Harmonizing National Forest Inventories

Ronald E. McRoberts, Erkki Tomppo, Klemens Schadauer, Claude Vidal, Göran Ståhl, Gherardo Chirici, Adrian Lanz, Emil Cienciala, Susanne Winter, and W. Brad Smith

National forest inventories are a primary source of data for national and large area assessments of sustainability and biodiversity and for international forest resource reporting. However, the ability of countries to produce compatible estimates using these data is impeded by the diversity of their national inventory definitions, sampling designs, plot configurations, measured variables, and measurement protocols. In addition, because the differing features of these inventories have historical, commercial, and environmental justification, prospects for standardizing inventories are minimal. The best current alternative is to harmonize estimates, a process that focuses on developing methods for producing compatibility despite the different inventory features. Action E43 (COST E43, 2008, Harmonization of national forest inventories in Europe: Techniques for common reporting; Available at online at www.metla.fi/eu/cost/e43/index.html; last accessed May 2008) of the European program, Cooperation in the Field of Scientific and Technical Research (COST), has focused on developing harmonization methods for European inventories in three areas: harmonized definitions, harmonized estimation procedures for carbon pools, and harmonized indicators for biodiversity assessments. The Forest Inventory and Analysis program of the US Forest Service has participated in COST Action E43 and has provided data for testing proposed harmonization methods. Although considerable progress has been made in developing methods to facilitate harmonization, considerable work still remains.

Keywords: carbon, COST Action E43, definitions, European Union, forest biodiversity, North American Forest Commission

Numerous international agreements require that countries report estimates of national forest resources. Parties to the United Nations Framework Convention on Climate Change (UNFCCC 1992) are required to produce annual reports of greenhouse gas emissions and removals by sources and sinks. The Convention on Biological Diversity (Convention on Biological Diversity 2007) requires that countries identify and monitor components of biological diversity for purposes of conservation and sustainable use. The primary forestry sustainability conventions, the Montreal Process (Montreal Process 2005) and the Ministerial Conference on Protection of Forests in Europe (Ministerial Conference on Protection of Forests in Europe 2003), require that member countries report on sustainability and biodiversity indicators.

Extensive and comprehensive data on the status of North American and European forests available for reporting under international agreements are provided by national forest inventories (NFI) [1]. In the United States, the NFI is conducted by the Forest Inventory and Analysis (FIA) program of the US Forest Service. NFIs share a primary objective of conducting forest resource assessments to assess the sustainable yield and management of forests. However, despite their common primary objective, NFIs do not assess common sets of variables or use...
The Effects of Disparate NFI Definitions and Methods

At least two sensitivity analyses have been conducted to assess the effects on forest resource estimates of using different national definitions. Köhl et al. (2000) report a study that used simulated forest cover patterns to investigate the effects on forest area estimates of using different national forest area definitions. As expected, the greatest effects were found for scattered, fragmented forests with gradual transitions between forest and nonforest land cover. The magnitude of these effects is illustrated by noting that the estimate of the total forest area of Spain decreases by 8% when the United Kingdom’s definition of forestland is used and increases by 6% when Luxembourg’s definition is used. The pan-European estimate of forest area decreases by 6% when the United Kingdom’s definition is used and increases by 3% when Luxembourg’s definition is used. Of potentially more importance, the national forestland definitions of Finland, Sweden, and Norway cannot be applied elsewhere because they include a criterion related to wood production capability and, as such, are not compatible with the definitions of other countries. However, all three countries use the international definition compiled for the Temporal and Boreal Forest Resource Assessment 2000 (TBFRAs) (UNECE and Food and Agriculture Organization [FAO] 2000) in parallel with their national definitions.

Cienciala et al. (2008) used data from the 9th (1996–2003) Finnish NFI to compare carbon pool change estimates based on Finnish national definitions of forestland and growing stock volume and estimates based on the TBFRAs 2000 definitions. Finland’s forest area estimate increases 10.6% from 50.26 million ac (20.34 million ha) when using the Finnish production-oriented definition to 55.57 million ac (22.49 million ha) when using the TBFRAs 2000 definition. Similarly, Finland’s estimate of growing stock volume increases from 71.94 to 73.84 billion ft³ (2.04 to 2.09 billion m³), a 2.7% increase, while the corresponding estimate of annual volume increment increases from 3.01 to 3.06 billion ft³ (85.2 to 86.7 million m³), a 1.8% increase. The smaller percentage increases for estimates of volume and volume increment relative to the percentage increase in the estimate of forest area are attributed to the inclusion of poorer sites with less mean volume and mean volume increment under the TBFRAs 2000 definition; these sites are not considered forestland when using the Finnish definition with the production component.

More striking, however, are the effects of minimum dbh on estimates of volume and volume increment. If a minimum dbh of 4.1 in (10.4 cm, a selected upper limit of a 1-cm dbh class) was used for Finnish forests instead of 0 cm, the volume estimate would decrease by 14%, the volume increment estimate would decrease by 25%, and the carbon sink estimate would decrease by 26% (Cienciala et al. 2008).

The effects of these disparities may be minimized using two approaches, standardization and harmonization. Köhl et al. (2000) describe standardization as a top-down approach that follows a common system of nomenclature and focuses on common standards with regard to NFI definitions and methods. Although standardization of NFIs would produce the most direct route to compatible estimates, other factors must be considered. For example, NFI features such as sampling designs and plot configurations for individual countries have been developed over time to accommodate their unique topographies, climates, forest types, and commercial interests. Thus, standardization is often not a realistic option. Harmonization acknowledges that individual countries have developed the unique features of their NFIs for specific purposes and are justified in their desire to maintain them. Harmonization, therefore, focuses on development of methods for producing compatible estimates despite the lack of standardization. Köhl et al. (2000) describe harmonization as a bottom-up approach that begins in divergence and ends in comparability.

The issue of harmonization has received increased international attention in recent years. Monitoring guidelines developed by the Intergovernmental Panel on Climate Change (IPCC) address issues of transparent and harmonized reporting. The Good practice guidance (IPCC 2003, Eggleston et al. 2006) for land use, land use change, and forestry provides detailed guidance for selected aspects of reporting. The UNECE and the United Nations FAO jointly compile the TBFRAs covering the forest resources of North America, Europe, the Commonwealth of Independent States, Australia, New Zealand, and Japan. For the 2000 assessment, the UNECE/FAO team compiled international definitions and then harmonized national estimates to conform to these definitions (UNECE and FAO 2000).

Objectives

The objectives of this report are threefold: (1) to describe a comprehensive European project to harmonize NFI estimates, (2) to illustrate harmonization methods, and (3) to provide examples of European and North American harmonization issues.

Harmonization in Europe: COST Action E43

The most comprehensive effort directed toward harmonization of NFI estimates is conducted under the auspices of the European program Cooperation in the field of Scientific and Technical Research (COST) (COST 2008). Founded in 1971, COST is an intergovernmental framework to facilitate coordination of European research. COST activities are based on networks of coordinated research projects characterized as Actions that are of interest to member states. COST Actions focus on maximizing synergy, adding value via cooperative research, and promoting integration. Currently, there are more than 200 Actions including more than 30 dealing with forestry issues. Interested institutions from non-COST member countries are welcomed without regard to geographic location.

COST Action E43, Harmonization of national forest inventories in Europe: Techniques for common reporting (COST E43 2008), was initiated in June 2004 under the supervision of the COST Domain Forests, their Products and Services. The primary objectives of COST Action E43 are threefold: (1) to harmonize existing European NFIs, (2) to support new forest inventories for the purposes of satisfying requirements for providing current and harmonized forest resource information, and (3) to promote scientifically sound forest inventory designs, data collection, and data analyses (COST E43 2008). Participating institutions in-
clude government agencies or universities from 27 European countries in which their NFI's conduct inventories of slightly more than 590,000 mi² (1.53 million km²) of forestland (Figure 1; Vidal et al. 2008). In addition, the FIA program and Scion, the New Zealand Forest Research Institute participate as non-COST institutional members. COST Action E43 is organized into three working groups: working group 1 (WG1) addresses harmonization of NFI definitions and measuring practices, working group 2 (WG2) addresses harmonization of estimation procedures for carbon pools and carbon pool changes using NFI data, and working group 3 (WG3) addresses harmonization of indicators and estimation procedures for assessing components of biodiversity using NFI data.

**Harmonized Definitions and Measuring Practices.** The primary task of WG1 is to develop operational guidelines for interpreting existing definitions and to recommend new definitions and measuring practices for NFI applications. In particular, WG1 focuses on developing precise definitions called *reference definitions* that can be used to compare and integrate national definitions. In the development of a reference definition, nine features are sought (Vidal et al. 2008):

1. Acceptability, meaning adoption at national and international levels for international reporting.
2. Objectivity, meaning free of particular interests of individual NFIs or stakeholders.
3. Clearness, meaning easily grasped and clearly stated.
4. Sufficiency, meaning covering all relevant cases.
5. Usefulness, meaning satisfaction of forest, industry, and environmental needs and industrial requirements at national and European levels.
6. sustainability, meaning long-term validity.
7. Neutrality, meaning not to be used as a means of assessing the quality of national NFIs or national definitions.
8. Practicality, meaning NFIs must be able to provide results conforming to the reference definitions.
9. Independence, meaning validity is independent of the measurement protocols and instruments.

The process of developing reference definitions used by WG1 begins with a review of existing national and international definitions and an analysis of responses to questionnaires that made inquiries regarding variables and variable thresholds used in national definitions. The process consists of four steps: (1) review national and international definitions, (2) decompose definitions by listing variables used and create classes for variable thresholds, (3) select relevant variables and thresholds, and (4) construct, review, and revise the reference definition until final acceptance by all countries.

We review the process used to develop a reference definition for forestland as described by Vidal et al. (2008) follows. Using information on national and international definitions of forestland obtained from WG1 questionnaires, variables were selected for integration into the reference definition. Variable selections were based on the number of countries using particular variables in their national definitions, the total areas of those countries, and the relative proportions of total European forest area included in the countries (Table 1).

The most commonly used variables in...
Table 1. Variables used in national definitions of forestland.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Proportion*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Countries</td>
<td>Area of countries</td>
</tr>
<tr>
<td>Minimum area</td>
<td>0.96</td>
</tr>
<tr>
<td>Minimum tree crown cover</td>
<td>0.81</td>
</tr>
<tr>
<td>Minimum width</td>
<td>0.74</td>
</tr>
<tr>
<td>Minimum tree height</td>
<td>0.59</td>
</tr>
</tbody>
</table>

* Proportions for 27 European countries participating in COST Action E43.

Table 2. Tree crown cover threshold used in national definitions of forestland.

<table>
<thead>
<tr>
<th>Tree crown cover threshold</th>
<th>Cumulative proportion*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Country area</td>
</tr>
<tr>
<td>0.05</td>
<td>0.12</td>
</tr>
<tr>
<td>0.10</td>
<td>0.67</td>
</tr>
<tr>
<td>0.20</td>
<td>0.79</td>
</tr>
<tr>
<td>0.30</td>
<td>0.84</td>
</tr>
<tr>
<td>0.50</td>
<td>0.94</td>
</tr>
<tr>
<td>Not used</td>
<td>0.06</td>
</tr>
</tbody>
</table>

* Proportions for 27 European countries participating in COST Action E43; Finland, Sweden, and Norway use the TB-FA 2000 definition.

definitions of forestland, as indicated by the proportions of countries that use them and the areas these countries represent, are minimum area, minimum tree crown cover, and minimum height. Of the five countries that do not use minimum tree crown cover in their national definitions, Finland, Sweden, and Norway use average annual increment of growing stock volume of 14.3 ft³/ac/yr (1.0 m³/ha/yr), which suggests a minimum tree density. However, these three countries use the TBFA 2000 definition with minimum tree cover of 10% in parallel with their national definitions. Most countries also use a minimum width to avoid characterizing linear formations, windrows, shelterbelts, and planted tree groupings as forestland. Thus, the proposed reference definition for forestland is based on four variables: minimum area, minimum tree crown cover, minimum height, and minimum width in cases of linear formations.

A reference definition must not only identify the relevant variables but must also specify thresholds for these variables. Because the selected reference definition variables are continuous in nature, thresholds may be ordered, and the cumulative proportion of countries using a particular threshold or lower may be tabulated (Table 2). For a tree crown cover class threshold of 0.10, data are currently available for countries representing 3/4 of the total area of the countries and nearly 3/4 of their total forest area. Thus, the proposed reference definition for forestland includes a tree crown cover threshold of 0.10.

Similar analyses were used to select a threshold of 1.24 ac (0.5 ha) for minimum area, 16.4 ft (5 m) for minimum height, and 65.6 ft (20 m) for minimum width. Thus, the COST Action E43 (COST Action E43 2008) reference definition constructed by WG1 for forestland is:

Forest is land spanning more than 0.5 ha [1.24 ac] with trees higher than 5 meters [16.4 ft] and with tree crown cover of at least 0.10, or able to satisfy these thresholds in situ. For tree rows or shelterbelts, a minimum width of 20 m [65.6 ft] is required. It does not include land that is predominantly agricultural or urban land use. (English units added).

Additional explanatory notes applicable to this definition address conditions such as reforestation areas, protected areas, plantations, orchards, and nonstocked areas.

In summary, WG1 has developed methods for establishing harmonized reference definitions that can be used for international reporting with either national or international data. In general, the reference definitions are similar to the TBFA 2000 definitions and are considered a relevant starting point for harmonizing forest resource information from different sources. For a region of the world with a long history of NFI's but with a great variety of definitions, agreement on fundamental reference definitions such as that for forestland represents an important harmonization milestone.

Harmonized Estimation Procedures for Carbon Pools. WG2 focuses on definitions and measurements of inventory variables related to harmonized estimation of forest carbon pools and carbon pool changes. Carbon sinks and sources are reported within land-use categories separately for lands without and with change of use in the past 20 years. Furthermore, sinks and sources are reported for five carbon pools: living aboveground biomass, living belowground biomass, deadwood, litter, and soil (IPCC 2003). Thus, the crucial harmonization issues relate to definitions of forestland, the ability to detect land-use changes, and approaches used to estimate biomass within carbon pools.

Based on the Marrakesh Accords (UNFCCC 2002), parties to the Kyoto Protocol (Kyoto Protocol 1997) are to define forestland using predefined ranges of three variables: (1) minimum area of 0.12–2.47 ac (0.05–1.0 ha), (2) minimum tree crown cover from 10 to 30% at maturity, and (3) minimum tree height of 6.6–16.4 ft (2–5 m) at maturity. Minimum levels for these three variables reported by 25 European COST Action E43 countries were all within the predefined ranges, although only 40–60% of reported national criteria satisfied the common forestland definition used for the 2005 Global Forest Resources Assessment (GFRA): minimum area of 1.24 ac (0.5 ha), minimum tree crown cover of 10%, and minimum height of 16.4 ft (5 m) (FAO 2005). Only 7 of the 25 countries adopted definitions that satisfied all three 2005 GFRA criteria.

Several national approaches were reported for determining changes in land-use categories (Cienciala et al. 2008). The primary approaches included sampling and assessment of land cover/use maps based on digital orthophotographs or satellite imagery. For countries claiming to be able to detect land-use changes, the time interval over which changes can be detected varied with most reporting the ability to detect 10-year changes and several reporting the ability to detect 3-year changes. An interpolation technique will be necessary to harmonize estimates to a common change detection interval.

A variety of approaches were reported for estimating carbon stocks and annual carbon stock changes within the five different pools (Cienciala et al. 2008). For estimating living aboveground biomass, some countries use data aggregated at stand level and higher, and others use tree-level data. For estimating living belowground biomass, most countries use approaches based on combining living aboveground estimates, model predictions, and either IPCC or country-specific default values for ratios of biomass categories. For the deadwood, litter, and soil pools, a variety of methods were used (Table 3).

The conclusions of WG2 were threefold: (1) European NFI's are far from harmo-
Table 3. Proportions of 25 countries using designated methods for estimating biomass by carbon pool.

<table>
<thead>
<tr>
<th>Method</th>
<th>Proportion*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deadwood</td>
<td>0.74</td>
</tr>
<tr>
<td>Litter</td>
<td>0.36</td>
</tr>
<tr>
<td>Soil</td>
<td>0.47</td>
</tr>
<tr>
<td>Models</td>
<td>0.37</td>
</tr>
<tr>
<td>IPCC default ratios</td>
<td>0.36</td>
</tr>
<tr>
<td>Country default ratios</td>
<td>0.53</td>
</tr>
<tr>
<td>Others</td>
<td>0.21</td>
</tr>
<tr>
<td>Undecided</td>
<td>0.18</td>
</tr>
</tbody>
</table>

* Proportions do not add to 1.0 because multiple responses per country were permitted.

Harmonized with respect to estimation procedures for carbon pools, and further harmonization efforts in areas such as soil and litter sampling are essential; (2) considerable differences in reporting under UNFCCC and FAO definitions are evident with different variable thresholds having potentially important effects on estimates of carbon pool changes and emissions by sources and sinks; and (3) data from NFIs are essential for estimating carbon stock changes in all five carbon pools (Cienciala et al. 2008).

Harmonized Indicators and Estimation Procedures for Biodiversity Assessments. The primary tasks of WG3 are to evaluate the utility of NFI variables and field methods for estimating components of tree biodiversity, to develop necessary reference definitions, and to develop methods for harmonizing estimates. Based on responses to an initial WG3 questionnaire on forest variables related to biodiversity, 16 variables were selected that simultaneously ranked most important for biodiversity assessments and most feasible for monitoring via NFIs. The 16 variables were assigned to seven categories: forest categories or type, forest age, forest structure, deadwood, regeneration, ground vegetation, and natural forest. Reference definitions were developed, and a second WG3 questionnaire was used to evaluate the degree to which the variables are already harmonized. The second questionnaire focused on methods and thresholds for observing or measuring the 16 variables, the level of expertise necessary, and the combinations of plot components and land-use categories for which observations or measurements are already obtained.

Following the assessment of the most important and feasible variables and the assessment of their existing degree of harmonization, WG3 investigated methods for producing harmonized biodiversity estimates. These investigations focused on constructing bridges that accept variables currently used in NFIs with their differing measurement thresholds and protocols as input and produce harmonized estimates of biodiversity based on reference definitions as output. In some cases, a bridge may be direct and quantitative. For example, as a measure of horizontal forest structure, the bridge begins with dbh of sample plot trees and produces estimates of the parameters of distributions of plot-level proportions of trees with dbh greater than a specified minimum threshold. The distributions are constructed separately by forest categories or types and require a minimum number of plots. For countries in which their minimum dbh threshold is less than the specified threshold, the bridge may be reductive in the sense that it entails no more than omitting trees with dbh below the threshold from analyses. However, for countries in which their minimum dbh threshold is greater than the specified threshold, the bridge may be expansive in the sense that it entails developing statistical methods for predicting or extrapolating the portion of the distribution less than the specified minimum threshold.

The primary conclusions drawn by WG3 from the results of its two questionnaires were threefold: (1) the responding countries are in general agreement regarding the NFI variables that are most important and feasible for assessing biodiversity; (2) because most NFIs already obtain data for a large proportion of the 16 variables, harmonization may require that only a few countries introduce substantial numbers of new variables; and (3) the lack of agreement on field observation and measurement methods and on necessary field crew expertise suggests that efforts to achieve harmonized biodiversity estimates may need to be redirected at least partially from estimation procedures to field procedures (Winter et al. 2008).

Harmonization in North America

United States. Until the late 1990s, forest inventories conducted under the auspices of the FIA program tended to be commodity oriented with primary emphasis on estimating forest area and growing stock volume. These inventories were administered by as many as seven regional FIA programs on a statewide basis on productive timberland but not other forestlands, not on reserved lands, and, depending on the region, not on national forestlands. The designs and implementation of these inventories were the responsibility of the regional FIA programs and featured a variety of plot configurations, sample designs, measurement protocols, estimation techniques, reporting standards, and inventory cycle lengths. The differing features of these statewide inventories made compatible estimation among states extremely difficult, even among states within the same region.

In 1998, in response to users’ concerns, the FIA program initiated actions to standardize inventories. The key features of the new inventory system included a national set of prescribed core variables with a national field manual, a nationally consistent plot configuration, a nationally consistent sampling design, common estimation techniques, and annual measurement of a proportion of plots in every state (McRoberts et al. 2005). With implementation of these key features, the FIA program now administers a standardized forest inventory covering approximately 1.2 million mi² (3 million km²) of forestland.

North America. The North American Forest Commission (NAFC) is one of six regional commissions of the FAO. Established in 1958, the NAFC provides a policy and technical forum for Canada, Mexico, and the United States to discuss and address forest issues on a North American basis. The NAFC carries out its mandate by supporting research and natural resource management activities through nine working groups of which one addresses issues of forest inventory and monitoring. Because all three countries recognize the need for basic harmonized environmental information to formulate effective land use and conservation policy, to plan and implement management activities, and to monitor results, the inventory working group seeks opportunities to foster compatible and harmonized approaches to forest inventory.

A brief description of the state of harmonization in North America for each topic area investigated by the COST Action E43 working groups follows with details provided in later sections. For topic areas for which information is available, assessments of the potential for harmonization in North America comparable with those conducted by COST Action E43 are reported. For topic areas without such data, an example is provided that relates to the potential for harmonization between COST Action E43
countries and the United States. In particular, sufficient information is available to show the ability of the three North American countries to construct a harmonized definition of forestland. For carbon reporting and biodiversity estimation, NFI observations and measurements are available for the United States, have recently become available for Mexico, and will be available in the near future for Canada (Canadian Council of Forest Ministers 2006). However, because North American analyses for harmonized carbon and biodiversity reporting still have not been conducted, a comparison of European and American carbon pools and the potential effects of incompatible definitions are provided. In addition, FIA data are used to illustrate the detrimental effects of differences in key NFI features on the ability to harmonize biodiversity estimates.

**Forestland Definition.** As in Europe, North American–level reporting using NFI data is impeded by the diversity of definitions, variable sets and thresholds, and measurement protocols (Gillis et al. 2004). A comparison of the inventory databases of Canada, Mexico, and the United States produced a short list of variables including area of forestland and stem volume per unit area that have potential for harmonization. Although all three countries use definitions for forestland based on criteria such as minimum area, proportion tree crown cover, and stocking [2], the thresholds for the criteria differ by country. Furthermore, estimates of forestland area by country are sensitive to these thresholds.

The new Canadian NFI does not have an official forestland definition (Mark Gillis, manager, pers. comm., National Forest Inventory, Natural Resources Canada, Apr. 29, 2008). Rather, because different clients define forestland differently, the new NFI design focuses on acquiring data for basic forest attributes that permit forest area to be estimated using a variety of definitions. For example, estimates compatible with the 2005 GFRA definition can be calculated using height, crown closure, and land-use data, and estimates compatible with the UNFCCC definition can be calculated using the same data subject to area requirements.

Mexico uses the 2005 GFRA definition of forestland, although linguistic issues influence specific applications (Alberto Sandoval Uribe, pers. comm., Comision Nacional Forestal, Sept. 10, 2007). The Spanish word bosque refers to what is elsewhere considered temperate forest, and the Spanish words tierra forestal, which translate literally to forestland, by Mexican law refer to a diversity of vegetation types of which some are not considered trees in assessments of temperate forests. To accommodate these considerations, the Mexican NFI, like the Canadian NFI, selects variables and variable thresholds to retain the flexibility to report using multiple definitions of forestland. Thus, Mexican NFI field crews measure and identify by genus and species all plants with a dbh of 2.95 in. or more (7.5 cm) without regard to minimum area or width considerations. This approach retains the ability to characterize as forestland the unique Mexican communities of plants that do not exist in other latitudes.

In the United States, the FIA program defines forestland using three variables and corresponding thresholds: minimum area of 1.0 ac (0.4 ha), minimum width defined as external crown-to-crown width of 120 ft (36.6 m), and minimum stocking of 10%. The FIA program further defines timberland as forestland that is not withdrawn from production and is capable of producing 20 ft³/ac (1.4 m³/ha) of commercial wood annually. The additional criterion for timberland is similar to the production capability criterion for forestland used by the Nordic countries, i.e., average annual increment of growing stock volume of at least 14.3 ft³/ac (1.0 m³/ha).

Thus, with respect to harmonization, Canada and Mexico both identify categories of land with less forest use intensity than forestland, whereas the United States identifies a category of land with greater forest use intensity than forestland. In addition, both Canada and Mexico acquire data in a manner that facilitates reporting estimates using a variety of definitions. The consequences of failure to harmonize definitions of forestland extend beyond incompatible estimates of forest area to incompatible estimates of other variables such as living aboveground biomass and carbon pools that depend on the definitions of forestland.

**Carbon Reporting.** COST Action E43 WG2 considered harmonization of carbon estimates for five pools: living aboveground, living belowground, deadwood, litter, and soils. Carbon is estimated and reported for the same pools in the United States as in Europe, although in the United States it is estimated separately for the following components: standing live trees, standing dead trees, understorey vegetation, down deadwood, forest floor, and soil (Smith et al. 2004). Estimates of carbon in standing live and dead trees and their coarse roots are obtained using regression models reported in and aggregated from the literature (Jenkins et al. 2003). When only plot-level volume data are available, carbon is estimated from regression models calibrated using FIA plot estimates of aboveground biomass and growing stock volume (Smith et al. 2003). Model predictions are obtained separately for five softwood species groups, four hardwood species groups, and one woodland species group. Estimates for foliage, stem wood, stem bark, coarse roots, and standing deadwood are obtained as products of model predictions of aboveground live biomass and selected constants. Thus, methods used in the United States are similar to the methods most commonly used in Europe.

Carbon for deadwood, forest floor biomass, and soil is also estimated in the United States using methods similar to those used in Europe. Down deadwood is large woody material left from live and dead standing trees with diameters of at least 3.0 in. (7.6 cm). Carbon estimates for down deadwood are obtained as the products of a constant (usually 0.3), deadwood volumes, and specific gravities by tree species (Woodall et al. 2008). Forest floor biomass includes nonliving plant mass in the form of leaves, twigs, bark, and woody stems, but excludes down deadwood. Estimates of forest floor carbon are obtained by forest type, region, stand age, and regrowth status after disturbance and are based on information compiled from individual reported studies (Smith and Heath 2002). For studies that report only forest floor mass, forest floor carbon is estimated as the product of that mass and a constant. Estimates of organic carbon for both mineral and organic forest soils are for depths of no more than 3.38 ft (1.0 m) and include fine tree roots. The estimates are based on soil types, forest types, and laboratory analyses of organic carbon from soil samples (Amichev and Galbraith 2004). Thus, as far as general approaches are concerned, prospects for harmonization of carbon estimates between the United States and Europe are positive.

Despite similarity in approaches, carbon estimates may be incompatible as a result of multiple factors including differences in measurement methods. Even for a primary component such as living aboveground biomass for which definitions are easily harmonized and measurement meth-
ods are similar, harmonization of estimates may still be difficult. Most countries estimate carbon for this pool as the product of constants and living aboveground tree biomass for growing stock on forestland. Growing stock volume, in turn, is usually estimated for trees with dbh above national thresholds growing on forestland as defined using national definitions. Thus, failure to harmonize definitions of forestland and dbh thresholds leads directly to incompatible estimates of living aboveground biomass and carbon pools.

**Biodiversity.** For purposes of harmonizing biodiversity assessments, WG3 of COST Action E43 selected multiple indicators of forest structural diversity. For horizontal diversity, the estimate of the $s_{dbh}$ of dbh for trees observed on an inventory plot was calculated as,

$$s_{dbh} = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} (y_i - \bar{y})^2},$$

where $n$ is the number of trees on the plot, $y_i$ is the measured dbh of the $i$th tree, and $\bar{y}$ is estimated mean dbh. For species diversity, the Shannon index (Shannon 1949) was calculated as

$$H' = -\sum_{j=1}^{S_{tot}} p_j \ln(p_j),$$

where $j$ indexes species, $p_j$ is the proportion of plot trees identified as being of the $j$th species, and $S_{tot}$ is the total number of species observed on the plot. McRoberts et al. (2008) used data acquired for FIA plots to investigate these WG3 indicators and to illustrate their utility for evaluating spatial patterns of forest structural diversity.

The effects of dbh thresholds on these structural biodiversity indicators have not been investigated previously. For the NFIs of European countries participating in COST Action E43, minimum dbh thresholds range from 0 in (0 cm) for Finland to 4.72 in (12 cm) for Cyprus and Switzerland (Winter et al. 2008). Because of the potential confounding effects of large numbers of small trees on the Shannon index, the recommendation of Staudhammer and LeMay (2001) to base calculation of the proportion, $p_j$, on basal area rather than tree counts was followed. Investigations were conducted using data for trees with a dbh 1.0 in. or more (2.54 cm) observed on FIA plots in the aspen/birch forest type in ecological province 212 (Bailey 1976) in the northern parts of the Lakes States (Figure 2).

The effects of increasing minimum dbh thresholds were pronounced decreases for both measures of structural diversity (Figure 3). The effect on mean $s_{dbh}$ can be attributed to a decrease in the range of dbh observations, and the effect on mean $H$ can be attributed to the decrease in number of species resulting from the decrease in the number of trees. Despite these reasonable explanations, the analyses illustrate the effects of failure to
harmonize estimates. When the dbh threshold increases from the 1-in. (2.54-cm) FIA minimum to the 4.72-in. (12-cm) Swiss minimum, the proportional decrease in mean \( \bar{dbh} \) is approximately 0.11 and the proportional decrease in mean \( H' \) is approximately 0.08. Although the effects of dbh thresholds on \( \bar{dbh} \) and \( H' \) should be expected to vary for different forest types observed for different climatic, topographical, and management conditions, these results indicate the effects can not be ignored. Thus, failure to harmonize NFI features such as minimum dbh adversely affect the ability to harmonize estimates of biodiversity indicators.

**Summary**

International agreements on climate change, forest sustainability, and biodiversity increasingly rely on data from NFIs. However, the diversity of the definitions of variables, sampling designs, plot configurations, variables and variable thresholds, and measurement protocols used by NFIs greatly inhibits reporting in a compatible manner. For a variety of historical, commercial, and environmental reasons, standardization of inventories is not currently a reasonable option. An alternative that is under consideration by COST Action E43 is to develop commonly applicable reference definitions and methods for harmonizing disparate inventory estimates. The process of developing reference definitions and then constructing bridges from the estimates based on national definitions and methods to estimates based on reference definitions greatly facilitates the harmonization process. Nevertheless, considerable work is necessary in both Europe and North America before a substantial degree of harmonization will be realized in the areas of carbon reporting and biodiversity assessment. An outcome of COST Action E43 is a set of reference definitions that can be used by national inventories as a step toward complete harmonization. In addition, an expected outcome is a set of recommendations to facilitate harmonization where appropriate.

**Endnotes**

[1] In the context of this article, NFI refers to a strategic inventory of forest resources conducted at the national level rather than an inventory of a national forest as it might be construed in the United States.

[2] Stocking is a measure of current stand density relative to the stand density that would be optimal for a desired condition such as growth or site occupancy (Stage 1969).

**Literature Cited**


