pcs/ha			preferably different species	Gimpl *et al.*, 2018
Belgium (Wallonia)	9110	> 3 pcs/ha	2-3 pcs/ha	< 2 pcs/ha	Ø > 80 cm for hardwood Ø > 50 cm for softwood	Thauront and Stallegger, 2008
Bulgaria	91M0	> 10 pcs/ha			snags, on at least 60% of the area	Zingstra *et al.*, 2009
Bulgaria (South)	91AA, 91M0, 91Z0	> 10 pcs/ha	less	less		Dimitrov and Petrova, 2014a
Bulgaria (West)	9110, 9130, 9150, 9170, 9180, 91E0, 91H0, 91M0, 91W0	> 10 pcs/ha	less	less		Dimitrov and Petrova, 2014b
France	9110, 9130, 9140	> 2 pcs/ha			Ø > 35 cm	Winter *et al.*, 2014
France (Franche-Comté)	9110, 9130, 9140	to increase			Ø > 35 cm	Winter *et al.*, 2014
Germany	9110	≥ 6 pcs/ha	≥ 3 pcs/ha	< 3 pcs/ha	Trees with cavities or nests or Ø > 40 if cavities, dead parts, degraded bark or Ø > 80 cm for beech and oak and noble deciduous or Ø > 40 cm for other species	Thauront and Stallegger, 2008
Germany (Bavaria)	9110, 9130	> 2 pcs/ha				Winter *et al.*, 2014
Germany (Bavaria)	9110, 9130, 9160	tessellated distribution of different phases of different age				Winter *et al.*, 2014
Germany (Nordrhein Westfalen)	9110	≥ 6 pcs/ha	1-5 pcs/ha	< 1 pcs/ha	Ø ≥ 80 cm in lowlands, Ø ≥70 cm in uplands Ø ≥ 60 cm in high mountain	Thauront and Stallegger, 2008
Italy (Ticino)	9160, 9190, 91E0, 91F0	> 8-10 pcs/ha				Casale *et al.*, 2016
Luxembourg	9110	> 5 pcs/ha	1-5 pcs/ha	< 1 pcs/ha	Ø > 60 cm for beech and oak Ø > 40 cm for other species	Thauront and Stallegger, 2008
Romania	91E0, 92A0	extensive presence	predominately present	only partially present		BeNatur, 2013
Slovakia	9110	≥ 5 pcs/ha (very good) 1-4 (good)	3-9 pcs/10 ha	< 3 pcs/10 ha	Ø ≥ 60, equally distributed	Thauront and Stallegger, 2008

Table 9: density of large size deadwood proposed for the conservation status assessment of forests in countries or regions involved in Natura 2000

Country	Habitat types	Large size deadwood				Reference
		Favourable	Unfavourable inadequate	Unfavourable bad	Criteria and Notes	
Austria	9130	2 pcs/ha				Winter *et al.* , 2014
Austria	9160, 9170, 91G0, 91H0, 91I0	> 1-2 pcs/ha			ø > 20 cm	Gimpl *et al.* , 2018
Austria	9430, 9530	> 3 pcs/ha			ø > 10 cm	Gimpl *et al.* , 2018
Belgium (Wallonia)	9110	> 2 pcs/ha	1-2 pcs/ha	< 1 pcs/ha		Thauront and Stallegger, 2008
France	9110	> 1 pcs/ha			ø > 35 cm	Thauront and Stallegger, 2008
France	9110, 9130, 9140	3 pcs/ha			Standing and lying ø > 35 cm	Winter *et al.* , 2014
France (Franche-Comté)	9110, 9130, 9140	to increase			Standing and lying ø > 35 cm	Winter *et al.* , 2014
Germany	9110	> 3 pcs/ha	1-3 pcs/ha	< 1 pcs/ha	Standing and lying, L > 3 m DBH > 50 cm or branches ø > 30 cm	Thauront and Stallegger, 2008
Germany (Nordrhein Westfalen)	9110	> 3 pcs/ha	1-3 pcs/ha	< 1 pcs/ha	Standing and lying L > 2 m, ø > 50 cm	Thauront and Stallegger, 2008
Germany (Bavaria)	9110, 9130	2 pcs/ha			Standing and lying L > 3 m, ø > 50 cm	Winter *et al.* , 2014
Italy (Ticino)	9160, 9190, 91E0, 91F0	2 uprooted, 2 broke pcs/ha			ø > 40 cm	Casale *et al.* , 2016
Luxembourg	9110	> 3 pcs/ha	1-3 pcs/ha	< 1 pcs/ha	Standing and lying L > 2 m, ø > 40 or 60 cm depending on the species	Thauront and Stallegger, 2008
Poland	91E0	> 5 pcs/ha	3-5 pcs/ha	< 3 pcs/ha	Standing and lying L > 3 m, ø > 50 cm	Baran *et al.* , 2017
Slovakia	9110	≥ 4 very good, 2-3 good	1 pcs/ha	< 1 pcs/ha	Standing and lying L > 3 m, ø > 40 cm, with different categories of decaying wood	Thauront and Stallegger, 2008

Table 10: allowance of extraction proposed for the conservation status assessment of forests in countries or regions involved in Natura 2000

Country	Habitat types	Extraction of deadwood				Reference
		Favourable	Unfavourable inadequate	Unfavourable bad	Criteria and Notes	
Austria	9430, 9530	not to happen				Gimpl *et al.* , 2018
Bulgaria	91M0	no threat	impacting <1%/year	impacting >1%/year	Percentage of interested area	Zingstra *et al.* , 2009

Table 11: Distribution in percentage of forest of retention trees proposed for the conservation status assessment of forests in countries or regions involved in Natura 2000; in brackets the percentage of forest that should be left completely unmanaged

Country	Habitat types	Retention trees				Reference
		Favourable	Unfavourable inadequate	Unfavourable bad	Criteria and Notes	
France	9110	5% (3% decaying) of forests in Natura 2000 areas				Thauront and Stallegger, 2008

The tables offer many aspects that can be analysed.

Regarding the two biogeographic regions, the Continental region is more represented, while the Alpine habitats are seldom mentioned: still, Austria underlines how alpine habitats are negatively more affected by wood extraction (Gimpl *et al.*, 2018) due to the time necessary to the ecosystem to generate new deadwood; for this reason the same guideline accept a minimum diameter of 20 cm in high elevations and even 10 cm for *Larix decidua* and *Pinus cembra* forests, species that can reach 2000 meters, where achieving such diameters requires more time than in the lowlands.

So the main difference between the two biogeographical regions is that, even if in the alpine region the deadwood amount is usually higher due to less exploitation (Christensen *et al.*, 2005), the thresholds appear lower because of the lower productivity.

At least two descriptors are always used for every habitat, so that more than one suggested value can be considered: this aspect underlines the importance of deadwood, since one definition, or threshold, is not enough to include all the processes that are driven and supported by it.

Some of the habitats appear seldom, also because their scarce distribution: Figure 6 shows the total number of thresholds (considering hence all the descriptors) found in the literature regarding a single habitat, while Figure 7 shows how many countries have dealt with the single habitats. Finally, Figure 8 shows how many habitats the single countries have dealt with (Austria is the country that provides thresholds for more habitat types with 16). From Figure 6, three FFH types appear to be more often considered by several countries:

- 9110, *Luzulo-Fagetum* beech forests, is the most often mentioned habitat type in the tables, also thanks to the relevant literature found on the topic. Seven countries defined a total of 23 different thresholds for this habitat, a common and important ecosystem in Central Europe.
- 9130, *Asperulo-Fagetum* beech forests, is well distributed in whole Central Europe, with Austria, Bulgaria, France and Germany that established 14 thresholds for deadwood in this habitat.
- 91E0, Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior* (*Alno-Padion*, *Alnion incanae*, *Salicion albae*), are endangered according to EEA (EEA, 2018). More than 6300 Natura 2000 sites all over Europe are protecting this habitat type, so 13 thresholds were retrieved from literature in 5 countries.

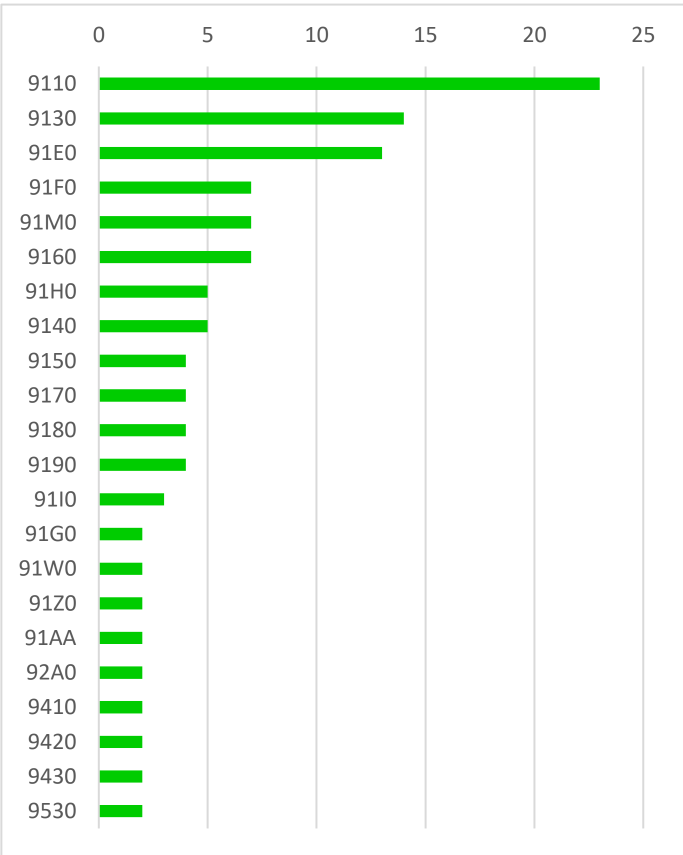


Figure 6: Numbers of retrieved thresholds for every habitat type

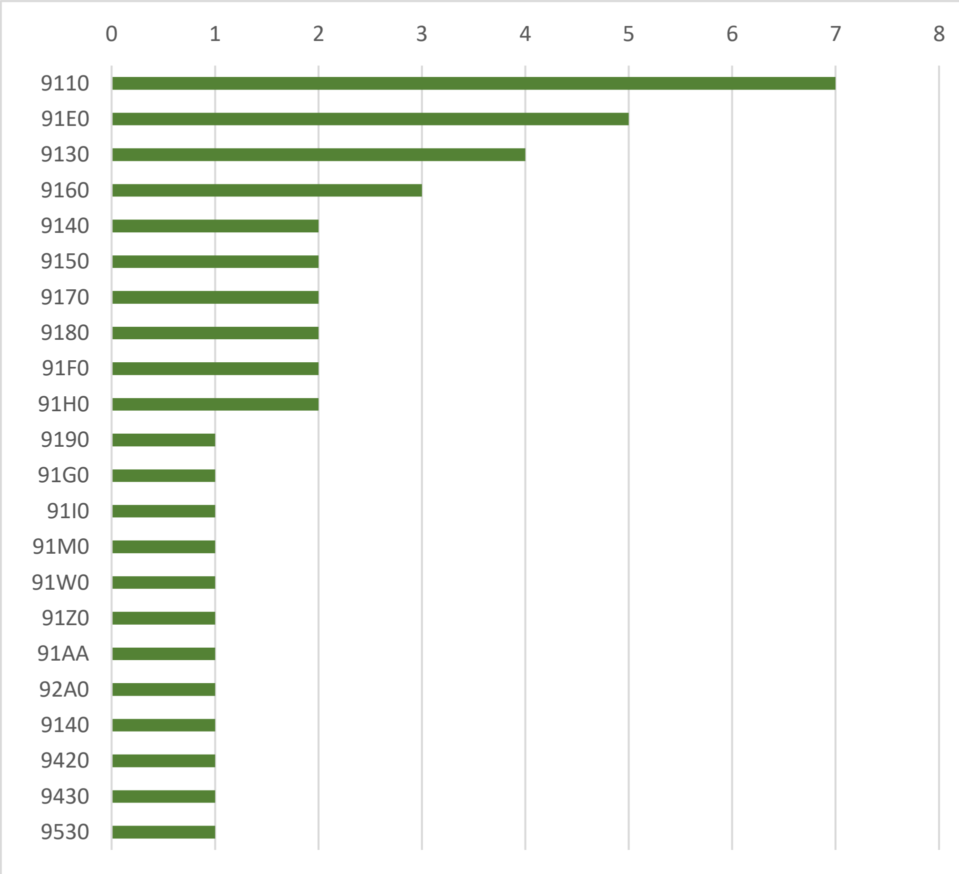


Figure 7: Number of countries proposing thresholds for deadwood for selected single habitat types

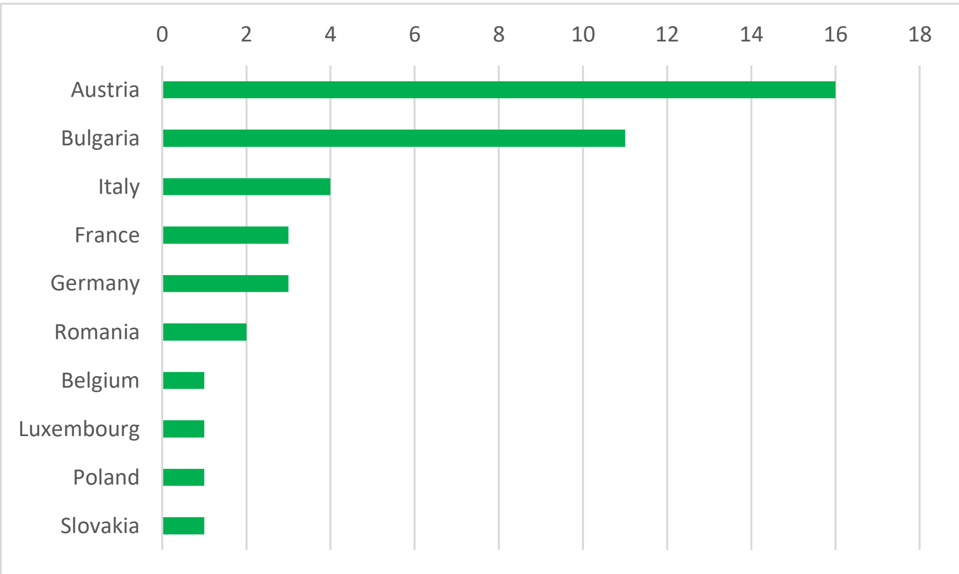


Figure 8: Number of habitat types mentioned by the single countries

Around 35% of the retrieved guidelines include the ranking system *a*, *b*, and *c*, while 50% give indications regarding minimum dimensions for being inventoried. Regarding the total *amount of deadwood,* the ranges of diameter is not often mentioned, but indicatively Austria accepts 20 cm (10 cm in high elevations) as minimum diameter, while Germany considers only deadwood larger than

35 cm; length is not considered. For *habitat trees* the minimum dimensions fluctuate between 35 and 80 cm to be considered, but the definition may include trees that are hosting nesting birds (*e.g.* according to some guidelines in Germany or Austria), regardless the diameter.

Finally, for *large size deadwood* the limits range between 10 and 60 cm, but for this descriptor length is more mentioned (50% of the minimum diameters are associated with a minimum length to consider, from 2 to 3 meters). The 10 cm value for diameter in the Austrian guidelines, a small value compared to *e.g.* the 60 cm of Luxembourg, can be related to the mountainous habitats, where the conditions do not often allow the production of such large deadwood parts.

Another observation is the scarcity of suggestions regarding quality: only 7 guidelines consider the tree species for deadwood, while only the Slovakian guideline explicitly requires different stages of decaying, despite scientific literature stresses the importance of this quality aspect (above all, Merganičová *et al.*, 2012).

Finally, the position of deadwood is considered: while *habitat trees* are by definition standing, *total deadwood amount* and *large size deadwood* can always be both standing and lying: a differentiation between the two is not necessary when dealing with general biodiversity, but it has to be considered for specific conservation measures: *e.g.* woodpeckers' presence is affected more by standing deadwood rather than lying (Ranius and Fahrig, 2006).

Regarding the amounts for every single descriptor, there is no clear threshold. For the *total amount of deadwood*, literature suggests 20-30 m^3/ha as a good value for general biodiversity

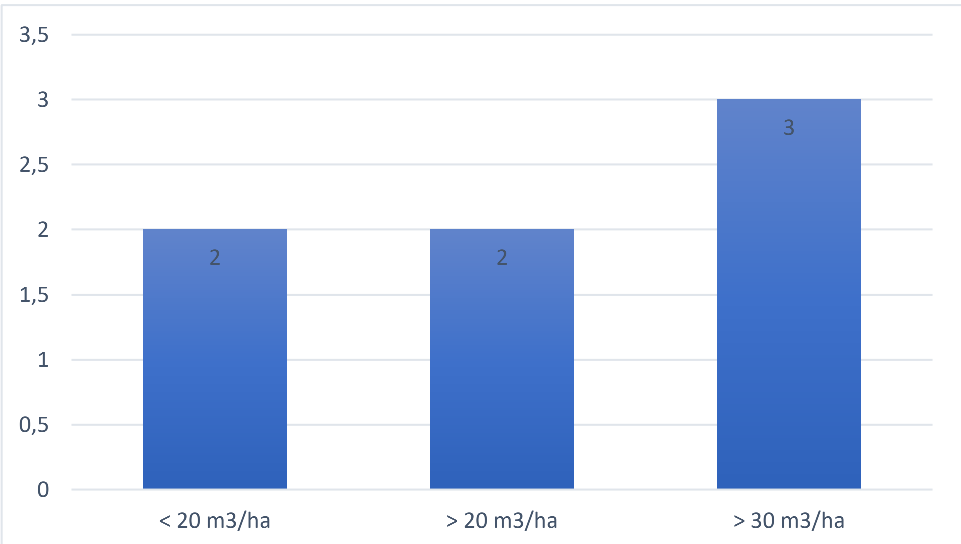


Figure 9: Number of guidelines considering different thresholds as favourable for deadwood amount

(Merganičová *et al.*, 2012), a value not considered by all the retrieved guidelines (Figure 9); it should be noted that of the 14 thresholds retrieved for *total amount of deadwood*, only 7 are expressed in cubic meters per hectare, while the remaining 7 are expressed as a percentage: Figure 9 do not consider them due to the different measure, expressed as a percentage. In order to allow further comparison, also including Austria and Bulgaria, absolute values have been roughly estimated from suggested percentage and national averages (Table 12). These results, however, may not reflect the real threshold to be applied in single sites, hence have not been considered in Figure 9.

Country	**Percentage in the thresholds**	**National average in m^3/ha**	**Equivalent in m^3/ha**	**References**
Austria	6-12%	291	17,5 - 35	European Commission, 2009
Bulgaria	8%	161	12,9	European Commission, 2009

Table 12: Conversion from percentage to m^3/ha using the national average living wood stock

Regarding *habitat trees* (Figure 10), the majority of the guidelines suggests more than 5 individuals per hectare, while Bulgaria is more demanding, with more than 10 individuals per hectare; France, Belgium and Bavaria on the other hand require as threshold only two or three individuals per hectare.

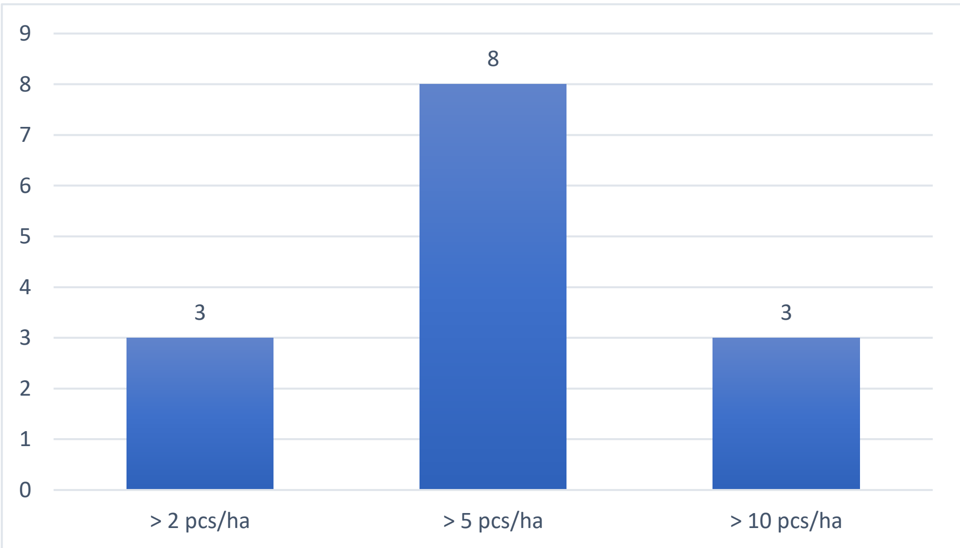


Figure 10: Number of guidelines considering different thresholds as favourable for habitat trees

For the definition of *large size deadwood* (Figure 11) there is no common value, but the majority of the guidelines indicates more than 3 individuals per hectare as a threshold to maintain favourable conditions in the forests. Still, as already mentioned the dimensions are ranging from 20 to 60 cm for the diameter and with two or three meters for the length, when specified, so that comparison may be poorly meaningful.

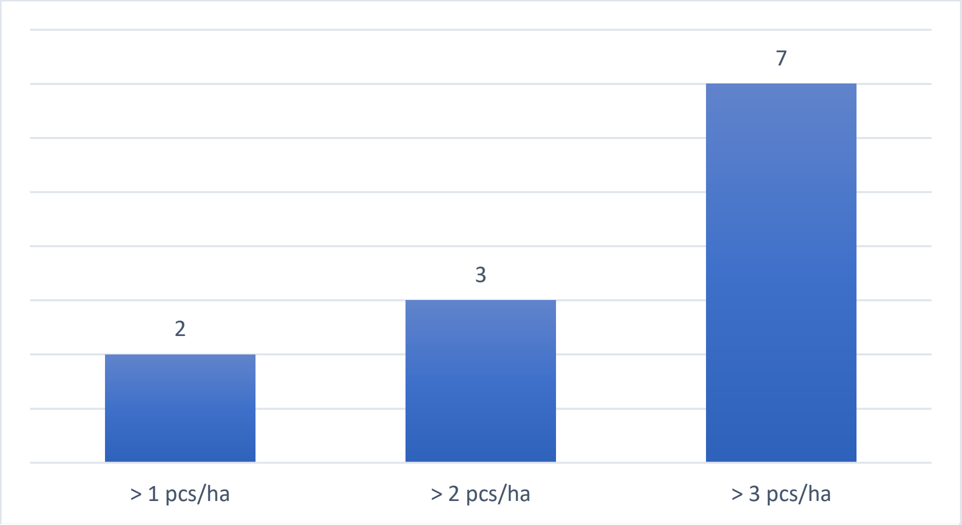


Figure 11: Number of guidelines considering different thresholds as favourable for large size deadwood

A last possible consideration is that different countries had different reasons to create the guidelines: this is seldom explicit, but still some differences can be observed. For example, Romanian and Bulgarian guidelines never mention goals different from biodiversity conservation (Dimitrov and Petrova, 2014a, 2014b, Zingstra *et al.*, 2009); also the Natura 2000 source regarding the habitat type 9110 *Luzulo-Fagetum* beech forests obviously only mentions conservation as a goal, and rather blames the production and the excessive exploitation as one of the reasons why European forests need today conservation measures (Thauront and Stallegger, 2008). The Italian guideline created distinct thresholds for areas where conservation assumes a primary role and for areas where timber production still represents the main objective, in one of the rare cases where the goals are explicitely mentioned (Casale *et al.*, 2016). Austrian guidelines insist on the protective functions of the mountain forests, probably due to the high share of the population depending on the protection function of the forest regarding rockfall or avalanches (Gimpl *et al.*, 2018).

3.5. A framework for decision-making

A simple framework was designed to help decision-makers in deadwood management in selected Natura 2000 forest habitats and, particularly, in proposing an amount of deadwood in its different forms to leave in a forest to ensure a healthy and stable forest condition.

The framework includes a decision tree (Figure 12) and 4 tables (Tables 13 to 16).

3.5.1. The decision tree

When using the decision tree, the first step to undertake is to decide whether the conservation goal is improving general biodiversity, probably the most common case in Natura 2000 sites, or just the status of one or few *taxa* that requires specific management measures. Should the latter be the case, the user will find in the first table, "Specific conservation goals for deadwood-dependant *taxa*" (Table 13), the values suggested by the literature to improve the status of several *taxa*. It is worth noting that in retrieved guidelines for Natura 2000 sites there are no suggestions for species-dependant management measures. Hence the table "Specific conservation goals for deadwood-dependant *taxa*" includes thresholds coming from literature unrelated to Natura 2000, but mostly arising from single experiments and researches discussed in a paper by Müller and Bütler (2010).

If the user identified that no specific *taxon* represents a management goal, the second step would be to extrapolate valuable information from similar situations. The best option would probably be a literature review regarding amounts and thresholds for similar sites, especially from the same region or country in order to consider similar conditions. However, literature reviews are time consuming since the information is scattered in the scientific literature, and, even when available, may be poorly significant due to differences in elevation, exposure, slope, precipitation, *etc*.

If no suitable thresholds have been retrieved, the user may move forward in the decision tree, which at this point offers three main descriptors: total amount of deadwood, number of habitat trees, and amount of large size deadwood. Once identified which descriptor is the most relevant to achieve his goals, the user finds suggested thresholds collected in three tables, one for each descriptor. The user can also choose a combination of descriptors and, in this case, thresholds from more tables will be considered.

3.5.2. The tables

Regarding the tables, the first one ("Specific conservation goals for deadwood-dependant *taxa*", Table 13) collects the suggested quantity of deadwood to preserve some important deadwood-dependant *taxa*. The table collects suggestions for three forest typologies (deciduous, beech, and coniferous/alpine forests) associated to 22 habitats of Natura 2000 (Table 3). Starting from more detailed information (Müller and Bütler, 2010), deadwood dependant *taxa* have been clustered into four groups:

- Birds
- Insects
- Fungi
- Others (*Gastropoda*, mosses and lichens)

In the three tables collecting thresholds for deadwood amount ("Total amount of deadwood for habitat type", "Number of habitat trees for habitat type", "Amount of large size deadwood for habitat type", Tables 14 to 16) the suggested values are arranged according to the Habitats Directive definitions (Council of the European Union, 1992) and related to the 22 habitats from Continental and Alpine biogeographical regions (Table 3). Contrasting values have been harmonised following the most recent suggestions from the selected literature. In few cases, however, the tables suggest more than one value per single habitat type: this mainly happens when different criteria are proposed (*e.g.* m^3/ha or percentage of living wood stock) or when the different values are associated with specific conditions (*e.g.* elevation).

Empty cells in the matrixes correspond to no values found in the literature, which indicates lack of information regarding such cases and hence the need for further research.

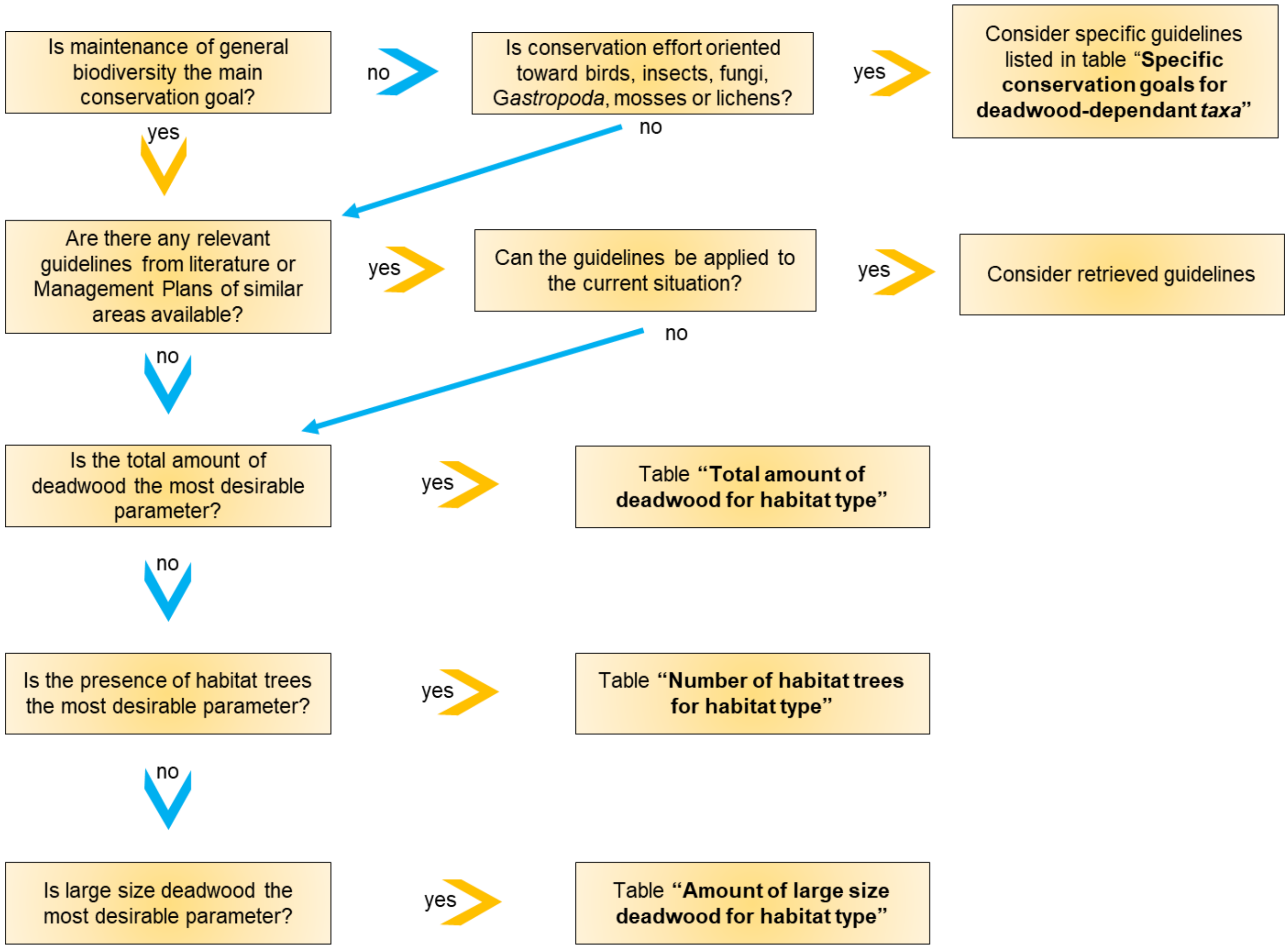


Figure 12: Decision tree

Table 13: Specific conservation goals for deadwood-dependant taxa

	Deciduous	**Beech**	**Coniferous/Alpine**
Natura 2000 habitats	**9160, 9170, 9180, 9190, 91E0, 91F0, 91G0, 91H0, 91I0, 91M0, 91Z0, 91AA, 92A0**	**9110, 9130, 9140, 9150, 91W0**	**9410, 9420, 9430, 9530**
Birds	> 36 m^3/ha (8-17 m^3/ha snags)		20-60 m^3/ha to ensure the presence of most of the cavity breeding birds
Insects	> 40 m^3/ha	29-140 m^3/ha depending on species	> 37 m^3/ha
Fungi		> 61 m^3/ha	20-220 m^3/ha depending on the species
Others		> 30 m^3/ha, partly laying (for *Gastropoda*)	> 17 m^3/ha (for mosses) > 127 m^3/ha (for lichens)

Table 14: Total amount of deadwood for habitat type

Habitat code	Habitat description	Total deadwood amount		Country
		Values	Notes	
9110	*Luzulo-Fagetum* beech forests	6-12% of wood stock	Minimum 2-5 m^3/ha	Austria
		>20 m^3/ha	Standing and lying	Belgium
		> 8% of wood stock		Bulgaria
9130	*Asperulo-Fagetum* beech forests	6-12% of woodstock		Austria
		> 8% of wood stock		Bulgaria
		>40 m^3/ha	ø≥40 cm	Germany
9140	Medio-European subalpine beech woods with *Acer* and *Rumex arifolius*	6-12% of wood stock	Minimum 2-5 m^3/ha	Austria
9150	Medio-European limestone beech forests of the *Cephalanthero-Fagion*	6-12% of wood stock	Minimum 2-5 m^3/ha	Austria
		> 8% of wood stock		Bulgaria
9160	Sub-Atlantic and medio-European oak or oak-hornbeam forests of the *Carpinion betuli*	6-12% of wood stock		Austria
		3 m^3/ha	for oak ø> 20 cm	Germany
9170	*Galio-Carpinetum* oak-hornbeam forests	6-12% of wood stock		Austria
		> 8% of wood stock		Bulgaria
		3 m^3/ha		Germany
9180	*Tilio-Acerion* forests of slopes, screes and ravines	6-12% of wood stock		Austria
		> 8% of wood stock		Bulgaria
		3 m^3/ha		Germany
9190	Old acidophilous oak woods with *Quercus robur* on sandy plains	> 33-35 m^3/ha	For conservation purposes	Italy
		> 15 m^3/ha	For production purposes	Italy
91E0	Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior* (*Alno- Padion, Alnion incanae, Salicion albae*)	6-12% of wood stock	Minimum 2-5 m^3/ha	Austria
		> 8% of wood stock		Bulgaria
		>30 m^3/ha	ø≥ 35 cm	Germany
91F0	Riparian mixed forests of *Quercus robur, Ulmus laevis* and *Ulmus minor, Fraxinus excelsior* or *Fraxinus angustifolia*, along the great rivers (*Ulmenion minoris*)	6-12% of wood stock	Minimum 2-5 m^3/ha	Austria
		> 8% of wood stock		Bulgaria
		>30 m^3/ha	ø≥ 35 cm	Germany
91G0	Pannonic woods with *Quercus petraea* and *Carpinus betulus*	6-12% of wood stock		Austria
91H0	Pannonian woods with *Quercus pubescens*	6-12% of wood stock		Austria
		> 8% of wood stock		Bulgaria
		>30 m^3/ha	ø≥ 35 cm	Germany
91I0	Euro-Siberian steppic woods with *Quercus* spp.	6-12% of wood stock		Austria
		>30 m^3/ha	ø≥ 35 cm	Germany
91M0	Pannonian-Balkanic turkey oak — sessile oak forests	> 8% of wood stock		Bulgaria
91W0	Moesian beech forests	> 8% of wood stock		Bulgaria
91Z0	Moesian silver lime woods	> 8% of wood stock		Bulgaria
91AA	Eastern white oak woods	> 8% of wood stock		Bulgaria
92A0	*Salix alba* and *Populus alba* galleries	> 30 m^3/ha		Romania
9410	Acidophilous *Picea* forests of the montane to alpine levels (*Vaccinio- Piceetea*)	6-12% of wood stock	Minimum 5-9 m^3/ha, ø> 20 cm	Austria
9420	Alpine *Larix decidua* and/or *Pinus cembra* forests	6-12% of wood stock	Minimum 5-10 m^3/ha, ø> 10	Austria
9430	Subalpine and montane *Pinus uncinata* forests			
9530	(Sub-) Mediterranean pine forests with endemic black pines			

Table 15: Number of habitat trees for habitat type

Habitat code	Habitat description	Habitat trees		Country
		Values	Notes	
9110	*Luzulo-Fagetum* beech forests	≥ 6 individuals/ha	Trees with cavities or nests Ø > 40 if cavities, dead parts, degraded bark Ø > 80 cm for beech, oak, noble deciduous Ø > 40 cm for other species	Germany
		≥ 5 individuals/ha	Ø ≥ 80 cm in lowlands, Ø ≥70 cm in uplands Ø ≥ 60 cm in high mountain	Germany
9130	*Asperulo-Fagetum* beech forests	5-10 trees/ha	preferably different species	Austria
9140	Medio-European subalpine beech woods with *Acer* and *Rumex arifolius*	5-10 trees/ha	preferably different species	Austria
9150	Medio-European limestone beech forests of the *Cephalanthero-Fagion*	5-10 trees/ha	preferably different species	Austria
9160	Sub-Atlantic and medio-European oak or oak-hornbeam forests of the *Carpinion betuli*	tessellated distribution of different phases of different age	trees with holes, decay or cracks	Germany
		8-10 trees/ha		Italy
9170	*Galio-Carpinetum* oak-hornbeam forests	tessellated distribution of different phases of different age	trees with holes, decay or cracks	Germany
9180	*Tilio-Acerion* forests of slopes, screes and ravines	tessellated distribution of different phases of different age	trees with holes, decay or cracks	Germany
9190	Old acidophilous oak woods with *Quercus robur* on sandy plains	8-10 trees/ha		Italy
91E0	Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior* (*Alno- Padion, Alnion incanae, Salicion albae*)	5-10 trees/ha	preferably different species	Austria
91F0	Riparian mixed forests of *Quercus robur, Ulmus laevis* and *Ulmus minor, Fraxinus excelsior* or *Fraxinus angustifolia* along the great rivers (*Ulmenion minoris*)	5-10 trees/ha	preferably different species	Austria
91G0	Pannonic woods with *Quercus petraea* and *Carpinus betulus*			
91H0	Pannonian woods with *Quercus pubescens*	5-10 trees/ha	preferably different species	Austria
91I0	Euro-Siberian steppic woods with *Quercus* spp.	5-10 trees/ha	preferably different species	Austria
91M0	Pannonian-Balkanic turkey oak — sessile oak forests	>10 trees/ha	snags, ø≥ 20 cm	Bulgaria
91W0	Moesian beech forests	>10 trees/ha		Bulgaria
91Z0	Moesian silver lime woods	>10 trees/ha		Bulgaria
91AA	Eastern white oak woods	>10 trees/ha		Bulgaria
92A0	*Salix alba* and *Populus alba* galleries	Extensive presence		Romania
9410	Acidophilous *Picea* forests of the montane to alpine levels (*Vaccinio- Piceetea*)	5-10 trees/ha	preferably different species	Austria
9420	Alpine *Larix decidua* and/or *Pinus cembra* forests	5-10 trees/ha	preferably different species	Austria
9430	Subalpine and montane *Pinus uncinata* forests			
9530	(Sub-) Mediterranean pine forests with endemic black pines			

Table 16: Amount of large size deadwood for habitat type

Habitat code	Habitat description	Large size deadwood		Country
		Values	Notes	
9110	*Luzulo-Fagetum* beech forests	≥ 3 pcs/ha	≥ 1 standing	Germany
		> 3 pcs/ha	Standing and lying L> 2m, ø> 40 or 60cm	Luxemburg
9130	*Asperulo-Fagetum* beech forests	3 pcs/ha	Standing and lying ø> 35 cm	France
9140	Medio-European subalpine beech woods with *Acer* and *Rumex arifolius*	3 pcs/ha	Standing and lying ø> 35 cm	France
9150	Medio-European limestone beech forests of the *Cephalanthero-Fagion*			
9160	Sub-Atlantic and medio-European oak or oak-hornbeam forests of the *Carpinion betuli*	> 1-2 pcs/ha	ø≥ 20 cm	Austria
9170	*Galio-Carpinetum* oak-hornbeam forests	> 1-2 pcs/ha	ø≥ 20 cm	Austria
9180	*Tilio-Acerion* forests of slopes, screes and ravines	> 1-2 pcs/ha	ø≥ 20 cm	Austria
9190	Old acidophilous oak woods with *Quercus robur* on sandy plains	2 uprooted, 2 broke pcs/ha	ø > 40 cm	Italy
91E0	Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior* (*Alno- Padion, Alnion incanae, Salicion albae*)	≥ 3 pcs/ha	ø≥ 40 cm	Germany
91F0	Riparian mixed forests of *Quercus robur, Ulmus laevis* and *Ulmus minor, Fraxinus excelsior* or *Fraxinus angustifolia*, along the great rivers (*Ulmenion minoris*)	≥ 3 pcs/ha	ø≥ 40 cm	Germany
91G0	Pannonic woods with *Quercus petraea* and *Carpinus betulus*	> 1-2 pcs/ha	ø≥ 20 cm	Austria
91H0	Pannonian woods with *Quercus pubescens*	> 1-2 pcs/ha	ø≥ 20 cm	Austria
		≥ 3 pcs/ha	ø≥ 40 cm	Germany
91I0	Euro-Siberian steppic woods with *Quercus* spp.	> 1-2 pcs/ha	ø≥ 20 cm	Austria
		≥ 3 pcs/ha	ø≥ 40 cm	Germany
91M0	Pannonian-Balkanic turkey oak — sessile oak forests			
91W0	Moesian beech forests			
91Z0	Moesian silver lime woods			
91AA	Eastern white oak woods			
92A0	*Salix alba* and *Populus alba* galleries			
9410	Acidophilous *Picea* forests of the montane to alpine levels (*Vaccinio- Piceetea*)			
9420	Alpine *Larix decidua* and/or *Pinus cembra* forests			
9430	Subalpine and montane *Pinus uncinata* forests	> 3 pcs/ha	ø≥ 10 cm	Austria
9530	(Sub-) Mediterranean pine forests with endemic black pines	> 3 pcs/ha	ø≥ 10 cm	Austria

4. Discussion

The problems encountered in this thesis are partly attributable to the language barriers and to the complexity of a project such as Natura 2000, but further discrepancies appear also when discussing about the role of measurements and thresholds.

Because of its importance for sustainable societal development, biodiversity conservation in forests could be more efficient if based on strong international cooperation and trustworthy information (Kovac *et al.*, 2015), while instead every institution moves independently, and countries not always express their purposes and goals. So, a first suggestion could be to translate general or poorly formulated policy objectives (*e.g.* stop the loss of biodiversity, increase protected forest areas) into quantitative targets (*e.g.* thresholds) (Barbati *et al.*, 2014).

The next chapters analyse more in detail several aspects regarding techniques, thresholds and the proposed framework.

4.1. Comparison of deadwood assessment techniques and descriptors

Among protocols for assessing deadwood, differences can be found regarding:

- techniques for deadwood amount assessment
- descriptors for deadwood categories
- thresholds for the specification of diameter and length
- requirements in quality (level of decay, tree species, *etc.*)

Regarding the techniques for deadwood assessment, flaws are present in the inventorying process: if countries use the same inventorying methodologies but separate diameters for either standing or downed deadwood, then their resulting estimates are not comparable. Furthermore, the factors that drive deadwood inventories have to be considered. The main purpose of such inventories may be to assess fuel loadings, or carbon sequestration, or biodiversity assessment; even economic constraints have to be considered when writing the protocols (Woodall *et al.*, 2006).

Apparently, the major threat to the homogeneity of the NFIs comparison is not only the differences in procedures such as sampling density and frequency, or sampling technique (*e.g.* fixed radius plot or line intersect), but the differences in definitions, the lack of clarity in sample protocol or estimation procedure, and sparse availability of inventory data to compare deadwood data all over Natura 2000 sites. Woodall *et al.* (2006) offer as possible solutions to increase the flexibility in order to accommodate varying definitions (as already mentioned, a similar process had to be done for this thesis), to make thresholds similar, to increase the inventory procedures and protocols publication and their submission to international peer review, and to increase the communication among the organisms in charge of the NFIs, avoiding independent and incomparable solutions (Woodall *et al.*, 2006).

Regarding the descriptors, the most commonly found is the *total amount of deadwood*. It allows an immediate evaluation of the forest conditions, if compared to values originating from old-growth stands such as National Parks, natural reserves and so on. Cubic meter per hectare is the most common unit of measurement. Still, the *total amount of deadwood* alone is not a suitable descriptor on a European scale: countries like Austria and Bulgaria opted for a measure of deadwood as percentage of living wood stock, in order to combine the amount of deadwood to the productivity of every site (Gimpl *et al.*, 2018, Zingstra *et al*., 2009).

For *habitat* trees, in the process of harmonisation many definitions entered this descriptor, which includes veteran trees, snags, senescent individuals *etc*.

Regarding the management of *habitat trees*, during the inventorying phase it has to be considered also that not only existing habitat trees must be excluded from eventual felling operations, but also trees with a possible development into habitat trees must be noted and looked after (Zehetmair *et al.*, 2015).

Furthermore, even if leaving old trees in the stand may appear non-economical, it may be inexpensive to leave reasonable amounts of naturally dying trees. According to Banas *et al.* it may be economically more advantageous to retain them than to harvest them, hence leaving some single trees to die naturally may represent a good management practice. Other solutions, like increasing the rotation period to reduce the management impact on deadwood, are too expensive to be realistic options (Banas *et al.*, 2014).

Many countries highlight also the importance of *large size deadwood* as suitable habitat for hundreds of species: deadwood persistence in forests varies according to its dimensions, and some of these larger parts (some guidelines indicate more than 50 centimetres) can persist more than 40 years (Terzuolo *et al.*, 2009), offering durable source of shelter and food for many generations of organisms.

Extraction of deadwood and *retention trees* are much rarer, but still may represent important starting points for future guidelines: e*xtraction of deadwood* is considered a threat only by Bulgaria, that considers extraction of dry and fallen deadwood as one of the main factors leading to a loss of biological diversity: the reason of removal is because deadwood is considered to be a source of diseases and infections (Zingstra *et al*., 2009). Also Austria, however, discourages the extraction of deadwood. Other countries do not consider this parameter probably due to the fact that in many European situations (including Bulgaria, even if it's a more recent phenomenon) rural economies are decreasing, and forest management is now carried with high mechanization and awareness, so that extraction, carried on for example after severe disturbances, is often controlled and hence does not represent a threat.

Finally, among the retrieved guidelines, France is the only member state that considers an important action ensuring the presence of *retention trees*, forest patches where trees are left unmanaged for longer times, and in small proportion are not managed at all, until mortality takes place (Thauront and Stallegger, 2008). This action is applied on small patches, 5% of the whole area, but could represent an opportunity to increase naturalization of not only French forests, but in the whole Europe.

Regarding the differences in diameters and lengths, the vast ranges of dimensions could be again associated with productivity: it is affected by latitude, altitude, climate, exposure, soil and many other characteristics so that one single definition for deadwood could never represent a valid European standard. For this reason, countries such as France, Germany or Luxembourg determine different diameters for the same descriptor, such as *veteran trees*: if 60 centimetres of DBH is considered enough for a veteran tree in the German mountains, 80 centimetres is the threshold for trees in the lowlands, considering that the diameter increment is proceeding at different velocities (Thauront and Stallegger, 2008).

Furthermore, for some forest types dimensions are apparently not so relevant, so *e.g.* for the mountainous habitats 9430 (Subalpine and montane *Pinus uncinata* forests) and 9530 ((Sub-) Mediterranean pine forests with endemic black pines) Austria does not provide thresholds in cubic meters nor percentage of living wood stock, but rather as a number of dead trees that is thought to be sufficient to ensure a good level of biodiversity (Gimpl *et al.*, 2018): the reason may be that in such habitats, where productivity is drastically reduced by the climatic conditions, other indications may be not relevant or of difficult application.

About the quality of deadwood not many standard definitions could be collected, and in the guidelines this aspect was seldom mentioned. The importance of the presence of different stages is well acknowledged by the scientific literature, and several sources suggest considering this aspect, but no indications at all regarding what stage or in what share a stage has to be favoured are reported. Regarding the tree species, felling trees from alien species may seem the best way to increase the deadwood amount and reduce their presence (Cavalli and Mason, 2003), but in particular cases the endangered microfauna is associated to the indigenous tree species, so these are to be preferred also when actively providing deadwood.

4.2. Comparison of the absolute values proposed for deadwood management

Regarding the values, it is common understanding in scientific literature that for the *total deadwood amount*, 20-30 m^3/ha is a suitable amount to safeguard a wide range of deadwood-depending species (Merganičová *et al.*, 2012). This level, however, is explicitly mentioned in only 5 of the 14 retrieved guidelines. Other recommended values to apparently satisfy the majority of species are >30-50 m^3/ha for broadleaves forests and 20-30 m^3/ha for boreo-alpine forests (Müller and Bütler, 2010).

For *habitat trees* the results are more scattered and no clear number is given by literature, but apparently 10 individuals per hectare is the amount that satisfies the more scrupulous guidelines, with some countries such as France, Germany and Slovakia that accept much smaller numbers (only 2 individuals per hectare for France and Bavaria).

Similar are *large size deadwood* and *coarse dead trees*, descriptors not so often mentioned in the scientific literature: apparently, in the guidelines 3 pieces per hectare is the most common value, only Poland requires 5 to satisfy the favourable conditions.

In conclusion, since it's poorly meaningful to calculate an average of thresholds, not all the guidelines apparently satisfy the common knowledge for deadwood amounts, but for further decisions there are enough sources available to understand what amount is suitable for any forest with any provision goal. Of course these values must be compared to current values, to avoid the establishment of unrealistic thresholds.

4.3. Differences in guidelines and thresholds for deadwood management

Comparison among the guidelines was, as a consequence of their diversity, poorly meaningful; thus, there is a strong need to define and implement homogeneous guidelines for deadwood management at a European level (EEA, 2015).

A first division appears when dealing with the different biogeographical regions. These are differentiated mostly by the climate (*e.g.* cold and harsh for the Alpine region) and the morphology (*e.g.* the Continental region has a relatively flat landscape), so that pronounced differences are easy to find *e.g.* in productivity. In different contexts, deadwood assumes different roles, and the identification of these roles is fundamental to provide the best management solutions. The use of different descriptors or the setting of different thresholds are the most common differences between Alpine and Continental regions, and these changes are expected to be find also in other biogeographical regions, in order to associate properly the deadwood functions to the environment.

Even once the biogeographical context is established though, differences can be quite surprising and apparently excessive. Taking the example of the habitat type 9130 (*Asperulo-Fagetum* beech forests), in Brandenburg and in Saxony the suggested thresholds for *total deadwood amount* consider, in the first region, 35 cm as minimum diameter considered, while in Saxony is 40 cm. For the same FFH type, values are different both in thresholds and amounts in Austria and Hungary, where the minimum diameter is respectively 20 and 30 centimetres (Schroiff, 2011).

Also in other contexts, definitions are too wide to allow any further analysis: for *large size deadwood*, Austria proposes 20 cm as minimum diameter (Gimp *et al.*, 2018), while Germany proposes 50 cm but, still, different German regions apply different lengths (2 or 3 meters) in order to be considered (Thauront and Stallegger, 2008).

Some guidelines prefer not to give values, but underline the importance of some parameters, recommending some improvements on the current situations. Romania considers veteran trees' condition favourable when "extensively present" (BeNatur, 2013), while France suggests increasing the amount of dead trees, lying or standing, with a diameter larger than 35 cm, assuming a general lack of such structures in the national forests (Winter *et al.*, 2014).

Similarly, a German guideline doesn't provide numbers for veteran trees but suggests a tessellated distribution of different phases of different age, to increase the number of habitats and hence the biodiversity in the forests (Winter *et al.*, 2014).

The reasons why countries act so independently are not easy to be understood. They may be found in different member states' aims and goals (Woodall *et al.*, 2006), often not explicitly mentioned.

Indicatively, lower thresholds regarding amounts and dimensions could be associated with lower interests in nature conservation, since, due to the "reverse j" distribution of tree stem numbers in forests, smaller dimensions are easier to achieve, and low thresholds imply low amounts of deadwood in the forest.

Besides timber production as main goal, also other services may be associated with a higher productivity or a lower amount of deadwood. (Gimpl *et al*., 2018).

Some effects regarding the provision of ecosystem services are listed:

- *Timber production*. Historically deadwood was seen as possible source of pathogens (Kirisits, 2017) and fuel for wildfires (Sotirov *et al.*, 2017). Hence the deadwood amounts are consequently lower under such conditions. It has been shown that in managed forests deadwood amounts are clearly lower than in unmanaged ones (Keren and Diaci, 2018). Natura 2000 has to protect biodiversity, but many forests are managed and exploited for wood production, so this may affect the threshold setting.

- *Non-Timber Forest Products (NTFPs)*. Depending on the type of NTFP considered, deadwood is fundamental *e.g.* for fungi such as *Inonotus obliquus*, or Chaga mushroom, a basidiomycete that grows on birch, whose benefits are increasing its popularity; higher level of biodiversity shouldn't affect negatively the provision of such products. A completely different, rather particular case is offered by some Swedish and Finnish companies, who exploit explicitly deadwood as raw material for construction (*kelo*).
- *Site and infrastructure protection*. Deadwood has a marginal but still present role in avoiding erosion, slowing water flows, creating water storage (VV.AA., 2013) and reducing rock fall (Fuhr *et al.*, 2015). Still, a protective forest has to be healthy: high amounts of deadwood may represent a threat to the stability of the forest, hence particular attention should be paid when provisioning protection.
- *Water*. Apparently, water quality is not strongly affected by deadwood: downed logs may obstacle infiltration, but at the same time can also slow down run-off (VV.AA., 2013), so aquifers are not influenced relevantly.
- *Climate*. Deadwood may be relevant in carbon storage, with an estimated 14% of the total forest carbon pool contained in dead organic material (excluding fine woody debris) (Woodall *et al.*, 2006).
- *Recreation*. Tourism may be affected by deadwood amounts in different ways, depending on how the user perceives nature; an increase in biodiversity should definitely favour certain activities (birdwatching, nature photography, *etc.*), but high amounts of deadwood may also induce negative impressions (Nosswitz, 1998).

In conclusion, apparently timber production and maintaining the protective function are negatively affected by higher deadwood amounts and, due to the importance of these aspects, they are expected to have strong influence on management decisions.

It's impossible to cluster the countries according to their goals, but it can be observed how some guidelines only consider biodiversity conservation, while others integrate biodiversity with other ecosystem services. This might be one of the reasons for Austria, an important timber producer and a country with many protection forests, to use lower thresholds, in order to maintain the ecosystem services. Biodiversity may be ranked lower than other services such as protection, production or water provision, historically fundamental functions of Austrian forests. As a comparison, in an area in Northern Italy ("Parco Lombardo della Valle del Ticino"), the threshold for deadwood in exploited forests is more than three times higher than the minimum proposed by Austria for the same habitat (Casale *et al.*, 2016): this is an area where timber production, even if still practised, doesn't have strong importance. Moreover, it is a flat area, so the protection role is marginal, while heavy human impact in the surroundings may have driven local decision-makers to focus their goals on biodiversity conservation.

Different is Germany, where timber production is clearly an economic interest (third European producer in 2015, only behind Finland and Sweden): still, German thresholds are among the highest (Schroiff, 2011), maybe due to the fact that decision-makers still recognize biodiversity as a main aspect in forest management.

4.4. Consequences for the management

Once the differences in guidelines are observed and discussed, other problems appear. A major negative aspect has to be connected with the whole threshold idea, a simple concept but with clear limitations. The most obvious criticism is that once a threshold is derived to ensure the suitable conservation status for a larger set of species, some may still become extinct (Müller and Bütler, 2010), since there is no research about the thresholds for every species and many will be somehow "left behind".

The thresholds found in literature are furthermore very diverse, so that some authors questioned the feasibility of their application (Ranius and Fahrig, 2006): this idea is supported also by the fact that there is no widely established method to obtain values, and once the information is acquired, it gets scattered throughout the scientific literature, with the consequent difficulties for decision-makers to gather and apply them (Müller and Bütler, 2010).

Another criticism may be that the presence of an endangered species in a protected environment is not enough to ensure its survival: species can become extinct even after deadwood volumes lie above the critical threshold. According to Tilman *et al.* (1994), a metapopulation decline in response to habitat destruction occurs with a time delay, a phenomenon called the ‘‘extinction debt’’: this means that such a species could survive as ‘‘living dead’’ for a certain period of time in an ecosystem that is no longer suitable in the long term (Kraus and Krumm, 2013). Both these aspects may show the limitation of such general deadwood thresholds, and the necessity for more studies that also consider the landscape scale and connectivity of the metapopulation in threshold analyses (Müller and Bütler, 2010).

Time is an aspect that has to be taken into account when dealing with operations for conservation purposes. Natura 2000 is a project with long-term objectives, constantly evolving, but there is an urgency of undertaking all the possible actions to minimize the risks regarding the loss of biodiversity. So there is a need to consider long term monitoring of deadwood and its continuous presence over time.

Similar to the time problem, also space may represent a challenge: as already mentioned, when watching at the average distribution of deadwood in national reports, it has to be considered that managed forests have much lower values, in some context very close to zero (Christensen *et al.*, 2005), while according to some French studies it is very important to encourage biodiversity at landscape scale, rather than maximize it at parcel scale, regarding conservation both of habitats and species (Thauront and Stallegger, 2008). Some authors consider the eventuality of the climate change as a threat to the concept of biodiversity “islands”, so that the survival of some habitats and species may only be ensured by sustainable management at large scales, and not with protecting only few sites (Schulze, 2018). The feasibility of this concept is though complex, so that a Polish guideline actually prefers to isolate specially established preserves of biodiversity in State Forests, for example refuge areas for xylobiotic species: in these areas it discourages the removal of dead and dying trees even when the threshold value for favourable status (20 m^3/ha) is considerably exceeded (Baran *et al.*, 2017).

Both of the two options present advantages, but their application may be possible only in some contexts: for sites with heavy human impact, a better solution may be establishing refuge areas (Müller and Bütler, 2010), such as the *retention trees* present in the French guidelines, while for sites with a low human influence may be possible to distribute the efforts on the whole surface.

In addition, other authors discuss that even if it is possible to obtain high levels of dead wood amounts in managed forests (but only during some phases of the rotation period), these amounts are likely insufficient to allow sensitive saproxylic species to occur continuously in the long term. Hence, unmanaged forests are generally more important than managed forests for these species because their quantities of deadwood are enough to sustain an uninterrupted presence (Ranius and Fahrig, 2006).

Another aspect to be mentioned, is that the two-thresholds ranking system provided by Europe has been effectively used to describe the conservation status of the network, but nevertheless some difficulties arise from its use. Again, no explicit criteria have been found to set the thresholds.

For instance, referring to the *total deadwood amount* both Germany and Poland apparently consider 50% of the optimal amount as the threshold for a further division between "inadequate" and "bad" (Schroiff, 2011, Baran *et al.*, 2017).

Country	**Habitat**	**a**	**b**	**c**
Poland	91E0	> 20 m^3/ha	10-20 m^3/ha	< 10 m^3/ha
Germany	9130	> 40 m^3/ha	21-40 m^3/ha	< 20 m^3/ha

Romania opted for a different procedure, defining a very low second threshold at 4 m^3/ha for describing a "bad" status of conservation (BeNatur, 2013).

Country	**Habitat**	**a**	**b**	**c**
Romania	91E0 and 92A0	> 30 m^3/ha	4-30 m^3/ha	< 4 m^3/ha

Bulgaria, in its turn, choose a different unit of measurement for the *total deadwood amount* (as percentage of total living woodstock) and defined only one threshold, explicitly considering any lesser value as negative status, but still retains the three levels *a, b* and *c* since other parameters in the evaluation form are provided with two thresholds (Zingstra *et al*., 2009).

Country	**Habitat**	**a**	**b**	**c**
Bulgaria	91M0	> 8% of wood stock	less	less

Finally, Slovakia opted for three thresholds, defining an upper class labelled "very good", when dealing with veteran trees (Thauront and Stallegger, 2008).

Habitat	very good	a	b	c
9110	≥ 5 individuals/ha	1-4 individuals/ha	3-9 individuals/10 ha	< 3 individuals/10 ha

Furthermore, the *a*, *b* and *c* levels are often defined only for the three main descriptors encountered (*total deadwood amount*, *veteran trees*, *large size deadwood*), while for the rarer indicators this ranking system is not mentioned.

Thus, apparently, different management plans offer different interpretations of the ranking system. A possible way to reduce incongruences is to utilize ranges instead of single values as thresholds, hence increasing flexibility. The *a*, *b* and *c* ranges may overlap in a national context (*e.g.* 20-40 m^3/ha for *c*, 30-50 m^3/ha for *b* and 40-60 m^3/ha for *a*) and only when dealing with specific situations a single value could be extrapolated. This would still prevent full comparison, but it would increase the system use and its acceptance.

4.5. The proposed framework

Regarding management of sites for which suitable guidelines have not been yet established, the proposed framework provides suggestions for deadwood amounts.

The goal to cope with different methods and thresholds from different countries is clearly hard to achieve. This particularly holds for the total amount of deadwood, a measure that varies too much in definitions and thresholds to defined values to be agreed by all countries. Values for habitat trees and large size deadwood were defined in a narrower range and proved to be easier to harmonize.

The decision tree is quite basic, with some criticalities due to over-simplification: for example, it only provides suggestions for the main descriptors (*total deadwood amount*, *habitat trees* or *large size deadwood*), since information about other indicators, such as *extraction of deadwood* and *retention trees* is too scarce to provide a proper support.

Furthermore, due to the already discussed difficulties related to the implementation of the three levels (and two thresholds) ranking system, in the tables only one value is proposed, except for

Austria, where sometimes both an optimum quantity (given as percentage and included between 6 and 12% of the living wood stock) and a minimum quantity (given as cubic meters per hectare and included between 2 and 10 m^3/ha) are provided.

5. Conclusions

Only recently, biodiversity loss has become a relevant topic in the environmental debate like climate change or ozone depletion. Currently, however, it is considered the main threat the world is facing (Rockström *et al*., 2009), and Natura 2000 is in charge of contrasting this process: actions are today needed on every scale, in order to maintain biodiversity. Deadwood management is an important element for that.

About this, a major problem appears to be the impossibility to have comparable guidelines by the member states, due to language barriers and poor accessibility to knowledge (Woodall *et al.*, 2006). The idea of negotiating common definitions and thresholds for each forest habitat is perhaps out of reach, but the process of decision-making would be improved and harmonized by a better spread of available knowledge, *e.g.* by publishing procedures and protocols, submitting inventory data and reports to international peer review, and increasing communication among countries.

The task of decision-makers may be simplified by the availability of easy schemes, such as the framework proposed in this thesis. According to it, the first step would be to identify the goals of forest management, and, especially regarding conservation, a good strategy would be identifying umbrella species that represent different assemblages of saproxylic species dependant on certain typologies of deadwood (Ranius and Fahrig, 2006).

Then, an inventory can provide a reliable measure of the deadwood already present in the forest. Should this information have never been collected, this inventory phase may need some adjustments, for example differentiating the stages of decay and the type (standing, lying, veteran trees, species *etc.*). Eventually, any difference between the current and the ideal situation should be filled with either active actions (felling of trees) or passive ones (avoiding any deadwood removal and relying on natural mortality), considering that the management should include all deadwood types and a range of dimensions and decay stage as wide as possible (Keren and Diaci, 2018).

Many authors stressed the importance of applying a close-to-nature silvicultural approach (*e.g.* Lombardi *et al.*, 2012, Pignatti *et al.*, 2009), but the management abandonment cannot be generalized as a best practice for biodiversity conservation. Instead, enhancing forest landscape heterogeneity through the creation of a mosaic of non-intensively managed forests could better help the presence of ecologically different species (Sitzia *et al.*, 2017).

Particular attention should be paid to alpine forests, especially to those that have not been intensively managed in the last decades and have retained or re-established some important features of the natural ecosystems, since these environments require a longer time to develop old-growth characteristics (Motta *et al.*, 2006).

If dealing with frameworks, any framework, and particularly the decision trees, would require improvements regarding both structure and contents, mainly in order to offer valuable suggestions also for habitat types different from those dealt with in this thesis.

In addition, more research is still heavily needed to clarify some of the processes regarding deadwood and the use of thresholds. Thus, further investigation is needed on both amounts and functions of belowground component of deadwood, currently neglected most of the times since its effects on the environment are almost unknown.

Furthermore, many authors denounce scarce information on biodiversity as well (above all Müller and Bütler, 2010), since many *taxa* don’t have any deadwood threshold to be associated with. Amelioration on this topic would also increase the sensitivity and the acceptance of threshold setting. Finally, Müller and Bütler also highlight how almost all the information regarding single *taxa* come from single stands, sampling points or anyway researches on small scale, while on larger scales there is very scarce knowledge (Müller and Bütler, 2010).

Overall, however, there is little doubt that with more effort and communication, deadwood management will be more and more improved and harmonised in the next future.

6. List of abbreviations and symbols, list of terms, list of figures, list of tables

List of abbreviations and symbols

CWD	Coarse Woody Debris
DBH	Diameter Breast Height
EEA	European Environment Agency
EU	European Union
FFH	Fauna-Flora-Habitat, habitats in German publications
FWD	Fine Woody Debris
LWD	Large Woody Debris
m^3/ha	Cubic meters per hectare
NFI	National Forest Inventory
NTFP	Non-Timber Forest Product
pcs/ha	Pieces/individuals per hectare
SAC	Special Area of Conservation
SCI	Sites of Community Importance
SDF	Standard Data Form
Ø	Diameter

List of terms

- *Coarse woody debris (CWD)*: fallen trees or branches on the ground at any level of decay; under certain dimensions the inventories do not consider it as relevant, but in certain environments, *e.g.* young forests, it may represent the only source of deadwood available.
- *Fine woody debris (FWD)*: there is no clearly defined criterium for separating the different woody debris classes, and not many countries inventory this particular class: usually the minimum size for CWD represents the maximum for FWD; it is often included into CWD.
- *Habitats Directive*, or *Council Directive 92/43/EEC*: the text that ensures the conservation of a wide range of rare, threatened or endemic animals and plants, *ca.* 1000 species, and of

some 220 rare and characteristic habitats. Adopted by the European Union in 1992, it also contains all the definitions necessary to understand and apply its contents.

- *Large woody debris (LWD)*: trees or branches fallen on the ground, with remarkable dimensions. When falling into a river or a stream, it may change the morphology and influence the hydrology, especially on steep terrain. Seldom encountered in the review, LWD is relevant in habitats such as 91E0 and 91F0, where water plays a fundamental role in shaping the forest.
- *Microhabitats*: encompasses several structural features on single trees and small substrates used by numerous species, or groups of species, to grow, nest or forage. Microhabitats might be associated with decreasing tree vitality, which is commonly caused by a combination of fungi, viruses and bacteria. They are useful indicators of biodiversity, since they can describe the level of forest naturalness (Lombardi *et al.*, 2016)
- *Snags*: standing dead or dying trees, embedded in the forest; another definition is vertical piece of dead tree (Merganičová *et al.*, 2012); most of the papers cite them as standing dead wood. They can also fit in the descriptor of habitat trees, since they provide many niches for a vast range of species.

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7. References

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