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Forest Ecology and Management 229 (2006) 98–110
Forest Ecology and Management
www.elsevier.com/locate/foreco

Development of total aboveground volume equations for seven important forest tree species in France

Patrick Vallet[a,*], Jean-François Dhôte[a], Gilles Le Moguédec[a], Michel Ravart[a], Gérôme Pignard[b,1]

[a] Laboratoire d'Étude des Ressources Forêt Bois, UMR INRA-ENGREF 1092, Centre INRA de Nancy, F-54280 Champenoux, France
[b] Inventaire Forestier National, Cellule Évaluation de la Ressource, Montpellier, France

Received 10 June 2005; received in revised form 20 February 2006; accepted 20 March 2006

Abstract

In order to improve the estimation of carbon stored in the French forest biomass from National Forest Inventory data, we developed six species-specific equations for estimating the total aboveground volume of trees, including merchantable volume, branches and twigs. Equations use circumference at breast height and total height as independent variables. They were built from even-aged forests of the *Landes* massif, the northern half and the eastern mountain regions of France. The sample was selected within archives of volume measurements taken in growth and yield permanent plots between 1920 and 1955. It is made up of 4619 trees belonging to seven important species: 1222 Sessile Oak, 1293 Common Beech, 347 Douglas Fir, 309 Norway Spruce, 389 Scots Pine, 297 Maritime Pine and 762 Silver Fir. These trees were felled and measured in 26 different forests (62 stands). Tree form factor was analysed, rather than volume, to remove heteroscedasticity, and height was substituted by a hardiness coefficient to remove diameter–height correlation. The analysis identified species-specific modes of variation of tree form with respect to developmental stage and tree hardiness. Maritime and Scots Pine did not differ statistically, despite large differences between ecological and silvicultural situations of both species. This suggests the possibility to use identical volume equations for species belonging to the same genus. Regional variations of tree form were explored by a cross-validation technique. Prediction biases did not exhibit a clear geographic structure. A 5% overestimation for hardwoods in southern sites is possible, and would deserve further testing. The hypothesis that recent growth changes may have slightly altered tree form is also discussed. Finally, a national-scale application provided Biomass Expansion Factors consistent with former studies and suggested that these volume equations behave well in extrapolation to coppices, uneven-aged or mixed stands.

Keywords: Volume equations; Form factor; Biomass; Carbon stocks; Kyoto Protocol; France; *Fagus sylvatica*; *Quercus petraea*; *Pinus pinaster*; *Pinus sylvestris*; *Picea abies*; *Abies alba*; *Pseudotsuga menziesii*

1. Introduction

The evaluation of carbon stocks in the forest biomass is an important issue for national policies and international negotiations (Kauppi et al., 1992; Dixon et al., 1994). It contributes to a broad range of issues regarding climate, greenhouse gases emissions, energy and forestry (Cannell, 2003). Countries that ratified the Kyoto Protocol (UNFCCC, 1997) are engaged to achieve national inventories of all greenhouse-gases sinks and sources, including the land-use and forestry sector (Riedacker, 1999; Brown, 2002). Since carbon trade is becoming a close perspective, there is a need for accurate, precise and transparent methods of forest carbon accounting (Prisley and Mortimer, 2004). Not only the accounting of present carbon is needed, but also some medium or long-term projections under various scenarios of climate change, forest product use and supply–demand trends (Karjalainen et al., 2002; Cannell, 2003; Loustau, 2004). For example, according to Cannell (2003), the global storage in biomass could be realistically raised up by 50–100 Gt C over the next 50 years. This value can be compared to the 750 Gt C contained in the atmosphere, and to the present increment of 3.2 Gt C/year. The magnitude of expected trends calls for better estimates of forest carbon. To estimate the present carbon stocks in the aboveground forest biomass, the conventional method is based upon the combined use of large-scale data

* Corresponding author. Tel.: +33 3 83 39 68 56; fax: +33 3 83 39 40 69.
E-mail address: vallet@nancy.inra.fr (P. Vallet).
[1] Present address: DDAF de l'Hérault, Maison de l'Agriculture, Place Chaptal, F-34960 Montpellier Cedex 2, France.

0378-1127/$ – see front matter
doi:10.1016/j.foreco.2006.03.013

bases provided by National Forest Inventories and specific models designed to estimate biomass and/or carbon from usual mensurational data (Brown, 2002).

Although National Forest Inventories are largely available, at least in the developed countries, and are based on appropriate sampling schemes for large-scale applications, they have several drawbacks: forest growing stock is generally measured in units of merchantable volume; seedlings and saplings are ignored or subject to specific sampling and measuring procedures; the threshold size and volume definitions differ between the National procedures, preventing from straightforward comparisons. To solve these problems, the method generally adopted is to convert measured merchantable volumes into biomass, using Biomass Expansion Factors (BEFs: see Schroeder et al., 1997; Dupouey et al., 1999; Lehtonen et al., 2004; Van Camp et al., 2004). Direct methods apply a single BEF to convert volume to aboveground biomass, whereas indirect methods use several successive steps (converting merchantable volume to total aboveground volume, then to biomass). Schroeder et al. (1997) claim that the former are preferable, in order to avoid composing errors.

The inconsistency between BEFs used in various studies, sometimes for similar forest types, has been pointed out (Löwe et al., 2000; Dupouey and Pignard, 2001). Although aboveground biomass is certainly the best known compartment of forest C-stores, as shows the review of biomass and stem volume equations by Zianis et al. (2005), we still need more robust methods, adapted to the situations under study. But biomass studies are very expensive: for example, the study by Van Camp et al. (2004) is based on 24 trees for three species. This led Brown (2002) to suggest the development of generic regression models for ecological zones and/or species groups. Parresol (1999) made a critical review of several sampling, statistical and mathematical issues for the design of regression models to estimate biomass from easily measurable tree dimensions. Zianis and Mencuccini (2004) focused on the most frequent model, a simple power function relating stem diameter at breast height to tree biomass. Their meta-analysis of 279 published equations showed that the exponent of diameter–biomass allometries is related to the exponent of height–diameter allometries. Since the latter is known to depend on the population structure, this suggests that one-way regressions (diameter–biomass) should be applied carefully. In their large-scale study on Beech in western Germany, Joosten et al. (2004) concluded that tree height brings information in addition to diameter.

Although French forests share their structuring species with neighbouring European countries, the high frequency of low-stocking and coppice-with-standards stands deserves special attention with regard to biomass or carbon estimation. Trees growing in these stands exhibit slower height growth, faster diameter growth and different morphologies and volume distribution (Bartet, 1891; Bouchon et al., 1981; Bryndum, 1987; Dhôte et al., 2000a), as compared to trees grown in dense high-forests which are more common in Central Europe and Scandinavia.

As a consequence, the conversion of IFN volumes into biomass normally implies large expansion factors. During the 1970s, French biomass studies recommended to use stand-structure-specific expansion factors (Bouchon et al., 1981). This procedure used the category of stand structure noted in the field by IFN teams (high forest, coppice-with-standards, coppice). However, this distinction between stand types introduces a discontinuity into biomass estimation: this is not desirable, since many stands in conversion are intermediate: when coppice removals slow down, coppice-with-standard mature and turn progressively to high forest; this gradually impacts tree morphology and hence volume–carbon expansion factors. Existing volume tables or volume equations available in Europe refer mainly to merchantable timber: e.g. the Common Beech volume table by Bouchon (1982) stands for diameter over bark larger than 7 cm. Thin wood (branches and twigs of diameter less than 7 cm) is a significant percentage of the total. In Common Beech (Fig. 1), thin wood represents 100% of the total volume in saplings and still 10% in the thickest trees.

The research reported in this paper is a contribution to a better estimation of carbon stored in the French forest biomass. In France, the *Inventaire Forestier National* (IFN, National Forestry Inventory) measures each tree larger than 7.5 cm for diameter at breast height and total height; merchantable volume is estimated using local volume equations. These volume equations are calibrated for each species and each *Département* (on average, 150,000 ha of forest area), at each inventory cycle (12-year return intervals).

The present method devised by Dupouey et al. (1999) converts volume to total aboveground carbon for each individual tree, using the following equation:

$$C = V_{IFN} \times \text{BranchEF} \times \text{DEN} \times \text{CAR}$$

where V_{IFN} is the merchantable volume estimated by IFN, BranchEF the Branch Expansion Factor, DEN the basic density for the species, and CAR is the proportion of carbon in the dry matter.

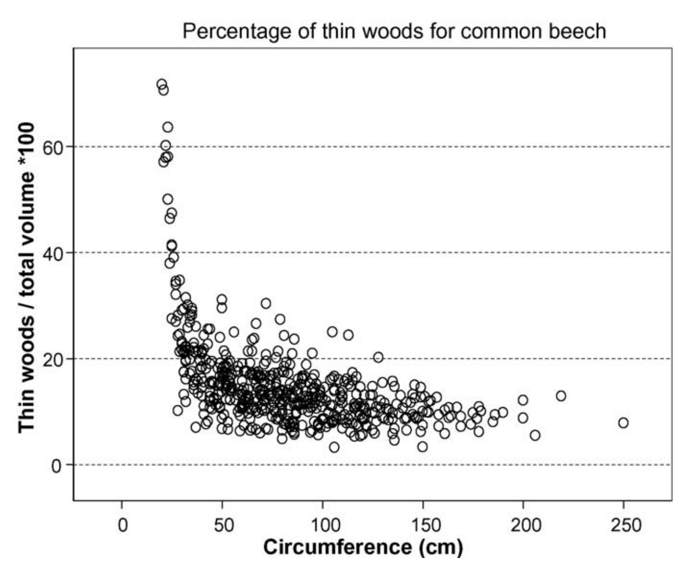

Fig. 1. Percentage of thin wood compared to circumference for Beech. "Thin wood" is the volume of aboveground branches with a diameter ≤7 cm.