Harmonizing Greenhouse Gas Reporting from European Forests: Case Examples and Implications for European Union Level Reporting

Karsten Dunger, Sven Hans-Olof Petersson, Susana Barreiro, Emil Cienciala, Antoine Colin, Gro Hylen, Gal Kusar, Katja Oehmichen, Erkki Tomppo, Tarja Tuomainen, and Göran Ståhl

Abstract: Most European countries have signed the United Nations Framework Convention on climate change and its Kyoto Protocol. Because the European Union is a party to the convention just like the individual countries, there is a need for harmonizing emissions reporting. This specifically applies to the Land Use, Land-Use Change, and Forestry sector, for which harmonized reporting is complex and generally challenging. For example, parties use a variety of different methods for estimating emissions and removals, ranging from application of default factors to advanced methods adapted to national circumstances, such as ongoing field inventories. In this study, we demonstrate that without harmonization, national definitions and methods lead to inconsistent estimates. Based on case studies in Finland, Germany, Norway, Portugal, Slovenia, and Sweden, we conclude that common reference definitions and country-specific bridges are means to harmonize the estimates and make greenhouse gas reporting from forests comparable across countries. FOR. SCI. 58(3):248–256.

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Most European countries have signed the United Nations Framework Convention on Climate Change (UNFCCC) as well as its Kyoto Protocol (KP) (UNFCCC 1998). Because of a burden-sharing agreement among the European Union member states (Commission of the European Communities 2006), emission reduction targets for these countries may be determined by the European Union. Thus, there is an obvious need for coordinating the reporting, including the harmonization of reported emissions and removals of greenhouse gases. The requirements for reporting and accounting for greenhouse gas emissions have been developed in several steps, including general reporting guidelines (Intergovernmental Panel on Climate Change [IPCC] 1997) under the UNFCCC and the subsequent Good Practice Guidance (GPG) reports (IPCC 2000, 2003) under both UNFCCC and KP. Examples of requirements include the following: data must be consistently reported over time, data must be comparable among parties, and data must be subject to annual quality control.

For the Land Use, Land-Use Change and Forestry (LULUCF) sector, harmonized reporting is a challenge for a number of reasons. First, GPG allows freedom to parties to use nationally specific definitions. Second, reports are required annually whereas forest inventories in most countries are often conducted at irregular intervals (e.g., Tomppo et al. 2011, Heikkinen et al. 2012). Third, parties use a variety of methods for estimating emissions and removals, ranging from application of default factors as recommended by IPCC (2003) to advanced country-specific approaches based on local models and factors from recent field studies (e.g., Cienciala et al. 2008).

The main focus for reporting and accounting within the LULUCF sector is changes in five different carbon pools within six different land use categories (and transitions between the categories). The pools are (1) aboveground biomass, (2) belowground biomass, (3) deadwood, (4) litter, and (5) soil organic carbon. The land use categories are (1) forestland, (2) grassland, (3) cropland, (4) wetlands, (5) settlements, and (6) other land (IPCC 2003). Because of the generally large amounts of biomass in forests and the potentially large changes due to growth, removals, and mortality, forestland is a very important land use category. As shown by Cienciala et al. (2008), most countries in Europe conduct sample-based national forest inventories (NFIs), which generally provide a substantial portion of the data needed for reporting and accounting for the LULUCF sector.

Whereas some NFIs have been developed fairly recently and thus have been able to fully account for greenhouse gas reporting as an important issue, most NFIs were originally developed for purposes other than monitoring carbon stocks (e.g., Tomppo et al. 2011). Thus, various adaptations of

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Karsten Dunger, Johann Heinrich von Thünen-Institut; Federal Research Institute for Rural Areas, Forestry and Fisheries, Institute of Forest Ecology and Forest Inventory, Alfred-Möller-Straße 1, Eberswalde, 16225, Germany—Phone: 0049-33343820328; Fax: 0049-33343820354; karsten.dunger@vti.bund.de. Sven Hans Petersson, Swedish University of Agricultural Sciences, Department of Forest Resources Managment 901 83 Umeå, Sweden—hans.petersson@srh.slu.se. Susana Barreiro, Centro de Estudos Florestais, Instituto Superior de Agronomia, Lisbon's Technical University, Tapada da Ajuda, 1349-017 Lisboa, Portugal—smb@isa.utl.pt. Emil Cienciala, Institute of Forest Ecosystem Research, Areal 1, jilovske a.s., 254 01 Jílové u Prahy, Czech Republic—emil.cienciala@ifer.cz. Antoine Colin, French National Forest Inventory, Chateau des Barres, 45290 Nogent-sur-Vernisson, France—antoine.colin@ifn.fr. Gro Hylen, Norwegian Forest and Landscape Institute, P.O. Box 115, N-1431 Ås, Norway—gro.hylen@skogoglandskap.no. Gal Kusar, Sustainable Forestry Initiative–Slovenian Forestry Institute, Vecna pot 2, SI–1000 Ljubljana, Slovenia—gal.kusar@guest.arnes.si. Katja Oehmichen, Johann Heinrich von Thünen-Institut; Federal Research Institute for Rural Areas, Forestry and Fisheries—katja.oehmichen@vti.bund.de. Erkki Tomppo, Metla, Finnish Forest Research Institute, P.O. Box 18, 01301 Vantaa, Finland—erkki.tomppo@metla.fi. Tarja Tuomainen, Metla, Finnish Forest Research Institute, P.O. Box 18, 01301, Vantaa, Finland—tarja.tuomainen@metla.fi. Göran Ståhl, Swedish University of Agricultural Sciences, Department of Forest Resources Management, 901 83 Umeå, Sweden—goran.stahl@srh.slu.se.

methods and developments of new conversion factors and models (e.g., Jalkanen et al. 2005, Sandström et al. 2007) have been necessary. Most countries are still in the process of improving their procedures for providing accurate and comparable estimates of carbon stock changes. These improvements include the adoption of common reference definitions and development of bridging procedures to convert estimates from local definitions to reference definitions (e.g., Rondeux et al. 2012, Ståhl et al. 2012). Three types of bridges can be distinguished, i.e., reductive, expansive, and neutral bridges (Ståhl et al. 2012), depending on the available data. With reductive bridges, harmonization is a matter of removing some of the observations acquired according to a national definition that is broader than the reference definition. This type of bridging normally is very straightforward. With neutral bridges, the same target population is included with both definitions, but the classes are defined differently and thus bridging procedures are required to facilitate reclassification. Finally, with expansive bridges, the reference definition targets a larger population than the national definition according to which measurements have been made. Thus, expansive bridges are a means to convert national estimates to supranational estimates corresponding to a reference definition; in general, these types of bridges are the most difficult to develop.

As an example, biomass is often estimated through regression models using stem dbh as the most important independent variable. The degree to which estimates are harmonized includes both the quality of the models and the dbh thresholds used for calipering trees. Minimum dbh used in European NFIs ranges between 0 and 12 cm (Tomter et al. 2012). Further, different diameter thresholds are also used for deadwood, ranging from 0 to 15 cm (Rondeux et al. 2012), and only about half of European countries have the capacity to measure or model the changes in soil organic carbon; in addition, it is often difficult to separate litter from the deadwood carbon pool (Cienciala et al. 2008).

The objective of this study was to illustrate how bridging procedures can be developed and applied to aid consistent LULUCF sector reporting. Further, we discuss the importance of harmonized estimates in relation to the impact of other error sources. The study was based on case studies in selected European countries, focusing on three different types of variables related to the LULUCF sector reporting: area of forest and managed forest, aboveground biomass, and deadwood.

Materials and Methods

Common and Specific Definitions in Case Study Countries

To harmonize estimates, a common reference definition is needed (e.g., Vidal et al. 2008) for the target variable. Each country then has to develop its country-specific bridging procedures (e.g., Ståhl et al. 2012), whereby available data are used to compile estimates according to the reference definition. This may sometimes be a matter mainly of using available data for recalculation (reductive or neutral bridges), whereas in other cases new sources of data or new conversion factors have to be applied (expansive bridges).

In this study, we mostly used the reference definitions developed within COST E43 (Tomppo et al. 2011) as a basis for the work. These are as follows:

- *Forest* is land spanning more than 0.5 ha with trees higher than 5 m and a canopy cover of more than 10% or trees able to reach these thresholds in situ. Forest excludes land that is predominantly under agricultural or urban land use. The E43 reference definition essentially coincides with the definition developed and used by the Food and Agriculture Organization of the United Nations (2006).
- *Forest management* is the formal or informal process of planning and implementing practices aimed to fulfill relevant environmental, economic, social, and cultural functions of the forest. A *managed forest* is a forest subject to forest management. All forests that are accessible are considered managed, regardless of the purpose for which they are used (production, recreation, preservation of biodiversity, or other). This definition is within the range of allowable definitions offered to UNFCCC/KP parties in the GPG by IPCC (2003). In the context of greenhouse gas reporting, forest management and managed forests are important concepts, because they specify the areas that should be included in the LULUCF sector reporting.
- *Aboveground biomass* is the total of all aboveground tree components, except the leaves of broadleaved trees, regardless of size. Nontree biomass is excluded. This definition is based on IPCC (2003).
- The *deadwood* pool includes aboveground nonliving woody biomass, either standing or lying. The pool includes standing trees, snags (broken standing dead trees), and down woody material. The threshold diameter is 10 cm; to be included a piece of deadwood must have at least a 1.3-m long section coarser than 10 cm. (Tomppo et al. 2011).

The case studies were based on data from the NFIs of Finland, Germany, Norway, Portugal, Slovenia, and Sweden. Detailed descriptions of the scope and methods of these NFIs are provided in Tomppo et al. (2011). The countries represent different European conditions and face different challenges with regard to developing bridging procedures for harmonized reporting (Tomppo and Schadauer 2012).

The country-specific definitions of forestland in comparison with the COST E43 reference definitions are shown in Table 1. Although national definitions are mostly similar to the reference definitions, deviations do exist in minimum area and crown cover. Note that Table 1 also shows a minimum width threshold, by which linear forest formations qualify as forest under the KP reporting of LULUCF activities.

Similar observations also apply to the definition of aboveground biomass in the case study countries (not shown): whereas most countries include all biomass (0 cm dbh threshold) and do not deviate from the reference definitions, Norway and Portugal use a dbh threshold of 5 or 7.5 cm. Similarly, all case study countries except Finland ignore understory vegetation in their aboveground biomass estimates, whereas the reference definition includes it

Table 1. Core variables and thresholds for the definition of forest land in the case study countries and for the COST E43 reference definition (crown cover and height refer to conditions at maturity in situ).

Country	Minimum area (ha)	Minimum crown cover (%)	Minimum height	Minimum width
			...............(m)...............	
Finland	0.5	10	5	
Germany	0.1	10 (50)[1]		10
Norway	0.5	10	5	20
Portugal	0.5	10	5	20
Slovenia	0.25	30[2]	5	
Sweden	0.5	10	5	
Reference	0.5	10	5	20

[1] 50% applies to overgrown heaths, moor land, pastures, alpine pastures, and rough pastures.
[2] Applies only for newly afforested/reforested land.

(Tomppo et al. 2011). Note, however, that for the case study, all countries excluded ground vegetation in their calculations. The definitions of deadwood adopted in the case study countries were particularly different across countries (Table 2).

Case Studies on Forest Area and Forest Management

In the first set of case studies (Germany and Sweden), we demonstrate the implications of different definitions on biomass estimates for the individual pools when using different definitions of forestland and forest management. According to the Marrakech Accords (UNFCCC 2001), there is flexibility for countries to choose a national definition of forest. For example, Sweden has adopted the FAO definition, whereas Germany uses a 0.1-ha minimum area of forestland, a minimum height of 5 m and a minimum crown cover of 10% (Table 1). Hereafter, the area of forestland is called forest area in the continuation. Further, countries may choose to either include or exclude areas set aside for conservation purposes within the areas reported under forest management. We also demonstrate the effects of these differences.

Input Data

German data on forest areas and timber stocks were acquired in 2002 within the second NFI (Bundeswaldinventur 2008). Data on emission factors and carbon stocks were taken from the UNFCCC German National Inventory Report (Umweltbundesamt 2006). The Swedish estimates of living biomass and land use originated from the permanent sample plots of the Swedish NFI (e.g., Ranneby et al. 1987), from the years 2003 to 2005.

Methods

For the German case study, biomass was estimated by combining the forestland areas of the German NFI with average assumed emission factors for stock changes and average combined expansion and conversion factors. For Sweden, biomass models (Marklund 1988) were applied to all trees on the sample plots, and carbon amounts were estimated based on the conversion factor 0.49 between biomass and carbon.

The Swedish NFI assesses all land cover and land use types, and thus it is possible to evaluate the effects of various types of exclusions (e.g., different forest and forest management) by applying different inclusion/exclusion rules directly on the NFI plot data. This was done to assess the effects of different definitions of protected areas or areas under KP activity of forest management, through applying GIS layers for protected forests, as used by the Swedish NFI. A similar procedure was used in Germany. However, because the German NFI only assesses forests according to the national definition, a separate map-based study was conducted to assess the additional areas and amounts of biomass that would be included if the reference forest definition would be adopted.

Table 2. Core variables and thresholds for the definition of deadwood in the case study countries and for the reference definition.

Country	Minimum diameter (cm)	Minimum length or height (m)	Standing and lying stems	Stumps
Finland	10	1.3	Included	Included
Germany	20 (60)[1]	0.1 (0.5)[2]	Included	Included
Norway	5, 10[3]	1.3 and > 0[4]	Included	Excluded
Portugal	5 or 7.5[5]	1.3	Lying excluded	Excluded
Slovenia	10	0.2 or 0.5[6]	Included	Included
Sweden	10	1.3	Included	Excluded
Reference	10	1.3	Included	Excluded

[1] 20 cm applies to dbh for standing pieces or thickest end of lying pieces, 60 cm applies for stumps.
[2] 0.5 m applies for stumps.
[3] 5 cm for standing and 10 cm for lying trees and 10 cm at the thickest end.
[4] No minimum length for down material.
[5] 5 cm dbh for eucalypt trees and 7.5 cm dbh for all other species.
[6] 0.2 m for stumps and 0.5 m for other pieces.

Case Studies on Aboveground Biomass

Aboveground biomass is the key forest variable needed for reporting on forest resources and the corresponding carbon pools. A common issue for harmonized reporting is the effect of various thresholds for dbh applied in different countries for reporting stem volume and/or biomass. In this set of case studies we estimate the proportion of the aboveground biomass that would be missed when a minimum dbh greater than 0 cm (the reference) is used. Further, we demonstrate how an expansive bridge for reporting aboveground biomass according to the reference definition can be developed and applied.

Input Data

NFI data from three countries (Finland, Portugal, and Slovenia) were acquired for the studies. For Finland, data from the period 1996–2003 were used; for Slovenia, data from 2007 were used, because before this a 10-cm dbh threshold had been applied. For Portugal, the latest NFI still has a dbh threshold greater than 0 cm (the thresholds are species-specific); therefore, to account for the biomass of trees with dbh less than the threshold, an expansive bridge was developed and applied to NFI data from 2005.

In most sample-based NFIs, trees are measured either as tally trees or sample trees. For the first category only dbh and species are recorded (for all trees on a plot), whereas more detailed data are acquired from the latter trees (from a sample of the trees on a plot) so that tree level volume models can be used. For example, in most parts of Finland every seventh tree was measured as a sample tree (Tomppo et al. 2011).

For Portugal, the development of a model to estimate stand biomass of trees with dbh greater than 0 cm required a different set of data. This type of data was available from forest management data from eucalypt stands, and thus this species was selected for the bridge building example. In total, data from 178 eucalypt permanent plots were used.

Methods

With the Finnish data, individual tree biomass models (Marklund 1988) were applied to all NFI sample trees. Because the sampling fraction of each diameter class was known, it was straightforward to estimate both the total biomass within each diameter class and the proportion of aboveground biomass below different dbh thresholds.

With the Slovenian data, biomass models were not available, and thus volume was first estimated. Subsequently, volume was converted and expanded to biomass through density and biomass expansion factors (IPCC 2003). Local volume models (Cokl 1957, 1959) were applied to all trees with dbh greater than 10 cm. For smaller trees, the simple volume model $\hat{V} = \text{dbh}^2 \cdot H \cdot \pi/12$ was used. As for the Finnish data, the proportion of aboveground biomass below different dbh thresholds could then be calculated.

Based on Portuguese data, we developed an expansive bridge that facilitates reporting using the reference definition for aboveground biomass (dbh threshold 0 cm) as well as assessing the impact of using different dbh thresholds. Two regression models were developed. The first model predicted stand-level biomass according to the reference definition as a function of stand-level biomass of trees above dbh 5 cm (Equation 1). The other one predicted stand-level biomass of trees above any predetermined dbh, from 0 up 10.5 cm, as a function of total biomass of trees above the predetermined dbh and the stand-level mean diameter (Equation 2):

$$\hat{W}_t = W_d e^{-\beta_0 (d/d_g)^{\beta_1}} \quad (1)$$

$$\hat{W}_d = W_t e^{\beta_0 (d/d_g)^{\beta_1}} \quad (2)$$

In these models, d is a predetermined dbh threshold above which stand biomass is calculated, d_g is the stand's quadratic mean dbh, W_t is the stand's total biomass according to the reference definition (Mg ha^{-1}), and W_d is the stand's total biomass above the dbh threshold (Mg ha^{-1}).

Models were selected through evaluation of their predictive ability. The predicted residual sum of squares (PRESS) (a cross-validation technique for model assessment) residual mean value, Mr_{PRESS}, was used for evaluating model bias and the absolute PRESS residual mean value (e.g., Tarpey 2000), $\text{MAr}_{\text{PRESS}}$, for evaluating model precision (SAS Institute Inc. 1989). To further assess the performance of the model, predictions were compared with the observed data using a statistic analogous to R^2, usually called modeling efficiency (ME) or proportion of variability explained by the model (Soares and Tomé 2000). In the modeling process, both normality and homoscedasticity tests were performed for model errors. To overcome non-normality and heteroscedasticity problems, weighted nonlinear regression and Huber's estimation method (Myers 1986) were used in the SAS statistical package (SAS Institute Inc. 1989).

Case Studies on Deadwood

Similarly as for aboveground biomass, assessment of deadwood differs among countries due to country-specific definitions. However, this can be addressed by constructing a bridge to use the country-specific definitions and data to convert the country-specific estimates to the estimates according to a common reference definition. This is exemplified for two case studies (Norway and Slovenia), for which bridges were developed to convert the deadwood estimates from local definitions to estimates corresponding to the reference definition. Such conversions are important when changes in this carbon pool are compared across countries in connection with greenhouse gas emission reporting under UNFCCC.

Input Data

From 1994 to 1998 Norway surveyed the total amount of deadwood, both standing and lying, on permanent NFI plots on forestland. The total volume of standing deadwood (over bark), calculated according to the national definition, was based on the volume of the stem wood above stump to the top of all standing dead trees and snags with dbh greater than or equal to 5 cm. The stump was defined as 1% of the tree height. For lying trees to be included, the dbh had to be at least 10 cm (this section could be outside the plot boundary, but only the part inside the plot was included). For woody debris, the threshold diameter was 10 cm at the thickest end, with no length limit. Standing tree volume was estimated using national models (Braastad 1966, Brantseg 1967, Vestjordet 1967, Tomter 1997), whereas volume for down logs was estimated with Huber's model (e.g., Loetsch et al. 1973).

In Slovenia's latest NFI, deadwood (trees, large woody pieces, snags, and stumps) was measured over bark when present and under bark when absent. All pieces of deadwood, either standing or lying, with a minimum diameter of 10 cm and a minimum height/length of 0.5 m (0.2 m for stumps) were included. For dead trees that still had branches, volume was calculated in the same way as for living trees using local volume models (Cokl 1957, 1959). The volume of (standing/lying) trees without branches was calculated using Huber's model using dbh and height/length (Loetsch et al. 1973).

Thus, the Norwegian and Slovenian estimates of deadwood are not compatible with the reference definition (Table 2).

Methods

Standing deadwood in Norway was measured on trees and snags with dbh greater than 5 cm. Therefore, to comply with the reference definition, a reductive bridge was established in which the trees and snags with dbh less than 10 cm were excluded. Another bridge was developed to estimate the volume of lying deadwood according to the reference definition. According to the Norwegian definition of down woody debris, there is no length threshold but the maximum diameter must be at least 10 cm at the thickest end. To construct this bridge, it was assumed that logs taper at a rate of 1 mm/10 cm length; undersized and too short debris that is undersized and does not satisfy length requirement can then be excluded.

For Slovenia, two reductive bridges were developed and used. The first was developed to exclude the volume of stumps and the second to exclude the volume of standing/lying deadwood with length between 0.5 and 1.3 m.

Results

The results from the case studies are reported separately for each category, i.e., forest area and forest management, aboveground biomass, and deadwood.

Forest Area and Forest Management

The living biomass stocks using different definitions of forest and forest management are presented in Table 3 (the table includes nonforest categories as well).

For Sweden, according to the national forest definition, forest area is approximately 28 Mha, whereas forestland without logging restrictions is approximately 23 Mha. Table 3 indicates a low living biomass stock on the approximately 5 Mha of forestland with logging restrictions. For Germany, the country with the largest deviation from the reference

Table 3. Percentage of living biomass included when different definitions of forest, forest management, and other land use categories are used.

Areas included	Sweden	Germany
	.......(%).......	
According to the national forest definition	100	98
Forest land without logging restrictions	92	95
Managed land excluding forest land	1.0	
Nonmanaged land	0.6	
All land including fresh water area	102	

Total biomass (100%) corresponds to living biomass estimated for forest land according to the reference definition.

forest definition among those involved in the case studies (Table 1), the absolute majority (98%) of the biomass was included under the national definition of forestland. Regarding areas set aside for forest protection, 8% of the carbon stocks in Sweden were found in such areas; for Germany, the corresponding estimate was 5%.

It can be concluded that bridge building for forest area is not as necessary as bridge building for the other parameters in harmonizing greenhouse gas emissions from forests, provided the forest definitions do not deviate substantially from the reference definitions. In our examples, the impacts of the deviations from the reference definition on the carbon pools were minor. However, the impact of the definitions of managed and nonmanaged forest on the carbon pool estimates are greater, and thus the bridge building for the estimates is more necessary.

Aboveground Biomass
Impact of Threshold dbh

Based on the case studies in Finland and Slovenia, Figures 1 and 2 show the proportions of the aboveground

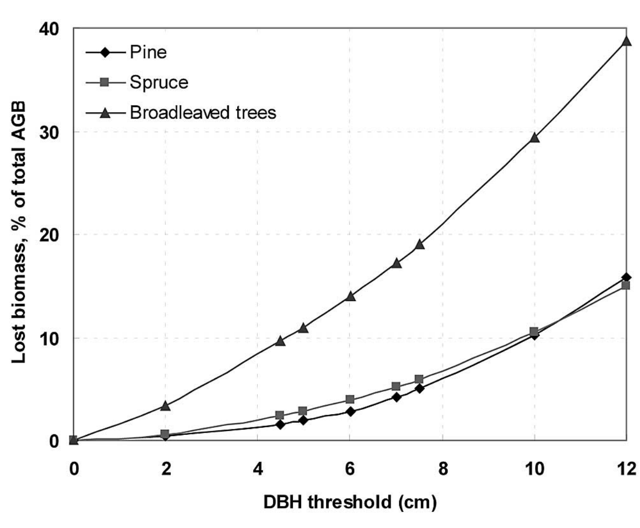

Figure 1. Percentage of missed aboveground biomass as a function of threshold dbh based on data from the Finnish NFI 1996–2003.

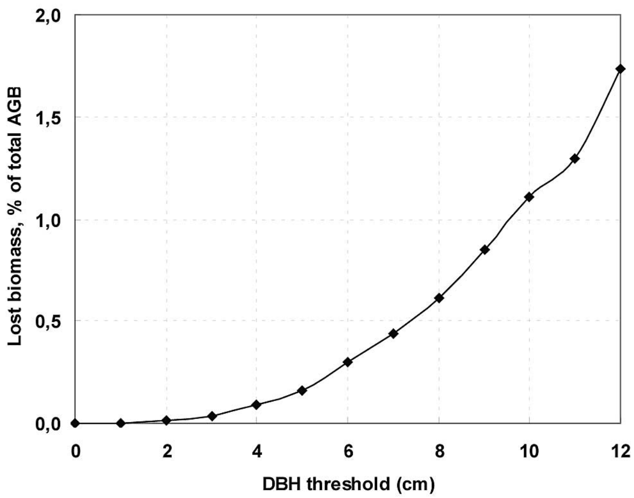

Figure 2. Percentage of missed aboveground biomass as a function of threshold dbh based on data from the Slovenian NFI 2007.

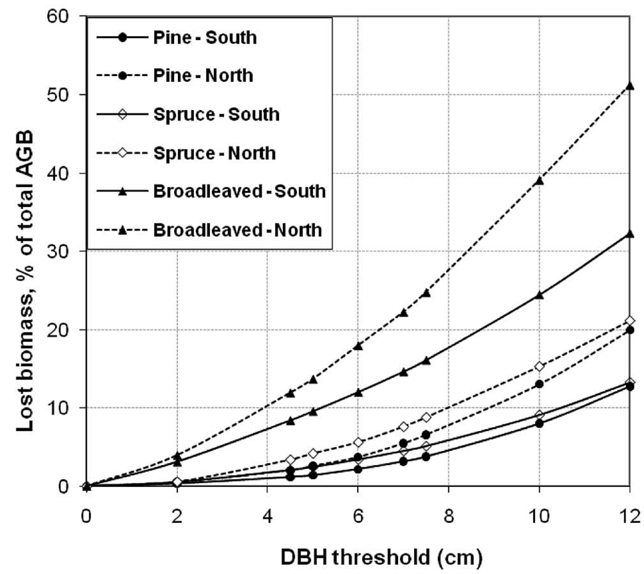

Figure 3. Percentage of missed aboveground biomass as a function of threshold dbh, separated by North and South Finland and different tree species groups. The results are based on data from the Finnish NFI 1996–2003.

biomass that were missed when dbh thresholds larger than 0 cm were used.

It is observed in Figure 1 that about 10% of the pine and spruce biomass would be missed if a dbh threshold value of 10 cm is used when reporting aboveground biomass for Finland. For broadleaved trees the loss would be considerably greater, about 30%. The results not only reflect the different allocation of the biomass of trees as a function of tree species and dbh but also the different diameter distributions of different tree species in the Finnish forests; e.g., the proportions, by tree numbers, of trees with dbh less than 10 cm by species groups are 70, 74, and 95% for pine, spruce, and broadleaved trees, respectively, and the corresponding proportions of the volume are 8, 7, and 25%.

In the case of Slovenia (Figure 2), the results differ very much from the Finnish case. A considerably smaller proportion of the total biomass was missed for a given dbh threshold. For example, only about 1% of the total biomass was missed when a 10-cm diameter threshold was used.

For the case of Finland, regional differences were also investigated. Thus, data were separated for two broad regions: South Finland and North Finland. The differences are shown in Figure 3. More than 90% of pine and spruce biomass would be included in South Finland using a 10-cm diameter threshold, whereas in North Finland the corresponding estimate would be about 85%. For broadleaved trees, the difference between the two regions is even larger.

Expansive Bridge

With the data from Portugal, two different expansive bridges were developed according to the models of Equations 1 and 2 (Table 4). The parameter estimates are reported in Table 4, together with statistics about model performance; ME expresses the proportion of the variation explained by the model.

Model 2 was applied to Portuguese NFI data to estimate the proportion of total aboveground biomass that is missed when different dbh thresholds are applied, similarly to what was done for Finland and Slovenia. The results revealed a situation similar to that of Finland because a 10-cm threshold implied that about 9% of the aboveground biomass was missed (Figure 4).

A conclusion is that bridges to include small-diameter trees can be developed rather straightforwardly and that this type of bridging would be important for some countries.

Deadwood

The total volumes of standing and lying deadwood according to both the national definitions, and the reference definition in the case study countries are given in Table 5.

Norway's estimates based on its national definition exceed the amount of deadwood by 9.4% compared with the reference definition. The exclusion of standing trees and snags with dbh less than 10 cm in the reference definition largely explains this difference.

Stumps are included in the Slovenian national definition of deadwood, and they represent 30.3% of all lying deadwood or 21.8% of the total deadwood biomass. Overall, the difference between the national and the reference definition for Slovenia was as great as 32.9%.

Deadwood is an area for which definitions vary substantially. The bridges developed have the capacity to make estimates between countries comparable, although carbon quantities not contained in the deadwood pool should otherwise occur in the litter or soil organic carbon pool. However, because some countries use only default estimates for the latter pools, application of harmonization procedures to deadwood might alter the reported totals.

Discussion

The definitions of forest and forest management in some cases had a large influence on the carbon stocks that were

Table 4. **Parameter estimates for models (Equation 1) and (Equation 2) using Portuguese eucalyptus stand data.**

Model	β_0	β_1	ME
(Equation 1) $\hat{W}_t = W_d/\exp-(\beta_0(d/d_g)^{\beta_1}$	−0.229	4.484	0.9992
(Equation 2) $\hat{W}_d = W_t\exp(\beta_0(d/d_g)^{\beta_1}$			0.9998

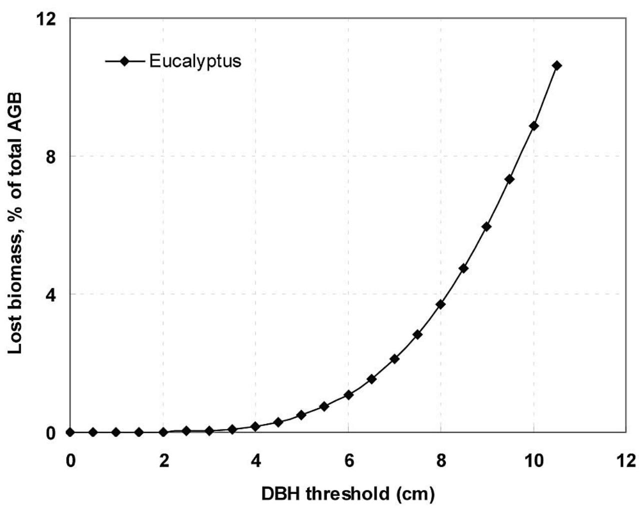

Figure 4. Percentage of missed aboveground biomass as a function of threshold dbh based on data from the Portuguese NFI 2005.

included, especially in the case of Sweden for which inclusion or exclusion of protected forests had a large impact. Further, because many of the protected areas in this country are still relatively young (Lundblad et al. 2009), the estimated changes in aboveground carbon pools would be substantially different if these areas were excluded. In addition, for Germany the difference between including and excluding protected areas was large. However, the basic forest definition had a rather limited impact, although Germany's national definition deviates quite substantially from the reference definition. Thus, harmonization of the definitions of forest and bridge building for forest area estimates in our example countries has a lower impact on the estimates of living biomass than harmonization of the definitions of managed and nonmanaged forests. This conclusion is important because forest area bridges would often be expansive and thus difficult to develop.

Although the differences in forest definitions between countries are generally fairly small (e.g., Tomppo et al. 2011) and mostly concern whether or not to include areas with sparse tree coverage and thus a low increment of tree biomass, the differences due to including or excluding protected areas are more substantial. As shown by Frank et al. (2007), many different definitions of "protected forest" exist, and it has been difficult to harmonize the usage between countries. Thus, we suggest that harmonizing reporting with regard to the treatment of areas that should be included under forest management is probably more important than harmonizing the basic forest definition.

Several conclusions may be drawn regarding the use of different dbh thresholds. First, as could be expected, the effects depend on the state of the forests. In Finland and Portugal, the differences in biomass stocks between using a 0- and 10-cm threshold were on the order of 10%, whereas in Slovenia the difference was on the order of only 1%. This reflects the differences in diameter distributions between the countries, with a large proportion of old forests and large trees in Slovenia. Large differences were also found between different species groups and different regions within a country (Finland). Thus, at least in countries with a high proportion of young forests (such as Finland and Portugal in our case studies), it would be important to also include small trees in the LULUCF greenhouse gas inventories. In the case example from Portugal, it was shown that accurate bridges, based on regression models, can be developed if data are available either from other inventories within the country (as in this case) or from other countries with similar forest conditions. Bridges of this kind, however, would sometimes need to be constructed separately for different species groups and regions of country, as indicated by the differences found in the case study from Finland. It was shown that even expansive bridges could be rather straightforwardly developed in case of including small trees in the growing stock.

Regarding deadwood, like other studies (e.g., Rondeux et al. 2012) our case studies showed that there are substantial differences among the national definitions. The bridges used in the case studies involved several steps to compute estimates according to the reference definition. In the reporting under the UNFCCC and the KP (IPCC 2003), the fractions that are not included under deadwood should be included either in the litter pool or in the soil organic matter pool and thus from the point of view of reported totals it should not matter which exact definitions are applied. However, for comparisons between countries, we argue that comparability is important and that the deadwood pool presents substantial challenges for building bridges.

In general, to provide comparable information reporting should specifically focus on those parts of the definitions and estimation procedures that may lead to different reported totals for the LULUCF sector. Important definitions in this context concern the basic definition of forest, but even more the definitions related to forest management. In addition, for KP reporting the definitions of afforestation/reforestation and deforestation are important. Although NFIs usually provide sufficient data for estimates related to deforestation, afforestation, and reforestation, areas of these activities in Europe are relatively small, which leads to low precision of the estimates. An example of this is Germany, where it was estimated in 2002 that only 1.7% of forests qualified as afforestation since 1987 and 1.0% of forests were deforested between 1987 and 2002 (Bundesministerium für Ernährung, Landwirtschaft und Verbraucherschutz 2006). Similarly, leaving out small trees in some countries could have a substantial impact on the reported estimates.

Table 5. Volume of types of deadwood according to national definitions of Norway and Slovenia and the reference definition.

Type of deadwood	Volume: National definitions, m^3/ha	Volume: National definitions, 1,000 m^3	Volume: Reference definition, m^3/ha	Volume: Reference definition, 1,000 m^3	Difference, m^3/ha	Difference, %
Norway						
Standing trees	1.94	16,918	1.59	13,848	0.35	22.0
Snags	0.83	7,231	0.67	5,866	0.16	23.9
Sum	2.77	24,149	2.26	19,713	0.51	22.6
Lying trees	2.17	18,866	2.17	18,866	0.00	0.0
Woody debris	2.50	21,789	2.37	20,633	0.13	5.5
Sum	4.67	40,655	4.54	39,498	0.13	2.9
Total	7.44	64,804	6.80	59,212	0.64	9.4
Slovenia						
Standing trees	1.83	2,134	1.83	2,134	0.00	0.0
Snags	3.40	3,976	3.27	3,822	0.13	4.0
Sum	5.23	6,110	5.10	5,956	0.13	2.6
Lying trees	2.72	3,175	2.72	3,175	0.00	0.0
Woody debris	6.60	7,714	6.19	7,225	0.42	6.8
Stumps	4.06	4,746				
Sum	13.39	15,635	8.90	10,400	4.48	50.3
Total	18.62	21,745	14.00	16,356	4.61	32.9

The definitions for individual carbon pools would generally be less important, because according to the basic completeness principle (IPCC 2003), the carbon stocks that are excluded from one pool should be included in another pool, and thus the totals will be the same regardless of definitions. However, use of different estimation methods for different pools (e.g., Cienciala et al. 2008) could still imply that different pool definitions would lead to different estimates of totals.

Conclusions

This study demonstrates how reporting on greenhouse gas-related variables from National Forest Inventories can be further harmonized. With use of aboveground biomass and deadwood volume as target variables, it was shown that suitable bridges between reported estimates according to country-specific definitions and common references could be rather easily constructed. Addressing these issues in a similar manner in all individual countries would significantly aid harmonization of reporting on greenhouse gas emissions from forests in Europe and beyond, ensuring comparability of strategic information needed for further mitigation and adaptation schemes.

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