Improving accuracy of estimates toward better use of tree allometric equations

Matieu Henry (FAO)
1. Context: importance of allometric equations (AE) in the REDD+ context
2. Status of tree allometric equations in South and Central America
3. Linking AE with national forest inventory data
4. How to select the best tree allometric equation?
5. Case studies
AN INCREASING NEED TO MONITOR FOREST & TREE RESOURCES ACCURATELY

Tree functions (allometric equation)

Field Inventory

Data analysis

BIO-ENERGY

CLIMATE CHANGE MITIGATION & ADAPTATION

TIMBER

NFRPS
1. Context: importance of allometric equations (AE) in the REDD+ context

Basic IPCC equation to assess GHG emission estimates

\[ E \text{mision Estimate} = \text{Activity Data} \times \text{Emission Factor} \]

- **Emission Estimates**
  - "Key Categories" (usually ~10-15 Sources) account for over 95% of a country's emissions, focus resources on these.

- **Official Statistics**
  - Activity Data usually can be found in national or international statistics.

- **Guidelines**
  - Most sources can use defaults from IPCC Guidelines—Only “Key Categories” (~10-15 Sources) need use more detailed parameters.
Most sources can use defaults from IPCC Guidelines—Only “Key Categories” (~10-15 Sources) need use more detailed parameters.
2. Status of tree allometric equations in South and Central America

- Volume and biomass allometric equations
  - Trees, sprouts and stands
  - 20 countries, Latin America

- Gaps in knowledge in availability, construction and reporting

- Recommendations to improve construction and reporting
Document types

- Journals: 250
- Books/reports: 144
- Theses: 61
- Proceedings: 9

n = 454
Data compilation & synthesis

Birigazzi et al. (2013) and Baldasso et al. (2012)

• Database:
  – 84 variables
  – Four categories:
    • Geographic location
    • Bioclimatic information
    • Equation: parameters, units and statistics
    • References
## Ecosystems & populations

<table>
<thead>
<tr>
<th>Ecosystem</th>
<th>Population</th>
<th>Number of equations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest</td>
<td>Tree</td>
<td>949</td>
</tr>
<tr>
<td></td>
<td>Liana</td>
<td>125</td>
</tr>
<tr>
<td></td>
<td>Mangrove</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>Palms</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Tree ferns</td>
<td>1</td>
</tr>
<tr>
<td>Plantation</td>
<td>Tree</td>
<td>128</td>
</tr>
<tr>
<td>Pasture</td>
<td>Tree</td>
<td>6</td>
</tr>
<tr>
<td>Agroforestry</td>
<td>Palms</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Tree</td>
<td>1</td>
</tr>
</tbody>
</table>

\[ \sum = 1237 \]
Geographic coverage

Holdridge’s Life Zones

- Boreal desert
- Boreal dry bush
- Boreal moist forest
- Boreal rain forest
- Boreal wet forest
- Cool temperate desert
- Cool temperate desert bush
- Cool temperate moist forest
- Cool temperate rain forest
- Cool temperate steppe
- Cool temperate wet forest
- Ice
- Polar desert
- Polar dry tundra
- Polar moist tundra
- Polar rain tundra
- Polar wet tundra
- Subtropical desert
- Subtropical desert bush
- Subtropical dry forest
- Subtropical moist forest
- Subtropical rain forest
- Subtropical thorn steppe
- Subtropical wet forest
- Tropical desert
- Tropical desert bush
- Tropical dry forest
Challenges & Limitations

• Copyright restrictions
• Format (paper vs. electronic)
• Taxonomy

◆ Lack of completeness in reporting
  – Listing tree components, units

◆ Lack of consistent definitions
  – “(total) aboveground biomass”
Quality control and assurance

• Reporting completeness/consistency

• Transcription errors

• Wrong citations
  – Wrong date
  – “Nested” or “chained” citations
  – Misattributed /non-existent citation
3. Linking AE with national forest inventory data

<table>
<thead>
<tr>
<th>DATA ACCESS</th>
<th>Data located in: Logging concession, scientific articles, Grey literature</th>
</tr>
</thead>
<tbody>
<tr>
<td>LIMITED INFO</td>
<td>Location, climate, altitude, vegetation, forest type Sample size, R2, RMSE, segmented equation etc.</td>
</tr>
<tr>
<td>ERRORS</td>
<td>25% of peer review articles report erroneous AE in Africa</td>
</tr>
<tr>
<td>INTERVAL OF VALIDITY</td>
<td>Precaution when using the AE outside the interval of calibration</td>
</tr>
</tbody>
</table>
6. Limits when using AE

DIFFERENT TREE COMPONENTS

- Tree height (m)
- Crown height (m)
- Log height (m)
- Basal circumference or diameter (cm)
- Circumference or diameter (cm) at 1.3m
- Log volume (m³)
- Branch volume (m³)
- Leaf volume (m³)
- Tree volume (m³)
- Basal area (m²)
- Crown area (m²)

- Bark
- Dead branches
- Gross branches: D>7cm
- Thin branches: D<7cm
- Leaves
- Large roots
- Fine roots
- Medium roots
- Stump
- Trunk-underbark
- Fruit/seed

Henry et al. 2010
Applicability of existing equations face several constraints

- BEF are rare and often not adapted;
- Interval of validity limits the us of equations (only 26 trees with Dbh>100cm measured in CA);
- Few equations for total aboveground biomass;
- For few tree species, there is no clear relationship between Dbh and other parameters;
- About 20% of tree species not identified;
- Often, measured tree variables during field inventories do not match with AE input variables;
- Inconsistent methods to measure tree characteristics (no consensus);
- Often, inaccurate documentation;
- Are the considered tree species representative?
- Raw data are rarely accessible.
Applicability of regional allometric equations in the context of a national forest inventory

Example of forest structure and interval of validity of available tree allometric equations in Cameroon

<table>
<thead>
<tr>
<th>Forest Type</th>
<th>Minimum Diameter</th>
<th>Maximum Diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forêt tropicale ombrophile</td>
<td>1 cm</td>
<td>138 cm*</td>
</tr>
<tr>
<td>Forêt tropicale humide décidue</td>
<td>Absent</td>
<td></td>
</tr>
<tr>
<td>Savane</td>
<td>Absent</td>
<td></td>
</tr>
<tr>
<td>Forêt tropicale sèche</td>
<td>3 cm</td>
<td>53 cm</td>
</tr>
</tbody>
</table>
The results of our study demonstrate that model-selection error may introduce 20 to 40% uncertainty into a live-tree carbon estimate, possibly making this form of error the largest source of uncertainty in estimation of live-tree carbon stores. The effect of model selection could be even greater if models are applied beyond the height and DBH ranges for which they were developed.

Figure 1 Percent uncertainty by DBH class and approach. A. Total live-tree C prediction envelopes by approach for Pseudotsuga menziesii (positive correlation). Melson, S. L et al. (2011)
Linking forest inventory data, land maps and tree functions

AE: Allometric equations, BEF: biomass expansion factor, WD: wood density, NFI: National Forest Inventory
Example of decision tree for national forest biomass assessment

- Maps of forest land
- Contribution to national estimates
- Min/max, thresholds, significant etc.

Forest Structure

NFI
PSP
TP

AGB

AGBg
AGBpa_ge
AGBto_ge
AGBsp
AGBtotal
AGBv

AGB= AE

AEg

AEge

AES

AEv

BEF

BEF

BEF

WD

Partial

Total

Total

Example of decision tree for national forest biomass assessment
Development of an allometric equation database for national forest assessment

1. Collect all the documentation containing tree allometric equations
2. Data entering using one template (for different objectives)
3. Perform the quality control (data + graphic analysis)
4. Selection of the appropriate allometric equation (manually is preferable)
5. One database
Visits:
- 50,805 visitors
- 00:06:33 average duration of visits
- 55.4% are new visits

Registration:
- >1500 registered users
- 125 countries
- 30 countries have > 10 registered users
- 80 institutions have more than 2 registered users

Launched in July 2013

www.globallometree.org
7. How to select the best tree allometric equation?

Building appropriate volume and biomass equations are then still challenging scientifically:

A good candidate set of volume or biomass equations should be simultaneously:

(i) **consistent**: standardized biomass partition and additivity of tree compartments;
(ii) **generic**: common form of the models whatever the tree species or the forest structure. Meaningful parameters (i.e. related to the biology);
(iii) **robust**: system operating correctly across a wide range of operational conditions with a low sensitivity to the sampling design and the methodological hypotheses;
(iv) **accurate**.
Recommendations on using tree allometric equations

- Scenario 1: Neither the models nor the inventory data are available. In this case it is better to use a generic model and validate it by destructive harvesting.

- Scenario 2: The raw data are not available but national allometric models were developed and data is being collected. It is then possible to use a Bayesian approach to simulate a dataset having the same properties as the original raw data (Picard, Henry et al. 2011; Zapata-Cuartas, Sierra et al. 2012) and results compared against scenario 1.

- Scenario 3: Reliable raw data, inventory data and models are available. In this case, models taking into account tree species, forest types, climate and interval of validity can be considered if the dataset is large enough and compared against scenario 1.
Chain of propagation of errors in estimating forest biomass
Contribution of the different sources to the total error

All allometric equations are equally likely
Contribution of the different sources to the total error

One allometric equation is more likely than the others (according to BMA)
Context: importance of allometric equations in the REDD+ approach

Allometric equations in France

1. Introduction

Panorama of the French Forest

Land cover area: 29.7% is Forests (Europe average, including Russia 32.2%)

Forest owners: 75% private, 25% public

Total Volume (m3): 2.4 billion = 4th European country after Russia, Sweden, Germany.

Forest Composition: Broadleaves species (67%), Coniferous species (22%), Mixed stands (11%)

12 tree species contribute to 80% of the total volume of French Forests
1. Introduction

National Forest Inventory: The Institute (IFN) in charge of the national inventory has been embedded into the National Geographic Institute in 2012.

Yearly assessment of forest inventory (it was every ten years before 2008).

Results provided by administrative departments and by SylvoEcological Regions: 91 SER and 12 GRECO.

Panorama of the French Forest

SER = SylvoEcologicalRegion (determinants of forest growth conditions and habitats)

GRECO = Ecological regions (one GRECO regrouping several SER)
2. Methodology

French National Carbon Stock assessment (before 2004)

Forest Inventory
- Permanent Plots
- Temporary Plots

Conversion factors

Partial volumes (IFN definition)
- \( \text{AE}_{\text{vol}} \) partial
- \( \text{VEF}_{\text{sp}} + \text{WD}_{\text{sp}} \)

Forest structure, etc...

Cartography

Forest Land area

\( \text{ABG}_{\text{biomass}} = \text{ABGv} + \text{DeadW Biomass} \)

\( \text{BLG}_{\text{biomass}} = \text{BLG} \)

\( \text{ABGv} = \text{RSratio}_g \)

\( \text{IFN, INRA, ONF, IRSTEA, CFBA} \)
2. Methodology

French National Carbon Stock assessment (after 2004)

Cartography
- Forest Land area by SER/GRECO

Forest Inventory
- Forest structure, etc...

Permanent Plots

Temporary Plots

Total volumes by SER/GRECO

\[ AE_{vol G} \]

\[ AE_{vol totSp} \]

\[ WD_{sp} \]

\[ ABG_{biomass} = \]

\[ ABG_{v} + \text{DeadW Biomass} \]

\[ RSratio_{g} \]

\[ BLG_{biomass} = \]

\[ BLG \]
2. Methodology

French National Carbon Stock assessment

<table>
<thead>
<tr>
<th>BRO. = BROADLEAFS, CON. = CONIFERS</th>
<th>AGRIGES 1999</th>
<th>CITEPA 1999</th>
<th>IGD 2000</th>
<th>CARBOFOR 2004</th>
</tr>
</thead>
<tbody>
<tr>
<td>Branch expansion factor</td>
<td>BRO.</td>
<td>CON.</td>
<td>BRO.</td>
<td>CON.</td>
</tr>
<tr>
<td>aerial wood volume / merchantable volume</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Root expansion factor</td>
<td>BRO.</td>
<td>CON.</td>
<td>BRO.</td>
<td>CON.</td>
</tr>
<tr>
<td>total wood volume / aerial wood volume</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall expansion factor</td>
<td>BRO.</td>
<td>CON.</td>
<td>BRO.</td>
<td>CON.</td>
</tr>
<tr>
<td>total wood volume / merchantable volume</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wood specific gravity</td>
<td>BRO.</td>
<td>CON.</td>
<td>BRO.</td>
<td>CON.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon concentration</td>
<td>BRO.</td>
<td>CON.</td>
<td>BRO.</td>
<td>CON.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall ratio (t C/m$^3$ IFN)</td>
<td>BRO.</td>
<td>CON.</td>
<td>BRO.</td>
<td>CON.</td>
</tr>
<tr>
<td>carbon mass / merchantable volume</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>“Secondary” compartments (t C/ha)</td>
<td>BRO.</td>
<td>CON.</td>
<td>BRO.</td>
<td>CON.</td>
</tr>
<tr>
<td>foliage, herbaceous and shrubby strata, non-recordable trees and dead wood</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>tree species used to calibrate the equation</th>
<th>species for which the equation was used</th>
<th>Parameters of the equations</th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quercus petraea</td>
<td>Quercus petraea, Q. robur, Q. pubescens, Q. rubra</td>
<td>0.471, -0.345, 0.377, 0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fagus sylvatica</td>
<td>Fagus sylvatica</td>
<td>0.395, 0.266, 0.421, 45.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quercus petraea &amp; Fagus sylvatica</td>
<td>Other broadleafs</td>
<td>0.428, -0.191, 0.456, 0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pseudotsuga menziesii</td>
<td>Pseudotsuga menziesii</td>
<td>0.534, -0.530, 0, 56.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pinus spp.</td>
<td>Pinus spp.</td>
<td>0.311, 0.405, 0.340, 191</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Larix spp.</td>
<td>Larix spp.</td>
<td>0.550, 1.350, 0.322, 0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abies alba</td>
<td>Abies spp.</td>
<td>0.550, -0.749, 0.277, 0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Picea abies</td>
<td>Picea abies &amp; other coniferous species</td>
<td>0.631, -0.946, 0, 0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


A posteriori calculation (V_{tot}/V_{partial}) (consistency checking with the previous methodologies)

Litterature review

Total volume: 8 equations for all tree species
3. Results

French National Carbon Stock assessment


Increase of forest areas, increase of carbon stock / ha, higher stocks for broadleaves species

Recolonisation of abandoned agricultural lands

57% of the biological increment is harvested (3/5 for commercial woods, 2/5 for self-consumption energy wood)

Higher wood density and higher branches proportion
4. Discussion

- Allometric equations

Although it comprised over 4000 trees, the sample used to build the \( V_{\text{tot}} \) allometric equations (Vallet et al. 2006) was probably not fully representative of the entire French forests.

- many species are absent especially for broadleaves species
- Trees mainly collected in the northern part of France
- Data are old (1920-1955) while several factors may have modified the shape of the trees (*sylvicultural changes, genetic improvement, environmental changes, etc*).
- Data have mainly been collected in high forest (half of the forest structure)
4. Discussion
- Conversion factors

French National Carbon Stock assessment

Representativeness of Wood density database?

Set 1 compilation of European references, including a very old French reference (Mathieu, 1877)

Set 2 old French reference only (Mathieu, 1877), woods from mountain regions or the Mediterranean zone, which are characterized by higher density, are more common in Mathieu’s work than in the other sources

Estimation of carbon stocks by “end-products”?

Volume expansion factors?

71.2 tC/ha)

77 tC/ha)
(+8%)
5. Current improvements

French National Carbon Stock assessment

ANR EMERGE project (funded by the French National Research Agency)

All R&D institutes working together
5. Current improvements

L’entrepôt de données du consortium

1 106 099 arbres IFN (mesures arbres sur pied)

118 505 tiges R&D

20 983 menus-bois et 31 439 profils UR2P

6 037 arbres pour la biomasse

1 797 arbres pour la minéralomasse

220 arbres échantillonnés en 2009 et 2010

Data Sharing among institutes, common database
5. Current improvements

Technics: Lidar (both terrestrials and airborne) and Photogrametry

Source: Dassot et al. (2011)

Source: Bock et al. (2012)
Context: importance of allometric equations in the REDD+ approach

Allometric equations in Viet Nam
8. Example of support from the UN-REDD programme in Vietnam

**AE development in Vietnam**

- Forest Stratification
- Allometric Equations
- National Forest Inventory (ongoing)

- AE Database
- Country specific Methodology
- Destructive measurements
- Training on model fitting
- Model Development
Context: allometric equations in Viet Nam

History of AE in Viet Nam

July 2012:
Training on allometric equation development

September 2012 - May 2013:
Publication of guidelines for destructive measurement

September 2012 - March 2013:
Development of new allometric models for three forest types and six regions

September 2012 - November 2013:
Database on allometric equations published
Context: allometric equations in Viet Nam

History of AE in Viet Nam: Outputs

New allometric equations, methodology and results

Harmonised guidelines for destructive measurement

Databases of allometric equations and raw data
History of AE in Viet Nam: Outputs

Context: allometric equations in Viet Nam

Subnational level

Differences in methodologies

- methodology and results
- measurement
- raw data
History of AE in Viet Nam: next steps (Phase II gaps analysis)

- National scale AE
- Digitization of more raw data
- Database of wood density
- New AE for Mangrove, Mixed forest and Dipterocarp forest could be useful
Context: importance of allometric equations in the REDD+ approach

Allometric equations in Mexico

FE
Medidas arboles individuales DBH, h
Área basal
Cluster análisis
BD INFyS
BD EC ALOMETRICAS
ESTIMACIÓN POR ARBOL
ESTIMACIÓN DE BIOMASA CONGLOMERADO
DA
IMÁGENES DE SENSORES REMOTOS
Pre-procesamiento
Cálculo de Índices (Pixel)
ENMASCARAMIENTO
BD Índices (Pixel)
Segmentación
Clasificación
Intersección conglomerados por clase
Función de probabilidad
Normal
Asimétrica
Estimación de contenidos de C/clase
Estimación de Incertidumbre Método 1 IPCC
U_{n+1} < U_n
Estimación de contenido total de C
Estimación de contenido total de C
Estimación de Incertidumbre Método 2 IPCC
Estimación de contenidos de C/clase
Función de distribución de probabilidad
Prueba de bondad de ajuste
BD contenidos de C/Clase
Generación de contenidos aleatorios de C/ha - Clase
Función de distribución de probabilidad
Prueba de bondad de ajuste
U_{n+1} < U_n
Estimación de contenido total de C
An exemple of decision tree

2.- Asignación y ejecución de modelo alométrico para cada individuo

\[ C = B \times FC \]

**Pinus Arizonica (D: 9.8cm, H: 5.69mts)**

\[ B = (e^{3.573} \times DAP^{2.743}) \]

**DB INFyS**

\[ DAP = 9.8 \text{cm} \]

\[ FC = 0.4936 \]

\[ C = (38.9477) \times (0.4936) \]

\[ C = 19.2246 \text{ Kg} \]
Carbon density per hectare
SITIO WEB

- http://www.mrv.mx