Estimating Dead Wood During National Forest Inventories: A Review of Inventory Methodologies and Suggestions for Harmonization

Christopher W. Woodall[1], Jacques Rondeux[2], Pieter J. Verkerk[3], and Göran Ståhl[4]

Abstract.—Efforts to assess forest ecosystem carbon stocks, biodiversity, and fire hazards have spurred the need for comprehensive assessments of forest ecosystem dead wood (DW) attributes around the world. Currently, information regarding the prevalence, status, and methods of DW inventories occurring in the world's forested landscapes is scattered. The goal of this study is to describe the current status of DW, including DW attributes measured, sample methods employed, and DW attribute thresholds used by national forest inventories (NFI) that currently inventory DW around the world. Study results indicate that most countries do not inventory forest DW. Only 13 percent of all countries inventory DW, and sample methods and DW component definitions are diverse. The major commonality among DW inventories was that most countries have only just begun DW inventories and employ very low sample intensities. Harmonizing NFI DW inventories will be a major hurdle due to differences in population definitions, lack of clarity on sample protocols and estimation procedures, and sparse availability of inventory data and reports are some of the inconsistencies. Increasing database and estimation flexibility, developing common dimensional thresholds, publishing inventory procedures and protocols, releasing inventory data and reports to international peer review, and increasing communication (e.g., workshops) among countries inventorying DW are suggestions forwarded by this study to increase NFI DW harmonization.

Importance of National-Scale Inventories of Dead Wood

Dead wood (DW) is typically defined as all nonliving tree biomass (excluding duff and litter), including woody debris that is standing or lying along with stumps (FAO 2006). National-scale inventories national forest inventories (NFIs) of forest ecosystem DW are critical to four broad scientific pursuits: carbon accounting, fire/fuels, biodiversity, and wildlife habitat. Carbon (C) sequestration is becoming an increasingly important estimate derived from NFIs because of the link between greenhouse gases accumulation in the atmosphere and possible climate change (Smith *et al.* 2004a). In 1992, 150 countries signed the United Nations Framework Convention on Climate Change, which requires annual reports of greenhouse gas inventories, including C in forests. In 2006, approximately 11 percent of all greenhouse gas emissions in the United States were sequestered annually in forests and forest products (Smith *et al.* 2004b, EPA 2006). In the United States, 35 percent of the total forest C pool is in live vegetation, 52 percent in the soil, and 14 percent in dead organic material (excluding fine woody debris [FWD]) (Heath *et al.* 2003). Therefore, accurately estimating baseline forest DW carbon stocks and monitoring stock changes over time is essential. Even so, estimates of DW have been omitted from some large-scale C assessments (Goodale *et al.* 2002) due to the lack of sufficient inventory data.

[1] Research Forester, U.S. Department of Agriculture, Forest Service, Northern Research Station, St. Paul, MN 55108. Phone: 651–649–5141; fax: 651–649–5140. E-mail: cwoodall@fs.fed.us.

[2] Professor, Gembloux Agricultural University, Gembloux, Belgium.

[3] Researcher, European Forest Institute, Joensuu, Finland.

[4] Professor, Swedish University of Agricultural Sciences, Umeå, Sweden.

Concerns about the increase of forest fire occurrences at national scales have brought attention to the critical role that DW plays in large-scale fire hazards. Estimates of DW are integral to numerous fire behavior models (for examples, see Albini 1976, Burgan and Rothermal 1984, Finney 1998, Reinhardt *et al.* 1997, Rothermal 1972). NFIs of DW can be used to estimate fuel loads and fire dangers at national scales (for example, see Woodall *et al.* 2005).

DW components, such as standing dead trees and coarse woody debris (CWD), increase a forest's structural heterogeneity and serve as critical habitat for numerous flora and fauna. Flora uses the microclimate of moisture, shade, and nutrients provided by CWD to establish regeneration (Harmon *et al.* 1986). Both standing and down DW provide a diversity (e.g., stages of decay, size classes, and species) of habitat for fauna (ranging from large mammals to invertebrates) (Bull *et al*. 1997, Heilmann-Clausen and Christensen 2005, Harmon *et al.* 1986, Maser *et al.* 1979, Siitonen 2001). Due to the possibility of dwindling habitat for many native species across many countries, inventories of DW are important for habitat assessments and wildlife conservation efforts (for examples, see Ohmann and Waddell 2002, Tietje *et al.* 2002). Volume of standing and lying DW has also been adopted as a pan-European indicator for sustainable forest management related to forest biodiversity (MCPFE 2002).

Given the importance of NFI DW inventories, the goal of this article is to broadly describe the current DW NFI methods used around the world and suggest opportunities for harmonization. Specific goals include the following: (1) to describe the current status (e.g., year of first inventory, number of plots and transects, publicly available data) of DW NFIs, (2) to describe the dead wood attributes (e.g., standing dead trees or FWD) inventoried in current DW NFIs, (3) to describe briefly the DW sample techniques (e.g., fixed area plots or line-intersect transects) used in NFIs, and (4) to suggest opportunities for international harmonization of DW NFIs.

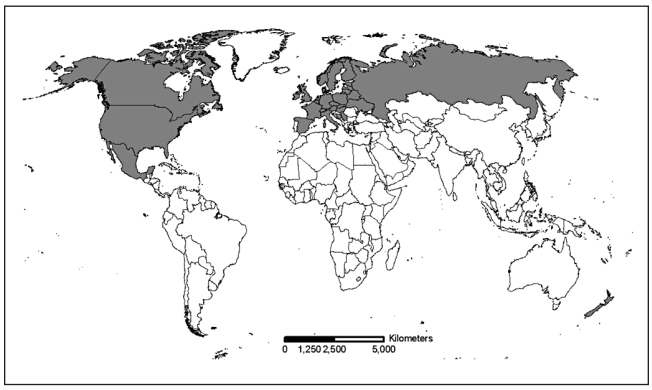
Study Survey Methods

Nearly 50 countries that were deemed most likely to have a DW inventory based on expert knowledge were contacted. For example, countries such as Libya or Afghanistan were unlikely to have DW inventories. Contacts for each country were based on advice from forestry colleagues and a list of participants in the Food and Agriculture Organization (FAO) of the United Nations's Global Forest Resource Assessment (FAO 2006). It was assumed that countries that did not respond to the DW survey either did not have a DW inventory, did not want to participate in the survey, or did not understand the English survey. Despite the authors' best attempts to accurately estimate the prevalence of DW sampling around the world, the results of this study's survey most likely underestimate the intensity of global DW sampling. The survey consisted of 21 questions in spreadsheet format grouped into four sections, which included (1) current status of inventory, (2) DW attributes inventoried, (3) inventory methods, and (4) attribute thresholds. All submitted surveys were summarized broadly so that individual countries could not be identified. For the purposes of the survey, in order to differentiate FWD from CWD, it was defined as downed and dead woody debris with a diameter less than 7 cm.

Current Status of Dead Wood National Inventories

This survey identified only 30 countries that currently inventory DW, representing only 13 percent of the world's 229 countries (FAO 2006) (fig. 1). Because most countries that inventory DW are located in the heavily forested regions of Europe and North America, this survey found that more than 41 percent of the forestland of the earth is inventoried for DW. DW inventories are a relatively recent phenomenon for most countries. More than 77 percent of DW inventories were initiated from 2000. The sample intensity (number of forested acres in any country divided by the number of DW inventory plots) varied widely with most countries having an intensity greater than one plot per 10,000 forested ha. Almost all countries had

Figure 1.—*Countries that currently have a national forest inventory of dead wood trees (shaded gray).*



an interval between plot remeasurement less than or equal to 10 years. Approximately 80 percent of countries have not publicly released their DW inventory data, while nearly 87 percent have not summarized the inventory in an official report. Overall, it appears that the majority of forests on earth are not inventoried for DW. In almost all countries where there is a history of forest inventories (e.g., Sweden and Germany), DW is inventoried. The analysis, dissemination, and review of these DW inventories is lacking given the dearth of publicly available DW inventory data and reports.

Dead Wood Components Measured in National Forest Inventories

Almost all countries that had a DW inventory compiled information on both standing dead and down dead trees (e.g., CWD). Of countries that had a DW inventory, 60 percent inventoried stumps, 73 percent inventoried residue piles, and 47 percent inventoried FWD. Almost all countries measured the species and decay class of DW. Notably, 68 percent of countries had a four- or five-decay-class rating system for DW. Overall, it appears that most DW inventories sample CWD, standing dead trees, stumps, and residue piles. Fine woody debris was only inventoried by 46 percent of surveyed countries. This lack of fine wood inventories may be because this DW component is being partially inventoried as part of the forest floor and because its contribution to the total forest biomass is relatively minor.

Dead Wood Sample Methods and Attribute Thresholds

Almost all countries used fixed-area plots for inventorying standing dead trees, but sample methods for dead and downed woody debris were more varied. Sixty-three percent of countries used fixed-area plots for CWD and 19 percent used line-intersect sampling. The remainder of countries used variable-radius plots or ocular estimation (i.e., expert observation/classification). The sample technique for FWD was evenly split between fixed-area plots (quadrat or fixed-radius) and line-intersect sampling. At the country-level, fixed-area plots were the most common DW inventory method, regardless of DW component. In terms of global forestland area, however, nearly 16 percent of the world's forest CWD is inventoried using line-intersect sampling techniques. In contrast, only approximately 3 percent of the world's forest CWD is inventoried using fixed-area plots. It appears that in countries with relatively large expanses of forest area (e.g., Canada and the United States) line-intersect sampling is the method of choice.

The definitions of DW variables, predominantly defined by measurement thresholds, varied among countries that inventory DW. Common minimum diameters at breast height for standing dead trees were 5, 7, 10, and 12 cm. A minimum diameter of 10 cm was the most common minimum diameter, with 19 percent of all countries having that minimum diameter. For CWD, 33 percent of countries inventoried CWD with a minimum diameter of 7.0 or 7.6 cm. The frequent minimum diameter was still 10 cm, however, with 27 percent of countries using that threshold. The threshold of 7.0 or 7.6 cm relates to a common break point between fine and CWD. A diameter of 7.6 cm is close to the English measurement unit of 3 in, which is used to differentiate between fine and heavy fuels in fuel and fire behavior models (Deeming *et al.* 1977). Minimum heights or lengths for standing and dead downed trees were overwhelmingly either 1.0 or 1.3 m, respectively. Dimensional thresholds for stumps were the most varied with minimum diameters appearing to be larger than for the standing and downed dead trees. Some countries that had a minimum diameter of 12 cm for standing dead trees had a minimum stump diameter of 30 cm. This result indicates that because stumps contain less biomass per cm of

diameter than standing dead trees, a larger stump diameter is needed to justify the effort to measure it. Most countries (53 percent) did not inventory FWD or even define it as a separate class of DW. As mentioned previously, the minimum diameter for CWD often defines the maximum diameter for FWD. Thus, 7.0 and 7.6 cm was the most common maximum diameter for FWD. Just a few countries specified minimum diameters for FWD, often 1.5 or 2.5 cm. Overall, the thresholds for DW components, in most cases, appear to be based on the relationship between sampling efficiency and the relative contribution of the DW component to overall stand biomass. Because the sampling of standing dead trees is probably the most efficient, along with being a major contributor to stand biomass, the population definition was the most inclusive (i.e., smallest minimum diameter). In contrast, either FWD was often not measured or its population was narrowly defined.

The Future of Dead Wood National Inventories

When viewing DW NFIs holistically, numerous similarities appear among them. First, standing dead and downed trees are often measured in unison. Rarely does a country inventory standing dead trees but not downed trees. Second, the size, species, and decay class of dead trees are ubiquitously measured. Most countries recognize the need to measure these parameters in order to more accurately estimate dead tree attributes such as volume, biomass, or carbon. Third, most countries have only recently started inventorying DW. This phenomenon can be most likely attributed to the relatively recent focus on national forest carbon stocks and indicators of biodiversity related to international agreements (e.g., greenhouse gas offset accounting, the Montreal Process indicators of sustainability, Pan-European Ministerial Conference on the Protection of Forests in Europe indicators for sustainable forest management). Fourth, fixed-radius sampling techniques were the most common technique for inventories of both standing and downed dead trees. Fixed-radius techniques were most likely adopted as efficient and logical extensions of fixed-radius techniques commonly used to inventory standing live trees. Fifth, most countries conducting DW inventories have neither publicly released their data nor summarized findings in a national report. These DW inventories are a recent activity for many countries, so it is likely that datasets are not complete or analytical expertise has not yet been developed. Finally, the remeasurement periods for DW NFIs is almost always 10 years or less, indicating countries' dedication to monitoring DW resources.

Despite the broad similarities among countries that inventory DW, even slight differences can cause problems with combining and comparing estimates in a regional/global context such as those required by global greenhouse gas offset accounting programs. The most prominent difference that can inhibit DW estimate comparison among countries is that of DW component population definitions. If countries use separate minimum diameters for either standing or downed dead trees then their resulting estimates are for different populations. At least two solutions can resolve this issue: common thresholds and database or estimation flexibility. Another apparent discrepancy was that of the number of DW components measured. Not all countries that inventory standing and downed dead trees also inventory stumps, residue piles, or FWD. Thus, national DW estimates may be incomparable. Total DW resource estimates may only be compared if the same DW components are measured or a common reporting framework is explicitly defined. The inherent nature of DW resources is that of decay and transition from standing dead trees, to coarse/FWD, to soil organic matter. Not only are dimensional thresholds (i.e., minimum diameter) important to define DW populations, defining the transition from standing dead to downed dead trees is important. How close to horizontal does a standing dead tree need to lean to be considered a downed dead tree? Finally, the force that may be driving DW inventories in different directions is the diversity of user groups demanding DW inventory information. For some countries, the main purpose of a DW inventory may be to assess fuel loadings, while in other countries it may be carbon accounting or biodiversity assessment. If inventory sample protocols are a reflection of inventory objectives, then the diversity of DW sample protocols reflects diversity in budgetary constraints and inventory objectives.

Forest DW inventories have expanded tremendously around the world during the past decade. Although numerous similarities bespeak a basis on ecological fundamentals (e.g., DW components of standing dead trees and CWD) and extensions

of historic standing live tree inventories (e.g., fixed-radius sample protocols), it is the inventory details that confound attempts to efficiently compare and combine DW resource estimates among countries. Differences in sample intensity, remeasurement period length, or sample technique (e.g., fixed-radius or line intersect) are not the major culprits in restricting global assessments. Almost all countries used defensible, peer-reviewed sample techniques for DW that should result in compatible estimates. It is the differences in population definitions, lack of sample protocol or estimation procedure clarity, and sparse availability of inventory data and reports that are the largest hurdles to harmonizating DW NFIs. Possible solutions to these problems include (1) increasing database or estimation flexibility to accommodate varying population definitions, (2) developing common dimensional thresholds, (3) publishing inventory procedures and protocols, (4) releasing inventory data and reports to international peer review, and (5) increasing communication (e.g., workshops or initiatives such as COST E43 in Europe) among countries inventorying DW. Given the substantial progress with DW inventories during the past years, there is little doubt that, with more effort and communication, these inventories may be more closely harmonized in the future.

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