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ABSTRACT

National forest inventories are a primary source of data for the assessment of forest resources and lastly more often biodiversity at national scales. The diversity of adopted sampling designs and measurements reduces the prospect for a reliable comparison of generated estimates. The ICP Forest dataset represents a unique opportunity for a standardized approach of forest estimates through Europe. This work aims to provide a distribution map of the mean deadwood volume in European forest. A total of 3243 ICP Forests plots were analysed and presented. The study area extends over 3,664,576 km^2 interesting 19 countries. We observed that the highest percentage of plots show a deadwood volume lower than 50 m^3 ha^{-1}, with a few of forests attaining around the maximum of 300 m^3 ha^{-1}. Forests with more than 100 m^3 ha^{-1} are concentrated in mountainous regions, central Europe and other regions, linked to high-forest management types, while coppices-derived forest systems (part of the Great Britain, Mediterranean region) show lower deadwood content. The map of deadwood volume on European Forests is of interests for scientists, land planners, forest managers and decision-makers, as a reference for further evaluation of changes, stratified sampling, ground reference for model validation, restoration and conservation purposes.

1. Introduction

Forest ecosystems and their management are of central importance in international debate, because they provide many important ecosystem services, from which carbon storage, nature conservation and timber production are the principals (Crecente-Campo et al., 2016). Data and information collected by Forest Inventories are fundamental to assess alternative policy approaches for a sustainable management of our natural environments (Forest Europe, 2015), more recently stimulated by concerns over the effects of climate change on environmental conditions (FCCC, 2015).

In this framework, forest deadwood covers a fundamental role. Deadwood is considered an important component in greenhouse gas cycle functioning as stock of huge quantity of carbon (Zell, Kändler, & Hanewinkel, 2009). It is also one of the most important structural and multifunctional component of many forest ecosystems (Travaglini et al., 2007). This is why the volume of both standing and lying deadwood is an indicator of the pan-European criteria for sustainable forest management (Forest Europe, 2015; Lassauce, Paillet, Jactel, & Bouget, 2011).

Mapping quantitative information on ecosystems is an important contribution towards the applications of the ecosystem service approach, both in scientific knowledge and management (Burkhard, Kroll, Nedkov,

& Müller, 2012; Pedrotti, 2013). Under this perspective, a large-scale distribution map of deadwood volumes can be a relevant outcome, and based on comparable measurements.

At European level, information and statistics on forest attributes, deadwood included, have been traditionally collected from national forest inventories (NFIs) at country level. Under this perspective, the lack of standardized deadwood-related definitions makes the comparison of different estimates hard, and a phase for data harmonization is indispensable (Ståhl et al., 2012). Methods for deadwood data collection and the issues for their harmonization in European NFIs were analysed in COST Action E43 (Tomppo & Schadauer, 2012). However, standardized methods for data collection are of course recommended (Köhl, Traub, & Paivinen, 2000).

The International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forest, http://icp-forests.net/) represents an unprecedented opportunity. ICP Forest is indeed the only existing field network that measures status of forests under a coordinated pan-European umbrella, including a spatially representative design (Ferretti & Fischer, 2013). Using ICP Forest Level I database on Biodiversity based on standardized protocols (Canullo, 2016; Working Group on Forest

Biodiversity, 2007), the objective of this study was to present the spatial distribution of results of deadwood volume mensuration in Europe.

2. Methods

2.1. Study area

ICP Forest Programme is responsible for the Level I and the more detailed Level II monitoring system of forest sites (Haußmann & Fischer, 2004), which have been in operation from 1986 and from 1994 respectively. The Large-scale Level I network derives from points placed on a 16×16 km virtual grid projected over Europe. Around these points, a system of three circular concentric subplots with surfaces respectively of 30, 400 and 2000 m^2 were built (Working Group on Forest Biodiversity, 2007). In this study we consider data from subplot 2. Despite plot dimensions are not optimal for tree stand biodiversity evaluations, they are appropriate for estimations of total deadwood volume (Lombardi et al., 2015).

The data used in this study were acquired in the field between 2006 and 2008 in the framework of the BioSoil Forest Biodiversity Demonstration Project (JRC, 2011). Raw data were obtained by ICP Forest partners and pre-elaborated in the framework of the official activities of the UNECE ICP Forest Network and stored in the ICP Forest Level I database on Biodiversity (Canullo, 2016; Working Group on Forest Biodiversity, 2007).

Diameter at breast height (DBH, in cm) and species of all living trees with DBH higher than 10 cm, and a sample of top height (TH, in meters) were measured, together with coarse woody debris (CWD, with diameter at half length higher than 10 cm). Canopy closure, number of tree layers and ground vegetation have been also recorded.

In this work, a total of 3243 Level I plots were considered with their associated spatial coordinates and general information. The study area covers a total of 130 ha (3243 plots of 400 m^2 each) and includes 19 European Countries: Austria, Belgium, Cyprus, Czech Republic, Denmark, Finland, France, Germany, Hungary, Ireland, Italy, Latvia, Lithuania, Poland, Slovakia, Slovenia, Spain, Sweden, United Kingdom.

2.2. Deadwood volume mensurations

Five deadwood components were considered in this work: entire standing dead trees (SDT), lying dead trees (LDT), snags (i.e. broken standing dead trees), CWD and stumps. For SDT and LDT, volume was calculated by the following equation:

$$V_{\text{trees}}[m^3] = f \cdot \text{TH} \cdot \pi \cdot [(\text{DBH}/2]^2, \tag{1}$$

where f is the species-specific shape coefficient. For SDT the volume was calculated using a shape coefficient of 0.5,

whereas for snags it was calculated using the formula for a truncated cone, assuming a taper of 1 cm m^{-1}.

The volume of each lying CWD and stump was calculated by means of Equations (2) and (3).

$$V_{CWD} = \pi/4 \cdot l \cdot d_{0.5}^2, \tag{2}$$

where V_{cwd} is the volume, $d_{0.5}$ the diameter at half length, and l is the length.

$$V_{\text{stump}} = \pi/4 \cdot h \cdot d^2, \tag{3}$$

where V_{stump} is the volume of the stump, d the diameter of the stump at the cutting or breaking point and h is the height of the stump.

The volume, expressed in m^3 of all deadwood elements, was summed up at plot level and scaled to m^3 ha^{-1}. In the map, these values were grouped in four classes: the first one relates to plots on which deadwood was not found (i.e. zero m^3 ha^{-1}). Plots with deadwood values ranging between 0 and 50 m^3 ha^{-1}, between 50 and 100 m^3 ha^{-1} and higher than 100 m^3 ha^{-1} were defined. The choice was due to the J-shaped distribution of deadwood volume (Figure 1), which highlights the plots with no deadwood (12%) or volumes up to 50 m^3 ha^{-1} (80%).

3. Conclusion

The aim of this paper was to present a large-scale distribution map of mean deadwood volume, as collected on 3243 plots over 19 European countries, along a spatially representative sampling design and adopting field standardized methods (Main Map).

This map is a methodological advance since is the first representation of the forest deadwood at a European continental scale, based on field surveys. The dataset allowed comparability of the collected parameters, so that the plot-based assessments of all the deadwood sources were expressed by a reasonable generalization of volume per area.

Quantitative representation highlights some general patterns. High concentration of plots with more than 50 m^3 ha^{-1} of deadwood in the Alpine regions, including Carpathians and central Europe, draws attention on the possible linkage with high-forest management, while the commonly lower values in the Mediterranean region and South Great Britain can be linked to coppice management with a more continuous timber removal (e.g. Kirby, 1992). NW Great Britain, and Ireland, both with a non-native tree stands, suggest a country-based differentiation due to management policies. Almost regular dispersed plots with high deadwood amount, on a matrix of forest plots with reduced volumes, are to be found in N-Europe-Scandinavia, as a possible management strategy.

This map represents a good reference for scientists, land planners, forest managers and decision-makers at a Continental scale.
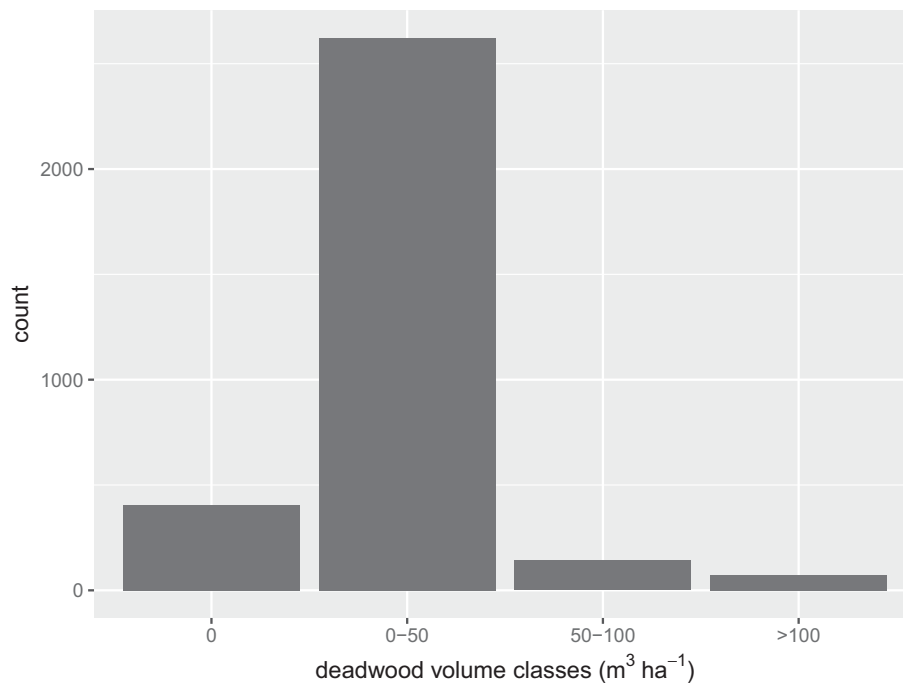
Figure 1. Frequency distribution (number of plots) against classes of total deadwood volume (m^3 ha^{-1}).

Extensive field knowledge helps improve classification accuracy of modelling derived assessments at large scale (e.g. Shrestha & Zinck, 2001; Tomppo et al., 2008). Moreover, being based on field assessments on the large-scale representative bases, the presented map *per se* is a benchmark to further monitoring of forest deadwood content, and for stratified sampling designs.

Deadwood is used as an indicator of naturalness (or forest health), or the evolution of large-scale forest biodiversity, to evaluate the trade-off between biodiversity and productivity, and represent a structural character in relations with local drivers, or for restoration and conservation perspectives (Branquart, Verheyen, & Latham, 2008).

The map allows to allocate deadwood figures according to the ecogeographic context (e.g. biomes, ecological regions, forests types, etc.) as well as the management policies in different Countries or areas (Hekkala et al., 2016; Korjus & Laarmann, 2015; Lassauce et al., 2011; Merganičová, Merganič, Svoboda, Bače, & Šebeň, 2012; Rondeux & Sanchez, 2010).

Moreover, standardized values of forest attributes (like e.g. deadwood), as well as associated maps, are expected to fill the current gap between forest monitoring and biodiversity conservation purposes within policy and governance processes from local to European scale (e.g. Barbati, Marchetti, Chirici, & Corona, 2014).

Software

R (R CoreTeam, 2016) was used for computations and main statistical analysis. The map was performed using Quantum GIS (QGIS) and Inkscape.

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Deadwood volume on plots (m³ ha⁻¹)

- • 0 (no deadwood found)
- • 0 - 50
- ● 50 - 100
- ● > 100

Forest cover

0   250   500   750   1000 km