Forest Ecology and Management 270 (2012) 78–84

Contents lists available at SciVerse ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Individual tree biomass equations or biomass expansion factors for assessment of carbon stock changes in living biomass – A comparative study

Hans Petersson [a,*], Sören Holm [a], Göran Ståhl [a], David Alger [a], Jonas Fridman [a], Aleksi Lehtonen [b], Anders Lundström [a], Raisa Mäkipää [b]

[a] Department of Forest Resource Management, Swedish University of Agricultural Sciences, SE-901 83 Umeå, Sweden
[b] Finnish Forest Research Institute, FI-01301 Vantaa, Finland

ARTICLE INFO

Article history:
Received 1 July 2011
Received in revised form 3 January 2012
Accepted 4 January 2012
Available online 9 February 2012

Keywords:
Greenhouse Gas Inventory
Kyoto Protocol
Stock change method
Sweden
Tree allometry

ABSTRACT

Signatory countries to the United Nations Framework Convention on Climate Change (UNFCCC) and its supplementary Kyoto Protocol (KP) are obliged to report greenhouse gas emissions and removals. Changes in the carbon stock of living biomass should be reported using either the default or stock change methods of the Intergovernmental Panel on Climate Change (IPCC) under the Land Use, Land-Use Change and Forestry sector. Traditionally, volume estimates are used as a forestry measures. Changes in living biomass may be assessed by first estimating the change in the volume of stem wood and then converting this volume to whole tree biomass using biomass expansion factors (BEFs). However, this conversion is often non-trivial because the proportion of stem wood increases with tree size at the expense of branches, foliage, stump and roots. Therefore, BEFs typically vary over time and their use may result in biased estimates. The objective of this study was to evaluate differences between biomass estimates obtained using biomass equations and BEFs with particular focus on uncertainty analysis. Assuming that the development of tree fractions in different ways can be handled by individual biomass equations, BEFs for standing stock were shown to overestimate the biomass sink capacity (Sweden). Although estimates for BEFs derived for changes in stock were found to be unbiased, the estimated BEFs varied substantially over time (0.85–1.22 ton CO_2/m^3). However, to some extent this variation may be due to random sampling errors rather than actual changes. The highest accuracy was obtained for estimates based on biomass equations for different tree fractions, applied to data from the Swedish National Forest Inventory using a permanent sample design (estimated change in stock 1990–2005: 420 million tons CO_2, with a standard error amounting to 26.7 million tons CO_2) Many countries have adopted such a design combined with the stock change method for reporting carbon stock changes under the UNFCCC/KP.

1. Introduction

Although signatory countries are obliged to report greenhouse gas emissions and removals according to the United Nations Framework Convention on Climate Change (UNFCCC) and its supplementary Kyoto Protocol (KP; United Nations, 1998), Löwe et al. (2000) have identified a lack of consistency in national reporting of changes in forest and other woody biomass stocks. In addition, calculation methods for converting forest data to carbon dioxide (CO_2) – the most important greenhouse gas – differ between countries. The accuracy of estimates of standing volume and volume of growth is often unknown, and the quality of data is sometimes poor. However, in recent years many countries have improved their National Forest Inventories (NFIs), which are typically used to provide data for UNFCCC/KP-reporting (Tomppo et al., 2010). Normally, these NFIs have a sample-based design with sample plots inventoried in the field. Thus in general, area-based estimators are used to estimate changes in carbon pools.

According to the Revised 1996 Guidelines for National Greenhouse Gas Inventories (IPCC, 1997) and the Good Practice Guidance for Land Use, Land-Use Change and Forestry (IPCC, 2003), the national reporting of changes of CO_2 equivalents (or Global Warming Potentials, see IPCC, 2003) in forest and other woody biomass stocks can be calculated by a default method as the difference between growth and drain (harvest, natural mortality and natural disturbances). Alternatively, these changes can be calculated by the stock change method as the change in stocks between two consecutive inventories. In NFIs, changes in growing stock are often quantified in terms of the volume of stem wood (merchantable). For the Greenhouse Gas Inventory, this change in volume is multiplied by constants (biomass expansion factors) to convert from stem wood volume to whole tree biomass and then CO_2

* Corresponding author.
E-mail address: Hans.Petersson@slu.se (H. Petersson).

0378-1127/$ - see front matter © 2012 Elsevier B.V. All rights reserved.
doi:10.1016/j.foreco.2012.01.004

equivalents (e.g., see Formula (5)). Another approach is to directly estimate the biomass per tree fraction by applying biomass regression equations (BiEqs) to sample trees and then converting the biomass to CO_2 equivalents by scaling (see, for example, Formula (1); Somogyi et al., 2007).

When estimating changes in living biomass at a national scale, it is usually difficult to obtain a reliable value for the whole tree biomass from the stem volume because stem proportion increases with tree size at the expense of branches, foliage, stump and roots (Fig. 1). Hence, the use of biomass expansion factors (BEFs) may lead to biased estimates because BEFs vary with tree size (age, etc.) and tree populations change over time (e.g., Satoo and Madgwick, 1982; Albrektson and Valinger, 1985; Pajtík et al., 2011).

When using the stock change method, to reduce the risk of bias BEFs should reflect the actual change in stock by incorporating the accumulation of growth per tree fraction with the effects of harvest and natural thinning patterns in one constant. Such BEFs can be derived but need to be updated if the allocation of growth and harvest patterns change. For practical reasons, instead of representing the actual change in stock, BEFs are often derived for the standing stock, which introduces an unknown bias into the estimates. To reduce the risk of bias, age-dependent (e.g., Lehtonen et al., 2004, 2007; Tobin and Nieuwenhuis, 2007) or volume-dependent (e.g., Schroeder et al., 1997; Fang et al., 2001) BEFs have been developed, which enable the ratio of whole tree biomass to stem volume to change with tree size. Levy et al. (2004) performed regression and variance analyses of BEFs and found that tree height was a better predictor than age. Therefore, in summary, there is a growing body of evidence that estimates based on BEFs are not constant but vary with tree, site and stand conditions (e.g., Jalkanen et al., 2005; Guo et al., 2010).

Currently, BEFs are frequently used for greenhouse gas reporting because the volumes of growing stock and stem-wood growth are usually the most reliable estimates in traditional forest inventories. However, only a few investigations have assessed the magnitude of potential error that may be introduced if the BEFs are incorrect (e.g., Lehtonen et al., 2007; Albaugh et al., 2009).

Using the Intergovernmental Panel on Climate Change (IPCC) stock change method (IPCC, 2003), the aims of this study were as follows:

(i) To compare differences between carbon stock change estimates of living biomass pools calculated using either individual tree volume equations combined with BEFs or individual tree biomass equations.
(ii) To assess differences between variances of estimators based on independent samples (temporary sample plots) and paired samples (permanent sample plots) in the BEF and in biomass equation approaches, respectively, and consider systematic errors.
(iii) To determine whether BEFs derived for change in stock (cf., BEFs for standing stock) are invariant over time.

2. Materials and methods

Data from the Swedish NFI (NFI; Ranneby et al., 1987; Axelsson et al., 2010) were used for greenhouse gas predictions. These data were suitable for two reasons: (i) they comprise individual tree data from about 30,000 permanent sample plots first inventoried before 1990 (base year of the KP) and re-inventoried every 5–10 years thereafter, (ii) national representative BiEqs and volume equations are available for all three species (Näslund, 1947; Marklund, 1987, 1988; Petersson and Ståhl, 2006). The data are summarized in Table 1.

The Swedish NFI (Axelsson et al., 2010) is a systematic cluster sample inventory that includes annual data for all land and fresh water areas (ca. 45 mill. ha), except for the high mountains in the northwest (ca. 2.3 mill. ha), which are not covered by trees, and urban areas (ca. 1.1 mill. ha). The clusters are square-shaped with sample plots along each side and are distributed throughout the country but have a higher density in southern than northern Sweden. Each year, about 6000 permanent sample plots are inventoried. For each circular sample plot (radius 10 m), extensive information is collected about the trees, stand and site. The main purpose of the Swedish NFI is to monitor forests for timber production and environmental factors.

In the present study, the FAO definition (FAO, 2004) of forest land was used, i.e., land areas spanning more than 0.5 ha with a tree crown cover of at least 10% and a minimum height of trees of 5 m. The values for crown cover and minimum height refers to trees maturing *in situ*, and the predominant land use must be forestry.

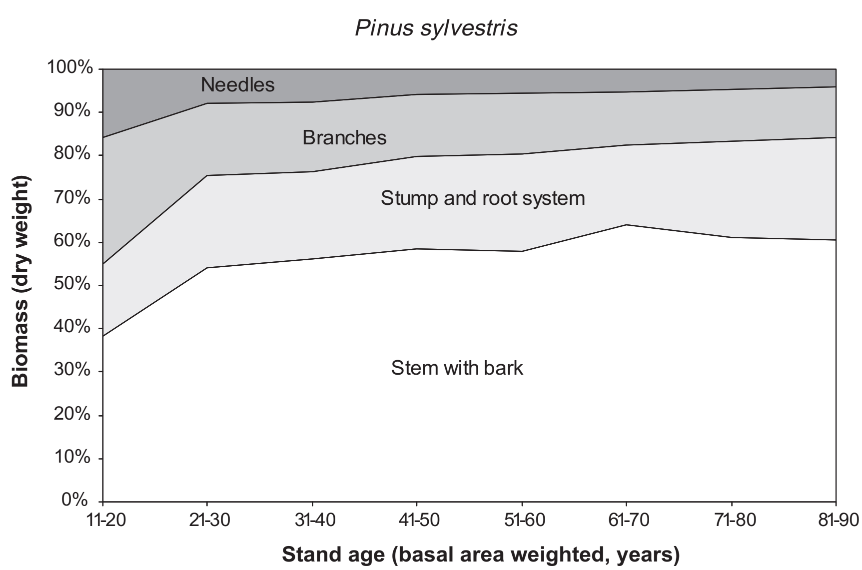

Fig. 1. Data showing the tree fractions for about 315 Scots pine sample trees collected during the summers of 1983–1985 (Marklund, 1987, 1988). The ratio stem with bark biomass (or volume) to whole tree biomass is normally not constant to tree or stand age (size).