The choice of definition has a large effect on reported quantities of dead wood in boreal forest

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Abstract

A survey was conducted to assess the impact of the choice of definition on reported quantities of dead wood in Swedish forests, which to more than 90% are located in the boreal zone. The data collection was made on a subsample of the permanent plots of the Swedish national forest inventory. The objects included were standing dead trees and snags down to 5 cm diameter at breast height, dead lying stems and branches down to a threshold diameter of 1 cm, and stumps down to a threshold diameter of 5 cm at normal stump height. Standing trees, snags, and stumps were inventoried on 10 m radius circular plots while the downed objects were inventoried using both circular plots and line intersect sampling; thin objects (diameter 1-5 cm) were assessed only through line intersect sampling. The results showed that the estimated volume of dead wood was as high as 25 m^3 ha^{-1} when all components were included. With the standard Swedish definition, the corresponding estimate was only 10.9 m^3 ha^{-1}, or 43 % of the total value. Since definitions of dead wood vary greatly between countries we conclude that great caution must be exercised when figures are compared in connection with international reporting. For example, adding stumps to the Swedish definition would increase the amounts of dead wood from 10.9 m^3 ha^{-1} to 15.7 m^3 ha^{-1}, i.e. with 44 %.

Keywords: coarse woody debris, forest inventory, harmonization, international reporting

Introduction

Dead wood has received much attention over the last couple of decades, mainly as this substrate has been identified as very important for the habitat quality of forest ecosystems (e.g. Samuelsson et al. 1994, Sippola and Renvall 1999, Christensen et al. 2005). Traditional forest management has led to decreases of this resource and thus dead wood, also known as coarse woody debris (CWD), has been adopted as an indicator in many systems aimed at ensuring sustainable forest management. Examples include the Ministerial Conference on the protection of forests in Europe (MCPFE 2003), nowadays known as Forest Europe, the Montreal Process (Montreal Process 2005), and the system of indicators adopted by the European Environment Agency for halting the loss of biodiversity in Europe (EEA 2007). Dead wood also plays a prominent role in the systems for greenhouse gas reporting and accounting under the Climate Convention and its Kyoto Protocol (Penman et al. 2003), where dead wood is one of five different carbon pools that need to be monitored for the reporting of greenhouse gas emissions from the land use, land-use change, and forestry sector.

However, while dead wood is pointed out as important in many different contexts there is still considerable lack of agreement regarding definitions. A majority of data about dead wood stems from national forest inventories (e.g. Cienciala et al. 2008, Woodall et al. 2009) but the definitions in these inventories are far from standardized (Rondeux et al. 2012). In many cases all pieces of dead wood larger than 10 cm in diameter and longer than 1 m are included (Ståhl and Dolloff 2012, Rondeux et al. 2012). These pieces may be either standing or lying; the former category is known as snags and the latter category as down or downed logs. However, by the normal definition short pieces of coarse dead wood, such as stumps, are excluded and this is the case also for all pieces finer than 10 cm, known as fine woody debris (FWD). Just like CWD, FWD has been identified as important for a large number of species depending on dead wood (e.g. Kruys and Jonsson 1999, Nordén et al 2004). Regarding decomposition the variability of definitions and methods are even bigger and sometimes decomposition is not assessed. The dominating method for assessment of decay class is visual inspection, while only a few countries use measurements (Winter et al. 2008). Some countries do not assess dead wood at all and some focus only on standing dead wood (Rondeux & Sanchez 2010).

Regarding greenhouse gas reporting, the amounts of dead wood that are not included in the deadwood pool should instead be included in the litter pool, and thus different definitions in theory should not lead to different estimates of total greenhouse gas emissions. However, in reality different methods or emission factors are adopted for different pools (e.g. Dunger et al. 2012) and thus differences in definitions are likely to affect the final estimates of total emissions. Furthermore, Herrmann and Bauhus (2013) suggest that it is too simple to model carbon emissions with constant decay rates and instead the decay stage of dead wood should be taken into account.

Only few studies exist, where dead wood quantities are reported for all categories of dead wood, including CWD, FWD and short pieces of coarse material, such as stumps. Nordén et al. (2004) surveyed 25 sites in southern Sweden, all with high conservation value, and found that on average the volume of FWD was almost as high as the volume of CWD. Transects were laid out within the sites and the threshold to separate between CWD and FWD was 10 cm. Woodall and Liknes (2008) compared CWD and FWD volumes for different climatic regions in the USA, and found that in many regions the amounts of the two categories were similar. Data were obtained from the line intersect sampling of the FIA, i.e. the national forest inventory of the USA; the threshold between CWD and FWD in this case was 7.6 cm diameter and 0.9 m length. Eaton and Lawrence (2006) surveyed 28 stands in southern Mexico and observed three times as much CWD compared to FWD; the threshold in this case was 10 cm diameter. Other studies (e.g. Krauss et al. 2005, Passovoy and Fulé 2006) report on different dead wood pools from smaller areas in connection with surveys focusing on, e.g., effects of wildfires and hurricanes.

Considering the importance of dead wood for biodiversity and for greenhouse gas reporting our current knowledge about the amounts of different categories in different forest ecosystems is limited.

The objective of this study was to assess the impact of using different definitions on reported quantities of dead wood. A combined sample plot and line intersect survey was linked to a subsample of the permanent plots of the Swedish national forest inventory (NFI). The same basic methods and definitions as those used in the NFI (Axelsson et al. 2010) were used, but in addition all components of dead wood were included in order to assess their relative abundances.

Materials and methods

A sample of the existing permanent plots from the Swedish NFI was selected for the study. The target was to include plots from within the entire country with proportions roughly corresponding to the sampling proportions for the different geographical strata in the ordinary NFI. To ensure a random selection with good geographic distribution, a grid was randomly allocated over each NFI stratum and the NFI plot cluster closest to each grid intersection was included. From each plot cluster, 3 to 4 plots were selected for the study. Thus, in total 286 plots were included (Fig 1) using both the methods employed by the ordinary NFI (Riksskogstaxeringen 2010) and additional methods specifically designed for this study in order to obtain information from all dead wood fractions.

Figure 1. Distribution of the 286 sample plots (within clusters) over Sweden.

The inventory was carried out by two NFI-experienced field teams, each comprising two people, after two days of training on the methods employed in this survey (sample plot and line intersect sampling, as described below).

Data acquisition

The following categories of dead wood were included:

- Standing dead trees, coarser than 5 cm diameter at breast height (1.3 m).

- Stumps, coarser than 5 cm diameter at top end and less than 1.3 m in height.
- Lying stems or stem parts, coarser than 1 cm diameter (no length restriction).
- Dead lying branches, coarser than 1 cm diameter (no length restriction). Dead branches on living trees were not assessed.

In the inventory, objects were measured on the plots; lying stems were measured with two different methods, sectioning and line intersect sampling, respectively.

For each object the following pieces of information were collected: geographical/administrative information, tree species, diameter, height/length, degree of decomposition, existence of bark, cause of death, and whether or not a standing dead tree was broken. For objects in the line intersect sampling the inclination of the object to the horizontal plane was classified into four classes (0-10, 11-30, 31-60, 61-90 degrees).

The degree of decomposition was registered using the definitions of the Swedish NFI (Table 1; Riksskogstaxeringen, 2010)

Table 1. Definition of degree of composition.

Code	Degree of decomposition
0	Raw wood, newly windthrown trees
1	Hard dead wood. The stem volume consists to more than 90 % of hard wood
2	Slightly decayed wood. The stem volume consists to 10-25 % of soft wood.
3	Decayed wood. The stem volume consists to 26-75 % of soft or very soft wood.
4	Very decayed wood. The stem volume consists to 76-100 % of soft or very soft wood.

Data were collected with handheld computers and stored in Excel worksheets.

In total 9 693 objects of dead wood were measured, distributed on categories and methods according to Table 2.

Table 2. Object distribution on categories and methods.

Category/method	Number of objects
Standing	1401
Lying	1884
Stumps	4641
Line intersect	1767

Methods

For standing trees, the diameter at breast height as well as the tree height or the height of the remaining (broken) tree were measured. Stumps were measured for stump height and diameter at the top of stump.

The volume of lying objects coarser than 5 cm was determined by sectioning. A 10 m plot radius was used for objects coarser than 10 cm and a 5 m radius plots for the other units. The number of sections was decided depending on length of the object; generally the section length was about 2 m. Several ”fixed” diameters were used as section endpoints in order to allow for volume estimates according to different definitions with regard to log diameter threshold.

Line intersect sampling of lying objects was conducted on three line transects of 8 m length on every plot (Figure 2). Fine pieces of lying dead wood (logs and branches between 1 cm and 10 cm diameter were measured along the first three meters of each line, while coarse objects (>10 cm) were measured along the entire lines.

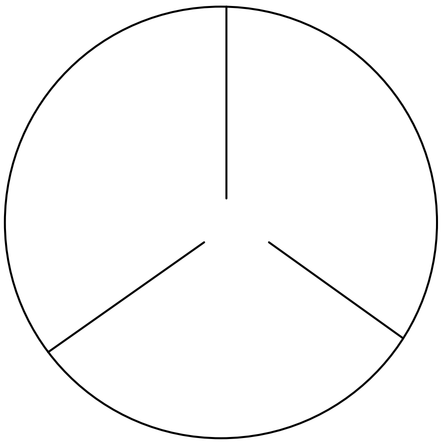

Figure 2. The transects started 2 m from the plot centre and were laid out in the directions 120, 240 and 360 degrees from the plot centre.

Estimations of different objects

Standing/broken trees

The volume of standing trees (including standing broken trees >1.3 m height) was estimated by existing volume functions for non-broken trees and by sectioning for broken trees. The sectioning was done by calculating a top diameter using a simple taper function and using Smalian's formula (Husch et al., 1982) for volume estimation.

Stumps

The volume of stumps was calculated based on measured top diameter and stump height together with estimated diameter at ground level. This diameter was estimated by the following function developed from data from the Swedish NFI (Cory, 2008)

$$D_{bh} = DS + 0{,}28 \times DS \times ln\left(\frac{SH+1}{2{,}3}\right) \quad (1)$$

and with SH=0

$$DS_0 = \frac{D_{bh}}{1+0{,}28 \times ln\left(\frac{1}{2{,}3}\right)} \quad (2)$$

Where

D_{bh} = diameter at breast height, cm

DS = diameter of stump at top, cm

DS_0 = diameter of stump at ground level, cm

SH = stump height, m

The volume of the stump was then calculated as the volume of a truncated cone.

Lying dead wood

The volume of the sections was calculated by Smalian’s formula for all section up to the given threshold diameter. As only a limited number of diameter thresholds were applied during the measurements, the length and top diameter of sections in some cases were obtained through interpolation.

In addition, the volume of lying dead wood was estimated according to the definitions of the Swedish NFI. Here the objects considered are those with a diameter ≥ 10 cm at 1.3 m length up to a top diameter of 10 cm.

Line intersect sampling

The volume/ha of the objects inventoried in the line intersect sampling was estimated according to the formula (De Vries, 1986)

$$V = \frac{10000 \times \pi^2}{8 \times L} \times \sum d_i^2 \;/\; cos\beta_i \qquad (3)$$

Where

V = volume per hectare

L = total transect length

d_i = diameter of object at line intersection

β_i = inclination of the object relative to the horizontal plane

Combined estimation

As some categories of lying dead wood (those coarser than 5 cm) were assessed using two different methods, estimates based on sample plots (method S) and line intersect sampling (method L) were combined. Using the information on variances and co-variances of the estimates, the weights were calculated as:

$$a_L = \frac{\sigma_S^2 - Cov_{SL}}{\sigma_L^2 + \sigma_S^2 - 2Cov_{SL}} \quad (4)$$

Where

a_L = weight for the volume estimate according to method L

σ^2_S = variance of estimated mean volume based on method S

σ^2_L = variance of estimated mean volume based on method L

Cov_{SL} = covariance between estimated mean volumes based on methods S and L

σ^2_S and σ^2_L are estimated using SRS

The volume estimate with $a_S = 1 - a_L$ was then obtained as

$$V = a_L * V_L + a_S * V_S \quad (5)$$

The variance of the estimate of the mean volume was derived according to the principles of Swedish NFI (Fridman & Walheim 2000), although in this study simplified to standard procedures from SRS as mostly one plot per cluster was used. Thus,

$$Var(V) = a_L\ \sigma^2_L + a_S\ \sigma^2_S + 2Cov_{SL} \quad (6)$$

Similarly, the variance estimator of the total volume/ ha of all categories is

$$var\ (a_1V_L + a_2V_T + a_3V_S) = a_1^2 var\ (V_L) + a_2^2 var\ (V_T) + a_3^2 var\ (V_S) + 2\ a_1\ a_2 cov\ (V_L,\ V_T) + 2\ a_1\ a_3 cov\ (V_L,\ V_S) + 2\ a_2\ a_3 cov\ (V_T,\ V_S) \quad (7)$$

Where

$Var(V_L)$ = variance of volumes for lying dead wood

$Var(V_T)$ = variance of volumes for standing dead wood

$Var(V_S)$ = variance of volumes for stumps

a_1 = weight for mean volume lying dead wood

a_2 = weight for mean volume standing dead wood

a_3 = weight for mean volume stumps

Results

The volume of dead wood was estimated using different diameter and length thresholds for the different categories.

The amount of dead wood decreased quite rapidly over diameter for lying dead wood, while stumps had the slowest decrease (Figure 3). The total volume of dead wood greater than 5 cm was 21.0 m^3 ha^{-1}. Adding the amount of lying dead wood between 1 and 5 cm (3.6 m^3 ha^{-1}) leads to a total volume of about 25 m^3 ha^{-1} when all categories were included.

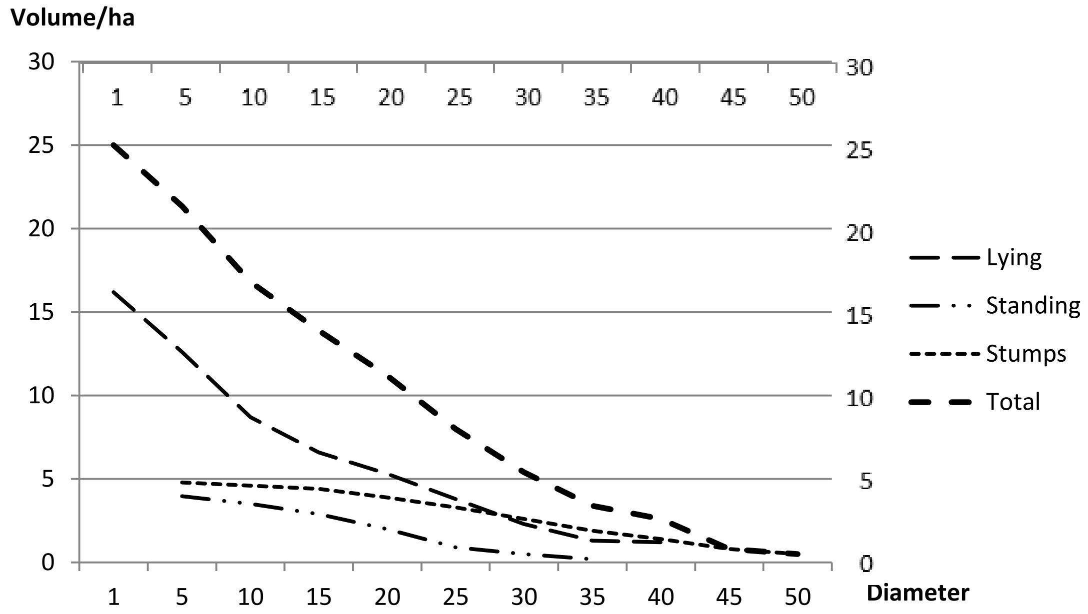

Figure 3. Amounts of deadwood (m^3/ ha) using different diameter thresholds for the different categories of dead wood included in the study. No length restriction is used.

A change from a 10 cm to a 5 cm diameter threshold resulted in a 4% increase of the volume for stumps, a 14% increase for standing trees, and a 44% increase for lying dead wood (Table 3). The ratios were found to be fairly stable between northern and southern Sweden.

Table 3. The ratio between deadwood volume for objects > 5 cm and objects > 20 cm related to the reference (> 10 cm).

Category	> 5 cm	> 10 cm	>20 cm
Lying	144	100	60
Standing	114	100	57
Stumps	104	100	85
Total	127	100	67

The effects on volume of different length thresholds for lying objects are shown in Table 4.

Table 4. Estimated volume /ha for objects >10 cm using different length thresholds for lying deadwood.

min. length	m^3/ha
length >1.3m	8.09
length >1.0 m	8.19
length, >0 m	8.36

The results show that the choice of length threshold between 0 and 1.3 m does not affect the volume estimates very much. For example, the volume using a minimum length of 1.0 m was only 0.1 $m^3 ha^{-1}$ (1.2 %) higher than the volume corresponding to the 1.3 m threshold.

Using the Swedish NFI definition results in 7.4 m^3 ha^{-1} of lying dead wood, which together with standing dead wood makes a total of 10.9 m^3 ha^{-1}.

The proportion of lying dead wood increases when the threshold diameter is changed from10 cm to 5 cm (Table 5). The volume of stumps amounts to a considerable volume and is higher than the volume of standing/broken dead trees.

Table 5. Estimated dead wood (m^3/ha) for different categories of objects at different minimum diameters at minimum length 0 m. Lying dead branches are included, while dead branches on living trees are excluded. Standard errors are given within parentheses. Note that the figures in italic for the column > 1 cm relate to standing and stump objects > 5 cm.

Category	>10 cm	> 5 cm	> 1 cm
Lying	8.5 (1.9)	12.2 (2.2)	16.2 (2.4)
Standing	3.5 (0.8)	4.0 (0.8)	*4.0*
Stumps	4.6 (0.5)	4.8 (0.5)	*4.8*
Total	16.6 (0.4)	21.0 (0.4)	*25.0*

The line intersect inventory results show an increasing proportion of decayed wood with increasing diameter (Figure 4). The proportion of hard dead wood was 65% and 32% for diameter 1-5 cm and >10 cm, respectively. Very decayed was 8 % for diameter 1-5 cm, while it was 33% for diameter >10 cm.

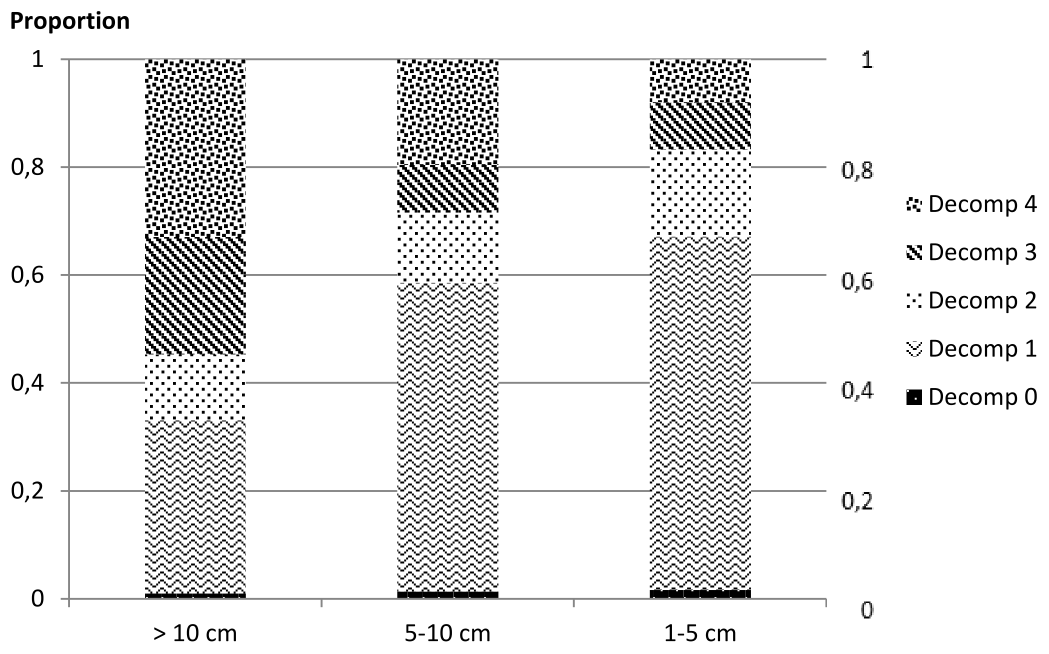

Figure 4. Distribution of decomposition classes for objects of different diameters for the line intersect sampling data.

Discussion

The findings of this study clearly show the sensitivity of reported quantities of dead wood to the definitions used. When all components of dead wood were included our estimate was 25 $m^3 ha^{-1}$, while the estimate using the Swedish definition of dead wood was only 10.9 $m^3 ha^{-1}$, i.e. 43 % of the total amount. The difference was composed of stumps (4.8 $m^3 ha^{-1}$), downed fine woody debris (7.5 $m^3 ha^{-1}$), standing trees and snags finer than 10 cm diameter at breast height (0.5 $m^3 ha^{-1}$), and downed coarse woody debris shorter than 1.3 m (0.3 $m^3 ha^{-1}$).

Increasing the threshold diameter to 20 cm, corresponding to the national definition used in some central European countries (e.g. Rondeux et al. 2012), our estimate was 7.3 m^3 ha^{-1}, i.e. only 60 % of the estimate using the Swedish definition.

Our study was carried out in boreal forests, where a substantial portion of the growing stock is composed of fairly small trees (e.g. Dunger et al 2012). Thus, it is not surprising that a threshold diameter around 10 cm leaves out a fairly large amount of the total pool of dead - wood. Findings similar to ours have been reported by Nordén et al (2004) and Woodall and Liknes (2008). Rondeux et al. (2012) assessed the impact of using different threshold diameters in the range from 10 to 20 cm and found that a 20 cm threshold decreased the volumes of dead wood with 30%. In this case, most of the data emanated from temperate forests. In tropical forests, the impacts from fine categories of dead wood might be smaller due to the rapid turnover of fine fractions of dead organic materials under most tropical conditions.

Whether or not fine categories of dead wood should be included in the reporting depends on the specific reporting requirements which, in turn, depend on the intended use of data. While most authors agree that the coarse dead wood category is the most important one in relation to biodiversity, several authors (e.g. Kruys and Jonsson 1999) have also pointed out the importance of fine woody debris in this context. In connection with greenhouse gas reporting (e.g. Dunger et al 2012) all categories are important, although the persistence of the finer categories normally is shorter.

Many countries use a diameter threshold of about 10 cm for measuring and reporting dead wood (Tomppo et al 2010). Mostly, only standing and lying trees and trunks are included, while stumps and branches are left out. As international comparisons are becoming increasingly important, e.g. due to the climate change and biodiversity conventions, countries need to improve the comparability of reported figures. For example, the definition for reporting used by Forest Europe is not harmonised. Countries can report dead wood according to their national definitions, but specifications of the diameter and length limits used are required.

Due to the importance of dead wood in several contexts, and the findings in this study, we argue that further steps towards harmonisation of international reporting are required. Appropriate first steps could be that reference definitions of dead wood are provided in connection with the reporting linked to different multilateral agreements. Countries would then ideally recalculate their dead wood estimates so that estimates become comparable in each specific context. To achieve this, so called bridging procedures (Ståhl et al 2012) need to be developed and applied. Such procedures may be straightforward in the case of reductive bridging, i.e. when the recalculation only is a matter of leaving out some categories among those already included in an inventory. Bridging is more difficult in the case of expansive bridges, as certain dead wood components in this case need to be added on the basis of models or experiences from other countries or pilot studies (e.g. Rondeux et al. 2012). Thus, to be able to develop high-quality bridging procedures, countries should ideally include all dead wood components in the inventories and perform the inventories according to protocols that allow for estimates using different dimension thresholdss. However, the increased costs for such inventories may be prohibitive. A useful alternative would be to establish recalculation models or factors from limited inventories, like the one we present, where all components have been included. For example, based on our inventory the expansion factor to calculate the volume of dead standing trees/snags and CWD using a 5 cm diameter threshold from inventory data based on the Swedish definition would be 1.37. Such factors may need to be re-estimated at certain time intervals as it cannot be taken for granted that the structure of the pool of dead wood in forests remain the same over time. Bridges of this kind are crude, but would assure fair comparisons of figures across different countries.

In conclusion, our study revealed that reported amounts of dead wood to a large extent depend on what definition of dead wood is applied. Further, we suggest that calibration models or factors be derived from pilot studies of the kind we present in this study in order to facilitate bridging towards the definitions specified under different conventions or other agreements.

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