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Guidance for tree measurement in tropical forest ecosystems using non-destructive sampling to develop stem biomass and volume models

G.H. Sabin Guendehou, Aleksi Lehtonen

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Office
Post Box 18
FI-01301 Vantaa, Finland
tel. +358 10 2111
fax +358 10 211 2101
e-mail julkaisutoimitus@metla.fi

Publisher
Finnish Forest Research Institute
Post Box 18
FI-01301 Vantaa, Finland
tel. +358 10 2111
fax +358 10 211 2101
e-mail info@metla.fi
http://www.metla.fi/

Authors
G. H. Sabin, Guendehou, Aleksi, Lehtonen

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Abstract
The lack of guidance on tree measurements applying a non-destructive approach in tropical forest ecosystems motivated the drafting of this paper. The paper guides step by step on how to conduct tree measurements to generate data for biomass and volume modelling. How basic wood densities and carbon content can be determined in the laboratory is also addressed. Guidance and references are provided to assist developing species specific models, generic models, as well as to quantifying forest biomass and carbon stocks.

Keywords
Tropical forest, tree measurement, non-destructive sampling, biomass model, volume model, carbon stocks

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Contact information
G. H. Sabin Guendehou, *Centre Béninois de la Recherche Scientifique et Technique, 03 BP 1665, Cotonou, Bénin*. E-mail: sguendehou@yahoo.com

Other information
Aleksi Lehtonen, *Finnish Forest Research Institute, PO Box 18, FI-01301 Vantaa, Finland*. E-mail: aleksi.lehtonen@metla.fi

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1 Introduction

The role of forests in climate change mitigation has been recognized by the international community (UNFCCC, 2008, 2010). Forests can provide several economic and social benefits when forest management systems are sustainable and moreover these practices can protect forests and reverse the human-induced destruction and degradation processes (for e.g. conversion of forest to cropland, commercial exploitation of timber, fuel wood extraction). However, the knowledge of the forest productivity and the forest reference level (i.e. the level of the carbon sink under prevailing forest policy) which are supposed to provide the basis for forest management and quantification of the climate change mitigation potential are still poor in Benin as well as in many other tropical countries (Guendehou et al. 2012). The collection of new data and the development of methods and tools to address these issues will help to fill this gap.

In the current context of using forests for climate change mitigation, in particular in nature conservation areas, a destructive sampling method which cut down trees may not be appropriate as it involves an important carbon loss from biomass and soil and therefore appears as a source of carbon dioxide (CO_2) emissions to the atmosphere. It also contributes to the destruction of the forest ecosystems. The scientific research dealing with forest biomass and carbon quantification should be oriented towards approaches, which cause minor injury to the trees, limit the ecosystems disturbance and at the same time provide accurate scientific results.

The objective of this technical paper is to provide scientists, students, forestry project managers, and teachers with guidance for biomass measurement using non-destructive sampling in tropical forest ecosystems.

2 Non-destructive sampling

This approach includes all measurement techniques, for e.g. of biophysical properties of tree, causing limited damage which does not threaten the life of the tree. The diameter, height, and specific wood density have been measured using this approach. The method has the advantage that it can be used also with protected trees and ecosystems. Further, non-destructive sampling allows re-measuring the tree biomass increment for monitoring purposes.

3 Measurement of tree dimensions and wood density

Tree diameters from different heights, total height and basic wood density are prerequisite parameters if we want to quantify forest biomass. The sampling approach described below was conducted on standing trees. Hollow trees and pollard trees are not to be measured. In order to develop appropriate volume and biomass models, it is good practice to measure sufficient quantity of trees (this quantity depends on the objectives of the work, for local biomass models smaller quantities are needed, while for national level one should have lot of stands and several trees from those stands) in each diameter class of 5 cm width (Guendehou et al. 2012). Consider dominant tree species in a multispecies forest.

3.1 Diameter measurement

The following approach describes how a tree diameter can be measured through a non-destructive sampling:

- Conduct measurements over bark. Remove loose bark and spine to have accurate measurements.
- Use a diameter tape and measure diameter at breast height: Dbh usually 1.3 m from the ground (Figure 1)
- Measure the stem diameter at 1.0 m intervals starting from 1.3 m and stopping at the possible highest height reachable using a ladder or other device that can help to climb the tree (Figure 2)
- In lower diameter classes (for e.g. Dbh less than 15 cm), measure only Dbh as the stem form is mostly cylindrical
- The diameter at the crown base, if not measured directly using the diameter tape, can be approximated by a linear extrapolation of the last two measured diameters.

3.2 Height measurement

- A stem height can be derived using an optical clinometer, or an hypsometer
- Record observations of the bottom, the crown base and the top of each standing tree (Figure 3)
- Derive the stem height and the total height using these observations following the instructions for use of the clinometer.
- In lower diameter classes, which usually include small trees, the height can be directly measured without using a clinometer; rather use a graduated pole which is faster and gives more precise measurements.

3.3 Core sampling for basic wood density

- Use an increment borer and collect wood samples at two points diametrically opposed at 1.3 m without removing the bark (Figure 4); an increment borer is a specialized tool consisting of a handle, an auger bit, and a core extractor, which is used to extract a section of wood from a living tree with a relatively minor injury to the tree
- Record the length of the collected samples
- Measure the fresh sample mass with an electronic balance immediately after collection;
- Oven-dry the samples at 75 ºC to a constant weight (Figure 5) and measure the mass (drying at higher temperature may burn the samples)
- Calculate the fresh volume of samples based on the measured length of the collected samples and the diameter of the increment borer (cylinder volume)
- Calculate the basic wood density of each sample (dry mass per fresh volume)

Figure 1: Stem diameter measurement using a diameter tape

Figure 2: Diameter measurement along the stem using a ladder and a diameter tape

Figure 3: Tree height measurement on standing trees using an optical Suunto clinometer PM-5

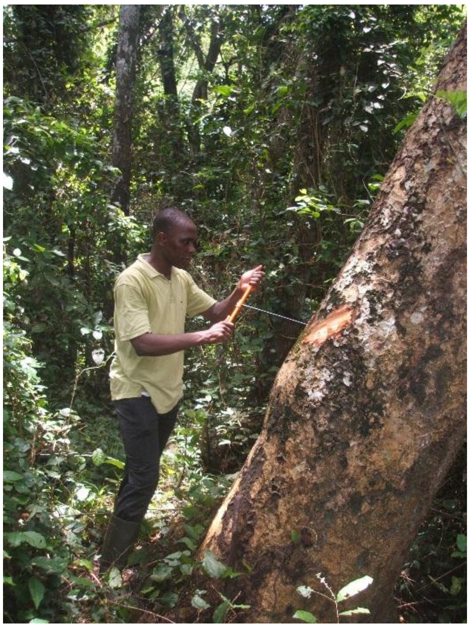

Figure 4: Collection of wood samples using an increment borer.

Figure 5 : Wood samples oven-dried at 75 ºC to a constant weight

3.4 Carbon content

- The carbon content can be determined using a Leco CHN analyser (Leco, St Joseph, Michigan);
- It can also be determined by loss-on-ignition: measure dry weight of the samples Burn the sample at 550 ◦C and measure the remaining mass which is the mineral portion of the sample. Mass loss is the amount of organic matter of which approximately 58% is carbon. Thus, the amount of organic matter divided by the van Bemmelen factor 1.724 gives the amount of carbon.

4 Application of data on tree dimensions and basic wood density

4.1 Stem volume and stem biomass

- For each tree measured in lower diameter class (Dbh ≤ 15 cm) and those having only one diameter measurement, calculate the stem volume using Equation 1 (cylinder taper function)

$$V = {d^2 \pi h}/{4} \quad (1)$$

where π = pi, h = height of the stem, and d = the diameter

- For each tree in higher diameter class (Dbh ≥ 15 cm) and those having several diameters measured calculate the volume of each measured section having each the height of 1.0 m using Equation 2 (truncated cone taper function) and sum to obtain the stem volume

$$V = ({\pi h}/{12})(d_1^2 + d_2^2 + d_1.d_2) \quad (2)$$

where π = pi, h = height of the stem section, d_1 = the greater diameter and d_2 = the smaller diameter.

- Convert the stem volume into stem biomass using the basic wood density (biomass = volume x density)

4.2 Volume model and biomass model

A volume model or biomass model is a mathematical function which links the volume or the biomass of trees to their biophysical properties (usually Dbh, height). Examples of models that were fitted to observations on volume, biomass, Dbh, and height and tested using the statistical computing software R (Guendehou et al. 2012) are presented below.

$$\ln(X) = x_o + x_1 \ln(Dbh)$$
$$\ln(X) = x_o + x_1 \ln(Dbh) + x_2 \ln(H)$$
$$X = x_o(Dbh)^{x1} + x_2(H)$$
$$X = x_0(Dbh)^{x1} * (H)^{x2}$$
$$X = x_o + x_1 \ln(Dbh)$$
$$X = x_0(Dbh^2 * H)^{x1}$$
$$X = x_0(Dbh * H)^{x1}$$

where X = biomass (kg) or volume (m^3), *Dbh*: diameter at breast height (1.3 m) (cm), *H* = stem height (m), x_0, x_1, x_2 are model parameters.

4.2.1 Specific model (for dominant tree species)

- Use the volume calculated for each tree in each diameter class and develop the species specific stem volume model (Guendehou et al. 2012). See Equations 3 and 4 as examples of volume models for *Afzelia africana*, using a combination of Dbh, H and only Dbh as variables, respectively.

$$\ln(V) = -2.6838 + 1.7892 \ln(Dbh) + 1.2067 \ln(H) \quad (3)$$

$$\ln(V) = -1.5444 + 2.2165\ln(Dbh) \quad (4)$$

where V = Volume (10^{-3} m^3); Dbh = the Dbh at 1.3 m (cm); H = tree stem height (m).

- Use the biomass calculated for each tree in each diameter class and develop the species specific stem biomass model. (Guendehou et al. 2012). See Equations 5 and 6 as examples of biomass models for *Afzelia africana*, using a combination of Dbh, H and only Dbh as variables, respectively.

$$\ln(M) = -3.2024 + 1.8850\ln(Dbh) + 1.0885\ln(H) \quad (5)$$

$$\ln(M) = -2.17462 + 2.27035\ln(Dbh) \quad (6)$$

where M = Biomass (kg); Dbh = the Dbh at 1.3 m (cm); H = tree stem height (m).
When back-transforming from logarithmic scale to arithmetic scale to predict the stem volume and stem biomass, the model correction factor should be taken into account (Guendehou et al. 2012).

4.2.2 Generic model (applicable to non-dominant tree species)

Combine all observations on 1) volume and 2) biomass (from all measured trees) to determine a generic volume model and a generic biomass model.

4.3 Quantification of forest biomass stock

- Install plots in the forest (using for e.g. systematic sampling, or stratified sampling) and geo-reference the plots (latitude, longitude)
- Measure the Dbh of each tree species in each plot
- Use the Dbh of each dominant tree species as input to the corresponding species specific biomass model to determine the corresponding biomass stock
- Use the Dbh of non-dominant tree species as input to the generic model to determine the corresponding biomass stock
- Sum the biomass stocks and determine the biomass stock per hectare
- Use the total area of the forest to determine the total biomass stock of the forest ecosystem.

5 Implications for the development

The application of this approach will allow the estimation and the monitoring of carbon stocks in forests. It will help to quantify the forest reference level and the climate change mitigation potential of the forest. It provides data and information required for forest management policies and decision making for improving the livelihoods of population and the ecosystem services by the forest.

6 Conclusions

The generation of data and information on forest ecosystems is a prerequisite for the development and implementation of sound forest management policies. The guidance provided in this paper will contribute to fill the data gap observed in tropical countries in Africa. It helps to build/strengthen the capacity of researchers, students in forestry science, in particular on forest carbon balance, and to disseminate the experience gained in Benin in other regions.

7 References

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