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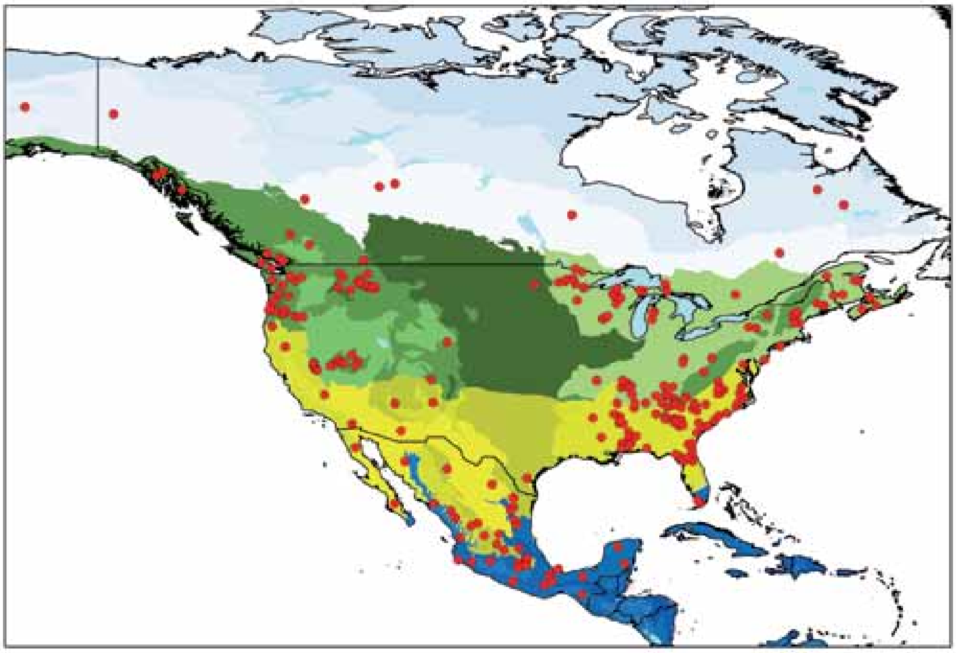

Georeferenced database of tree volume and biomass allometric equations for North America

UN-REDD PROGRAMME

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The UN-REDD Programme, implemented by FAO, UNDP and UNEP, has two components: (i) assisting developing countries prepare and implement national REDD strategies and mechanisms; (ii) supporting the development of normative solutions and standardized approaches based on sound science for a REDD instrument linked with the UNFCCC. The programme helps empower countries to manage their REDD processes and will facilitate access to financial and technical assistance tailored to the specific needs of the countries.

The application of UNDP, UNEP and FAO rights-based and participatory approaches will also help ensure the rights of indigenous and forest-dwelling people are protected and the active involvement of local communities and relevant stakeholders and institutions in the design and implementation of REDD plans.

The programme is implemented through the UN Joint Programmes modalities, enabling rapid initiation of programme implementation and channeling of funds for REDD efforts, building on the in-country presence of UN agencies as a crucial support structure for countries. The UN-REDD Programme encourage coordinated and collaborative UN support to countries, thus maximizing efficiencies and effectiveness of the organizations' collective input, consistent with the "One UN" approach advocated by UN members.

Contacts:
Matieu Henry
UN-REDD Programme
Food & Agriculture Organization of the United Nations (FAO)
Email: Matieu.Henry@fao.org

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1. Introduction

Since 2000 the interest in forest biomass has been growing (Zianis and Mencuccini,2004, Henry, et al., 2011, Parresol, 1999). Estimation of aboveground tree biomass is mainly conducted to support sustainable management of forest resources. While tree volume equations were mainly developed for timber management (Lanly and Lepitre,1970) and biomass equations for fuel wood production (Millington, et al., 1994) the climate change crisis highlights the need to better assess the contribution of terrestrial ecosystems to the global carbon cycle.

Better understanding tree growth is crucial to accurately quantify ecosystems' contribution to the global carbon cycle and to elaborate effective climate change strategies for mitigation and adaptation (Bombelli, et al.,2009). Vegetation biomass, in particular, is an important ecological variable for understanding the evolution and potential future changes of the climate system. Vegetation is storing a large amount of carbon (550±100 Pg) on the order of the amount in the atmosphere (800 Pg) (Houghton,2007). Changes in the amount of vegetation biomass already affect the global atmosphere by being a net source of carbon, and having the potential either to sequester carbon in the future or to become an even larger source (GTOS,2008, IPCC,2007).

Reducing Emissions from Deforestation and forest Degradation (REDD) may play an important role for climate change mitigation and, moreover, an accurate estimate of emission factors is also fundamental to develop and verify environmental policies and strategies. The Conference of the Parties held in Copenhagen in 2009, under the UN framework convention on climate change (UNFCCC), requests developing country Parties to establish robust and transparent monitoring systems for forest and carbon stock (UNFCCC,2009).

Several methods have been used and tested to estimate tree biomass and carbon stocks (Valentini, et al.,2000, Luyssaert, et al.,2007, Asner, et al.,2012, Kindermann, et al.,2008). The most common method to assess forest biomass is based on the application of tree allometric equations to the forest inventory data. Tree allometric equations relate difficult-to-measure tree parameters (such as volume or biomass) to easy-to-measure dendrometric variables (such as diameter at breast height or tree height) (Picard, et al.,2012). Different methods exist for developing tree allometric equations depending on the objective (commercial volume, bio-energy, biomass or carbon), forest type (mono-specific or pluri-specific forest), tree size, accessibility of the tree, forestry law, technical, financial and human capacities. In consequence, the quality of the estimates varies between allometric equations and depends on the method for destructive and semi-destructive measurements, individual tree assessment, and adjustment method and model selection. The inappropriate use of tree allometric equations can also introduce significant bias and errors. Therefore it is important to collect not only the mere formulas but also, if available, all the related statistical, geographical, ecological parameters of the equation. Unfortunately, tree allometric equations are often not easily available and, especially in developing countries, quite rare.

In order to identify the gaps and to make available the equations developed so far, comprehensive collections of tree biomass regressions for North American species were compiled in the last years. A diameter-based database of allometric equations for USA and Canada was developed in 2003 (Jenkins, et al.,2003), while a collection of equations for Mexico was published in 2009 (de Jong, et al.,2009a) and then updated (Rojas et al. 2009) and published on line in 2012 (CONAFOR,2012).

As an identical forest classification was developed using the land cover classification system (Di Gregorio and Jansen,2005) for the three countries, it appears that a more large scale database, such as the present work, will facilitate data exchange and assessment of forest carbon stocks at regional scale. Furthermore, geo referencing the data allows unambiguously identifying the equation ecological zones, improving estimates of the equations geographic distribution and identifying the potential gaps.

2. Objectives of the report

The objectives of this report are to (1) provide an overview of the current status of tree volume and biomass allometric equations in North America, (2) identify the gaps and future needs, (3) provide recommendations for volume, biomass and carbon stock assessment, and (4) provide examples of how to use the database and select the appropriate equation. The report analyses the various tree allometric equations and identify their potential for assessing national volume, biomass and carbon stocks and the validity and suitability for use in species that are found under the country's climatic characteristics.

3. The Compilation of the data

3.1 Review of available allometric equations

The first phase focuses on collection and review of selected literature concerning volume, biomass and carbon stocks in North America.

The equations selected were mainly diameter-based with other possible co-variables such as height, age, etc. No other selection criteria (such as R^2-values, species, ages, sizes, site conditions, or sampling methods) were used *a priori*.

The literature-survey was conducted on Internet and in specialized libraries and it is mainly based on the contributions of Jenkins et al. (2003) and de Jong et al. (2009a). Online literature research was conducted for sources that reported biomass and volume equations. A survey of online libraries (Springerlink, Google Scholar etc.) and journals such as Canadian Journal of Forest Research, Forest Ecology and Management, Forest Science, Ecological Monographs, Journal of Environmental Science and Management, Oecologia .

It is worth remembering that the data compilation is not exhaustive and may have not considered all the data. However, it is a first regional database that will be progressively completed.

During the data collection, both the hard and soft copies of all the documents cited in the database were collected in order to make them available for further studies. With particular regard to Mexico, the research was also conducted at the FAO FRA (Forest Resources Assessments) Library. The FAO FRA library comprises a collection of FAO working papers, project field documents, country reports, volume tables and forest inventories from the early 50s to the late 90s, and it was a precious source of data and information which would otherwise be difficult to obtain. Other worldwide reviewed libraries were, among others, the University of Idaho Library, Fort Hays State University Library, David Lubin Memorial Library.

For U.S.A and Canada the thorough work of Jenkins at al. (2003) was a valuable source of information, as well as previous regression compilations such as the one from Tritton and Hornbeck (1982), Ter-Mikaelian and Korzukhin (1997) and Means et al (1994). For Mexico, the mentioned national allometric equation database for aerial tree biomass, developed by de Jong et al. (2009a), was used.

To make the consultation of bibliography and references easier and to export them in excel database we used a RIS format reference management software (Thomson,2005).

3.2 Data classification and georeferencing

Once the documents were collected, the data were geo referenced and organized in order to make them consistent with the template database that was elaborated.

A problematic point was related to the tree compartments predicted by the equation. In fact, there is not a unique way to define the vegetation components (Fine roots-large roots, big branches-small branches etc.) as well as there is not a standard and common definition for aboveground biomass or growing stock (it may or may not include the stump, the bark, the top etc.). Therefore, in order to standardize the data and make them easier to use, 11 different tree compartments have been selected (Figure 1), thoroughly checking the original sources before entering the equations in the database and carefully converting their component system into ours.

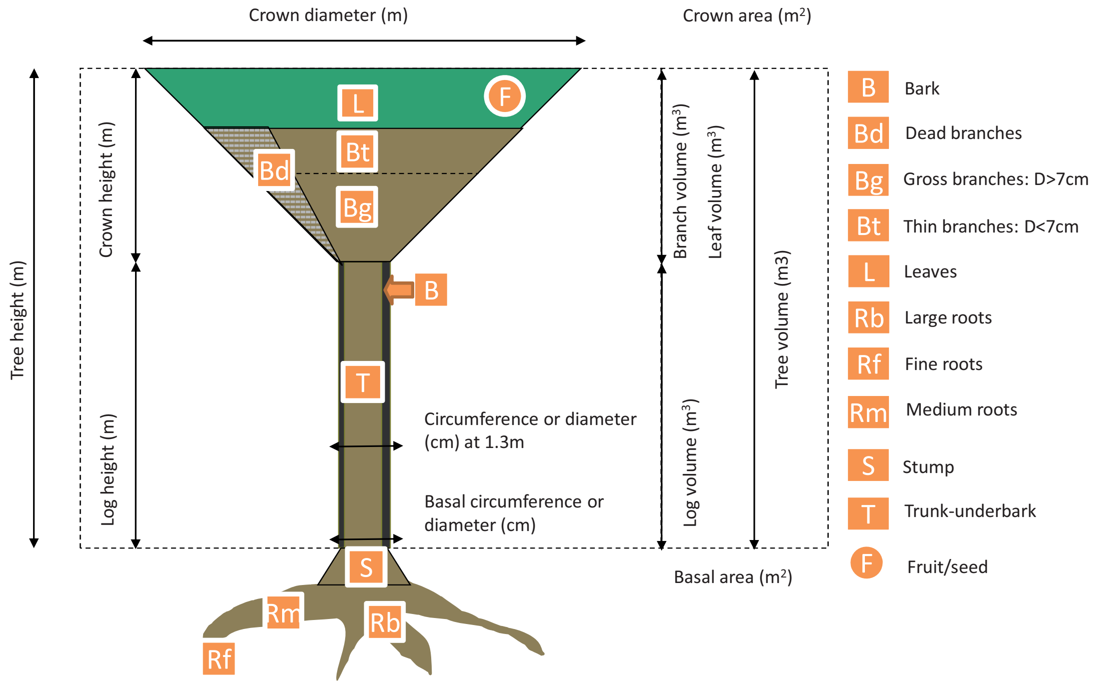

Figure 1. Tree components classification used in the present work (Henry, et al.,2011).

The name of the locations where the equations were developed and the corresponding latitude and longitude coordinate were identified using the geographical information provided by the documents. When only the name of the location was available, the geographic coordinates were obtained using administrative maps and Google Earth. When the names of the locations were missing and only a map with the localization of the plots in the field was available, the geographic coordinates were obtained using administrative maps and the GIS software “Quantum GIS” (2012). When it was not possible to unambiguously identify the location because the geographic position was missing or too vague, the lack was reported in the database. If the equation was developed in more than one location, all the locations were georeferenced.

Once the locations were georeferenced, they were categorized according to five ecological classifications: FAO (FAO,2001), Udvardy (Udvardy,1975), WWF (WWF,2000), Bailey (Bailey,1989), and Holdridge (Holdridge,1947, Leemans,1992). Climatic parameters, such as temperature (T), precipitation (ppt) and wind (W) were obtained using the software New LocClim (FAO,2005).

Additional classifications were achieved according to the ecosystem type (plantation or forest) and the level of population (Lianas, Mangroves, individual tree, sprouts and stand) considered. Where available, also some relevant regression statistics were reported, such as R^2 values (coefficient of determination of the equation), R^2 adjusted, the diameter ranges over which the equations were developed and the sample sizes of trees harvested to develop the regression.

A detailed bibliography is provided to allow readers to consult the original source of the equation. The present work tried to be more comprehensive as possible but some lacks in the documentation are inevitable. Anyway the database is designed to allow a constant updating of the data and existing gaps or inaccurate information can be addressed in the future.

3.3 Tutorial for data insertion

In order to facilitate the data insertion and the usability of the database, a specific tutorial (Baldasso, et al.,2012) was created. The tutorial provides detailed information on the database structure and proposed procedures and methodology for entering the data. Additional useful information is also provided such as how to search articles, reports and documents containing allometric equations; how to manage the references using RIS format reference management software; how to georeference and to spatialize the data.

4. Database Description and Structure

The database is composed by 71 variables (Appendix 2) that can be grouped in seven categories: (1) plant ecology (i.e. if the equation refers to trees, stands, mangroves, or sprouts) and provenance of the plants (forest or plantation). (2) Geographical localization of the plots where the plants were harvested (continent, country, location, latitude, longitude and the corresponding biome), (3) Equation parameters (dependant and independent variables, unit of measurement and range of application). (4) Plant vegetation components (a binary system of 11 columns as represented in Figure 1 allows the identification of considered tree components). (5) Botanical name (family, genus and species). (6) Statistical information (sample size, coefficient of determination, standard error etc.) (7) Bibliographic references (author, title, year of publication, reference index in the database library).

The table in Appendix 2 includes detailed definition for each variable. Please refer to Baldasso et al. (2012) for further information. The list of acronyms is available in Appendix 1.

5. Tree allometric equations in North America

5.1 Historical trend

The pioneering tree biomass studies in north America were conducted in the early 60s (Young, et al.,1980), and mainly in the USA and Canada. These early studies faced some logistic and statistical problems such as 1) individuate the most economical and efficient way to remove tree from the ground without damaging the roots, 2) elaborate size classes for categorize the major component of the trees, 3) identify the numbers of subsamples to be used for moisture content and leaf mass analysis.

Once these basic aspects of biomass data collection were solved the researches started focusing on sampling on a regional or state basis. During the following two decades (1970-1990) a considerable amount of state-specific equations were developed (Figure 2). In the last decade the interest in forest biomass started growing (Zianis and Mencuccini,2004), especially in tropical countries. In this period the number of tree allometry researches in Mexico has grown significantly, reaching an average of about 5 new articles per year in the period 2001-2009.

As the database is mainly based on the contribution of Jenkins for USA and Canada (Jenkins, et al.,2003), we have not yet enough data to infer a trend for that region for the period after 2003. However the database is designed to be constantly updated and the existing gaps will be addressed in the future.

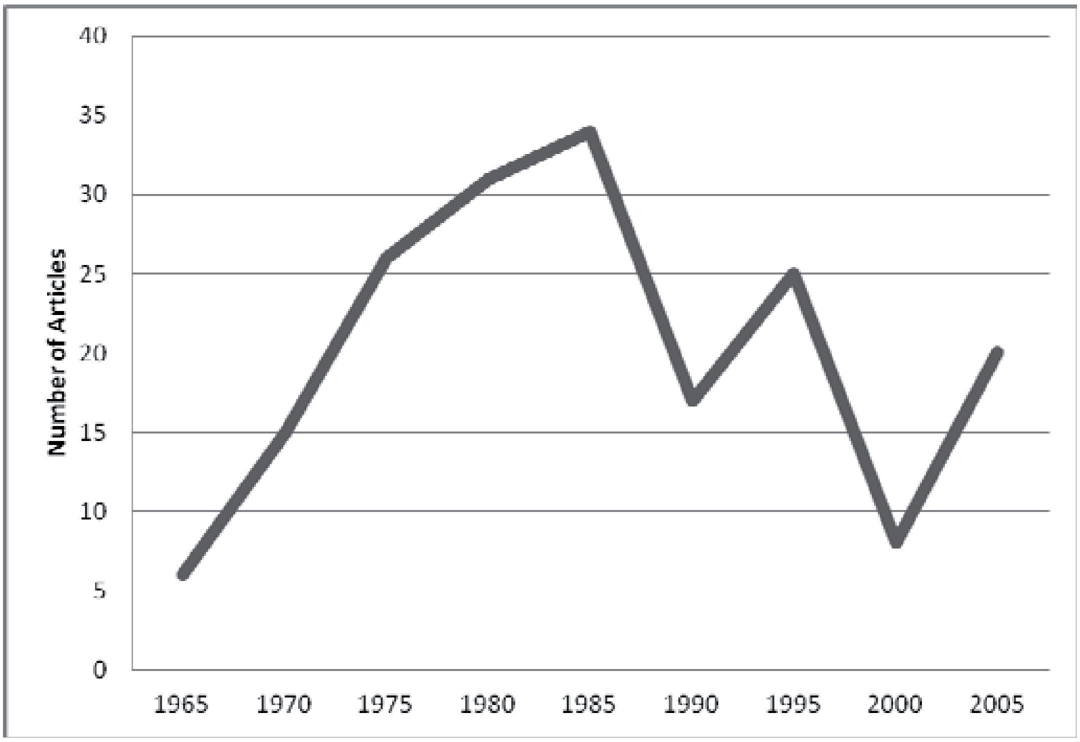

Figure 2. Number of published articles per year

Geographical Distribution of the Equations

The equations are unevenly distributed among the countries (Figure 3). Almost 70% of equations were developed in USA (n=1807), 18% in Canada (n=467) and 13% in Mexico (n=319).

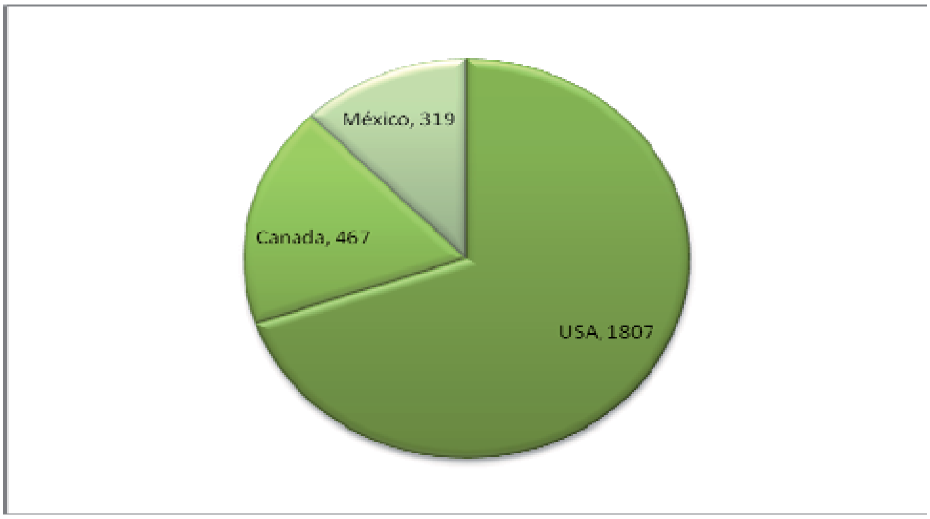

Figure 3. Number of equations per country

According with the FAO Global ecological zoning for the global forest resources assessment (FAO,2001), most of the equations were developed in temperate mountain system (29%), temperate continental forest (28%), subtropical humid forest (24%). The other 13 zones represent less than 18%. Tropical dry forests (n=11), boreal coniferous forests (n=10), boreal tundra woodlands (n=7) seem to be particularly under-represented, these three zones represent overall less than 1% (Figure 4).

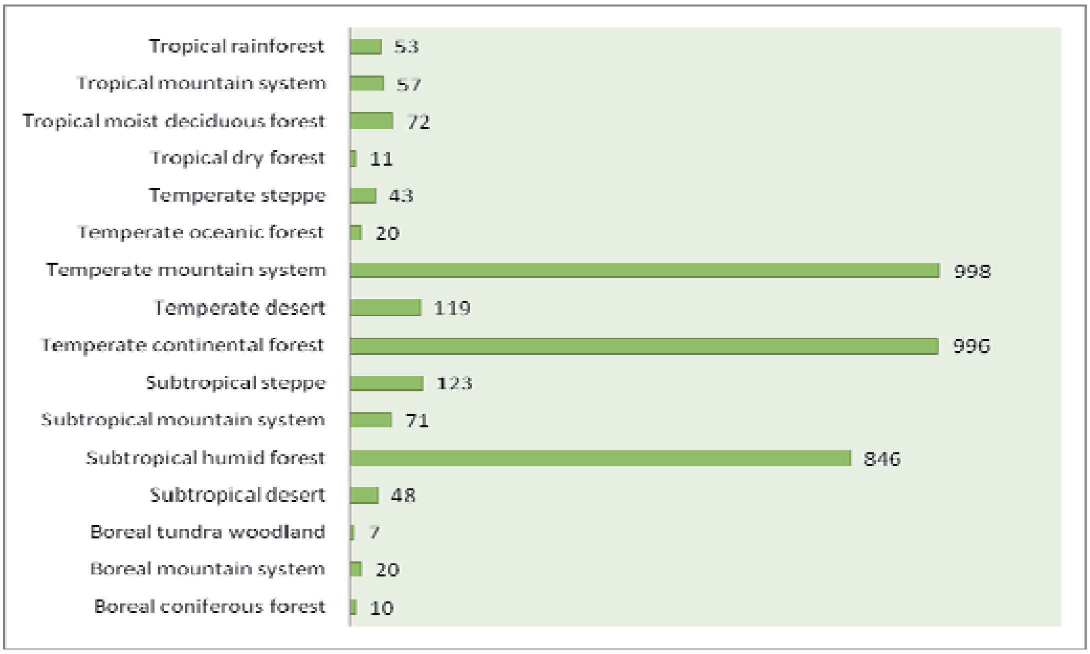

Figure 4. Number of equations per ecological zone classification. FAO ecological zone classification

In consequences, certain ecological zones such as subtropical dry forest are not represented in this database while this ecological zone is frequently found e.g. in coastal part of California. The figure below (Figure 5) represents the geographical distribution of the equations. It appears that more than 300 equations are mainly concentrated in the south east and in the pacific northwest of USA.

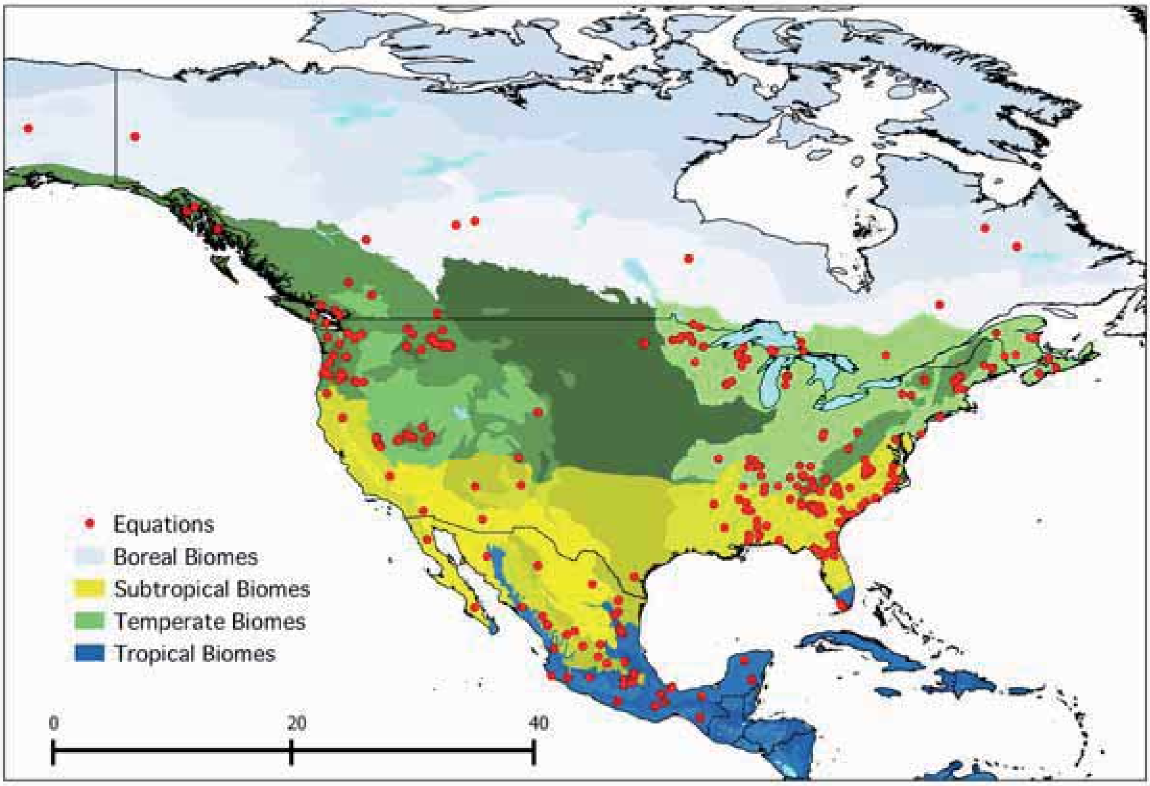

Figure 5. Geographical distribution of the sample plots in North America. The red dots represent the sites where equations were developed.

Tree Species to which equations Refer

266 species are present in the database, belonging to 116 genera and to 61 families. The families most frequently studied were Pinaceae (Figure 6), representing the 36% of the equation (n=1002), Fagaceae 14% (n=405) Aceraceae 8% (n=222), Betulaceae 7% (n=201), and Salicaceae 6% (n=178).

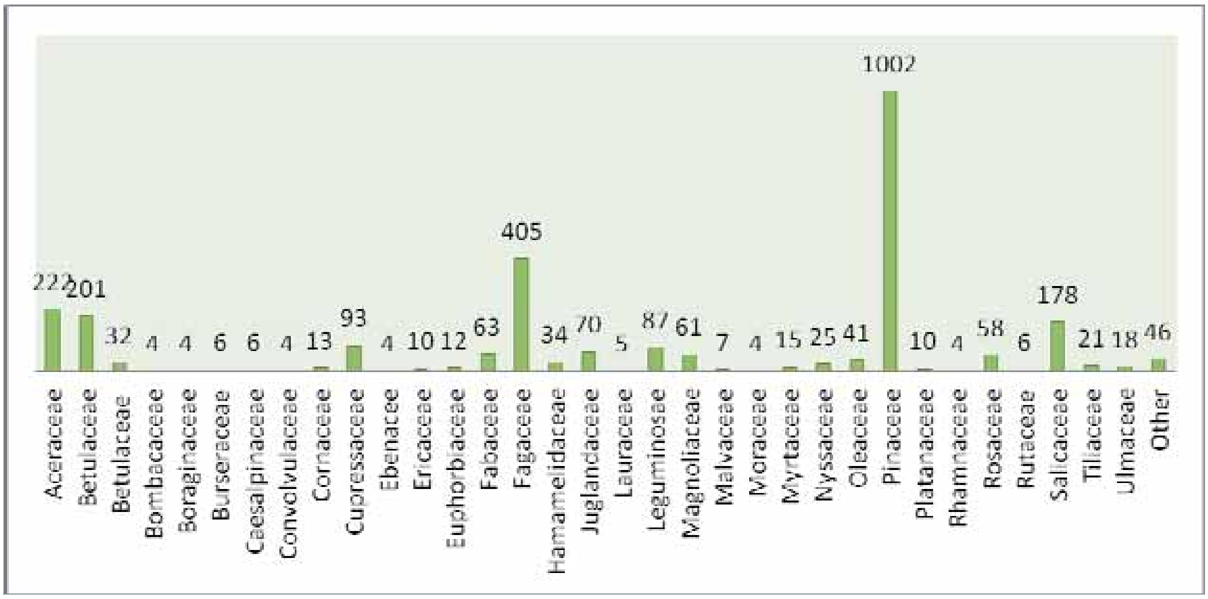

Figure 6. Number of equations per family

The most studied genera are *Quercus* (n=353), *Pinus* (n=334) , *Acer* (n=222), *Picea* (n=211), *Betula* (n=183), *Pseudotsuga* (n=170), *Populus* (n=167), respectively with the 12%,11%, 7%, 7%, 6%, 5%, 5% of the total equations (Figure 7).

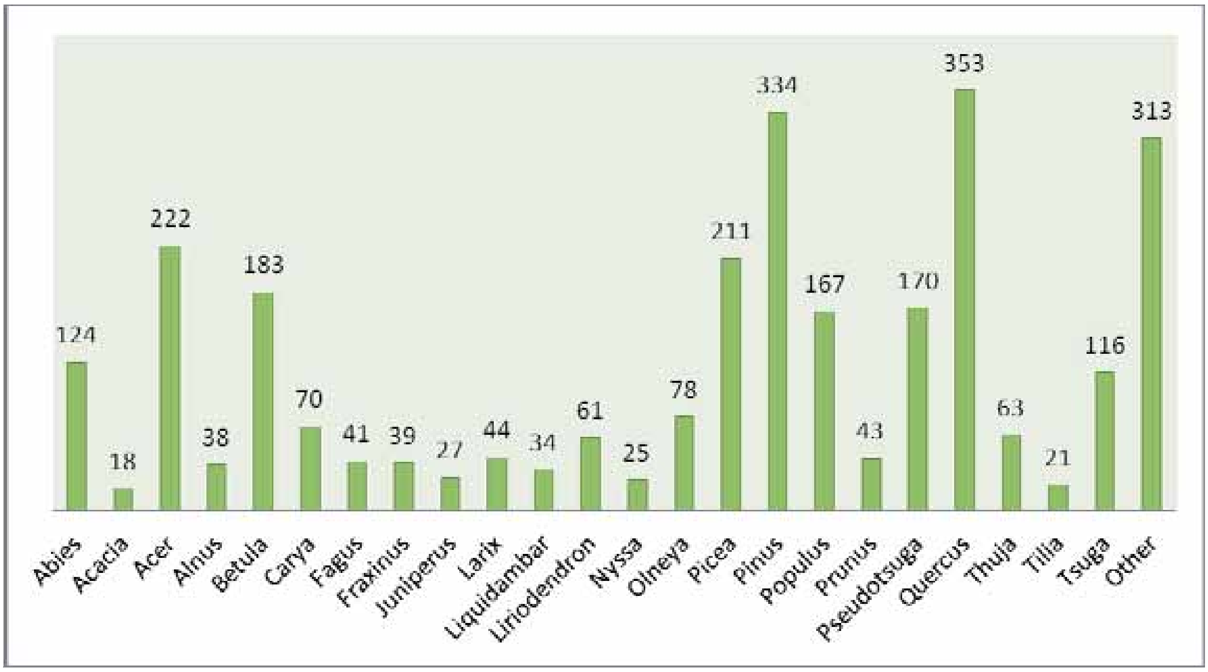

Figure 7. Number of equations per genus

The distribution of the equations per species is rather more homogenous (Figure 8). The most studied species were *Pseudotsuga menziesii* with the 5% of total equations (n=170), *Acer rubrum* 4% (n=125) *Populus tremuloides* 2% (n=82) *Acer saccharum* 2% (n=79) and *Olneya tesota* 2% (n=78).

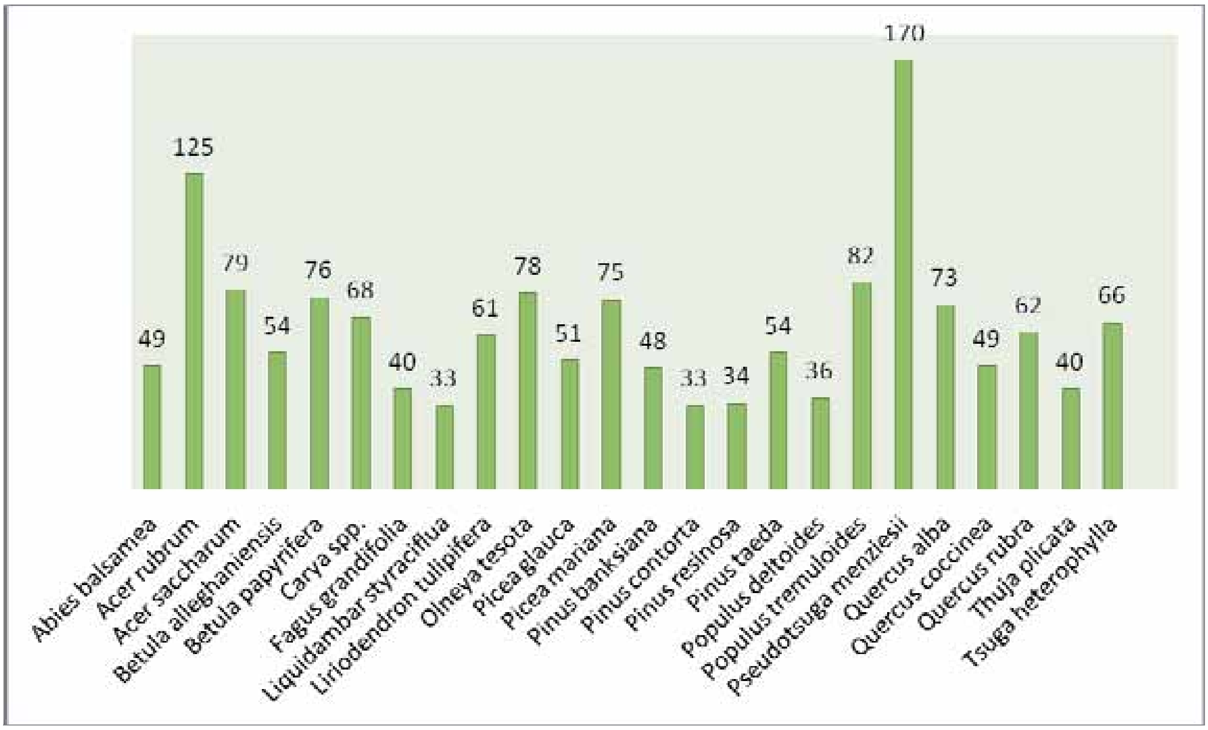

Figure 8. Number of equations per main species

The analysis reflects overall a certain disproportion in the interest for some families and for some genera, in particular for the more merchantable ones, such as *Pinus, Quercus, Picea*.

Figure 9 represents the number of studied species per country.

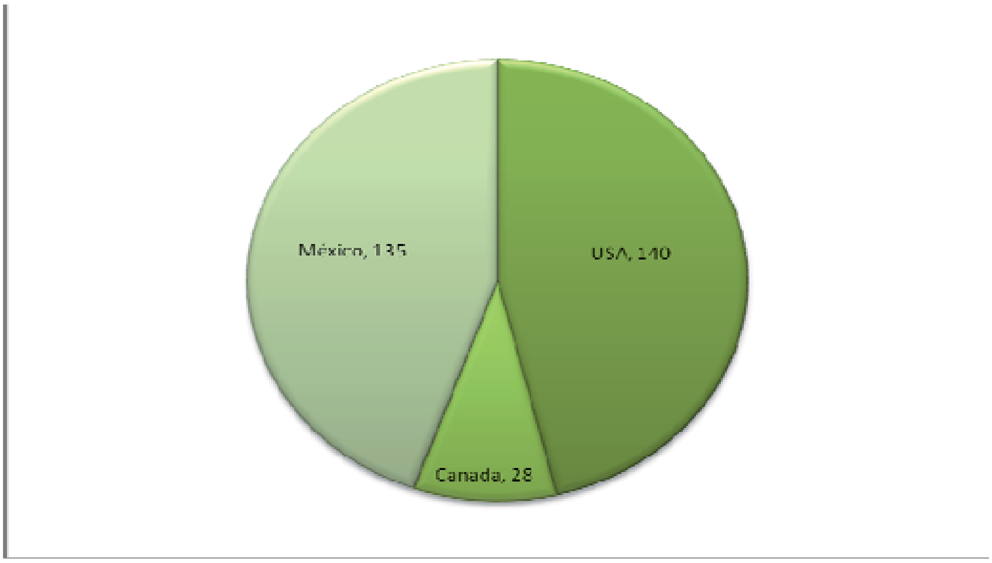

Figure 9.Number of studied species per country

According with the Global Forest Resources Assessment 2005 (FAO,2006) Mexico has the largest tree biodiversity (Mexico:1130 native tree species, USA:1051 and Canada:180 species). Comparing these data with the previous ones it appears that the analyzed trees species represent no more than 15% of the total existing trees for Canada, 13% for the USA and 12% for Mexico. Considering that the optimal condition would be to have at least an equation for each tree species, it is evident that there is still a relevant gap in the number of studied species. The situation in North America, however, is significantly better than other continents. For Sub-Sahara African forests, for example, only the 2% of tree species have been studied so far (Henry, et al.,2011).

Despite Mexico developed a much smaller quantity of equations than USA (319 rather than 1807) there is not a relevant difference in the proportion of studied trees species over the total of tree species (12% rather than 13%). It appears that the most part of biomass researches in USA focused mainly on a few number of trees whereas the Mexican studies analyzed a wider range of species. The bigger interest of the Mexican researches for biodiversity is also confirmed by the analysis of the number of studied plant families per country (Figure 10). Mexico has the largest number of studied families (n=45) followed by USA (n=33) and Canada (n=8). The small number of analyzed families for Canada is likely due to less rich flora diversity then the other two countries.

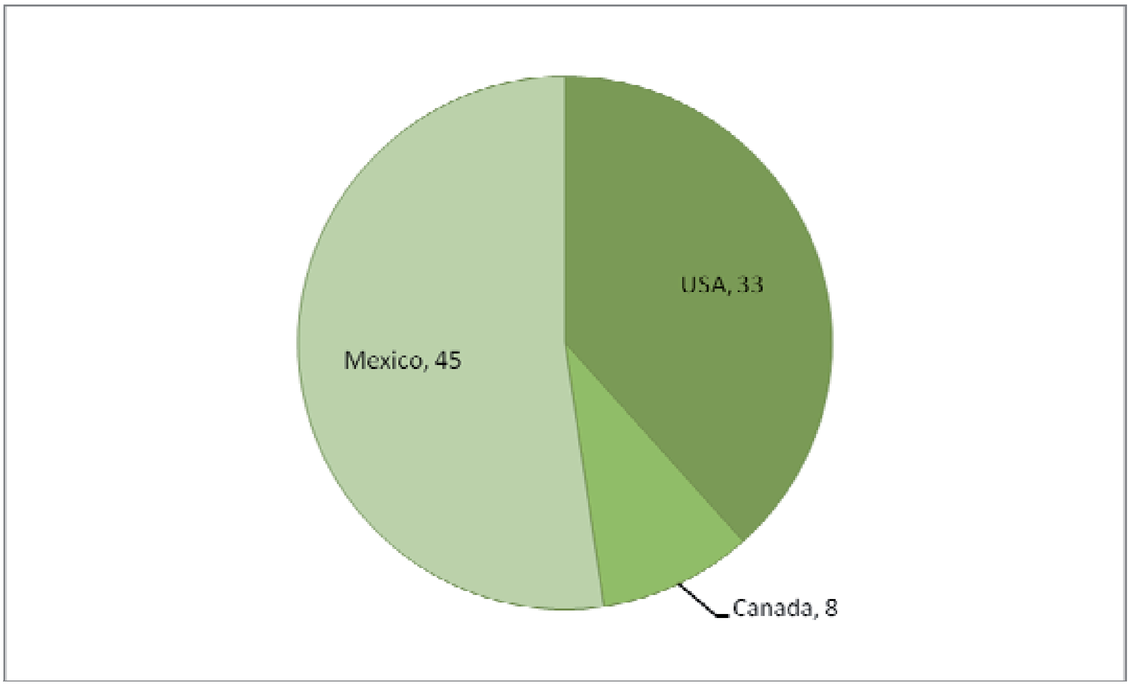

Figure 10. Number of studied plant families per country

Tree Compartments considered by the equations

Most of the studies focused on merchantable wood production would tend to consider only the stem, studies for fodder production would put more attention on the foliage, whereas C stock researches would tend to be more comprehensive as possible, including also roots, branches or twigs . As it is shown in Figure 11, most of the equations focused on the whole tree (above stump) (17%), stem (wood and bark) (13%) and foliage (11%).Equations for stem biomass represent about 41% of the total. Results suggests that researches mainly focused on commercial production. Interest in root biomass assessment is significantly lower (1.8%), and is probably related to time cost and difficulty for measurements. Equations predicting total (above ground and belowground) biomass are even less (1.7%).

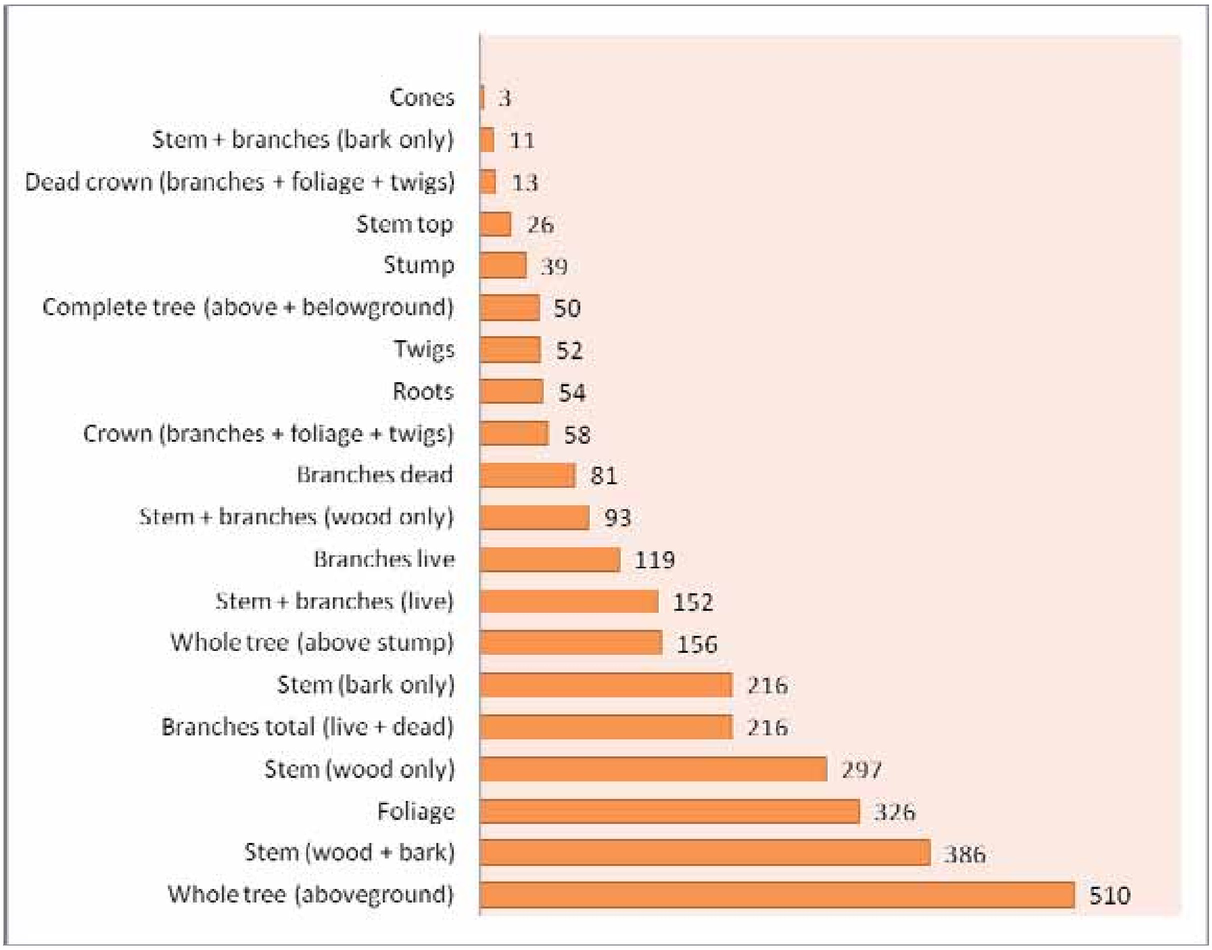

Figure 11. Number of equations per tree components

More of the 90% of the Mexican equations predict the whole tree biomass. The reason for this disproportion is that the Mexican part of the database is mainly based on the work of de Jong et al. (2009a) which is almost entirely a compilation of tree aerial biomass regressions.

6. Study case: assessing stem biomass of *Picea Glauca*

For more clarification an example of how to find and apply a specific equation from the database is provided. The example concerns quantifying the stem biomass (wood + bark) for a plot of *Picea glauca* in Canada within the "temperate continental forest" FAO biome classification.

In this example, data of DBH and species composition for the plot are already available.

Equations predicting biomass (column Output) for stem (Trunk + Bark) for Picea glauca (column genus and species) are selected for "temperate continental forest" zone (column Biome_FAO). Four equations meet these criteria: two equations from Freedman (1984), ID 3533 & ID 3521, one equations from Harding and Grigal (1985), ID 13521, and one from Ker (1980b), ID 3645.

Each equation predicts different biomass values and differs from the other ones for some relevant parameters such as sample size, diameter range of applicability and coefficient of determination. The four equations are plotted in the Figure 12.

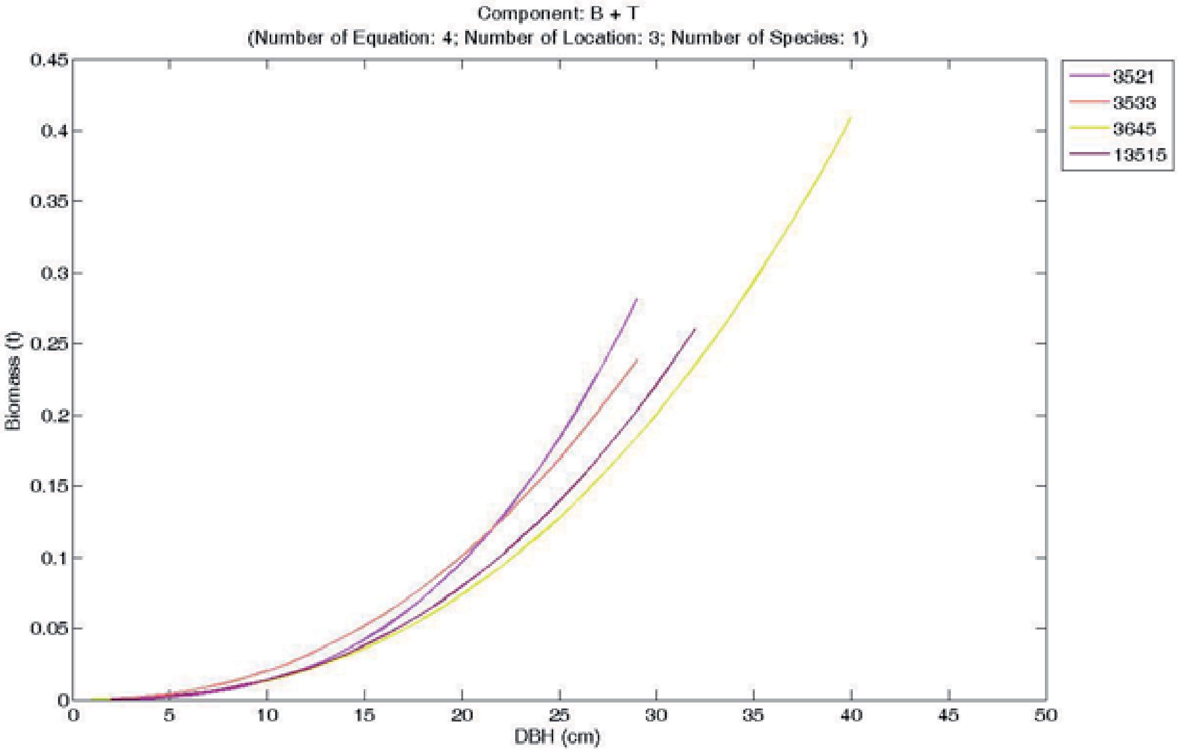

Figure 12. Plot of four equations predicting stem biomass for Picea glauca for temperate continental forest.

When choosing the equation that best fits the research's needs, the user can utilize the meta-information reported in the database. Considering that equation ID 3645 has the widest range of applicability (it was developed using trees whose DBH values ranges from 0.1 to 40 cm, while other equations do not range over 32 cm, as specified in columns "Min_X" and "Max_X") and the biggest sample size (n = 200, as specified in column "Sample_size") the user may prefer it to the other ones, especially in the case the plot contains trees bigger than 32 cm. It is clear from the graph that equation ID 3645 is also the one providing the most conservative biomass value.

On the contrary, if the plot does not contain trees bigger than 32 cm, and coefficient of determination of the equation (column "R2") is chosen as main selection criterion, the user may want to prefer equation ID 3533 that has the biggest R^2 value (R2=0.989).

7. Study case: National biomass and carbon estimation in Mexico using biomass allometric equations

As part of the project Reinforcing REDD+ Readiness in Mexico and Enabling South-South Cooperation1, a national-level estimation of forest biomass carbon was conducted using de Jong et al.'s (2009a) compilation as described in this paper. This compilation was updated to 2012 and 89 new equations were added (Appendix 3) . All equations employed are for whole tree biomass.

Our goal is to investigate how uncertainty associated to the national biomass carbon estimation in Mexico may be affected by the decision tree employed for the selection of biomass allometric equations. Differences in total biomass carbon estimated and associated uncertainty when using different decision trees have a paramount importance for countries when reporting carbon stock changes and to measure, report and validate carbon credits under different financial mechanisms, e.g., REDD+. This is particularly important for countries with a significant pool of allometry information such as Mexico.

To estimate national biomass carbon, we employed de Jong et al. (2009a) compilation, Mexico's National Forest Inventory data for 2004-2007 (CONAFOR,2011) and the national vegetation type and land use map provided by the National Institute of Statistics, Geography and Information for 2007 (INEGI,2007). INEGI's (2007) 152 vegetation types and land use classes were aggregated to 17 super classes as defined in Mexico's National Greenhouse Gas Inventory for 1990-2006 (de Jong, et al.,2009b). These classes were then post-stratified using a two-step cluster analysis based on plot-level basal area as estimated by National Forest Inventory data for closely 17,000 sampling plots which are systematically located across forests in Mexico. A total of 51 classes were used for biomass carbon and uncertainty estimation. Weighted means (tons of biomass carbon per hectare) were calculated in order to re-group results to the 17 classes for reporting.

Table 1. Area by forest stratum for INEGI (2007) and grouped by de Jong et al. (2009) for the 1990-2006 National GHG Inventory.

1990-2006 National GHG Inventory reporting classes	Area (km^2)	Vegetation types by INEGI (2007)	Area (km^2)
Coniferous Forests - P	107182	*Pseudotsuga* forest - P	263
Coniferous Forests - P		*Cupressus* forest - P	19
Coniferous Forests - P		*Abies* forest - P	1245
Coniferous Forests - P		Pine-oak forest - P	53070
Coniferous Forests - P		Pine forest - P	51124
Coniferous Forests - P		*Juniperus* forest - P	1461
Coniferous Forests - S	60312	*Pseudotsuga* forest - S	136
Coniferous Forests - S		*Cupressus* forest - S	1
Coniferous Forests - S		*Abies* forest - S	245
Coniferous Forests - S		Pine-oak forest - P	33126
Coniferous Forests - S		Pine forest - S	24919

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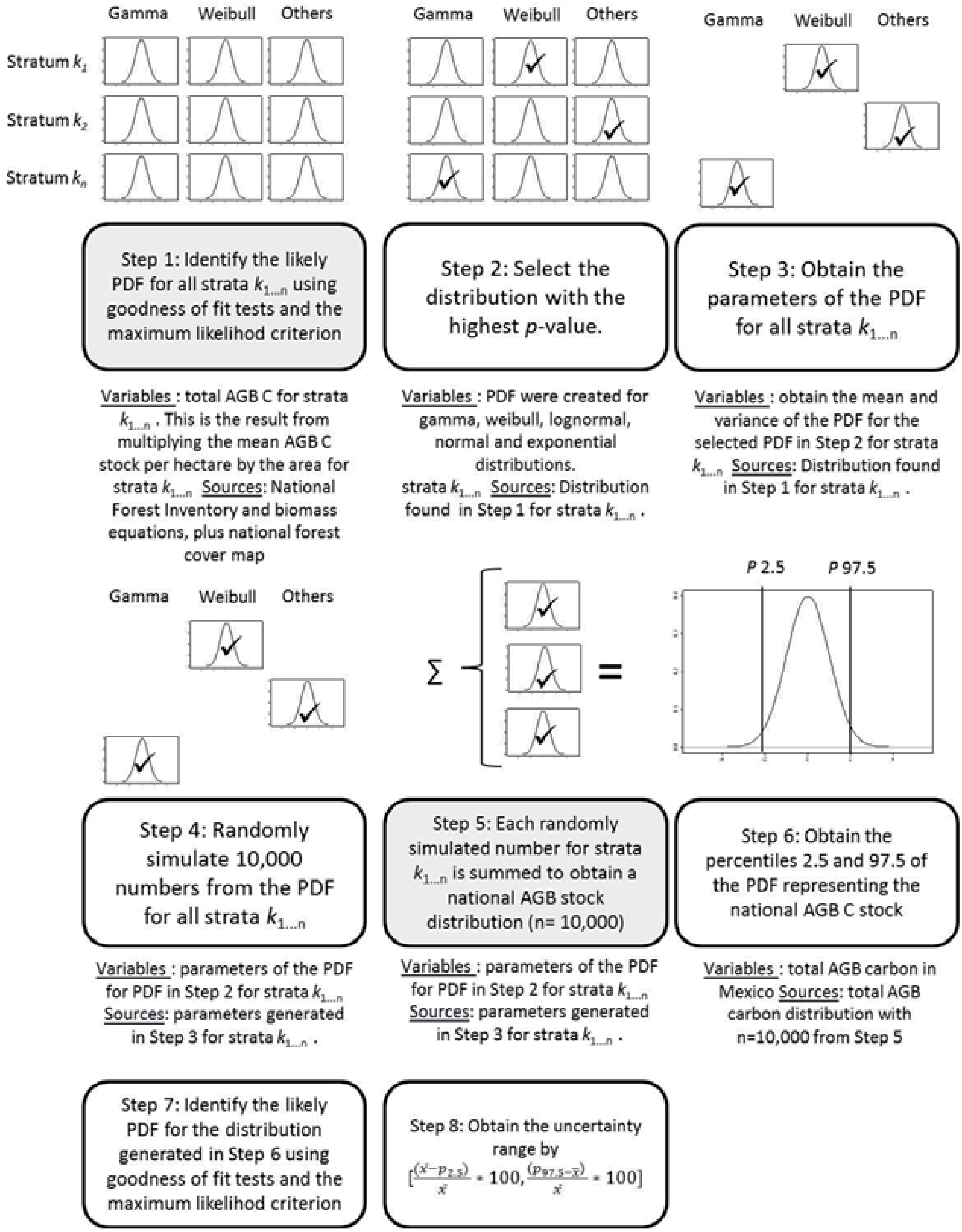
[1] See www.mrv.mx

1990-2006 National GHG Inventory reporting classes	Area (km^2)	Vegetation types by INEGI (2007)	Area (km^2)
Coniferous Forests - S		*Juniperus* forest - S	1885
Oak forest - P	95955	Oak-pine forest - P	29750
Oak forest - P		Oak forest - P	66205
Oak forest - S	59546	Oak-pine forest - S	13368
Oak forest - S		Oak forest - S	46178
Cloud forest - P	8475	Cloud forest - P	8475
Cloud forest - S	9942	Cloud forest - S	9942
Tropical dry forest - P	63924	Short stature, tropical dry forest - P	62547
Tropical dry forest - P		Medium height, tropical dry forest - P	1378
Tropical dry forest - S	90086	Short stature, tropical dry forest - S	80939
Tropical dry forest - S		Medium height, tropical dry forest - S	9147
Thorn woodland - P	6650	Thorn dry woodland - P	2265
Thorn woodland - P		Thorn evergreen woodland - P	4385
Thorn woodland - S	11355	Thorn dry woodland - S	4748
Thorn woodland - S		Thorn evergreen woodland - S	6607
Tropical evergreen forest - P	29773	Tropical evergreen forest - P	13408
Tropical evergreen forest - P		Tropical sub-evergreen forest - P	587
Tropical evergreen forest - P		Short stature, tropical evergreen forest- P	378
Tropical evergreen forest - P		Medium height, tropical evergreen forest - P	3
Tropical evergreen forest - P		Medium height, tropical sub- evergreen forest - P	15397
Tropical evergreen forest - S	61780	Tropical evergreen forest - S	19746
Tropical evergreen forest - S		Tropical sub-evergreen forest - S	1069
Tropical evergreen forest - S		Short stature, tropical evergreen forest- S	50
Tropical evergreen forest - S		Medium height, tropical evergreen forest – S	4
Tropical evergreen forest - S		Medium height, tropical sub- evergreen forest - S	40912
Tropical deciduous forest - P	4733	Short stature, tropical deciduous forest - P	460
Tropical deciduous forest - P		Medium height, tropical deciduous forest - P	4274
Tropical deciduous forest - S	39410	Short stature, tropical deciduous forest - S	225
Tropical deciduous forest - S		Medium height, tropical deciduous forest - S	39185
Swamp vegetation - P	9234	Temperate, riparian forest - P	200
Swamp vegetation - P		Mangrove - P	8546
Swamp vegetation - P		Tropical, riparian forest - P	33
Swamp vegetation - P		Peten vegetation - P	454
Swamp vegetation - S	949	Temperate, riparian forest - S	26
Swamp vegetation - S		Mangrove - S	912
Swamp vegetation - S		Tropical, riparian forest - S	11
Total	659307	Total	659307

National Forest Inventory data was standardized for tree DBH, tree total height and the relation of total tree height against DBH using a 3-standard deviation criterion for normal distributions. The same procedure was followed for standardizing plot-level biomass carbon. Quality controls were executed for tree taxonomy according to Valencia (2004), Villaseñor (2004), CONABIO (2008) and CONAFOR (2011).

Species-specific wood densities and carbon fractions values, that are not provided by the allometric equation database, were employed when available in literature (i.e. 61 carbon fractions from scientific literature and 214 wood density values obtained from Zanne et al. (2009), for example for Chave's et al (2005) pantropical equations. If this information was not available then forest type wood densities (i.e. according to de Jong et al. (2009b)) and a national carbon fraction average of 0.48 was employed (according to the 61 carbon fractions average).

Uncertainty for total biomass carbon was estimated using the Monte Carlo method (IPCC,2006). Maximum likelihood tests were employed to estimate probability density function (PDF) parameters by stratum. For temperate forests, strata are defined by floristic attributes (the dominant species serves as the main classifier) and for tropical forests climactic criteria are employed for stratification (phenology and rainfall seasonality). A total of 17 strata were defined (Table 1) which group INEGI (2007) original 152 classes. The 17 classes also have associated a successional stage attribute (primary or secondary formations). Ten thousand random numbers were generated using these parameters to create each stratum's simulated PDF. The mean and percentiles 2.5th and 97.5th were calculated from the simulated PDF to estimate uncertainty based on IPCC Guidelines (2006). Total uncertainty does not consider the allometric equation's error and only include the inherent variation of estimated biomass carbon by forest class. We recognize that allometric models may yield large estimation errors when applied ((Chave, et al.,2005), (Vieilledent, et al.,2012)) and this is why the estimation was mostly conducted within DBH applicability ranges of the models and statistical parameters of model error (mean quadratic error and R2) used as selection criteria.



Step 1: Identify the likely PDF for all strata $k_{1...n}$ using goodness of fit tests and the maximum likelihod criterion

Variables : total AGB C for strata $k_{1...n}$. This is the result from multiplying the mean AGB C stock per hectare by the area for strata $k_{1...n}$ Sources: National Forest Inventory and biomass equations, plus national forest cover map

Step 2: Select the distribution with the highest *p*-value.

Variables : PDF were created for gamma, weibull, lognormal, normal and exponential distributions. strata $k_{1...n}$ Sources: Distribution found in Step 1 for strata $k_{1...n}$.

Step 3: Obtain the parameters of the PDF for all strata $k_{1...n}$

Variables : obtain the mean and variance of the PDF for the selected PDF in Step 2 for strata $k_{1...n}$ Sources: Distribution found in Step 1 for strata $k_{1...n}$.

Step 4: Randomly simulate 10,000 numbers from the PDF for all strata $k_{1...n}$

Variables : parameters of the PDF for PDF in Step 2 for strata $k_{1...n}$ Sources: parameters generated in Step 3 for strata $k_{1...n}$.

Step 5: Each randomly simulated number for strata $k_{1...n}$ is summed to obtain a national AGB stock distribution (n= 10,000)

Variables : parameters of the PDF for PDF in Step 2 for strata $k_{1...n}$ Sources: parameters generated in Step 3 for strata $k_{1...n}$.

Step 6: Obtain the percentiles 2.5 and 97.5 of the PDF representing the national AGB C stock

Variables : total AGB carbon in Mexico Sources: total AGB carbon distribution with n=10,000 from Step 5

Step 7: Identify the likely PDF for the distribution generated in Step 6 using goodness of fit tests and the maximum likelihod criterion

Step 8: Obtain the uncertainty range by $[\frac{(\bar{x}-P_{2.5})}{\bar{x}} * 100, \frac{(P_{97.5}-\bar{x})}{\bar{x}} * 100]$

Figure 13. Graphical representation of the procedure to conduct the Monte Carlo uncertainty estimation for total AGB carbon at the national –level. Source: modified from IPCC (2006, Vol 1, Ch 3: Uncertainties). Shaded boxes indicate the steps were new PDF are created

Uncertainty as presented here is a measure of the variability of a particular variable, in this case total biomass carbon in Mexico (Figure 14). Because the uncertainty range is determined by the variability of the carbon stock, more aggregated strata will yield higher uncertainties in a Monte Carlo approach. The same stratification is employed for all decision trees so this would not be a factor affecting the final uncertainty estimates.

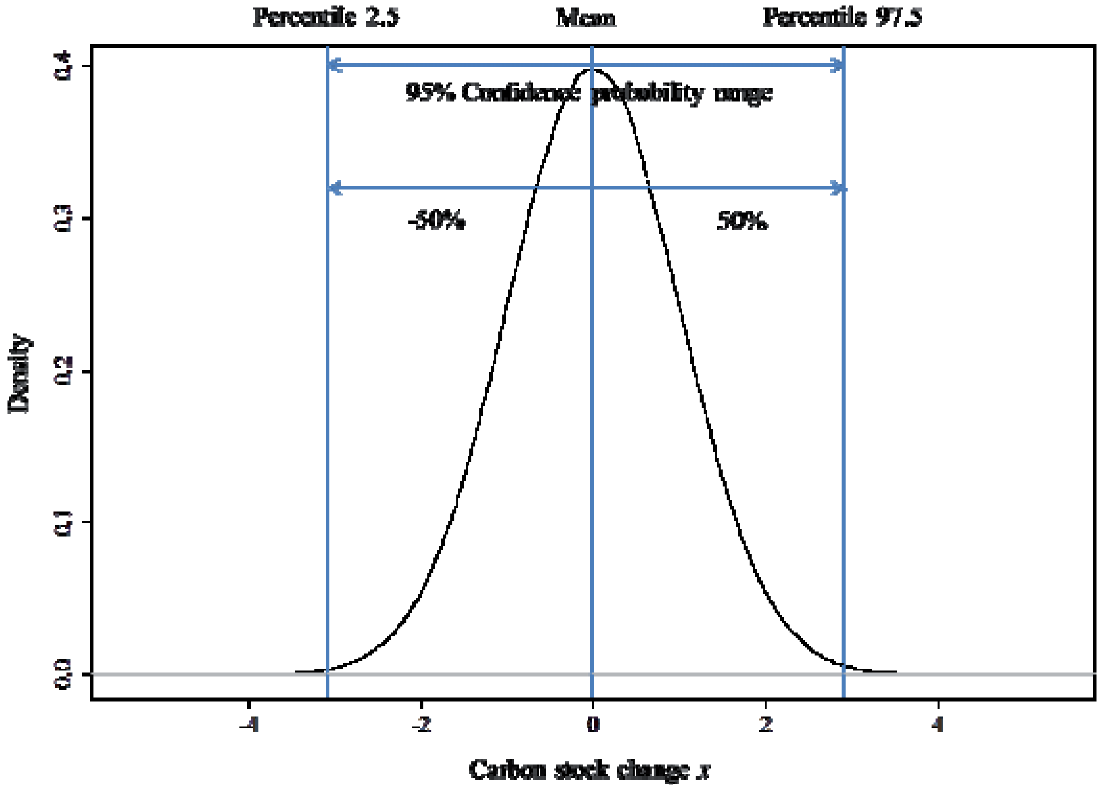


Figure 14. Graphical representation of the uncertainty range for carbon stock change x for a given stratum. Uncertainty is -50%, 50%, however, for asymmetric distributions the upper end may increase. Monte Carlo is thus able to account for asymmetric and non-normal distributions. Same procedure is followed for the uncertainty estimation for carbon stock *y*. Source: modified from IPCC (2006, Vol 1, Ch 3: Uncertainties).

Three equation selection decision trees were tested on the same National Forest Inventory data, forest stratification, following the same estimation methods (i.e. including wood density values and carbon fractions employed) and based on the same pool of equations. The decision trees differ in the criteria to rank and assign equations to individual trees. The flow charts of the decision trees are showed in Figure 15, Figure 16 and Figure 17.

Table 2. Characteristics of the decision trees employed for the estimation of biomass carbon in Mexico.

	Decision tree 1	Decision tree 2	Decision tree 3
Pre-requisites	None	All models are built with at least 30 trees	None
Statistical parameters	DBH range, MSE, R^2, tree species, genus, forest type associated and spatial location	DBH range, MSE, R^2, tree species, genus and forest type associated	Number of trees used to build the model, DBH range, MSE, tree species, genus and forest type associated
Goal	Prioritize species-specific equations within applicable DBH range	Prioritize species-specific equations within applicable DBH range	Compares the best model at different levels for each tree and selects for minimum MSE
Algorithm assumptions	Species-specific equations have lower uncertainties than higher-level equations (e.g. genus, forest type)	Species-specific equations have lower uncertainties than higher-level equations (e.g. genus, forest type)	Low error (uncertainty) models are more accurate in predicting tree biomass regardless of their level of application
Additional information	Adequate for conifer forests with low species diversity. Performs poorly in diverse tropical forests or where species-specific models are not available. If a model is applied outside its DBH applicability range it is done first using species-level models and then by genus- and forest type- level models	Prioritizes species-specific models but is more restrictive in their use. For example, raises standards for statistically robust models and thus increases the number of trees estimated with generic, forest type equations within and outside their applicability range	Adequate when model metadata is available; models lacking this information will be automatically excluded

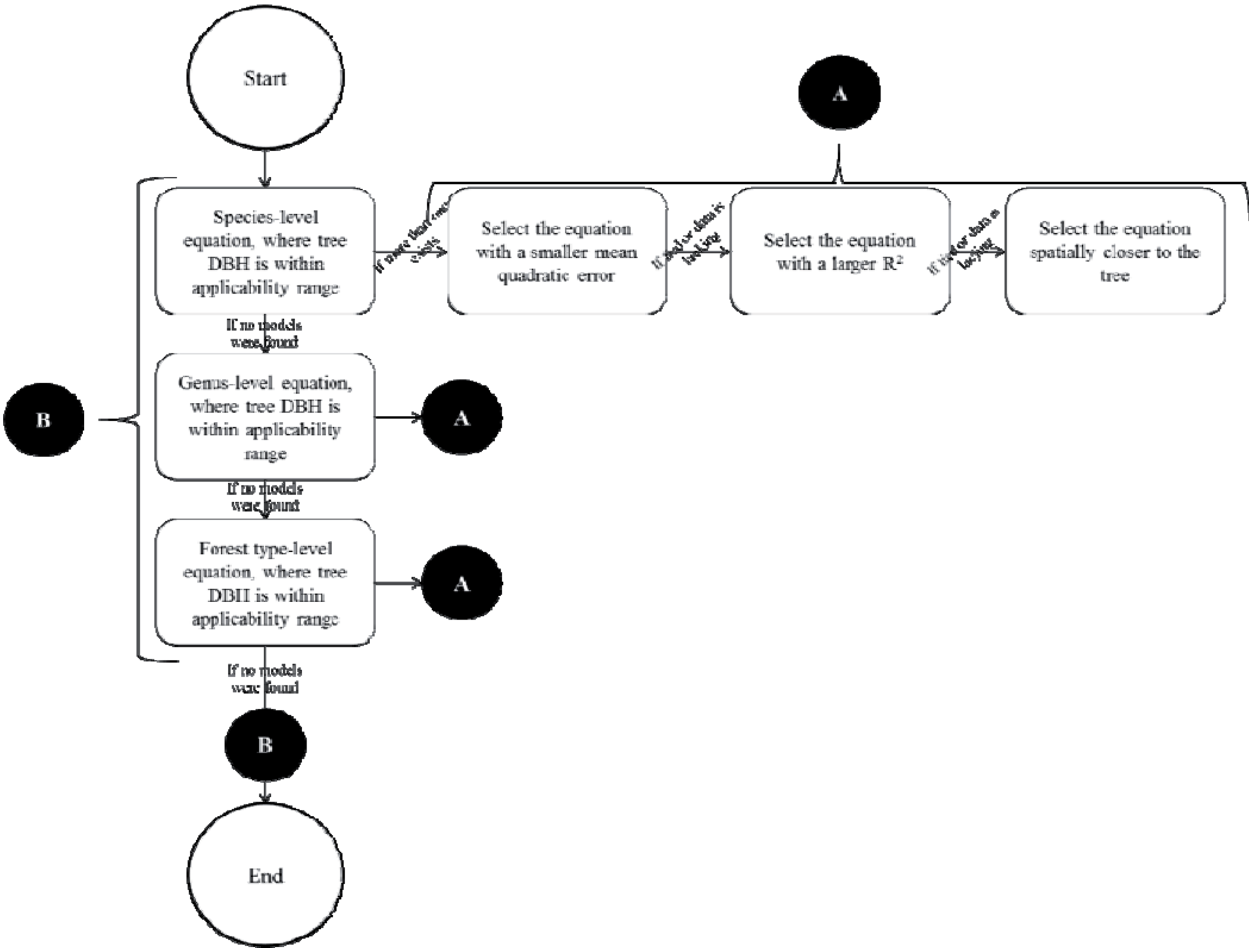


Figure 15. Decision tree 1. Species-specific allometric equations are prioritized within DBH applicability ranges for the models. If more than one equation is available at this level, the model with the smallest mean quadratic error, R2 or closer to the spatial location of the tree is selected, in that order. If no models were found at the species level, the same selection procedure is applied at the genus and forest type levels. This are also applied within DBH applicability ranges for the models employed. Similarly, if no models are found within these ranges then the same procedure is followed (i.e. from species to genus and forest type levels) outside the model's applicability ranges.

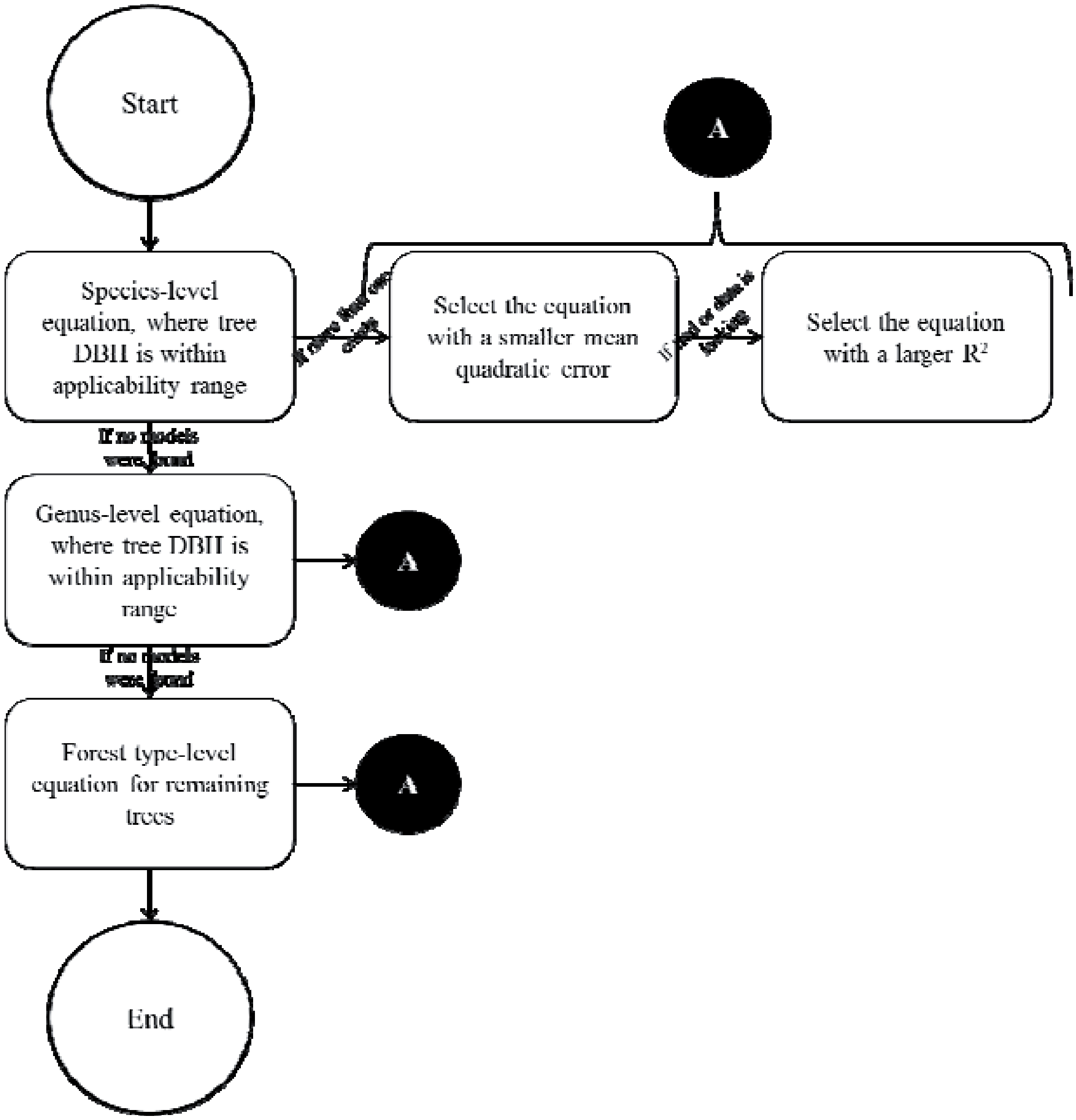
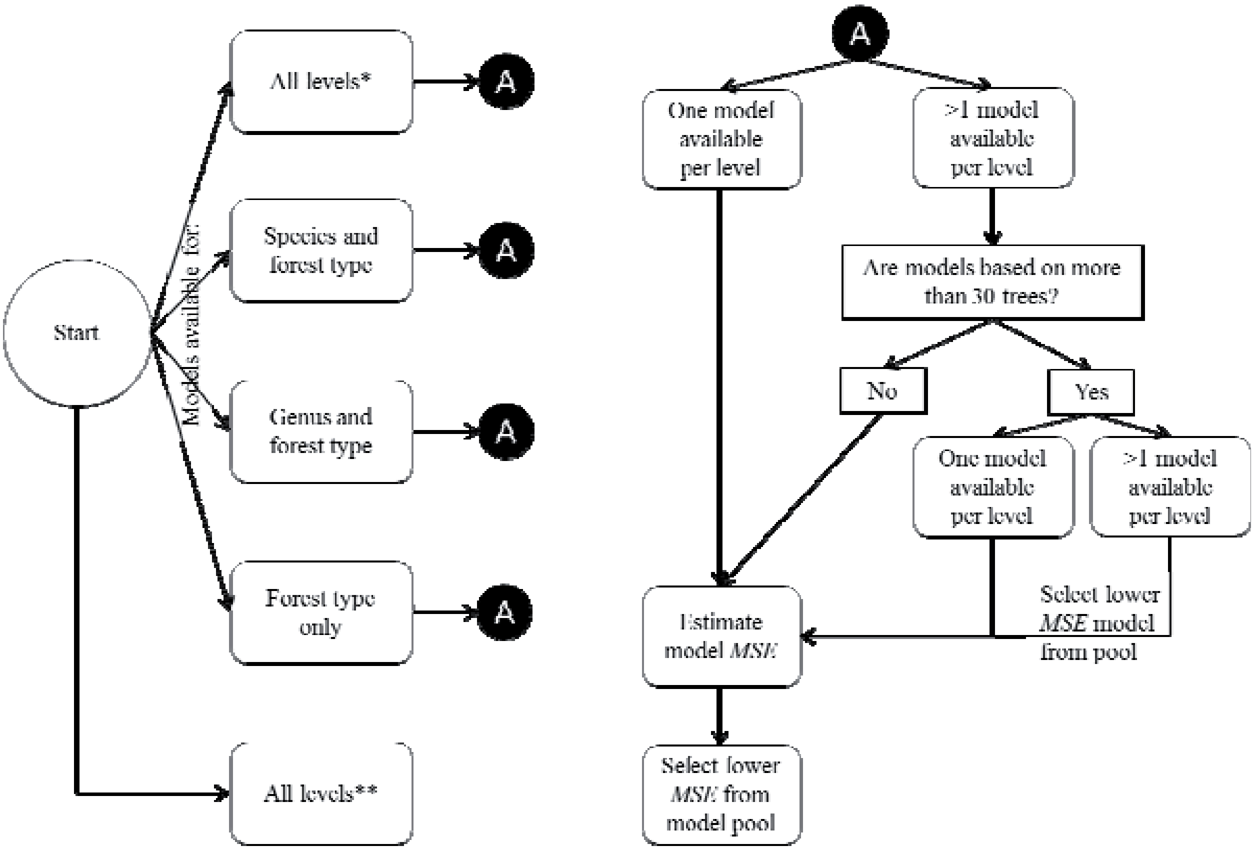


Figure 16. Decision tree 2. Species, genus and forest-type models are selected, in that order, within DBH applicability ranges defined in the models. The smallest mean quadratic error or the R2 is selected when >1 models are available at any level. *Only models built with >30 sampled trees are considered for the decision tree.* If the models do not have an R^2 associated, because it is not reported by the author o if the metadata has not yet been compiled, then the model is not accounted for in the decision tree. It is basically excluded from the analysis. If this happens , the selection process is taken to a higher level (genus or forest type equations) for a particular tree.



* Within model DBH applicability ranges
** Same as first step but outside model DBH applicability ranges

Figure 17. Decision tree 3. A preliminary assessment is undertaken to determine whether equations at different levels are applicable for a particular tree in the inventory (e.g. a species and genus-level equation could be used to estimate the biomass of a 20 cm DBH Pinus patula). Once the appropriate level(s) are chosen (boxes arranged vertically after start) the decision tree shown after "A" is followed. This is done within the models' DBH applicability ranges. If no models are applicable within their applicability ranges all levels are considered outside their applicability range and "A" is followed (See **). If the models do not have an MSE associated, because it is not reported by the author o if the metadata has not yet been compiled, then the model is not accounted for in the decision tree. It is basically excluded from the analysis.

Main findings

We found that uncertainty and total biomass carbon estimated varied according to the decision tree employed (Table 3). Differences in the uncertainty estimates were due to the application of different biomass models since the application of forest stratification, wood density values and carbon fractions was the same for all decision trees.

We also observed that uncertainty did not decrease with an increased use of species or genus specific models (Figure 18). Uncertainty was also not correlated to the number of equations employed in each decision tree (decision trees 1, 2 and 3 used 64, 29 and 114 equations, respectively, from the 339 equation pool; the first decision tree with 64 equations yielded the lowest uncertainty). This may provide an argument for creating generic or forest type models instead of investing in species- or genus-level equations, however, model error should be assess prior to this.

For example, decision tree 3 was more efficient in selecting species- or genus-level equations but only presented an averaged uncertainty.

Despite the similarity of Decision trees 1 and 2, their uncertainties were very different which may suggest that any additional criteria in Decision tree 1 may have contributed to a lower uncertainty. In this regard, using geographic coordinates to assign biomass allometric equation may have cause estimation errors at the small scale (i.e. stands may vary considerably in structure and biomass content within meters) but at larger scales the criterion could be useful to avoid using equations built in different geo-climatic conditions to where the tree that is being estimated is located.

Decision trees 2 and 3 used a minimum criteria of 30 trees used for constructing the biomass models. Both presented higher uncertainties than Decision tree 1, but it would be risky to conclude that this criterion accounted for an increased uncertainty in the estimates.

Generally, it appears that decision trees built using the criteria applied here (Table 3) will provide a good selection of equations if metadata is available (i.e. uncertainty was fairly constant in all decision trees in the range -13, +19%. Metadata is important as key information to select equations. Table 4 shows metadata available for the equations for Mexico. Given that we found no apparent correlation between the number of models used and uncertainty, it is advisable to employ as many and better models as possible to reduce bias.

Finally, if the models and data are available to countries we recommend that this process is repeated and several decision trees are tested prior to selecting one. Mexico is currently improving the information (metadata) that goes into informing the decision trees, collecting wood density values and creating better models at the forest-type level, since these are most frequently used in the estimation.

Table 3. National biomass carbon estimation using different decision trees for selecting biomass allometric models.

	Decision tree 1	Decision tree 2	Decision tree 3
Estimated biomass carbon at national level (10^3 millions of tons of C)	1.68	1.44	1.33
Probability density function	Log normal	Log normal	Log normal
Uncertainty lower end	-13%	-16%	-14%
Uncertainty higher end	+14%	+19%	+16%
***p*-value associated to the AIC criterion in the Monte Carlo analysis. The *p*-value indicates the probability that the PDF and, hence, the percentiles estimated to build the uncertainty range come from a known distribution that was fit using goodness of fit tests and the maximum likelihood criterion.**	0.27	0.20	0.85

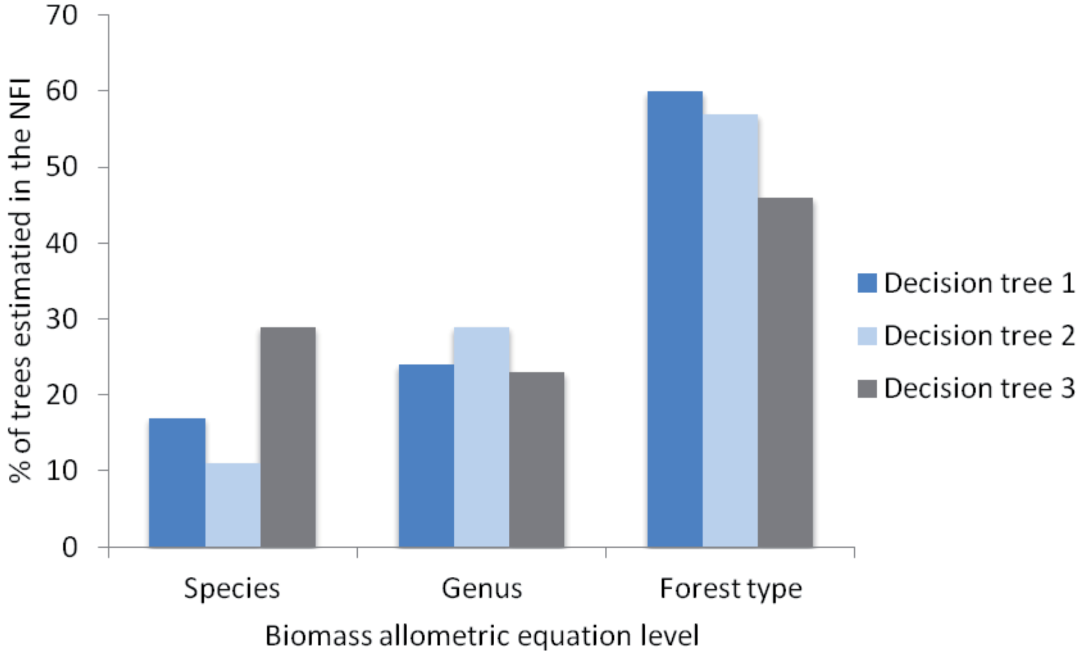


Figure 18. Application of biomass allometric equation by level for the three decision trees employed. Uncertainty estimates are -11, +12; -16, +19; and -14, +16, for decision trees 1, 2 and 3, respectively.

Table 4. Percentage (%) of available metadata associated to biomass allometric models in Mexico (n=339).

	All models	Species-level	Genus-level	Forest-type level
Number of models	**339**	**273**	**50**	**16**
r^2	35	37	22	43
Mean square error	8	7	8	31
Root mean square error	1	1	4	0
Standard error	14	13	14	25
Mean biomass	0	0	0	0
Biomass variance	1	1	0	0
Number of trees	36	36	28	62
Carbon fraction	2	1	10	0
Minimum wood density	0	0	0	0
Maximum wood density	0	0	0	0
Mean wood density	3	4	0	0
Minimum DBH	60	60	58	62
Maximum DBH	58	58	56	62
Mean DBH	8	7	8	12
Minimum rainfall	47	52	32	18
Maximum rainfall	11	11	12	0
Mean rainfall	11	11	14	6
Minimum temperature	7	6	12	0
Maximum temperature	7	6	12	0
Mean temperature	22	25	10	12
Maximum elevation	22	25	16	0
Minimum elevation	18	19	18	0
Mean elevation	5	6	2	0
Climate type	48	53	30	25
Soil type	34	37	30	6
Management type	0	0	2	0
Natural disturbances	2	2	6	0
State	64	66	68	18
Geographic coordinates	35	34	46	18
Year published	80	77	96	81

* Shaded lines are criteria used in the decision trees.

8. Gaps in assessing volume and biomass in North America

The database is only a first attempt to create a comprehensive collection of tree allometric equations for North America. Some lacks are inevitable. The database, however, is designed to allow a constant updating of the data and existing gaps can be addressed in the future.

Relying on the data collected as far, the present study shows that for Mexico there is a smaller number of available equations (only 319 compared with the 1809 of USA or 467 of Canada). It appears that three of the 14 ecological zones occurring in north America (FAO,2006) have more than 80% of the total equations. Important and widespread biomes, such as boreal coniferous forest, tropical rainforest, tropical dry forest are particularly under-represented.

The distribution of equations per tree species is not homogenous, with a marked preference for the more economically important family, such as Pinaceae and Fagaceae. The data suggest that only the 14% of the tree species of North America have been studied.

Concerning the tree component more than 40% of the equations refers to the tree stem, whereas the equations for aboveground biomass represent only the 14% and for underground biomass and roots less than 3%. Under-ground biomass is equally important for the estimate of carbon stock, and especially in dry region.

9. Recommendations

It would be important to update the database by conducting a literature review for USA and Canada for the period after 2003. For Mexico it is necessary to deepen the literature analysis, especially including in the database the regressions for tree above ground components.

The equations collected so far should be subjected to a quality control in order to check their consistence and the intervals of calibration (Henry, et al.,2011).

Further studies should also go in the direction to fill the existing gaps in the allometric equations inventory: 1) to improve the geographical distribution of the sample plots, including the under-represented biomes, such as boreal coniferous forest, tropical rainforest, tropical dry forest and subtropical dry forests; 2) to develop equations for new tree species that are prioritized according to their contribution to total volume/biomass/carbon; 3) to increase the production of new allometric equation for Mexico; 4) to stimulate allometry research for tree aboveground components.

In order to improve the quality of biomass assessment and to develop new and more accurate models, it is also necessary to develop a comprehensive wood density and raw data database at regional scale, collecting all the available measured tree biomass values for North America.

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Appendices

Appendix 1. List of the Acronym used in the database.

Acronym	Description	Unit	Population
BA	Basal area: Stem cross-sectional area at DBH (1m30 height)	cm^2	TREE
BA0	Stem cross-sectional area at the soil	cm^2	TREE
BD	Basal diameter	cm	TREE
C	Circumference at 1.3m	cm	TREE
C10	Circumference at 10 cm height	cm	TREE
C180	Circumference at 180 cm height	cm	TREE
C20	Circumference at 20 cm height	cm	TREE
C30	Circumference at 30 cm height	cm	TREE
C50	Circumference at 50 cm height	cm	TREE
Ca	Canopy area	m^2	TREE
CA	Crown area	cm^2	TREE
Cb	Basal circumference	cm	TREE
Cb5	Circonference at 5 cm from soil	cm	TREE
CD	Crown diameter	Cm	TREE
CH	Crown height	cm	TREE
CR	Crown radius	cm	TREE
CV	Canopy volume	cm^3	TREE
D20	Diameter at 20cm height	cm	TREE
D30	Diameter at 30cm height	cm	TREE
DBH	Diameter at breast height	cm	TREE
H	Height	cm	TREE
Hd	Stand dominant height	cm	STAND
Hme	Merchantable height	cm	TREE
Ht	Height of the trunk	cm	TREE
M_DBH	Average of DBH	cm	STAND
N	Number of trees	$Tree*ha^{-1}$	STAND
R	tree ring	nr	TREE
SUMD10	Sum of the diameters at 10 cm from the soil	Cm	STAND
Yr	Year	yr	TREE
Vs	Stem volume	dm3	TREE
WD	Wood density	$g*cm^{-3}$	TREE
Age	Age of the trees	yr	STAND

Appendix 2. List of data needed to insert a new allometric equation into the database.

N.	FIELD	DESCRITPION	EXAMPLES	Notes
1	ID	Identification number of the allometric equation. Each equation has its own ID reference, two different equations cannot have the same ID.	1188	a. c.
2	Population	Lianas: woody climbing plants mainly of tropical forests; Mangroves: evergreen trees or shrubs of tropical forests, having prop roots and stems and forming dense thickets along tidal shores; Sprout: is a shoot which grows from a bud at the base of a tree or from a shrub or from its roots; Stand: contiguous area that contains a number of trees; Tree: woody plant having a main trunk and usually a distinct crown.	Tree	a.
3	Ecosystem	Forest Plantation Hedgerow Home garden Tree outside forest	Forest	a.
4	Continent	Name of the continent where the equation was developed	Africa	a.
5	Country	Name of the country using the GAUL nomenclature (Global Administrative Unit Layers, FAO). Write "None" when the allometric equation does not refer to any country.	Burkina Faso	a.
6	ID_Location	Identification number of the location. In the same article for the same location they could be more than one equation.	6772	a. c.

7	Group_Location	Identification number of the group locations. When an allometric equation is valid for a group of locations. Write "None" when the allometric equation does not refer to any group location. Always provide a separate list with the Group_Locations you used in the database, each one with the corresponding ID.	24	c.
8	Location	Location corresponds to the name of the place where the equation was developed It can be a precise location (city, village..) or a geographical area. Search a location as precisely as possible. Write "None" when the allometric equation does not refer to any location.	Laba	a.
9	Latitude	Decimal degrees Write "None" when the allometric equation does not refer to any latitude.	41.899566	b.
10	Longitude	Decimal degrees Write "None" when the allometric equation does not refer to any longitude.	12.515275	b.
11	Biome_FAO	Global Ecological Zones	Tropical dry forest	b.
12	Biome_UDVARDY	Global Ecological Zones	Tropical dry forests / Woodlands	b.
13	Biome_WWF	Global Ecological Zones	Tropical & Subtropical Grasslands, Savannas & Shrublands	b.
14	Division_BAILEY	Global Ecological Zones	SAVANNA DIVISION	b.
15	Biome_HOLDRIDGE	Global Ecological Zones	Tropical dry forest	b.

16	X	Independent variable (see below). e.g.: BA (basal area, the cross-sectional area of the stem at breast height), Bd (diameter at soil), Bd5 (diameter at 5 cm from soil), C (circumference at breast height), Cb (circumference at soil), Cd5 (circumference at 5 cm from soil), D10 (diameter at 10 cm of height from the soil), DBH (diameter of the stem at breast height), H (height), wd (wood density).Look at the end of the tutorial for an exhaustive list of the acronyms to be used.	BA	a.
17	Unit_X	Unit measure (mm, cm, cm2, cm3, dm, gcm-3, m, m2...).Always keep the unit of measurement reported by the author.	cm	a.
18	Z	Independent variable. Cannot be there a second variable. Write “None” when you have not this data.	DBH	
19	Unit_Z	Unit measure Write “None” when you have not this data.	cm	
20	W	Independent variable. Write “None” when you have not this data.	H	
21	Unit_W	Unit measure. Write “None” when you have not this data.	m	
22	U	Independent variable. Write “None” when you have not this data.	-	
23	Unit_U	Unit measure Write “None” when you have not this data.	-	
24	V	Independent variable. Write “None” when you have not this data.	-	
25	Unit_V	Unit measure. Write “None” when you have not this data.	-	

26	Min_X	It is the minimum X value. Write “None” when you have not this data.	10 cm	
27	Max_X	It is the maximum X value. Write “None” when you have not this data.	40 cm	
28	Min_Z	It is the minimum Z value. Write “None” when you have not this data.	3,6 m	
29	Max_Z	It is the maximum Z value. Write “None” when you have not this data.	7,8 m	
30	Output	It is the dependent variable: Y It can express: - Biomass - Volume	biomass	a.
31	Output_TR	The output of the equation can be expressed in the Log(Y) or in the arithmetic value of Y, in which case you don’t specify anything. When the result of the equation is a logarithm you have to specify if it is a natural logarithm (Log) or a logarithm to base b = 10, the common logarithm (Log10). Write “None” if “Y” does not refer to any log.	Log10	a.
32	Unit_Y	Unit measure of Y (e.g. cm3, dm3, m3, m3/ha, g, kg, Mg, kg/ha, Mg/ha...).	kg	a.
33	Age	Age of the population considered in the experiment (years). It can be a precise number (e.g. 20) or a range (e.g. 20-40) or a definition (eg. young...). Write “None” when you have not this data.	20	

34	Veg_Component	They are the vegetation components of the plants considered in the equation (see below). e.g. : Branch biomass Branch biomass without twigs Biomass of roots (RC+RF+RS) Biomass of dead branches Biomass of stem bark Biomass of small roots Biomass of fine roots Crown biomass (BR+FL) Prop roots Stem volume Stem wood biomass Stump biomass Total aboveground biomass Total foliage biomass Total stem biomass (SW+SB) Total tree biomass (AB+RT) Total aboveground biomass without leaves Total aboveground woody biomass	Total stem biomass (SW+SB)	a.
35	B	Bark Write “TRUE “if bark is considered in the output; Write “FALSE “if this component is not considered.	TRUE	a.
36	Bd	Dead branches Write “TRUE “if dead branches are considered in the output; Write “FALSE “if this component is not considered.	-	a.
37	Bg	Gross branches: D>7 cm Write “TRUE “if gross branches are considered in the output; Write “FALSE “if this component is not considered.	-	a.
38	Bt	Thin branches: D<7 cm Write “TRUE” if thin branches are considered in the output; Write “FALSE” if this component is not considered.	-	a.

39	L	Leaves Write “TRUE” if leaves are considered in the output; Write “FALSE” if this component is not considered.	-	a.
40	Rb	Large roots Write “TRUE” if write are considered in the output; Write “FALSE” if this component is not considered.	-	a.
41	Rf	Fine roots Write “TRUE” if fine roots are considered in the output; Write “FALSE” if this component is not considered.	-	a.
42	Rm	Medium roots Write “TRUE” if medium roots are considered in the output; Write “FALSE” if this component is not considered.	-	a.
43	S	Stump Write “TRUE” if stump is considered in the output; Write “FALSE” if this component is not considered.	-	a.
44	T	Trunk-underbark Write “TRUE” if trunk-underbark is considered in the output; Write “FALSE” if this component is not considered.	FALSE	a.
45	F	Fruits Write “TRUE” if fruits are considered in the output; Write “FALSE” if this component is not considered.	-	a.
46	ID_Species	Identification number of the species. Each species has its own ID, two different species cannot have the same ID. Write “1” when the allometric equation does not refer to any particular species.	450	a. c.
47	Genus	It is the name of the genus in the binomial literature in a Latin grammatical forms.	Anogeissus	a.

48	Species	It is the name of the species in the binomial literature in the Latin grammatical form.	leiocarpa	a.
49	Family	It is the name of the Taxonomic family to which belongs the species		a.
50	Group_Species	Write “1” when an allometric eq. refers to a group of species. Write “None” when the equation does not refer to any group of species. Always provide a separate list Group_Species you used in the database, each one with the corresponding ID.	1	a.
51	ID_Group	Identification number of the group species. Each group has its own ID, two different groups cannot have the same ID. Write “None” when the equation does not refer to any group of species.	-	c.
52	Equation	It is the allometric equation.	3.21*X+11.74*X^(2)	a.
53	Sample_size	Number of plants measured to obtain the equation. Write “None” where there is not this data.	32	
54	Top_dob	For equations that include a portion of the merchantable stem. Top d.o.b. describes the minimum diameter in cm, outside bark (d.o.b.) of the top of the merchantable stem. Write “None” where there is not this data.	-	-
55	Stump_height	For equations that predict the biomass of any component that includes the tree stem or the stump, this variable lists (in m.) the estimated or measured stump height. Write “None” where there is not this data.	-	-
56	ID_REF	Identification number of the reference. One reference can correspond to more than one equation. In the case one equation is found in more than one document, the oldest document becomes the reference	579	a. c.
57	Label	Identification number of the pdf/word copy of the article in your library. Hard or soft copies are identified with one label number. One label can correspond to more than one equation. The label can correspond to the ID_REF.	3832	a. c.

58	Author	Author's surname. Write only the first two authors. If there are two authors use "**and"** between the names of the two authors. If more than two authors, write "surname of the first author et al.".	Sawadogo et al.	a.
59	Year	Year of publication of the document. When an author has written more than one work in the same year, use **a**, **b**, etc. to differentiate, e.g. **2000a**, **2000b**. Write "None" where there is not this data.	2010	a.
60	Reference	Authors, year of publication, title of issue, journal, volume number, number of the issue, pages . The reference should be entered in using the Fao bibliography editorial guidelines (look at page 24 for more information).	**Barney, R., Van Cleve, K. & Schlentner, R.** 1978. Biomass Distribution and Crown Characteristics in Two Alaskan Picea Mariana Ecosystems; . *Canadian Journal of Forest Research* (8): 36-41	a.
1	R^2	Coefficient of determination of the equation. Write "None" where there is not this data.	0.878	a.
62	R^2_adjusted	This is an adjustment of the R-squared that penalizes the addition of extraneous predictors to the model. Adjusted R-squared is computed using the formula 1 - ((1 - R^2)((N - 1) /(N - k - 1)) where k is the number of predictors.	0.489	
63	Corrected for bias	A "1" value in this column means that the original author developed and reported a correction factor to compensate for the potential underestimation resulting from backtransforming logarithmic predictions to arithmetic units, as suggested by Baskerville (1972), Beauchamp and Olson (1973), and Sprugel (1983). In many cases where (7) is "yes," item (8) will list CF, the bias correction factor to be used. In other cases, the authors embedded the correction factor into the equation parameters, or did not publish the value of CF since it can be obtained from the regression statistics. In such cases, the value of CF in the database will be zero even though the authors used the correction factor (Jennifer C. 2004). Write "None" when there is no "corrected for bias".	-	

64	RMSE	Root-mean-square deviation or error of the equation. Write “None” where there is not this data.	-	a.
65	SEE	Standard error of the mean of the equation. Write “None” where there is not this data.	-	
66	Bias correction (CF)	Value of CF, to correct for potential underestimation resulting from back-transformation of logarithmic predictions to arithmetic units. Write “None” when there is no “CF”.	-	
67	Ratio equation	Some authors present methods for predicting the biomass of the merchantable stem to a user-defined top diameter. A “1” value in this column means that a separate ratio equation was presented by this author. Write “None” when there is no “ratio equation”.	-	
68	Segmented equation	Paired equations for the same species. E.g. one equation was applicable at the lower end of the diameter range and a second equation was applicable at the upper end of the range. A “1” value in this column means that the equation is one-half of a segmented equation. Write “None” when there is not this data.	-	
69	Contributor	Name of the institution who worked on entering data in the database.	FAO	
70	Name_operator	Name of the operator who entered the data		
71	Remarks	Any other relevant information such as silvicultural treatment, fertility class, soil description etc.	Evergreen forest	

NOTES

a. Very important data
b. Data obtained with other software
c. Data obtained from pre-existing database

Appendix 3. Additional allometric equations to De Jong et al.'s (2009a) original compilation.

Equation	Species or vegetation type	Reference
B = (0.0841*d130^2.41)	*Tropical deciduous forest*	Návar 2009
B = (0.1229*d130^2.3964)	*Juniperus sp*	Návar 2010a
B = (0.0173*d130^2.3824)	*Pinus sp*	Silva-Arredondo and Návar. 2009
B = (0.1192*d130^2.3231)	*Pinus sp*	Silva-Arredondo and Návar. 2009
B = (0.1229*d130^2.3964)	*Pinus sp*	Návar 2010a
B = (0.1229*d130^2.3964)	*Pseudotsuga sp*	Návar 2010a
B = (0.004*d130^3.0799)	*Quercus sp*	Silva-Arredondo and Návar. 2009
B = (0.010702*d130^3.05082)	*Quercus sp*	Rodríguez-Laguna et al. 2009
B = (0.038424*d130^2.82139)	*Quercus sp*	Rodríguez-Laguna et al. 2009
B = (0.0706*d130^2.4077)	*Quercus sp*	Silva-Arredondo and Návar. 2009
B = (0.089*d130^2.5226)	*Quercus sp*	Návar 2010a
B = (0.45534*d130^2)	*Quercus sp*	(Aguirre-Calderón and Jiménez-Pérez.,2011)
B = (0.0713*d130^2.5104)	*Abies religiosa*	Avendaño et al. 2009
B = (0.1229*d130^2.3964)	*Abies religiosa*	Návar 2010a
B = (0.479403*d130^2.0884)	*Brosimum alicastrum*	Rodríguez-Laguna et al. 2009
B = (0.064808*d130^2.46998)	*Bursera simaruba*	Rodríguez-Laguna et al. 2009
B = (0.311733*d130^2.04754)	*Ceanothus caeruleus*	Rodríguez-Laguna et al. 2008
B = (0.4632*d130^1.8168)	*Clethra mexicana*	(Acosta M., et al.,2011)
B = (0.037241*d130^2.99585)	*Dendropanax arboreus*	Rodríguez-Laguna et al. 2008
B = (0.232435*d130^2.21906)	*Guazuma ulmifolia*	Rodríguez-Laguna et al. 2008
B = (0.209142*d130^1.698)	*Juniperus flaccida*	Rodríguez-Laguna et al. 2009
B = (0.23855*d130^1.92242)	*Mimosa albida*	Rodríguez-Laguna et al. 2008
B = (1.30454*d130^1.73099)	*Pinus montezumae*	Rodríguez-Laguna et al. 2009
B = (0.128495*d130^2.36444)	*Pinus pseudostrobus*	Rodríguez-Laguna et al. 2009
B = (0.35179*d130^2)	*Pinus pseudostrobus*	Aguirre and Jiménez 2011
B = (0.032495*d130^2.76658)	*Pinus teocote*	Rodríguez-Laguna et al. 2009
B = (0.40196*d130^2)	*Pinus teocote*	Aguirre and Jiménez 2011
B = (0.064066*d130^2.62323)	*Piscidia piscipula*	Rodríguez-Laguna et al. 2008
B = (0.246689*d130^2.24992)	*Psidium guajava*	Rodríguez-Laguna et al. 2008

B = (0.892617*d130^1.84697)	*Quercus germana*	Rodríguez-Laguna et al. 2009
B = (0.970526*d130^1.83733)	*Quercus rysophylla*	Rodríguez-Laguna et al. 2009
B = (0.132193*d130^2.49568)	*Ternstroemia sylvatica*	Rodríguez-Laguna et al. 2009
B = (0.130169*d130^2.34924)	*Trichilia havanensis*	Rodríguez-Laguna et al. 2008
B = (0.346847*d130^1.99059)	*Wimmeria concolor*	Rodríguez-Laguna et al. 2009
B = (1.16935*d130^1.698)	*Clethra pringlei*	Rodríguez-Laguna et al. 2009
B = (0.407073*d130^2.02617)	*Pinus patula*	Rodríguez-Laguna et al. 2009
B = (0.0345*d130^2.9334)	*Quercus magnoliifolia*	Gómez Días et al. 2011
B = (0.766406*d130^1.93843)	*Quercus xalapensis*	Rodríguez-Laguna et al. 2009
B = (0.1649*d130^2.2755)	*Alnus acuminata*	Acosta et al. 2011
B = (0.197575*d130^2.34002)	*Bauhinia divaricata*	Rodríguez-Laguna et al. 2008
B = (0.222776*d130^2.33953)	*Cinnamomum tampicense*	Rodríguez-Laguna et al. 2008
B = (0.401524*d130^1.83808)	*Harpalyce arborescens*	Rodríguez-Laguna et al. 2008
B = (0.182197*d130^2.22818)	*Nicotiana glauca*	Rodríguez-Laguna et al. 2008
B = (0.062394*d130^2.71448)	*Aphananthe monoica*	Rodríguez-Laguna et al. 2008
B = (0.181077*d130^2.29418)	*Cestrum dumetorum*	Rodríguez-Laguna et al. 2008
B = (0.078545*d130^2.58952)	*Casimiroa greggii*	Rodríguez-Laguna et al. 2008
B = (0.23736*d130^2.16175)	*Robinsonella discolor*	Rodríguez-Laguna et al. 2008
B = (0.048454*d130^2.58164)	*Tilia americana*	Rodríguez-Laguna et al. 2008
B = (Exp(-3.182)*d130^2.702)	*Pinus teocote*	Návar 2010b
B = (Exp(-3.532)*d130^2.731)	*Pinus durangensis*	Návar 2010b
B = (Exp(-3.416)*d130^2.715)	*Pinus durangensis*	Návar 2010b
B = (Exp(-2.108)*d130^2.373)	*Pinus durangensis*	Návar 2010b
B = (Exp(-2.084)*d130^2.323)	*Pinus durangensis*	Návar 2010b
B = (Exp(-3.573)*d130^2.746)	*Pinus arizonica*	Návar 2010b
B = (Exp(-1.482)*d130^2.129)	*Pinus arizonica*	Návar 2010b
B = (Exp(-0.877)*d130^1.98)	*Pinus arizonica*	Návar 2010b
B = (Exp(-3.264)*d130^2.707)	*Pinus arizonica var. cooperi*	Návar 2010b
B = (Exp(-1.922)*d130^2.321)	*Pinus arizonica var. cooperi*	Návar 2010b
B = (Exp(-3.065)*d130^2.625)	*Pinus oocarpa*	Návar 2010b

B = (Exp(-2.611)*d130^2.531)	*Pinus pseudostrobus*	Návar 2010b
B = (Exp(0.685)*Ht^1.218)	*Yucca sp*	Návar 2010b
B = (Exp(-3.066)*d130^2.646)	*Pinus ayacahuite*	Návar 2010b
B = (Exp(-3.549)*d130^2.787)	*Pinus leiophylla*	Návar 2010b
B = (Exp(-3.039)*d130^2.523)	*Pinus leiophylla*	Návar 2010b
B = (Exp(-2.874)*d130^2.631)	*Quercus sp*	Návar 2010b
B = (Exp(-2.754)*d130^2.574)	*Quercus sp*	Návar 2010b
B = (Exp(-2.144)*d130^2.403)	*Quercus sp*	Návar 2010b
B = (Exp(0.685)*Ht^1.218)	*Bosque de pino*	Návar 2010a
B = (Exp(-2.818)*d130^2.574)	*Pinus sp*	Návar 2010b
B = (Exp(-2.523)*d130^2.437)	*Oak-pine forest*	Návar 2010b
B = (Exp(-2.592)*d130^2.585)	*Quercus sideroxyla*	Návar 2010b
B = (5338.61 + (18.635*d130^2*Ht))	*Pinus patula*	(Aguirre-Salado, et al.,2009)
B = (5.338 + (0.018635*d130^2*Ht))	*Pinus patula*	Figueroa-Navarro et al 2010
B = (10^-0.8092*(1*AB130*Ht)^0.8247)	*Caesalpinia coriaria*	Martínez-Yrizar,et al.. 1992
B = (Exp(-2.4099)*d130^1)	*Tropical wet forest*	Brown et al. 1989
B = (Exp(-3.1141)*(d130^2*Ht*1)^0.9719*1)	*Tropical moist forest*	Brown et al. 1989
B = (34.4703+-8.0671*d130+0.6589*d130^2+0*d130^2*d130)	*Tropical deciduous forests*	Brown et al. 1989
B = (11.509+-3.1229*d130+0.31*d130^2+0.0004*d130^2*Ht)	*Pinus arizonica var. cooperi*	Pimienta et al. 2007
B = (22.3476+-4.947*d130+0.4911*d130^2+0.0039*d130^2*Ht)	*Pinus arizonica var. cooperi*	Pimienta et al. 2007
B = (2543.05*Exp(-56.209/d130) + 1.3)	*Pinus teocote*	Domínguez et al. 2008
B = (2354.14*Exp(-57.453/d130) + 1.3)	*Pinus pseudostrobus*	Domínguez et al. 2008
B = (29.4408*Exp(-26.519/d130) + 0)	*Pinus patula*	Aguirre-Salgado et al. 2009
B = (4371.4*Exp(-70.972/d130) + 1.3)	*Quercus sp*	Domínguez et al. 2008
B = (P * Exp(-1.499 + 2.148*ln(d130)+ 0.207*ln(d130)^2 + -0.0281*ln(d130)^3))	*Tropical evergreen forests*	Chave et al. 2005
B = (P * Exp(-1.349 + 1.98*ln(d130)+ 0.207*ln(d130)^2 + -0.0281*ln(d130)^3))	*Mangrove*	Chave et al. 2005
B = (P * Exp(-0.667 + 1.784*ln(d130)+ 0.207*ln(d130)^2 + -0.0281*ln(d130)^3))	*Tropical deciduous forests*	Chave et al. 2005
B = (0.5+ ((25000 * d130^2.5) / (d130^2.5 + 246872)))	*Conifer forests*	IPCC default equations

B = (0.887+ ((10486 * d130^2.84) / (d130^2.84 + 376907)))	*Oak-pine forest*	IPCC default equations
B = (0.0551 * (d130 * Ht) ^1.3895)	*Pinus maximinoi*	Gonzáles Zárate 2008

Appendix 4. References used to compile the allometric equation database

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