



A dataset of forest volume deadwood estimates for Europe

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Abstract

• **Key message** ICP-Forests relies on a representative pan-European network based on a 16 × 16 km grid-net covering around 6,000 plots. Dead wood volumes for 3,243 plots, related to 19 European Countries, are presented in this data paper as a result of harmonised sampling procedure, and under compliance with FAIR Data Principles. Dataset access is at <https://doi.org/10.5281/zenodo.1467784>. Associated metadata are available at <https://metadata-afs.nancy.inra.fr/geonetwork/srv/fre/catalog.search#/metadata/a27d2a8f-1a2d-4a1c-b932-86ec5f4bd8a6>.

Keywords Deadwood decay classes · Stand management · Stand age · European Forest Types · ICP Forests monitoring programme

1 Background

Deadwood covers a fundamental role in forest ecosystems because stocks huge quantities of forest carbon and is a relevant resource for a wide range of organisms (Zell et al. 2009). Therefore, it has been recognised as one of the most important structural and multifunctional components of many forest ecosystems and selected as criterion of the pan-European indicators for sustainable forest management (Lassauce et al. 2011).

Despite its importance, studies, information, and statistics on forest deadwood on very large scales are scarce or missing

(Seibold et al. 2015). Current experiences are based on data collected through National Forest Inventories (NFIs) (Rondeux et al. 2012) or forest inventories at subnational scale (e.g. Corona et al. 2010; Lombardi et al. 2015), but the lack of standardised deadwood-related definitions makes the comparison of estimates from different countries hard (Stähl et al. 2012).

The ICP Forests programme (<http://www.icp-forests.org>) is the only existing network that monitors the status of forests under a coordinated pan-European umbrella, using common standards and harmonised methods for data collection. This involved also tree stand and biodiversity issues, including deadwood

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measurements, which represents a unique opportunity to develop comparable deadwood volume estimates at regional level.

The aim of the data paper is to increase the diffusion of a high-value dataset, providing the added-value results of harmonised sampling procedure and moving, at the same time, towards the compliance with the FAIR principles (Wilkinson et al. 2016).

2 Methods

ICP Forests Programme is responsible for level I and more detailed level II monitoring system of forest sites (Haußmann and Fischer 2004; Ferretti and Fischer 2013), which have been in operation since 1986 and 1994, respectively. The large-scale level I network is dedicated to investigations on forest condition monitoring and was built as a dense and spatially representative 16×16 km virtual grid of forest sampling points placed over Europe. Around these points, a system of three circular concentric subplots with areas respectively of 30 m², 400 m², and 2000 m² were built, and data on stand structure and biodiversity have been collected, based on common definitions and protocols, as described below, together with the measures and assessments used for further calculations (Bastrup-Birk et al. 2008).

In this study, basic data collected between 2006 and 2008, from 3243 level I-subplot 2 (ICP Forests LI-sub2, the ones within 400 m² subplots) have been extracted, pre-processed, and merged. The 19 European Countries involved were France, Belgium, Germany, Italy, the UK, Ireland, Denmark, Spain, Sweden, Austria, Finland, Hungary, Poland, Slovak Republic, Lithuania, Czech Republic, Slovenia, Latvia, and Cyprus (Fig. 1; Canullo 2016; Puletti et al. 2017).

2.1 Definitions of deadwood components, mandatory measures, and measures conditions

Various deadwood categories have been considered and measured (Table 1): standing and lying dead trees, coarse woody debris, snags, and stumps. Here, following the used definitions are reported (Bastrup-Birk et al. 2008):

- a *standing dead tree* (SDT) is defined as dead tree not lying on the forest floor, to be measured as DBH and total height;
- conversely, *lying dead tree* (LDT) defines any dead trees lying on the forest floor. LDT is considered when the rooted part falls within the plot. Mandatory measures are DBH and total height;
- *coarse woody debris* (CWD) includes stems, limbs, branches lying on the forest floor, and with a diameter at the thicker end of the debris larger than 10 cm. CWD pieces must be detached from a bole and not self-supported by a root system. Such CWD are surveyed if

more than 50% of its thicker end lies within the plot. Mandatory measures are total length and diameter at half-length;

- a *snag* is defined as pieces of standing dead trees (i.e. standing dead wood) without branches, and is measured as total length and diameter at half-length;
- a *stump* is defined as a short vertical piece, lower than 1.3 m, resulting both from cutting or natural processes. Stumps are measured in height from the ground and diameter of the top section.

2.2 Deadwood volume calculation

Starting from the above basic measurements, the wood volume of SDT and LDT was calculated by the following equation:

$$V_{\text{tree}} = f \cdot H_{\text{tot}} \cdot \pi/4 \cdot DBH^2$$

where V_{tree} is the volume expressed in m³, H_{tot} is the total tree height expressed in m, DBH is the diameter at breast height expressed in m, and the shape coefficient f was set equal to 0.5, because a species-specific value is not available for all the considered tree species.

The volume of snags and CWD elements was calculated by the following equation:

$$V_{\text{snag/cwd}} = \pi/4 \cdot l_{\text{tot}} \cdot d_{\text{half}}^2$$

where $V_{\text{snag/cwd}}$ is the volume expressed in m³, d_{half} is the diameter at half-length expressed in m, and l is the length of the element expressed in m.

The volume of each stump was calculated as follows:

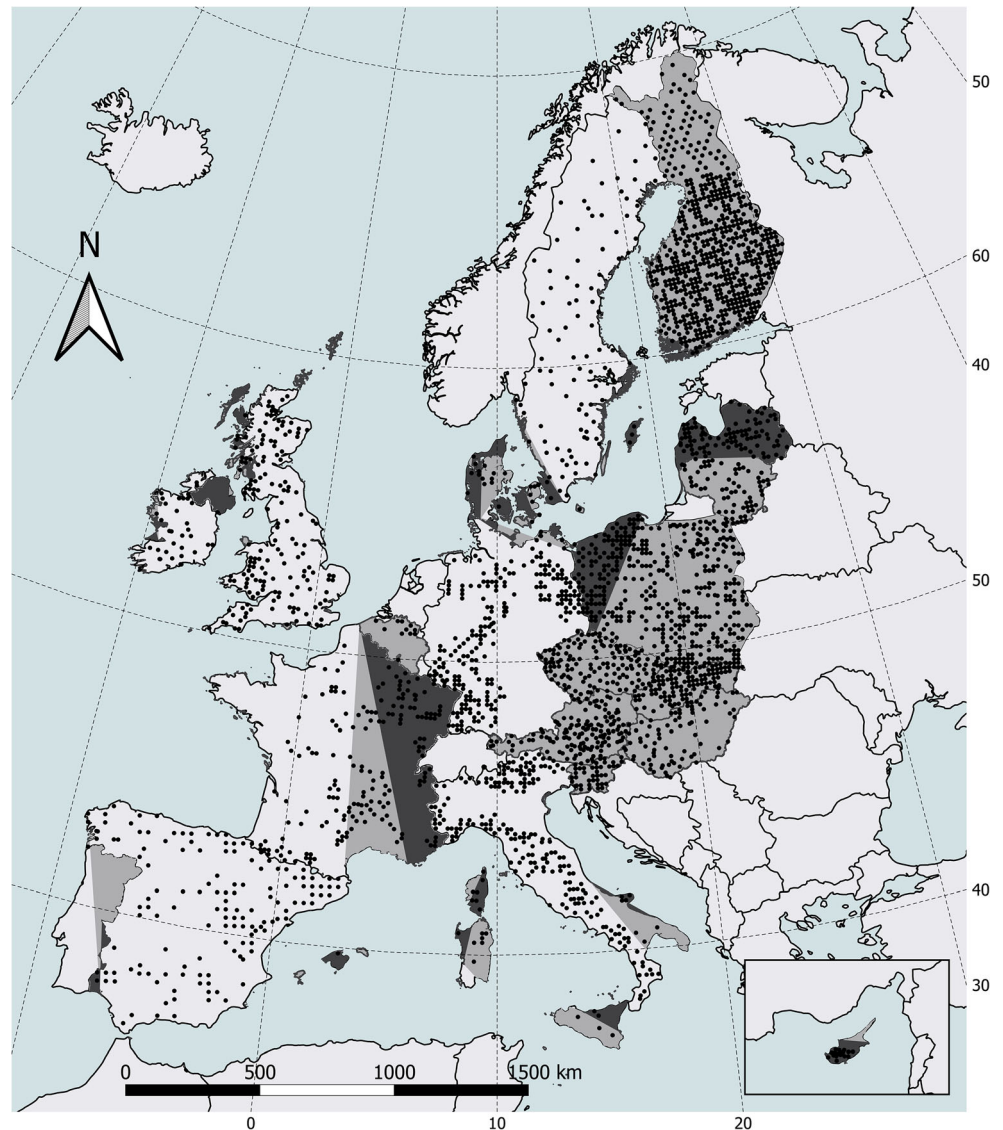
$$V_{\text{stump}} = \pi/4 \cdot h_{\text{cut}} \cdot d_{\text{cut}}^2$$

where V_{stump} is the volume of the stump expressed in m³, d_{cut} is the top section diameter of the stump expressed in m, and h_{cut} is the height of this section from the ground, expressed in m.

2.3 Decay status

Decay status (DEC) of each dead element were recorded for all the five components and reported in the original datasets. Decay level classification of each deadwood piece was visually assessed by the system proposed by Hunter (1990). Such classification uses simultaneously both morphological features of deadwood, presence of bark, integrity of wood structure, and wood colour to classify deadwood elements into five decay levels: (1)

Fig. 1 Spatial distribution of ICP forest LI-sub2 points considered in the dataset (in black). In dark-grey, the 19 Countries containing the selected points (for map details, please see Puletti et al. 2017)



No evidence of decay; (2) *Solid wood*. Less than 10% changed structure due to decomposition; the wood is solid at its surface. The wood is attacked only to a very small degree by wood decomposing organisms; (3) *Slightly decayed*. 10–25% of the wood has a changed structure due to decomposition. This can be assessed by sticking the wood with a sharp object; (4) *Decomposed wood*. Twenty-six to 75% of the wood is soft to very soft; (5) *Very decomposed wood*. Seventy-six to 100% of the wood is soft.

2.4 Stand management

Forest stand management ranges among five possible classes: 1, *unmanaged*: no evidences of management; 2, *management*: evidence of past management (more than 10 years ago); 3, *managed*: human activities were clear and undeniable; 4,

unknown: is not possible to identify a class; 5, *NA*: information is not available/collected.

2.4.1 Stand age

The stand age parameter was assigned to each plot adopting nine forest age classes. One class is specific for uneven-aged stands, seven classes for even-aged stands (six classes of width equal to 20 years in the range 0–120 and one for stands with age higher than 120 years), and the remaining class was adopted for those stands whose age class was not assessed on the field.

2.4.2 EFTC

European Forest Types and Categories have been attributed to each plot, following the system adopted by European Environmental Agency (EEA 2006; Barbati et al. 2014).

Table 1 Mandatory measures of deadwood elements, in ICP Forests Level I plots, according to deadwood type and description of deadwood type

Mandatory measures of deadwood elements	Deadwood type	Description of deadwood type
DBH: diameter at breast height	<i>SDT</i> : standing dead trees	A standing dead tree recorded if $DBH \geq 10$ cm and $H_{tot} \geq 1.3$ m
H_{tot} : total height	<i>LDT</i> : lying dead trees	Lying dead trees was recorded if $DBH \geq 10$ cm
l_{tot} : total length	<i>snag</i>	Snag recorded if $l_{tot} \geq 1.3$ m and $d_{half} \geq 10$ cm
d_{half} : diameter at half-length	<i>CWD</i> : coarse woody debris	<i>CWD</i> recorded if $d_{half} > 10$ cm
h_{cut} : height from the ground	<i>stump</i>	Stump recorded if $h_{cut} < 1.3$ m and $d_{cut} \geq 10$ cm
d_{cut} : diameter of the top section		

3 Access to the data & metadata description

The data are freely accessible from Puletti et al. (2018) at <https://doi.org/10.5281/zenodo.1467784>. Associated metadata is available at <https://metadata-afs.nancy.inra.fr/geonetwork/srv/fre/catalog.search#/metadata/a27d2a8f-1a2d-4a1c-b932-86ec5f4bd8a6>.

In Zenodo repository, eight files can be found. The most important is the “Reference_dataframe.csv” file containing all the 3243 plots with volume values in columns. Other five files, namely, “Age classes.csv”, “Country.csv”, “Management.csv”, and “EFTC.csv”, describe codes contained respectively in the columns *age*, *country*, *manage*, and *EFTC* and the file “Decay status.csv” contributes to understand tail of code in several

columns of the “Reference_dataframe.csv”. The file “calculation.R” is an R script allowing preliminary calculations, as performed also in this paper.

Lastly, the file “Excerpt from BE Demonstration-project_biosoil_2008.pdf” fits with Bastrup-Birk et al. (2008).

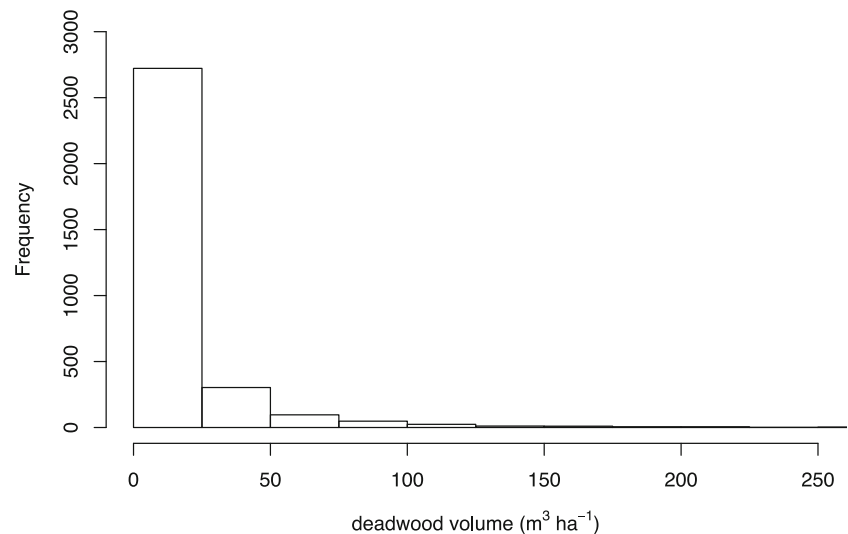
4 Results and technical validation

A total of about 38,000 deadwood elements have been considered in the database here presented, with 1738 SDTs, 338 LDTs, 10,904 CWD, 2606 snags, and 22,414 stumps. Some general results and considerations from these data are following reported.

Table 2 Mean values of deadwood volume ($m^3 ha^{-1}$) and their 95% confidence interval estimates distinguished by Country and deadwood type (see the text for acronyms)

Country	SDT	LDT	Snag	CWD	Stump	Number of plots	Mean volume
Austria	9.1 $^{\pm 2.9}$	0.0	0.0	14.6 $^{\pm 3.3}$	0.0	136	23.7 $^{\pm 4.6}$
Belgium	4.8 $^{\pm 2.4}$	6.0 $^{\pm 4.8}$	1.3 $^{\pm 1.3}$	3.6 $^{\pm 2.3}$	1.0 $^{\pm 0.2}$	10	17.5 $^{\pm 8.1}$
Cyprus	0.2 $^{\pm 0.2}$	1.0 $^{\pm 0.6}$	24.9 $^{\pm 24.9}$	0.2 $^{\pm 0.2}$	0.5 $^{\pm 0.3}$	19	26.9 $^{\pm 24.8}$
Czech Rep.	0.0	0.0	0.0	3.8 $^{\pm 0.7}$	5.7 $^{\pm 0.5}$	146	9.8 $^{\pm 1.0}$
Denmark	1.4 $^{\pm 0.9}$	0.0	0.0	4.8 $^{\pm 3.2}$	0.0	22	6.2 $^{\pm 3.2}$
Finland	1.6 $^{\pm 0.3}$	0.6 $^{\pm 0.2}$	0.4 $^{\pm 0.1}$	2.1 $^{\pm 0.2}$	2.4 $^{\pm 0.1}$	630	7.1 $^{\pm 0.5}$
France	7.9 $^{\pm 1.9}$	0.0	2.0 $^{\pm 0.4}$	9.7 $^{\pm 1.0}$	2.2 $^{\pm 0.1}$	548	22.3 $^{\pm 2.4}$
Germany	3.3 $^{\pm 0.8}$	1.3 $^{\pm 0.4}$	7.0 $^{\pm 2.5}$	11.9 $^{\pm 1.1}$	5.8 $^{\pm 0.5}$	226	29.6 $^{\pm 3.0}$
Hungary	3.6 $^{\pm 1.5}$	0.1 $^{\pm 0.1}$	1.1 $^{\pm 0.4}$	3.9 $^{\pm 1.0}$	0.7 $^{\pm 0.2}$	78	9.7 $^{\pm 1.9}$
Ireland	0.0	0.0	0.0	1.4 $^{\pm 0.4}$	4.5 $^{\pm 1.1}$	35	6.1 $^{\pm 1.4}$
Italy	5.8 $^{\pm 1.3}$	1.3 $^{\pm 0.5}$	2.7 $^{\pm 1.6}$	2.7 $^{\pm 0.5}$	2.0 $^{\pm 0.3}$	224	14.9 $^{\pm 2.4}$
Latvia	7.1 $^{\pm 1.3}$	3.8 $^{\pm 1.6}$	3.0 $^{\pm 0.8}$	10.7 $^{\pm 1.6}$	1.2 $^{\pm 0.2}$	95	26.4 $^{\pm 3.2}$
Lithuania	5.8 $^{\pm 2.0}$	5.4 $^{\pm 3.2}$	1.5 $^{\pm 0.4}$	3.0 $^{\pm 0.7}$	2.0 $^{\pm 0.3}$	62	17.7 $^{\pm 3.9}$
Poland	2.4 $^{\pm 1.1}$	0.1 $^{\pm 0.0}$	0.8 $^{\pm 0.3}$	3.9 $^{\pm 0.8}$	2.6 $^{\pm 0.2}$	438	9.9 $^{\pm 1.8}$
Slovak Rep.	9.7 $^{\pm 2.1}$	0.0	0.0	12.1 $^{\pm 1.8}$	4.8 $^{\pm 0.5}$	108	27.3 $^{\pm 3.5}$
Slovenia	18.3 $^{\pm 7.6}$	5.0 $^{\pm 2.0}$	0.9 $^{\pm 0.4}$	5.2 $^{\pm 1.5}$	3.2 $^{\pm 0.5}$	44	33.1 $^{\pm 7.8}$
Spain	1.8 $^{\pm 0.5}$	0.1 $^{\pm 0.1}$	0.5 $^{\pm 0.2}$	2.1 $^{\pm 0.5}$	1.0 $^{\pm 0.2}$	155	5.6 $^{\pm 0.9}$
Sweden	2.4 $^{\pm 1.2}$	2.3 $^{\pm 1.1}$	3.2 $^{\pm 0.8}$	15.3 $^{\pm 3.5}$	1.1 $^{\pm 0.1}$	100	24.4 $^{\pm 5.2}$
United Kingdom	0.0	0.0	4.7 $^{\pm 2.7}$	9.3 $^{\pm 1.9}$	1.3 $^{\pm 0.2}$	167	15.5 $^{\pm 4.2}$
<i>EU19</i>	4.1 $^{\pm 0.4}$	0.7 $^{\pm 0.1}$	1.8 $^{\pm 0.3}$	6.4 $^{\pm 0.3}$	2.5 $^{\pm 0.1}$	3243	15.8 $^{\pm 0.7}$

Fig. 2 Frequency distribution of plots in deadwood volume quantity classes with size of $25 \text{ m}^3 \text{ ha}^{-1}$ each



4.1 Deadwood volume at country level

At country level, the amount of deadwood ranges from 5.6 to $33.1 \text{ m}^3 \text{ ha}^{-1}$, with an average value of $15.8 \text{ m}^3 \text{ ha}^{-1}$ (Table 2). Deadwood is mostly present in Central Europe, particularly in Slovenia (more than $30 \text{ m}^3 \text{ ha}^{-1}$), Germany ($29.6 \text{ m}^3 \text{ ha}^{-1}$), Slovak Republic ($27.3 \text{ m}^3 \text{ ha}^{-1}$), Latvia ($26.4 \text{ m}^3 \text{ ha}^{-1}$), Austria ($23.7 \text{ m}^3 \text{ ha}^{-1}$), and France ($22.3 \text{ m}^3 \text{ ha}^{-1}$) but high values are found also in Cyprus ($26.9 \text{ m}^3 \text{ ha}^{-1}$) and Sweden ($24.4 \text{ m}^3 \text{ ha}^{-1}$).

The plot frequency distribution with respect to deadwood amount is an inverse J-shaped: in about 12% of plots (374 over a total of 3243) deadwood is totally absent; in 72% of the plots with deadwood, volume is lower than $25 \text{ m}^3 \text{ ha}^{-1}$ (Fig. 2). SDTs are absent in about 77% of the plots (2495), LDTs in 95% (3072), CWD in 43% (1390), snags

in 86% (2802), and stumps in 28% (900). The highest deadwood values, with a volume greater than $500 \text{ m}^3 \text{ ha}^{-1}$, are reached in two plots from France ($883 \text{ m}^3 \text{ ha}^{-1}$ and $574 \text{ m}^3 \text{ ha}^{-1}$), one from Poland ($647 \text{ m}^3 \text{ ha}^{-1}$), and one from the UK ($630 \text{ m}^3 \text{ ha}^{-1}$).

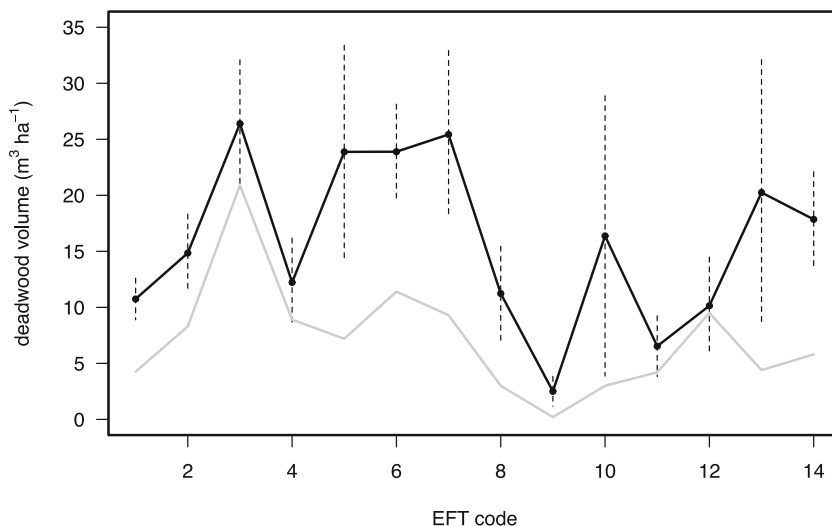
4.2 European Forest Types and Categories

Table 3 shows values of deadwood distinguished by EFTs (Barbati et al. 2014): the forest type with the highest value of deadwood volume (about $26 \text{ m}^3 \text{ ha}^{-1}$) is Alpine coniferous forest (EFT 3). In Fig. 3, the mean deadwood values by EFTs found in this study are compared with the ones obtained from NFIs in Europe (Rondeux et al. 2012). Higher differences in forest deadwood volume between this paper and NFI can be observed in EFT 5, 6, 7, 10, 13, and 14 (Fig. 3).

Table 3 Mean values of deadwood volume ($\text{m}^3 \text{ ha}^{-1}$) and their 95% confidence interval estimates distinguished by European Forest Types (EFT)

EFT code	EFT name	Mean volume ($\text{m}^3 \text{ ha}^{-1}$)
1	Boreal forest	$10.7^{\pm 1.9}$
2	Hemiboreal and nemoral coniferous and mixed broadleaved-coniferous forest	$14.8^{\pm 3.5}$
3	Alpine coniferous forest	$26.0^{\pm 5.7}$
4	Acidophilous oak and oak-birch forest	$12.2^{\pm 3.9}$
5	Mesophytic deciduous forest	$23.9^{\pm 9.5}$
6	Beech forest	$23.8^{\pm 4.2}$
7	Mountainous beech forest	$25.4^{\pm 7.5}$
8	Thermophilous deciduous forest	$11.2^{\pm 4.2}$
9	Broadleaved evergreen forest	$2.5^{\pm 1.3}$
10	Coniferous forests of the Mediterranean, Anatolian, and Macaronesian regions	$16.4^{\pm 12.5}$
11	Mire and swamp forest	$6.5^{\pm 2.7}$
12	Floodplain forest	$10.1^{\pm 4.3}$
13	Non-riverine alder, birch, or aspen forest	$20.3^{\pm 11.9}$
14	Introduced tree species forest	$17.9^{\pm 4.3}$

Fig. 3 Distribution of mean deadwood volume ($\text{m}^3 \text{ha}^{-1}$) by European Forest Types. Grey line shows values from National Forest Inventories data (see Rondeux et al. 2012, Table 2), black line the ones from results of this work



4.3 Decay status

The deadwood volume shows a J-shaped distribution with respect to the five decay classes. Decay class 1 is absent in 1934 plots (60%), decay class 2 in 1449 plots (45%), decay class 3 in 1423 plots (44%), decay class 4 in 1277 plots (39%), and decay class 5 in 1892 plots (58%).

The mean values of deadwood within classes from 1 to 5 are, respectively, $3.78 (\pm 0.6) \text{ m}^3 \text{ha}^{-1}$, $3.58 (\pm 0.5) \text{ m}^3 \text{ha}^{-1}$, $3.01 (\pm 0.5) \text{ m}^3 \text{ha}^{-1}$, $2.97 (\pm 0.4) \text{ m}^3 \text{ha}^{-1}$, and $1.41 (\pm 0.2) \text{ m}^3 \text{ha}^{-1}$. The main proportion of deadwood volume refers to decay class 2 for both standing and lying dead trees, while decay class 3 and decay class 4 are the most frequent for CWD, snags and stumps (Fig. 4).

4.4 Stand management

Deadwood volume is larger in unmanaged stands. Decay class 1 is relatively dominant in both managed and unmanaged stands (25.4% and 27.8% of all decay classes respectively)

and deadwood amount decreases with increasing decay levels, with exception of decay class 3 in the case of unmanaged stands.

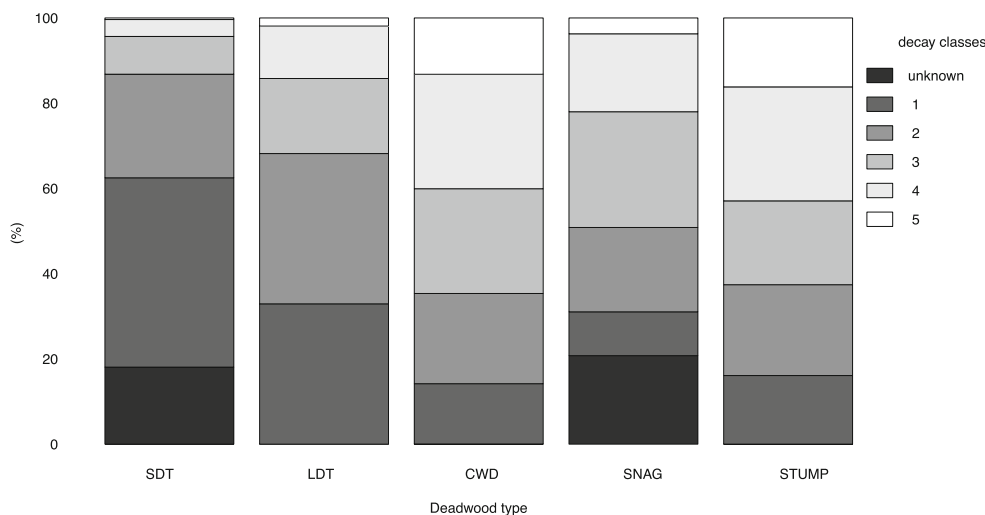
4.5 Stand age

Deadwood volume shows increasing values with stand age. Mean values range from $5.6 \text{ m}^3 \text{ha}^{-1}$ of the first age class (0–20 years) to $22.3 \text{ m}^3 \text{ha}^{-1}$ of plots with stand age higher than 120 years. The maximum values are reached in the uneven-aged stands ($30.4 \text{ m}^3 \text{ha}^{-1}$).

5 Reuse potential and limits

Any rational decision related to the maintenance and enhancement of the multiple functions provided by forests needs to be based on objective, reliable information (Corona 2018): as such, the dataset here presented provides substantial matter grounded on transparent methodology, coherent with the

Fig. 4 Percentage of the volume of deadwood by type and decay classes. SDT, standing dead trees; LDT, lying dead trees; CWD, coarse woody debris; SNAG, snags; STUMP, stumps. Decay classes: 1, No evidence of decay; 2, Solid wood; 3, Slightly decayed; 4, Decomposed wood; 5, Very decomposed wood



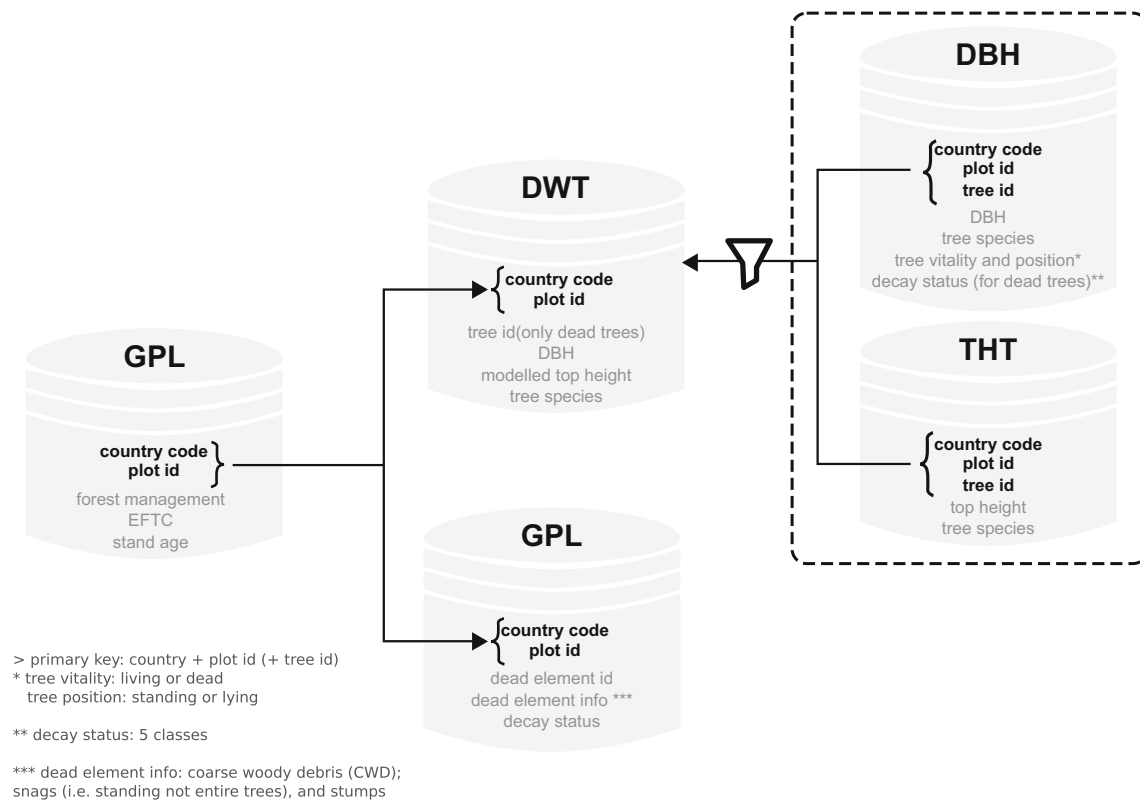


Fig. 5 ICP Forests database structure and links with dataset presented in this paper. GPL, General Plot Location and information; DWT, dead material lying on the ground; THT, Tree Top and crown base Height; DBH, tree diameter, status, and composition; DWT, deadwood trees

(standing dead material). DBH and THT have been used to calculate volume of standing trees, DWT to calculate volume of material lying on the ground. See the text for details

declared survey objectives and recognisable by the scientific community worldwide.

The original datasets used to produce the one presented in this work are stored into the collaborative ICP Forests database, at the Programme Co-ordinating Centre (PCC) of UNECE ICP Forests in Eberswalde, Germany. Access to the original data can be requested via the official project homepage: <http://icp-forests.net>. Under the menu “Plots and data - data requests”, the official data request form is provided. The requesting part must provide an abstract on the scientific purpose and approach to PCC, which will be evaluated by the ICP Forests.

The database presented in this paper is derived by merging and filtering four ICP Forests LI-sub2 datasets (Fig. 5), namely, GPL (General Plot Location and information), DWT (Deadwood material on the ground), THT (Tree Top and crown base Height), and DBH (tree diameter, status, and composition). Many other datasets are potentially available for other purposes (see, e.g. Fleck et al. 2016).

Acknowledgements The presented derivate aggregated database is based on four original datasets (GPL, THT, DWT, and DBH) as archived into the collaborative ICP Forests database, at the Programme Co-ordinating Centre (PCC) of UNECE ICP Forests in Eberswalde, Germany. Access to these data can be requested via the official project homepage (<http://icp-forests.net>). Under the menu “Plots and data - data requests”, the data

request form is provided. The requesting part has to provide an abstract on the scientific purpose and approach to PCC, which will be evaluated by the ICP Forests, and the expected delivery data will be communicated after a couple of weeks. The evaluation was based on data that are part of the UNECE ICP Forests PCC Collaborative Database (see www.icp-forests.org). Particularly, data from 19 countries (see § Methods), were used in the analyses. Data evaluation was co-financed by a scholarship fund of the Forest Research Institute (IBL), Poland.

Compliance with ethical standards

Conflict of interest The authors declare that there is no conflict of interest.

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