Forest Ecology and Management 312 (2014) 225–230

Contents lists available at ScienceDirect

Forest Ecology and Management

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

Is randomized branch sampling suitable to assess wood volume of temperate broadleaved old-growth forests?

Gherardo Chirici [a,*], Nicola Puletti [b], Riccardo Salvati [c], Francesco Arbi [d], Catherine Zolli [e], Piermaria Corona [b]

[a] University of Molise, Dipartimento di Bioscienze e Territorio, Pesche (IS), Italy
[b] Consiglio per la Ricerca e Sperimentazione in Agricoltura, Forestry Research Centre, Arezzo, Italy
[c] University of Tuscia, Dipartimento per l'Innovazione nei sistemi Biologici, Agroalimentari e Forestali, Viterbo, Italy
[d] ASD HUBBLE, Firenze, Italy
[e] Forestlab.net Network of Forest Geomatics Laboratories, Firenze, Italy

ARTICLE INFO

Article history:
Received 1 August 2013
Received in revised form 25 September 2013
Accepted 1 October 2013
Available online 26 October 2013

Keywords:
Horvitz–Thompson estimation
Randomized branch sampling
Old-growth
Precision
Simulation
Tree climbing

ABSTRACT

Old-growth forests are characterized by the presence of large and very large trees. The estimation of their wood volume and biomass is essential in order to monitor the ecological processes in these stands and their contribution to carbon cycle. However, conventional wood volume estimation techniques based on mensuration of stem diameter at breast height and tree height is most often unfeasible for large and very large trees in old-growth forests because volume models or tables are usually elaborated from trees of smaller size grown up in regularly managed forest stands. Random Branch Sampling (RBS) is often proposed as a possible estimation alternative under such conditions. Starting from the ground level some of the parts of the main trunk and of the branches are sampled and measured to estimate the overall wood volume (or other biophysical variables). The application of RBS in old-growth forests, where tree cutting is usually forbidden or very difficult, requires that the crown of the tree can physically be reached to measure the sampled parts. We argue that under such conditions it is usually preferable to fully measure all the components of the tree crown because RBS estimates are not precise if based on only one sampling path and that, on the other hand, measuring the main trunk and all the branches by tree-climbing consumes the same time as replicating several RBS paths on the same tree. To demonstrate our hypothesis we selected 16 large beech trees located in the old-growth forest of Mount Cimini in Central Italy. Using a modern tree-climbing approach the main trunk and all the branches were measured and recorded in the field. The database was used to simulate RBS paths. Real values from volume census were contrasted with estimates based on RBS. On the whole, RBS estimates based on one single path prove to be highly imprecise. Even for trees characterized by a rather regular form, at least three RBS paths should be repeated on the same tree to maintain the relative standard error under or near 15%. This paper introduces the problem and describes the experimental test. The results are discussed under the perspective of standardized application of the proposed methodology.

1. Introduction

1.1. Old-growth forests carbon pool assessment

Forest inventories are currently evolving towards multipurpose resource surveys and are broadening their scope in several directions: (i) expansion of the target population to include non-traditional attributes such as trees outside the forest and urban forests; (ii) assessment of forest health; (iii) inclusion of additional variables such as biodiversity attributes that are not directly related to timber assessment and wood harvesting; (iv) forest carbon pools and carbon sequestration estimation (Corona et al., 2011).

A large number of ecosystem services are provided by old-growth forests. They are important for biodiversity conservation and as carbon reservoirs, for spiritual and aesthetic reasons, but also because they offer to scientists the opportunity of studying ecological processes in nearly undisturbed natural conditions (Wirth et al., 2009). Several approaches for defining an old-growth forest exist, most of which are based on the use of multiple criteria; following the review by Wirth et al. (2009), based on 39 scientific publications, the criterion "large old trees" is ranked first among the different criteria more frequently mentioned in defining an old-growth forest.

* Corresponding author. Tel.: +39 0874404138.
E-mail addresses: gherardo.chirici@unimol.it (G. Chirici), nicola.puletti@entecra.it (N. Puletti), riccardo.salvati@unitus.it (R. Salvati), info@asdhubble.com (F. Arbi), cath.zolli@gmail.com (C. Zolli), piermaria.corona@unitus.it (P. Corona).

0378-1127/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.foreco.2013.10.001

Carbon pools of unmanaged forests are most often larger than those of managed forest stands under similar site and species composition conditions (Krug et al., 2012). Researchers have shown an increasing interest in the study of the spatio-temporal trends of old-growth carbon stocking in the framework of climate change scenarios, and the debate on the role of old-growth forests in carbon sequestration is still open (Knohl et al., 2009).

The most common method for assessing carbon stock in forest stands relies upon the estimation of tree wood volume through volume models on the basis of the mensuration of tree stem diameter at breast height (*dbh*) and tree height (*h*); then carbon is estimated taking into account the wood density and the expansion factors of the considered tree species. Sometimes biomass models are available, and in these cases biomass is directly estimated by *dbh* and *h*.

In Europe common beech (*Fagus sylvatica* L.) is one of the most important broadleaved species characterizing old-growth forests (Kucbel et al., 2012). According to the review by Zianis et al. (2005), 57 models are available in Europe for biomass and/or wood volume estimation of beech trees. Each model is based on multiple measured trees between 5 and 240, the maximum *dbh* of the measured trees is 78.8 cm and the maximum measured *h* is 33.9 m. A small number of models are available for southern Europe and those models are usually based on a few sampled sites with a very limited number of sampled trees. Large and very large trees, typical of old-growth forests, are usually not sampled.

Under these conditions, whenever destructive methods cannot be applied for assessing wood volume or biomass, as usually happens for old-growth forest stands, other estimation methods such as Randomized Branch Sampling (RBS) are proposed in order to support the assessment of carbon stock of single trees (Bascietto et al., 2012). RBS is a well-known multistage probability sampling method that can be used to obtain estimates of many different attributes of trees, e.g. the aggregate volume, dry weight, and chemical contents of the woody components (Gregoire and Valentine, 2008).

1.2. Accessing tree crown

The implementation of the RBS method requires the direct access to the tree crown. When investigating old-growth forest stands, a non-destructive framework has to be adopted since most often trees cannot be cut given their relevant ecological value. To this end two approaches can be used: climbing directly the tree trunk or climbing an adjacent artificial structure. Whatever the system is, it should be cheap, safe for the operators, and should avoid to disturb the ecosystem. Again, this last item is particularly relevant in old-growth forests.

Some of the most used artificial structures to reach tree crowns are scaffolding systems (Heichel and Turner, 1983), hydraulic lifts or cranes (Hutchison et al., 1986), ladders or tallescopes (Maillette, 1982), wooden poles (McCarthy, 1988). Barker and Pinard (2001), in an extensive review of canopy accessing systems based on a survey of 236 canopy studies, illustrated that artificial systems were used in 42% of the cases, trunk climbing systems were used in 25% of the cases and in the remaining 33% systems remote or proximal sensing techniques were used (binocular observation, hemispherical photography, etc.).

Climbing the tree trunk is a typical low-tech method requiring very light equipment (Barker and Sutton, 1997). In the last decades the demand for tree crown data by scientists evolved with tree climbing techniques. Free climbing the bole trunk with no safety apparels by locals in tropical areas was used in the past (Moffet and Lowman, 1995) while in temperate and boreal zones the main used method was based on ascender tools on a single rope (the Single Rope Technique – SRT) (Lowman and Moffeit, 1993; Lamant, 1995). Nowadays, a number of different modern tree climbing techniques can be used: a complete and detailed overview is reported by USDA (2005).

Climbing on large trees must be done by professionals or well-trained operators who should identify the best approach to ascend the tree on the basis of specific site and tree characteristics. According to the guidelines by USDA (2005), if large branches are not available near the ground the SRT or the Double Rope Technique (DRT) should be used: a rope is passed across a large branch up on the tree, and the operator ascends on the rope with specific apparels. Since SRT and DRT are slow and physically demanding, if large branches are available, the operators should prefer self-belaying or ground-belaying systems: the operator ascends climbing the tree with an elastic rope used for belaying in case of fall. These systems can be repeated and mixed together several times to ascend one single tree and also to reach all the branches to be measured.

When tree climbing is used for scientific reasons the use of equipment potentially dangerous for tree health should be avoided, especially on thin-barked trees: for instance, Swiss tree grippers should be preferred to climbing spurs, and ladders to pole steps.

1.3. Present investigation

This paper is aimed at investigating the precision of wood volume estimation by RBS on the basis of an experimental test carried out in the Cimino forest, a beech (*F. sylvatica* L.) old-growth forest located in Central Italy (Chirici and Nocentini, 2010). First, we fully measured the total volume of 16 large beech trees in the field by adopting a modern tree climbing approach. Then, through such a dataset, we simulated the application of RBS method and we compared the obtained estimates with the real data.

The paper is organized as follows: (i) materials are described in Section 2, highlighting the operative procedure of measuring the wood volume of old-growth trees by tree climbing; (ii) randomized branch sampling, along with the estimator of the total tree volume and its variance drawn from statistical literature, is presented in Section 3; (iii) a simulation study performed to give insights on the precision of the RBS estimators with respect to the measured old-growth trees in the Cimino forest is reported in Section 4; (iv) considerations of practical and theoretical nature conclude the paper.

2. Materials and methods

2.1. Data acquisition

The study area is a beech forest of nearly 60 ha growing on Mount Cimini, an isolated relief of volcanic origin located in Central Italy (Viterbo province, 100 km north from Rome). The site has a temperate oceanic semicontinental bioclimate and a very fertile soil with a mull horizon. The forest can be regarded as a newly untouched forest, as it has been essentially unmodified by forestry operations for the past 60 years, and it exhibits some typical characteristics (density, basal area, living trees volume) found in old-growth beech forests studied worldwide (Lamonaca et al., 2008).

In the Cimini old-growth forest 16 large beech trees were randomly selected. The trunk and the crown of the selected trees were recorded using the well-known RBS scheme based on nodes and segments: a node is the point at which a branch or part of a branch ramifies into subordinated branches, while a segment is a part of a branch between two consecutive nodes; a path is instead a series of successive segments between the first node and a final segment (Cancino and Saborowski, 2005; Gregoire and Valentine, 2008).

The field work was carried out by a team of three people: one professional tree climber, one expert tree climber, one assistant. The professional tree climber ascended and measured the trees, the second climber operated, when needed, for ground-belay and the assistant recorded the measures.