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Review of indicators and field methods for monitoring biodiversity within national forest inventories. Core variable: Deadwood

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Abstract Deadwood is one of the four elements taken into account in this review of indicators and field methods and is often considered as a key indicator of forest biodiversity. We have analysed the main types of surveys and have realised how greatly the needs and constraints used to monitor deadwood can vary among them. For instance, classical National Forest Inventories usually tend to avoid time-consuming collecting methods. In the wide variety of existing definitions of deadwood, such inventories require simple and clear definitions, especially in terms of quantified thresholds. Thus, deadwood is properly described by characterising several components, such as snags, logs, stumps, branches and fine woody debris. Deadwood sampling methods alter depending on the different components and dimensions considered (standing dead trees, lying dead trees and branches, etc. assessed quantitatively). Attributes such as tree species and stage of decay are used mainly to qualify the deadwood components. The deadwood volume estimations are usually based on classical approaches already applied to living or felled trees: volume equations and/or formulas giving the volumes of common geometric solids. The purpose of this paper is to focus on different deadwood assessment techniques and to provide the information necessary to identify the most relevant methods for collecting deadwood data. The latter is used to build indicators that characterise the evolution of forest biodiversity at the scale of large forest territories.

Keywords Deadwood · Deadwood attributes · Deadwood components · Forest biodiversity · National forest inventory · Sampling methods · Volume calculations

Introduction

As agreed by many authors, deadwood is an element of biodiversity and, to some extent, an indicator of forest management sustainability that deserves to be taken into account in inventories, especially at the national level. It is an important attribute because it was not measured in the majority of National Forest Inventories (NFIs) before the 1990s. It was during the 1990s that the first deadwood surveys were initiated within the NFIs of Finland, Sweden, Norway and Switzerland (Stokland et al. 2004; Böhl and Brändli 2007).

In this paper, deadwood is characterised in terms of identified attributes, used sampling methods, volume calculations and operational use

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of monitoring and assessment. The importance of deadwood and its role in the forest ecosystem is at stake, and a state of the art of deadwood assessment in European NFIs is done. It appears that deadwood is now assessed in many European countries and in the USA, especially in NFIs and that the methodology often differs. It is therefore important to investigate options for harmonising collected data, field measurements and the types of expected results for international reporting. Questionnaires sent to 26 European countries by the COST Action E43[1] (a project initiated by the European National Forest Inventory Network (ENFIN) network and financed by the European Union) have been used to identify the types of data collected as well as the methods and designs in current or past use. Some of the data and results from this questionnaire are briefly presented here.

This paper can be considered as a synthesis of numerous studies that take into account different objectives and different methodologies developed to provide estimations of standing and lying deadwood.

Importance of deadwood and its role in the forest ecosystem

Deadwood is considered as an important component of forest ecosystems and is of interest to ecologists, mycologists, foresters and fuel specialists. Information collected on debris is very useful and often constitutes an indicator of biodiversity (Humphrey et al. 2002). It is also a key factor in the nutrient cycle (Harmon et al. 1986) and provides habitat for numerous plants, animals and fungi (Ferris et al. 2000). Deadwood is known to be important or even critical for insects (e.g. many scolytids and buprestids, beetle species, etc.; Köhler 2000), fungi (Heilmann-Clausen and Christensen 2003; Möller 1994), epixylic lichens and bryophytes (Humphrey et al. 2002; Kruys and Jonsson 1999), arthropods (Alexander 2003; Komonen 2003), mammals (e.g. bats and dormice; Taake 1991; Erickson and West 2003) and also birds (Bunnel et al. 2002; Bursell 2002; Utschik 1991).

Consequently, many forest-occurring species characterised by high habitat diversity depend on the presence of decaying wood. Deadwood can also help to describe the quality and status of wildlife habitat, the structural diversity within a forest and the storage and cycling of nutrients and water. It is also an interesting indicator or a reference for sustainable forest management. Dead coarse woody debris serves as an important substrate for the regeneration of some tree species (Zielonka 2006). The new approaches taken into account by NFIs make it possible to describe the diversity of this core variable at a large scale.

It is important to recall here that the needs for deadwood quantification are not the same for a NFI, for nature reserve management (Bruciamacchie 2005) or for a forest management unit that wishes to analyse the amount and the quality of deadwood in relation to the influence of sylvicultural practices. For example, deadwood below ground as well as belonging to living trees (often branches) is conventionally excluded from NFIs because such data are generally too difficult to collect and to quantify.

Definitions and attributes

Definitions

Within the activities of COST Action E27[2] “Protected forest areas in Europe—analysis and harmonisation”, experts have gathered several definitions for deadwood:

- Material over a certain size (limit >10 cm diameter) that is no longer living and that is left in the forest
- Woody material from forest trees and shrubs no longer living in the stand
- All woody detritus in forests comprising stems, twigs and roots but excluding deadwood parts of living trees

[1] “Harmonisation of National Forest Inventories in Europe: Techniques for Common Reporting” (http://www.metla.fi/eu/cost/e43).

[2] COST E27 homepage: http://bfw.ac.at/020/profor/.

– Total amount of woody necromass in a stand, originating from the stand and from the natural processes of mortality and decay (windthrow, natural decline of old or suppressed trees) or silvicultural treatments (left crown wood, stumps, etc.)

The above-mentioned examples show the large variability of definitions for deadwood, which mainly depend on the aim for which the study is carried out. Obviously, the main objective for NFIs is not to evaluate the "reception capacity" of different organisms. In the context of a NFI, the definition has to be as simple as possible and should include quantified thresholds. The first definition of the COST E27 list seems to match these terms. For example, the definition used for the Walloon Forest Inventory (WFI) is: the sum of standing dead trees, lying dead trees, bolts or slash that can be found on the ground (age, over 3 years; Lecomte and Rondeux 2007). A tree is referred to as a "lying dead tree" or "blowdown" when it tilts at least at a vertical angle of 45°. In COST Action E43 reference definitions, the deadwood spatial position (standing/lying) was the subject of many discussions, and the final definition was adopted: A lying stem is a main stem that is not self-supporting and most of whose length lays on the ground. Otherwise, it is a standing stem.

Components

To take into account all the aspects of deadwood, we need to identify the different components that are present in a forest and whose terminologies can vary from one study to another. In that respect, a lot of recommendations have been made. Schuck et al. (2004) consider the following four main classes: whole standing dead trees, snags, stumps and lying deadwood. Kirby et al. (1998) also present four different types by describing the components: fallen material, standing dead trees, stumps and deadwood on or in living trees (used for the follow-up of deadwood in British forests and described in Ferris-Kaan et al. 1993). Fallen material includes dead twigs, branches and trunks.

Among the suggestions concerning deadwood assessment proposed by the ICP Forests monitoring Programme, Chirici et al. (2003) take into account five components: dead down trees, lying coarse wood pieces, lying fine wood pieces (lying dead fuel), stumps and accumulation (accumulated cutting debris).

General recommendations are also available in Harmon and Sexton (1996), where deadwood components are defined as follows. The terms *woody detritus* are *woody debris* are used to include all forms of dead woody material above- and belowground. Aboveground woody detritus usually are at least 10 cm in diameter and 1.5 m long (*coarse* woody detritus); smaller pieces usually are termed as *fine* woody detritus. Coarse fractions can be divided into *snags* (or standing deadwood) and *logs* (or lying deadwood). The limit of a 45° vertical angle is frequently used to distinguish standing and lying deadwood. In addition to snags, *stumps* are recognised in managed settings. Snags are the vertical pieces resulting from natural processes, while stumps are the short vertical pieces resulting from cutting. Fine fractions can also be divided into suspended or fallen fractions. In the case of suspended fine wood, we must distinguish between the pieces attached to living trees and those attached to dead trees. Belowground woody detritus has rarely been studied, but it is recommended to split it into *buried wood* (very decayed material in the mineral soil or forest floor) and *dead coarse roots*.

Further examples can be found in Fridman and Walheim (2000), Christensen et al. (2005) and Bate et al. (2002). We have highlighted here how greatly the considered components can vary. Study objectives clearly dictate the number of components as well as their characteristics, which in turn influences which sampling methods, measurement practices and attribute type needed for an appropriate description are selected.

Attributes

All attributes do not concern all deadwood components. An expert consultation mentioned in Schuck et al. (2004) led to the identification and listing of general deadwood attributes (Table 1).

Concerning the important attribute *stage of decay*, Hunter (1990) proposes a five-level classification for standing and lying deadwood.

Table 1 Listing of general deadwood attributes mentioned in Schuck et al. (2004)

Tree species	Considered important mainly because the stage of decay depends on the species. When it is impossible to identify the species (advanced stage of decay), the differentiation hardwood/softwood can be recommended (Broadmeadow et al. 2005) or "unidentified" when clearly impossible to determine
Metric attributes (dimensions)	For standing deadwood: diameter at breast height and height are the main attributes used (for quantifying and for volume calculation). Ocular estimation aiming at placing deadwood into broad diameter categories (with a given bottom threshold) could be an alternative
	For lying deadwood: the most simple and cost-effective method of measurement is the ocular estimation of the volume per hectare. A more accurate approach is to measure tree length and diameter or at least the estimation by diameter classes of log lengths
Stage of decay	Different approaches are applied for this attribute, and there is an urgent need for harmonised classification. The stage of decay (or putrefaction or decomposition) is without any doubts one of the main attributes to take into account in the biological evaluation of deadwood. In this context, although definitions are similar, most studies define their own class limits according to their own objectives. The criteria usually used are: amount of bark, wood texture and level of rottenness

Other attributes that are less frequent are also used to qualify the deadwood present in a stand (cause of damage/death, presence of cavities/hollows, amount of bark left, etc.).

All these attributes being defined, the following question arises: Is it possible and/or necessary to investigate them in NFIs? Some of them require in-depth studies involving high-intensity assessments, which are not compatible with the compromises necessary to carry out a multipurpose national inventory. This question certainly depends on the increasing importance given to deadwood assessment.

Sampling methods

Deadwood sampling methods present specific characteristics according to the particular spatial distribution and the variability of the deadwood elements (components). In general, the quantity of deadwood is lesser in managed forests compared to those that are not intensively managed and where deadwood is often abundant and found in aggregates.

As mentioned above, deadwood includes elements of different types: standing dead trees, candles, bolts, crowns, stumps, twigs, etc. Ideally, several of these should require their own survey method. Nevertheless, from a practical point of view, most studies are limited to the characterisation of some parts of the deadwood present. This statement is even more obvious in the case of regional or national inventories, considering the multiplicity of their assigned objectives. For example, total crown volume is particularly fastidious to measure (Bruciamacchie 2005) and too expensive to be considered in a NFI. Depending on the type of deadwood, the inventory thresholds are fixed differently. The principal differences are mainly between standing deadwood and the different components of lying deadwood.

COST Action E4 Forest Reserves Research Network (Hochblicher et al. 2000) and the activities of Forest Biota (Chirici et al. 2003) have already formulated recommendations on methods of global deadwood survey to be used at the stand management level. Grid spacing and sample plot size are chosen so that the total area sampled is 5–10% (preferably 10%) of the total area, and the minimum sample plot density should be one plot per hectare, with a plot size of 500–1,000 m^2 or greater. This type of survey is obviously not possible for NFIs, for which other methods exist. However, the measurements differ between countries according to the degree of detail sought (set of variables observed or measured, number of classes used, types of calculations, etc.).

Standing dead trees survey

Standing dead trees (including snags) are often inventoried with the same methodology as for living trees. In the framework of NFIs (regarding standing dead trees), two main types of methodologies are available on the basis of plot size, which can be fixed or variable. For example, the French NFI considers standing dead trees in a fixed circular plot of 15 m radius (Hamza and Cluzeau 2005), whereas the Walloon Forest Inventory considers standing dead trees in variable plot areas (4.5, 9 or 18 m radius) according to their girth ($C_{1.50}$) at 1.5 m (20 cm $\leq C_{1.50} <$ 70 cm, 70 cm $\leq C_{1.50} <$ 120 cm, $C_{1.50} >$ 120 cm). When we examine most NFIs, we see that the thresholds of inventory range between 0 and 20 cm diameter at breast height (Di Cosmo et al. 2005, report WG1 COST E43).

Lying deadwood survey

The thresholds of inventory are usually fixed on the basis of the dimensions (diameter and length) of deadwood pieces. They depend on the type of wood (branches, stumps, etc.) and on the type of sampling method selected. Eventually, the lying deadwood that has not been measured because its dimensions are below the inventory threshold is sometimes subject to a visual estimation as in the WFI. The main sampling methods or the other methods applied to inventory lying deadwood are the following.

Fixed-area sample plot

Various studies dedicated to deadwood (excluding NFIs, except for Fridman and Walheim 2000) have been analysed (Table 2), and it appears that important variations exists between survey characteristics. Thus, it seems that there are no established references and that the choice has to be made according to the objectives of the study and the time devoted to data gathering.

Non-fixed-area sample plot

Various criteria can be considered to define the size of the plot. For example, in the above-mentioned WFI, plot radius on which lying deadwood will be inventoried depends on the average circumference of the existing stand. An integrated application in the field computer automatically calculates this value and informs the field operator when necessary (Lecomte and Rondeux 2007).

Line intersect method

The method presented by Warren and Olsen (1964) for the inventory of coarse woody debris (CWD) used as fuel wood is always worth considering for this type of sampling. According to Harmon and Sexton (1996), while the principal advantages are its speed and its accuracy, this method (Warren and Olsen 1964) requires adaptations to characterise the biological interest of deadwood. Firstly, this type of sampling does not seem to be suitable to follow up in the long-term the evolution of the deadwood stock. Indeed, given the linear structure of the sample and the fact that deadwood elements may move, the rates of input and decomposition of wood pieces are not easily estimated. This observation is also true for circular plots, but its influence decreases as the plot area increases. Secondly, in practice, this method excludes standing dead trees (snags) and makes it impossible to consider them without coupling it with another method of inventory.

Examples of adaptation are available in Kirby et al. (1998), Bate et al. (2002), Mountford (2002), Chojnacky and Heath (2002), Bobiec (2002) or Green and Peterken (1997). In general, and

Table 2 List of references related to fixed sample plot methods

Author(s)	Shape	Plot area (m^2)	Minimum diameter (cm)	Minimum length (m)
Woldendorp et al. (2004)	Quadrat	625 [25 × 25 m]	10 [woodland], 15 [open forest]	0.5
Krankina et al. (2002)	–	–	10	1
Fridman and Walheim (2000)	Circular	155 [$R = 7$ m] or 314 [$R = 10$]	10	1.3
Idol et al. (2001)	Circular	500	10	–
Noorden et al. (2004)	Transect	1,000 [10 × 1,000 m]	10	0
Knapp et al. (2005)	Transect	800 [4 × 20 m]	15	1
Siitonen et al. (2000)	Circular	10,000 [1 ha]	10	0

especially for slash, Mc Rae et al. (1979; in Parminter 1998) recommend using 90 m lines for 20 ha. This distance can decrease if the presence of deadwood increases.

Böhl and Brändli (2007) use the line intersect sampling method (LIS) by overlapping three fixed transect lines on NFI circular sample plots. The length of each transect is 10 m starting at 1 m from the centre and at angles of 120°. The method seems to be practical enough to be applied in the field.

Point and transect relascope sampling

Methods based on angle-gauge sampling techniques, which are always tested for assessing downed coarse woody debris (Gove et al. 2001), could probably be applied to all types of deadwood too. In the point sampling method, the operator selects individual logs while visiting discrete sample points in the forest. Rather than using the diameter, the operator observes the log length to determine whether it is "in" or "out", and the angle gauge used determines a squared length factor. In the transect sampling method, the operator uses an angle gauge to select pieces of downed coarse debris whilst walking along a transect of a fixed length.

Visual estimation

In the framework of national inventories, the visual estimation of deadwood is usually additional to other methods, such as the ones previously mentioned. In this case, the visual estimation concerns the finest fractions for which measuring would be too time consuming (located below the threshold of measurement). Visual estimation of deadwood present on the plot can be carried out in two different ways. Either the field operator estimates the volume of deadwood directly or he/she assesses the diameter and length of balks whose volume is calculated *a posteriori*.

Visual estimation is obviously the method that is the most dependent on the field operator's evaluation and experience. According to Harmon and Sexton (1996), an experienced field operator over-estimates the length of logs by 5% to 7%, whereas an inexperienced field operator can over-estimate them by 20% to 26%.

Volume calculation

In general, the volume calculation of deadwood is based on classical approaches that are already applied to living or felled trees. It is also based on volume equations and/or formulas providing the volume of common geometric solids such as cylinders, cones and paraboloids, which the wood pieces resemble most. If a standing dead tree is broken, it is possible to estimate the proportion of the snag remaining intact or to use volume equations (if available) giving volume according to diameter at breast height (DBH) and different log lengths (Dagnelie et al. 1999). Opinions may vary as to whether the volume has to be determined by ocular estimation or by calculations. They often result from the desired balance between the amount of qualitative and quantitative aspects to be covered, the required accuracy, the time restrictions and the plot structure constraints.

If lying dead trees or coarse woody debris are to be considered, the most simple and cost-effective method is the ocular method, which requires length estimates and diameter at mid-length (classified by broad classes with a given lower threshold). In such a case, logs are usually assimilated to cylinders. The same method can be applied to standing trees or candles. Of course, another strategy could also consist in applying quick visual judgements of volume at each sample point using an enlarged reference area of around 0.3–0.5 ha (Stokland et al. 2004). A minimum diameter for taking a log into account is usually fixed. More accurate methods based on diameter and length measurements are necessary for using volume equations or tables and volume formulas. Several research projects have investigated the varying of diameters on sample elements. They include diameters at the bolt's midpoint, at both ends and even, in the case of the LIS method, at the point where the bolt intersects the sample line (Shiver and Borders 1996).

In the case of one diameter measurement (at midpoint or at the intersection point), the cylinder volume formula is used:

$$v = \left(\pi d^2/4\right) l \quad (d = \text{diameter},\ l = \text{length})$$

When diameters at both ends are measured, the *Smalian formula* is most frequently used since the central section of a tree bole is generally shaped as a paraboloid frustum (Rondeux 1999a, b):

$$v = \pi \,/\, 8 \left(d_\mathrm{o}^2 + d_\mathrm{e}^2\right) l \ (d_0 = \text{diameter at large end},$$
$$d_\mathrm{e} = \text{diameter at small end})$$

Indicators

Deadwood indicators

Most of the existing European NFIs collect variables that can be used to monitor the stock and the change of deadwood over time. Based on NFI plot data, it is possible to estimate the volume of deadwood (standing and lying) per hectare and to subdivide that volume into different attributes such as stages of decay, especially for lying pieces of wood (logs, debris, branches, etc.).

A simplified indicator can be used for NFIs with limited data: the presence or absence of coarse deadwood. According to many authors, only the total amount of deadwood (in m^3/ha) is used to compare forest ecosystems regarding their "deadwood naturalness". For instance, the quantity of deadwood (m^3 or m^3/ha) in a forest type/region/country or the quantity of deadwood per decay class or per species or group of species (hardwood/softwood) are frequent indicators. Also, it can be extended to the estimation of carbon stock (in tonnes/ha) using coefficients of transformation.

However, as highlighted by Albrecht (1991), this rough indicator cannot be used for an ecological assessment unless details are given about the tree species, the size of logs, the abiotic factors of decay and the decay level. Indeed, ranging from the hardest standing dead trees to the well-decayed twigs, a diversity of habitats is hidden behind the deadwood "pool".

Moreover, in European NFIs, the total volume of lying and standing deadwood is generally estimated with different methods (volume equations, formulas, ocular estimation), which often provide non-comparable results. The volume should be considered as total as possible, i.e. standing trees should include branches, and coarse woody debris should be calculated at least to an end diameter of 7 cm.

When considering only lying deadwood, a more meaningful indicator could be, inside forest types, the volume subdivided by species or groups of species (conifers, broadleaves, unidentified), stages of decay (three to four classes) and diameters (three to four classes).

Biodiversity indicator

Several studies (Haase et al. 1998; Kirby et al. 1998; Martikainen et al. 2000) concluded that a global deadwood stock of 40 m^3/ha seems to be a threshold compatible with the conservation or restoration of diversified saproxylic communities (i.e. saproxylic communities with a diversity similar to those found in virgin or old-growth forests) in West European deciduous forests.

This value is obviously purely indicative, as most saproxylic species have a "narrow" ecological niche and none of them are capable of exploiting the whole CWD stock. Up to 40 m^3 of deadwood per hectare, a slight increase in the total amount of deadwood results in a significant increase in saproxylic biodiversity. The likely explanation could be that, below this amount (taking into account the natural dynamic of deadwood: input rates, decay rates, etc.), not all types of deadwood are represented in the forest ecosystem. Thus, any stock increase could reveal the availability of another type of deadwood.

It should be noted that large diameter deadwood is particularly lacking in so-called "commercial forests" (Kirby et al. 1991; Green and Peterken 1997; Kirby et al. 1998). This is why more importance (from a biodiversity point of view) should be given to large-diameter deadwood categories (elements with a diameter >40 cm).

Ideally, the biodiversity indicator calculation should be based both on the volume as well as on the diversity of habitats available to saproxylic organisms: Beyond approximate volumes, the diversity of deadwood species, sizes, stage of decay, etc. should be considered, giving more weight to “more interesting” or rarer elements (such as large diameters and rare tree species).

However, setting up a universal indicator is extremely difficult as defining the interesting character of deadwood elements is highly subjective. Determining objectively the weight of the elements taken into account is quite a challenge. What is, for instance, the weight of a snag compared to the weight of a branch? What if the deadwood has decayed totally or not? How to take into account the species effect?

A possible approach would be to use red lists of saproxylic species to define the interest of the particular habitats where they live (i.e. oak trees >50 cm DBH in all decay classes, beech snags >60 cm in more advanced decay classes, etc.). For instance, the volume of those “critical” habitats would be multiplied by 10 (i.e. 2 m^3 of those rare habitats → Indicator score = 20), while other habitats are given weight 1 (15 m^3 of common habitats → Indicator score = 15).

Indicator 1: *forest surface containing at least 40 m^3 of deadwood per hectare*, which seems to be an amount allowing for the conservation of diversified communities of saproxylic organisms, such as Coleoptera (Martikainen et al. 2000), or birds.

Indicator 2: *forest surface containing at least 20 m^3/ha of deadwood with a diameter* > *40 cm* (for instance), which includes substrates particularly important for many invertebrate red list species (Speight 1989), fungi (Penttila et al. 2004; Simila et al. 2006) and birds (Utschik 1991).

Deadwood assessments in European NFIs

An analysis of the NFIs conducted in Europe is very useful to summarise the different existing methods (inventory and calculation of volume) that are used for the assessment of deadwood. This preliminary work will give the opportunity to the ComMon project to identify the similarities and the differences existing between different European NFIs of the ENFIN network.

The information that is presented in this chapter results from work achieved by the COST Action E43 project. The results originate mainly from two questionnaires: The first one was sent by Working Group 1 (WG1: “Harmonised Definitions and Measuring Practices”) and aimed precisely at inventorying principal characteristics of National Forest Inventories participating in the action. The second one was sent by Working Group 3 (WG3: “Harmonised indicators and estimation procedures for assessing components of biodiversity with NFI data”) and had as objective to identify the possible ways of measuring biodiversity components in the context of large area forest inventories so that the results were comparable between various vegetation zones.

Despite the general trends that we have already presented, the following paragraphs are more specifically based on answers to the questionnaire from 26 national or regional forest inventories: Greece (EL), Spain (ES), Hungary (HU), Ireland (IE), the United Kingdom (UK), Denmark (DK), Iceland (IS), Lithuania (LT), Latvia (LV), Estonia (EE), Sweden (SE), Italy (IT), Austria (AT), the Netherlands (NL), Norway (NO), Belgium (BE), the Czech Republic (CZ), the GD of Luxembourg (LU), Slovakia (SK), France (FR), Romania (RO), Finland (FI), Slovenia (IF), Switzerland (CH), Cyprus (CY) and Germany (DE). As can be seen from this list, nearly all European NFIs are participating in COST Action E43, which allows for a complete summary of the methods applied throughout Europe.

Attributes considered

Among the various types of deadwood that can be observed, most countries consider the following components: uprooted stems, broken lying stems without uprooting, intact and broken snags and pieces of stems. Pieces of branches and fine woody debris are rarely observed or measured.

The chosen thresholds of inventory are different whether dead trees are standing or lying. The stumps are also considered with their own

Table 3 Minimal DBH used in European NFIs for standing dead trees assessment

Minimal DBH (cm)	NFI
Not available	EL, ES, HU, IE, UK
0	DK, IS
2.1	LT, LV
4	EE, SE
4.5	IT
5	AT, NL, NO
6.4	BE
7	CZ, LU, SK
7.5	FR
8	RO
10	FI, SI
12	CH, CY
20	DE

thresholds. In the case of *standing dead trees*, a minimal diameter at breast height (in centimetres) is fixed varying from 0 to 20 cm (Table 3). Such limits are also applied usually to the inventory of candles (except for Hungary).

On the basis of the data collected on the inventoried trees, various inventories evaluate their volume with the same functions of volume dimension as the ones used for living trees.

In the case of *lying deadwood*, it can be observed that 15 out of 18 inventories with an answer to the question confirm that lying deadwood is inventoried: AT, BE, CH, OF, EE, FI, IS, IT, LT, LU, LV, NO, SE, IF, SK. French, Cypriot, and Romanian inventories only take into account standing deadwood. For this category of deadwood, the threshold of inventory is usually fixed according to a minimum diameter (D min) and a minimum length (L min) selected for the logs to be inventoried (Table 4).

Table 4 Minimal dimensions used in European NFIs for lying deadwood assessment

Country	Minimum diameter (cm)	Minimum length (m)
SK	1	0
LT	2.1	0
LV	6.1	0
BE	6.4	1
LU	7	1
EE	8	1
FI	10	1.3
IT	10	0
NO	10	1.3
SE	10	1.3
SI	10	0
CH	12	1.3
AT	20	0
DE	20	0.1

Table 5 Plot areas used in European NFIs for lying deadwood assessment

Country	Plot area (m^2)
AT	300
EE	314
CZ	500
ES	707
IT	531
DE	79
NO	250
LV	500

The questionnaire also makes it possible to characterise partially (data from eight countries out of 15 that assess lying deadwood) the type of plot on which lying deadwood is inventoried. Two types of plots are used: plots of fixed (Table 5) or non-fixed areas.

Belgium (the Walloon region) and Luxembourg, for which the NFI methodologies are similar, are the only ones using plots with variable areas (radius of 4.5, 9 or 18 m).

In the case of *stumps*, five national inventories (AT, CH, DE, LT, SK) take stumps into consideration in their inventories, whereas 13 countries do not consider them (BE, CH, EE, FI, FR, IS, IT, LU, LV, NO, RO, SE, SI). The threshold of inventory is fixed according to the diameter and is sometimes combined with the height of the stump (Table 6).

Stump inventory is often made on plots which have the same size as the ones used for the inventory of deadwood on the ground.

Table 6 Minimal dimensions used in European NFIs for stump assessment

Country	Minimum diameter [cm]	Minimum height [cm]
AT	20	0–30
LT	2.1	0
SK	15	0
DE	60	10
CH	Not available	Not available

Table 7 Examples of decay classes used in European NFIs

Country	Classes	Description
LT	1	Suitable for firewood
	2	Not suitable for firewood
BE	1	Beginning decomposition
	2	Ongoing decomposition
	3	Clearly decomposed
AT	1	Sound when kicking
	2	Slightly decomposed
	3	Totally decomposed, no core
SE	0	*Raw wood*. Newly dead trees where green needles or leaves are present
	1	*Hard deadwood*. More than 90% of the tree volume and the tree surface is hard. The stem has very little impact from decomposing insects or fungi
	2	*Slightly decomposed deadwood*. 10–25% of the tree volume is soft, and the rest is hard. A knife or a soil stick can be pressed through the wood surface but not through the sapwood
	3	*Decomposed deadwood*. 26–75% of the stem volume is soft or very soft
CH	1	*Fresh*. Cambium wet
	2	*Dry*. Cambium dry, knife penetrates with difficulty in fibre orientation
	3	*Decayed*. Knife penetrates easily in and with difficulty across fibre orientation
	4	*Fustiness*. Knife penetrates easily in and across fibre orientation
	5	*Duff*. Very fluffily, fibre hardly connected
ES	0	Green, it has just been cut
	1	Bark intact, small branches present, wood texture intact
	2	Bark intact, no twigs
	3	Trace of bark, no twigs, wood hard, texture with large pieces
	4	No bark, no twigs, wood soft, texture with blocky pieces
	5	No bark present, no twigs, wood soft and powdery texture
	6	No bark present, no twigs, wood soft and powdery texture and hollow inside

Stages of decay

The stage of decay is an important attribute for deadwood qualification. However, several national or regional forest inventories disregard it (Schuck et al. 2004), i.e. Switzerland, the Czech Republic, France, the Netherlands and the UK, whereas others take it into consideration: Spain, Lithuania, the Walloon Region (BE), Austria, Germany, Finland, Norway and Sweden.

The questionnaires reveal that the decay classifications are based on a number of classes ranging from 2 to 7 (Table 7). Four of the 14 countries collecting deadwood characteristics use five categories (CH, FI, IT, NO), for which the same criteria are globally used: bark adherence, wood texture as well as colonisation by plants, fungi, etc.

The stage of decay is very useful to predict the associated species composition. In Scandinavian countries such as Norway (Table 8) and Finland, a

Table 8 Decay classes used in the Norwegian NFI

Country	Classes	Description
NO	1	*Recently dead*: bark normally attached to the wood, any fungus mycelium developed under patches of loose bark
	2	*Slightly decayed*: loose bark, the rot extends less than 3 cm radially into the wood
	3	*Decayed*: the rot extends more than 3 cm into the wood (the log still has a hard core)
	4	*Very decayed*: the rot extends deeply throughout the log, which is shaped by the contours of the forest floor (cross section often collapsed to an ellipsoid)
	5	*Almost decomposed*: the log is completely decomposed in sections and the fragments are often overgrown

five-class system to categorise deadwood is used, with classes ranging from "recently dead" to "almost decomposed" (Naesset 1999).

Sampling methods

For a large majority of countries, some if not all the plots included in the NFIs are subject to deadwood assessment. When we consider the 16 countries that answered the questions in the WG3 questionnaire, we can observe that the sampling plot areas range from 154 to 706 m^2; nine countries use a defined circular plot (fixed radius), two use the line intercept method, and four have chosen variable area plots. Sometimes, subplots are also applied, and usually, standing dead trees are measured at the same time as living trees on the basis of the same conventions. As regards lying deadwood, more specifically pieces of wood, either the entire pieces are measured or only the parts located inside the plot or a given percentage of them.

Volume calculations

Different methods exist and depend on the type of deadwood: standing or lying. In the first case, volume functions (regression equations) are generally used when available, or estimations from formulas of well-known geometrical forms associated to trees, especially when it comes to candles or broken trees, are also applied.

Concerning lying deadwood, even if volume functions are always a good choice, the volume is preferably calculated on the basis of the cylinder, the truncated cone or the Smalian or other formulas. The use of the relascope is sometimes cited too. For small coarse woody debris or branches, a "calibrated" ocular estimation seems to be the most adapted method.

Causes of variability in the choice of methodologies

As expected, the results of the questionnaire presented above highlight the very significant variability existing between different NFIs as far as deadwood inventory methods are concerned. This variability is present at every stage of the assessment: Choosing the thresholds (between 0 and 20 cm) and the type and size of plots for the inventory of lying deadwood (between 79 and 2,000 m^2) are only some examples illustrating this variability.

The choice of methodologies depends, first, on practical contingencies such as time availability and financial constraints in the case of deadwood data gathering and, second, on historical contingencies related to the objectives pursued for the different inventories rather than on internationally recognised standards. It is likely that the NFIs considering deadwood volume estimations only from a biodiversity point of view also aim at evaluating the quantity in terms of carbon storage.

Although the assessment of deadwood (through all its components) was secondary when most European NFIs were established, it has become necessary only recently and has often been integrated in existing methodologies. The diversity of methods used for assessing deadwood must be analysed along with the general methodologies of the inventories. The development of procedures such as forest certification (based on Pan-European criteria of biodiversity evaluation) or the coming into force of the Kyoto protocol (which requires a standardised evaluation method for the carbon storage capacity of forests) reinforces the need for standardised methods, and this explains the interest in the ongoing work in projects such as ComMon and COST Action E43.

Conclusion

Monitoring and surveying the amount of deadwood present in forests provide useful indicators of habitat quality. At a national level, permanent forest inventories are increasingly concerned with collecting and analysing numerous data dealing not only with traditional forest resources but also with biodiversity and environmental data (Rondeux 1999a, b). The sampling strategies of NFIs are very useful tools for deadwood evaluation, but countries do not always use comparable methods and definitions. As it is difficult or impracticable to include every dead twig in a sampling design, some arbitrary criteria for exclusion must be applied. Permanent surveys will provide data for comparison between the current situation and previous surveys in order to monitor changes concerning the amount and type of present deadwood. At large scales, it is also particularly interesting to study potential correlations with stand structure, stand density, tree species and site productivity.

The important diversity of existing deadwood assessment methods in Europe is due not only to the structural diversity of European forests but also to the types of studies, their objectives, priorities and constraints.

This paper has listed different methods that exist for deadwood assessment, according to the different components and attributes. It is not simple to completely harmonise deadwood assessment within NFI methodologies because of their complexity and the objectives pursued by each independent methodology. In fact, this complexity seems more important for deadwood than for other forest variables (stand structure, vegetation, stand age, etc.). The aim of deadwood assessment should be profoundly analysed in order to suggest methods of investigation as similar as possible. It would be therefore possible to compile recommendations about deadwood assessment in a guideline document intended for the setting up of new regional or national forest inventories or for conducting thorough revisions of existing inventories.

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References

Albrecht, L. (1991). *Die Bedeutung des toten Holzes im Wald* (pp. 106–113). Forstw. Cbl.

Alexander, K. N. A. (2003). The British saproxylic invertebrate fauna. In *Proceedings of the second pan-European conference on saproxylic beetles*.

Bate, L. J., Torgersen, T. R., Garton, E. O., & Wisdom, M. J. (2002). *Accuracy and efficiency of methods to sample logs for wildlife research and management*. Electronic version available at: http://www.fs.fed.us/psw/publications/documents/gtr-181/060_BateLog.pdf [2005-11-16].

Bobiec, A. (2002). Living stands and deadwood in the Bialowieza forest: Suggestions for restoration management. *Forest Ecology and Management, 165*, 125–140. doi:10.1016/S0378-1127(01)00655-7.

Böhl, J., & Brändli, U.-B. (2007). Deadwood volume assessment in the third Swiss Forest inventory: Methods and first results. *European Journal of Forest Research, 126*, 449–457.

Broadmeadow, M. S. J., Matthews, R. W., Mackie, E., Wilkinson, M., Benhams, G., & Harris, K. (2005). Survey methods for Kyoto protocol monitoring and verification of UK forest carbon stocks. In R. Milne, & D. C. Mobbs (Eds.), *Emissions by sources and romovals by sinks due to land use, land use change and forestry activities. Report June 2005* (p. 6). United Kingdom: Department for the Environment, Food and Rural Affairs, Global Atmosphere Division.

Bruciamacchie, M. (2005). Méthodes d'échantillonnage du bois mort. In Vallaury et al. (Coord.), *Bois mort et à cavités, une clef pour des forêts vivantes* (pp. 227–235). Paris: Lavoisier TEC and DOC.

Bunnel, F. L., Boyland, M., & Wind, E. (2002). *How should we spatially distribute dying and deadwood* (pp. 739–752). USDA For. Serv. Gen. Tech. Rep. PSW-GTR 181.

Bursell, J. (2002). Winter abundance of hole-nesting birds in natural and managed woods of Zealand (Denmark). *Acta Ornithalogica Warsaw, 37*(2), 67–74.

Chirici, G., Corona, P., & Marchetti, M. (2003). *Proposal of deadwood monitoring*. Protocol for ForestBiota.

Chojnacky, D., & Heath, L. (2002). Estimating down deadwood from FIA forest inventory variables in Maine. *Environmental Pollution, 116*, S25–S30. doi:10.1016/S0269-7491(01)00243-3.

Christensen, M., Hahn, K., Mountford, E. P., Ódor, P., Standovár, T., Rozenbergar, D., et al. (2005). Deadwood in European beech (*Fagus sylvatica*) forest reserves. *Forest Ecology and Management, 210*, 267–182. doi:10.1016/j.foreco.2005.02.032.

Dagnelie, P., Palm, R., Rondeux, J., & Thill, A. (1999). *Tables de cubage des arbres et des peuplements forestiers* (3rd ed., 148 pp.). Gembloux, Belgium: Les Presses Agronomiques de Gembloux.

Di Cosmo, L., Gschwantner, T., Robert, N., & Lanz, A. (2005). *Scientific report from the short-term scientific mission carried out from 7–24 March 2005 at the Swiss Federal Institute for Forest, Snow and Landscape research (SWL) Birmensdorf*. COST Action E43, Working Group 1.

Erickson, J. L., & West, S. T. D. (2003). Association of Bats with local structures and landscape features of forested stands in western Oregon and Washington. *Biological Conservation, 109*(1), 95–102.

Ferris, R., Peace, A. J., & Newton, A. C. (2000). Macrofungal communities of lowland Scots pine (*Pinus sylvestris* L.) and Norway Spruce (*Picea abies* (L.) Karsten) plantations in England: Relationships with site factors and stand structure. *Forest Ecology and Management, 131*, 255–267. doi:10.1016/S0378-1127(99)00218-2.

Ferris-Kaan, R., Lonsdale, D., & Winter, T. (1993). *The conservation management of deadwood*. Farnham: Forestry Commission (Research Information Note No 241).

Fridman, J., & Walheim, M. (2000). Amount, structure and dynamics of deadwood on managed forestland in Sweden. *Forest Ecology and Management, 131*, 23–36. doi:10.1016/S0378-1127(99)00208-X.

Gove, J. H., Ducey, M. J., Stähl, G., & Ringvall, A. (2001). Point relascope sampling. A new way to assess downed coarse woody debris. *Journal of Forestry, 99*, 4–11.

Green, P., & Peterken, G. F. (1997). Variation in the amount of deadwood in the woodlands of the Lower Wye Valley, UK in relation to the intensity of management. *Forest Ecology and Management, 98*, 229–238. doi:10.1016/S0378-1127(97)00106-0.

Haase, V., Topp, W., & Zach, P. (1998). Eichen-Totholz im Wirtschaftswald als Lebensraum fur xylobionte Insekten, Z. Ökologie u. *Naturschutz, 7*, 137–153.

Hamza, N., & Cluzeau, C. (2005). Évaluation du bois mort par l'inventaire forestier national: Situation et perspectives d'amélioration. In Vallaury et al. (Coord.), *Bois mort et à cavités, une clef pour des forêts vivantes* (pp. 253–261). Paris: Lavoisier TEC and DOC.

Harmon, M. E., & Sexton, J. (1996). *Guidelines for measurements of woody detritus in forest ecosystems. LTER network office publication n°20*. Electronic version available at: http://intranet.lternet.edu/archives/documents/Publications/woodydetritus/woodydetritus.pdf [2005–10–25].

Harmon, M. E., Franklin, J. F., Swanson, F. J., Sollins, P., Gregory, S. V., Lattin, J. D., et al. (1986). Ecology of coarse woody debris in temperate ecosystems. *Advances in Ecological Research, 15*, 133–302. doi:10.1016/S0065-2504(08)60121-X.

Heilmann-Clausen, J., & Christensen, M. (2003). Fungal diversity on decaying beech logs—Implication for sustainable forestry. *Biodiversity and Conservation, 12*, 953–973.

Hochblicher, E., O'Sullivan, A., Van Hees, A., & Vandekerkhove, K. (2000). *Recommendations for data collection in forest reserves with an emphasis on regeneration and stand structure* (pp. 135–181). European Commission: COST Action E4, Forest Reserves Research Network.

Humphrey, J. W., Davey, S., Peace, A. J., Ferris, R., & Harding, K. (2002). Lichens and bryophite communities of planted and semi-natural forests in Britain: The influence of site type, stand structure and deadwood. *Biological Conservation, 107*(2), 165–180. doi:10.1016/S0006-3207(02)00057-5.

Hunter, M. L., Jr. (1990). *Wildlife, forests and forestry: Principles of managing forests for biological diversity*. Englewood Cliffs, New Jersey: Prentice-Hall.

Idol, T. W., Figler, R. A., Pope, P. E., & Ponder, F. (2001). Characterization of coarse woody debris across a 100 year chronosequence of upland oak-hickory forests. *Forest Ecology and Management, 149*, 153–161. doi:10.1016/S0378-1127(00)00536-3.

Kirby, K. J., Reid, C. M., Thomas, R. C., & Goldsmith, F. B. (1998). Preliminary estimates of fallen deadwood and standing dead trees in managed and unmanaged forests in Britain. *Journal of Applied Ecology, 35*, 148–155. doi:10.1046/j.1365-2664.1998.00276.x.

Kirby, K. J., Webster, S. D., & Antczak, A. (1991). Effects of forest management on stand structure and the quantity of fallen deadwood: Some British and Polish examples. *Forest Ecology and Management, 43*, 167–174. doi:10.1016/0378-1127(91)90083-8.

Knapp, E. E., Keeley, J. E., Ballenger, E. A., & Brennan, T. J. (2005). Fuel reduction and coarse woody debris dynamics with early season and late season prescribed fire in Sierra Nevada mixed conifer forest. *Forest Ecology and Management, 208*, 383–397. doi:10.1016/j.foreco.2005.01.016.

Köhler, F. (2000). Totholzkäfer in naturwaldzellen des nördlichen Rheinland. In *Naturwaldzellen teil VII, schriftreihe der landesanstalt für ökologie, bodenordnung und forsten/landesamt für agarordnung nordrhein-westfalen band* (Vol. 18, p. 352).

Komonen, A. (2003). Hotspots of insect diversity in Boreal forests. *Conservation Biology, 17*(4), 976–981. doi:10.1046/j.1523-1739.2003.02076.x.

Krankina, O. N., Harmon, M. E., Kukuev, Y. A., Treyfeld, R. F., Kashpor, N. N., Kresnov, V. G., et al. (2002). Coarse woody debris in forest regions of Russia. *Canadian Journal of Forest Research, 32*(5), 768–778. doi:10.1139/x01-110.

Kruys, N., & Jonsson, B. G. (1999). Fine woody debris is important for species richness on logs in managed boreal spruce forests of northern Sweden. *Canadian Journal of Forest Research, 29*(8), 1295–1299. doi:10.1139/cjfr-29-8-1295.

Lecomte, H., & Rondeux, J. (2007). *Inventaire permanent des ressources forestières de Wallonie. Guide méthodologique* (194 pp.). Gembloux, Belgium: Gembloux Agricultural University.

Martikainen, P., Siitonen, J., Punttila, P., Kaila, L., & Rauh, J. (2000). Species richness of Coleoptera in mature managed and old-growth boreal forests in southern Finland. *Biological Conservation, 94*, 199–209. doi:10.1016/S0006-3207(99)00175-5.

Mc Rae, D. J., Alexander, M. E., & Stocks, B. J. (1979). *Measurement and description of fuels and fire behavior on prescribed burns: A handbook, Canadian forestry service report O-X-287* (44 pp.). Sault Ste Marie, Ontario: Great lakes Forest Research Centre.

Möller, G. (1994). Alt- und Totholzlebensraüme-Ökologie, Gefährdungssituation, schutzmabnahmen. *Beitr. Forstwirtsch. Landschaftspfl., 28*(1), 7–15.

Mountford, E. (2002). Fallen deadwood levels in the near-natural beech forest at La Tillaie reserve, Fontainebleau, France. *Forestry, 75*, 203–208. doi:10.1093/forestry/75.2.203.

Naesset, E. (1999). Relationship between relative wood density of Picea abies logs and simple classifications systems of decayed coarse woody debris. *Scandinavian Journal of Forest Research, 14*, 454–461. doi:10.1080/02827589950154159.

Noorden, B., Götmark, F., Tönnberg, M., & Ryberg, M. (2004). Deadwood in semi-natural temperate broadleaved woodland: Contribution of coarse and fine deadwood, attached deadwood and stumps. *Forest Ecology and Management, 194*, 235–248. doi:10.1016/j.foreco.2004.02.043.

Parminter, J. (1998). *Coarse woody debris sampling intensity considerations*. Electronic version available at: http://www.for.gov.bc.ca/hre/deadwood/DTmes5.htm [2005–09–09].

Penttila, R., Siitonen, J., & Kuusinen, M. (2004). Polypore diversity in managed and old-growth boreal Picea abies forests in southern Finland. *Biological Conservation, 117*, 271–283. doi:10.1016/j.biocon.2003.12.007.

Rondeux, J. (1999a). *La mesure des arbres et des peuplements forestiers* (522 pp.). Gembloux, Belgium: Presses agronomiques de Gembloux.

Rondeux, J. (1999b). Forest inventories and biodiversity. *Unasylva, 196*, 35–41.

Schuck, A., Meyer, P., Menke, N., Lier, M., & Lindner, M. (2004). Forest biodiversity indicator: Deadwood–A proposed approach towards operationalising the MCPFE indicator. In M. Marchetti (Ed.), *Monitoring and indicators of forest biodiversity in Europe—From ideas to operationality. EFI proceedings no. 51* (pp. 49–77). European Forest Institute.

Shiver, B. D., & Borders, B. E. (1996). *Sampling techniques for forest resource inventory* (356 pp.). New York: Wiley.

Siitonen, et al. (2000). Coarse woody debris and stand characteristics in mature managed and old-growth boreal mesic forests in southern Finland. *Forest Ecology and Management, 128*, 211–225. doi:10.1016/S0378-1127(99)00148-6.

Simila, M., Kouki, J., Monkkonen, M., Sippola, A. L., & Huhta, E. (2006). Co-variation and indicators, of species diversity: Can richness of forest-dwelling species be predicted in northern boreal forests? *Ecological Indicators, 6*, 686–700. doi:10.1016/j.ecolind.2005.08.028.

Speight, M. C. D. (1989). *Les invertébrés saproxyliques et leur conservation* (69 pp.). Strasbourg, France: Conseil de l'Europe.

Stokland, J. N., Tomter, S. M., & Söderberg, G. U. (2004). Development of deadwood indicators for biodiversity monitoring: Experiences from Scandinavia. In M. Marchetti (Ed.), *Monitoring and indicators of forest biodiversity in Europe—From Ideas to Operationality. EFI proceedings no. 51* (pp. 207–226). European Forest Institute.

Taake, K.-H. (1991). Zur Besiedlung von Althölzern und Fledermauskästen durch Waldfledermäuse. *NZ NRW Seminarberichte, 10*, 57–58.

Utschik, H. (1991). Beziehungen zwischen totholzreichtum und vogelvielfalt in Wirtschaftswäldern. *Forstw. Cbl., 110*, 135–148. doi:10.1007/BF02741248.

Warren, W. G., & Olsen, N. P. F. (1964). A line intersect technique for assessing logging waste. *Forest Science, 10*(3), 267–276.

Woldendorp, G., Keenan, R. J., Barry, S., & Spencer, R. D. (2004). Analysis of sampling methods for coarse woody debris. *Forest Ecology and Management, 198*, 133–148. doi:10.1016/j.foreco.2004.03.042.

Zielonka, T. (2006). Quantity and decay stages of coarse woody debris in old-growth subalpine spruice stands of the western Carpathians, Poland. *Canadian Journal of Forest Research, 36*, 2614–2622. doi:10.1139/X06-149.