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Proceedings of the regional technical workshop on Tree Volume and Biomass Allometric Equations in South and Central America

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Contents

1. Introduction and objectives

Matieu Henry[1], *Miguel Cifuentes*[2]

Tree resources provide a large number of services such as wood, non-timber forest products, carbon sequestration, regulation of the water cycle, soil fertility, livestock fodder, etc. Assessing these resources, whether from trees inside or outside forests, is increasingly important given the continued degradation they face and the urgent need to design and implement appropriate policies and measures for their sustainable management.

Allometric equations are tools of the trade to quantify volume, biomass and carbon stocks, whether for bio-energy, commercial timber or mitigation and adaptation to climate change purposes. These equations quantitatively describe the statistical relationship between different dimensions of a tree; easy to measure variables are used to predict difficult to determine variables through allometric relationships (Picard, *et al.,* 2012). We assume, for example that the proportions between height and diameter, crown height and diameter, or between biomass and diameter follow similar rules for all trees, big or small, as long as they are growing under the same conditions.

Efforts to improve the accuracy of forest biomass and carbon stock change estimates increased with support toward the implementation of the REDD+ mechanism under the UNFCCC (Agrawal, *et al.,* 2011). REDD+ activities aim to reduce green house gas (GHG) emissions from the forest sector in developing countries, supported by a fair positive incentives system for participating developing countries while applying the principles encouraged by the UNFCCC. Decision 4/ CP.15, paragraph 1(d) (UNFCCC, 2009) “Requests” Parties to develop a national forest monitoring system (NFMS), and that countries must follow the most recent methodological recommendations issued by the IPCC, as adopted or encouraged by the COP, as a basis for estimating the sources of anthropogenic GHG emissions, their removal by sinks, and for measuring carbon stocks and changes in forest area (UNFCCC, 2009). The basic equation to assess emissions by sources and removals by sinks is based on activity data and emission factors (IPCC, 1996). Changes in forest carbon stocks through time are best appraised by a combination of remote sensing and field-based measurements.

Spatial and temporal variation in above-ground carbon is the largest source of uncertainty in measuring forest carbon change factors (Angelsen, 2008, Pelletier, *et al.,* 2011). Changes in forest carbon, or emission factors, are defined either as the average emission rate of a given GHG for a given source, relative to units of activity, or the average carbon stock increase, in the case of net removals. Estimations of emissions and removals can be obtained in different ways. Therefore, the IPCC has classified the methodological approaches in three different ‘Tiers’, which vary according to the growing quantity of necessary information and the degree of analytical complexity (IPCC, 2003, IPCC, 2006). While Tier 1 is the basic method and can be implemented using the default emission factors provided in the IPCC Emission Factor database[3], Tier 2 and Tier 3, which are meant to be more accurate methods, use more country specific emission factor depending on the targeted accuracy and complexity of measurement processes and analyses. Allometric equations (AE) used to predict biomass from tree diameter are of great importance because estimates of biomass per area in inventory or calibration plots are estimated as the sum of individual tree biomass across all trees in a plot, and individual tree biomass is estimated from tree characteristics (*e.g.,* trunk diameter, height, and wood specific gravity) using allometric equations.

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Several authors report the inappropriate use of tree allometric equations can result in important errors in estimating biomass, carbon stocks, and emission factors (Chave, *et al.,* 2005, Melson, *et al.,* 2011, Henry, *et al.,* 2011). Differences among estimates can reach upwards of 400% in some cases (Alvarez, *et al.,* 2012). To ensure implementation of an adequate robust national forest system able to provide reliable estimates of emission factors, it is important that tree allometric equations are used in the appropriate way. Thus, systematic errors in the allometric equations applied to trees propagate to plot-level errors (Chave, *et al.,* 2004, Molto, *et al.,* 2013), and then to national GHG (greenhouse gas) inventory.

Models for volume, biomass or nutrient content within the trees belong to the same class of models. In addition, methodologies for sampling trees and for fitting and using the equations are similar (Chave, *et al.,* 2004). All these models have the objective of evaluating some difficult-to-measure tree characteristics (*e.g.,* volume and biomass) from easily collected data such as dbh (diameter at breast height), total height, or wood density. Despite their apparent simplicity, these models have to be built carefully, using the latest regression techniques. An unsuitable application of biomass equations may lead to considerable bias in carbon stocks estimations. Biomass allometry varies systematically among tree species and sites, plant species and soil types as well as with individual tree age and local environment (Saint-André, *et al.,* 2005, Henry, *et al.,* 2010, Couturier, *et al.,* 2010, Nogueira, *et al.,* 2008). These differences are large and important for biomass estimates: different allometric equations applied to the same field measurements of tree diameter and height yield highly variable biomass estimates (Melson, *et al.,* 2011, Kenzo, *et al.,* 2009, Henry, *et al.,* 2010). Forest researchers in tropical countries lack species-specific, site-specific, ecosystem-specific allometric equations for assessing volume, biomass and carbon stocks needed to report emission reductions for REDD+. Often, the number of tree species may exceed 300 species per hectare (Gibbs, *et al.,* 2007) and it is not practical to develop tree allometric equations for the large diversity of tree species.

Before this event, a regional workshop on tree allometric equations had never been implemented and there is no overview available on tree allometric equation development for Latin America. An overview of data and efforts being implemented in the region is particularly relevant when similar forest types and capacities are present in different countries. A regional approach to support expensive measurements such as tree allometric equations is an efficient way to improve accuracy of measurements and reduce their cost. The main aim of the regional workshop was to identify the gaps and the needs in knowledge related to tree volume and biomass allometric equations in South and Central America. The regional workshop had the following specific objectives:

- Share the status of a compilation of existing tree allometric equations in Latin America;
- Identify data gaps and develop a strategy for filling them;
- Present practical case studies of application of AE for forest inventories in South and Central America;
- Present regional initiatives supporting volume and biomass allometric equations in South and Central America;
- Assess methods to improve the construction of allometric models for tropical tree biomass;
- Support networking of stakeholders involved in the development of tree allometric equations in Central and South America;
- Identify future research and implementation steps

2. Importance of allometric equations for national forest biomass assessment

Status of forest biomass and carbon stock assessment in South and Central America

Lars Marklund[4]

Introduction

This short summary is based on the Global Forest Resources Assessment (FRA) 2010 dataset, which in turn is based on data officially submitted by countries to FAO (FAO,2010). It looks at data availability and methods used for estimating national biomass and carbon stocks.

Methodology

Country reporting to FRA follows a comprehensive set of guidelines to ensure a transparent and consistent reporting over time. Countries are requested to provide best possible estimates on a large number of variables, including forest area, total stocks and stocks per hectare in terms of standing volume and biomass and carbon of all pools included in the IPCC guidelines.

If possible, national data or equations on volume and biomass should be used, and as a last resort, use the default values and expansion and conversion factors provided in the 2006 IPCC Guidelines (IPCC,2006).

Results

An analysis of the 21 countries and territories in South and Central America shows that 17 countries reported on growing stock and 16 reported on biomass and carbon. Among those not reporting we find countries like Ecuador, El Salvador, Paraguay and Venezuela. The reason given is lack of information.

Most countries have derived their forest area data from remote sensing derived maps. Only three countries have used national forest inventory (NFI) data to estimate forest area.

Seven countries have fairly recent NFI data that have been used for growing stock estimates. Recent NFIs have most likely used allometric equations although not always documented in the FRA country reports. Two countries have estimated growing stock by a reverse application of biomass conversion and expansion factors on existing national biomass estimates. Seven countries have estimated growing stock using data from partial inventories, management plans, etc.

Three countries (México, Guatemala and Honduras) have applied biomass equations on NFI data, and four countries have applied nationally "estimated" stocks per hectare. Remaining countries have used growing stock data as a basis and applied either a combination of wood density and biomass expansion factors, or directly applying biomass conversion and expansion factors. A few countries (Argentina, Brazil) have done this estimation by region or biome in order to come up with a national estimate. For below-ground biomass estimates, most countries have used the default IPCC root-shoot ratio.

In order to estimate carbon, most countries have applied a carbon fraction of 0.47 as recommended by the 2006 IPCC guidelines (IPCC,2006). A few have applied a fraction of 0.5 as of the 2003 IPCC Good Practice Guidance (IPCC,2003).

Conclusions

Growing stock data are still very weak in many countries, and some important countries completely lack growing stock data useful for national estimates. Other important countries rely on partial inventory data for their growing stock estimates. Biomass and carbon estimates are in most cases based on growing stock data, and only a few countries have used national biomass data.

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Many countries are currently in the process of updating or elaborating new forest maps as well as planning and implementing national forest inventories, so better data on forest area and growing stock will soon be available. Still more empirical biomass data are needed to develop and validate allometric equations in order to provide better national estimates of biomass and carbon stocks.

Impact of tree allometric equations on forest carbon stock changes

Matieu Henry[5]

Introduction

Allometric equations are the basis for estimating volume, biomass and carbon of trees in all types of land use, particularly in tropical forests. IPCC guidelines identify five carbon pools and at least three of them are estimated using allometric equations (aboveground biomass, belowground biomass, and dead wood). In this presentation, Allometric Equation is defined as the relationship between the relative increases between the different compartments of trees, for example between the diameter and tree biomass. There are different types of allometric equations based on objectives and the method used. Equations can use one or more inputs such as diameter, wood density, tree height, crown diameter. In addition, output variables can be biomass or volume and for different tree components, from the bark to total biomass.

Thus, there is a multitude of allometric equations and results will differ depending on equations used. Also, adequate use of allometric equation is crucial to obtain comparable estimates of emission reductions, particularly in the context of REDD+. Many sources of error are arising from the use of allometric equations; those are related to the interval of validity, considered explanatory variables, identification of tree species, measurement errors and extrapolation of results from the field to the national level. To estimate forest biomass at the national level, many allometric equations available (for a tree species, a climate zone, a forest type etc.). Also, there is never only one possible to estimate the national biomass and in all cases, a decision tree will be developed to identify how biomass is estimated for all trees at national scale. The objective of this presentation is to show the magnitude of the impact of allometric equations on carbon stock changes.

Impact of selecting allometric equations on carbon stocks

Most current scientific papers compare the impact of allometric equations on carbon stocks. The differences obtained between allometric may be significant, sometimes of the order of 2 or 3. The calculation of forest carbon stocks then encountered a multitude of allometric equations and the need to draw on the expertise and identify scientific hypotheses to justify an approach. Depending on different land transition forms (deforestation, forest degradation etc.), allometric equations will results in different forest carbon stock changes.

Impact of selecting allometric equations on carbon stock changes

To analyze the impact of allometric equations on changes in carbon stocks, we simulate a scenario of deforestation and degradation of three forest types in sub-Saharan Africa. Different allometric equations are selected and compared. It appears that carbon stocks are significantly different depending on the use of an equation or another. Significant differences persist in a scenario of deforestation. In the case of forest degradation scenarios, the differences are not significant and non-significance could be related to decreases in stocks that may important. When going on a regional scale, it appears that the differences in terms of emission reductions can be achieved between 7 and 20%. Furthermore, allometric equations have an impact on emission reductions and depending on the selection of an equation or another, reducing emissions can be more or less important. The selection and use of allometric equations must be done carefully to minimize uncertainty related to forest carbon stock change assessment.

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Manual for building tree volume and biomass allometric equations

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Introduction

Many forest services, such as timber and fuelwood production, but also climate change mitigation through the forestry sector for example, require accurate estimations of carbon stocks. Allometric equations (AEs) are of great importance in this regard, because they are the most used tool for predicting forest volume or biomass from easy-to-measure tree characteristics (tree diameter, height or wood density for example) and statistically determined parameters.

This manual has been designed in answer to a general knowledge deficit and the methodological issues associated with the development of allometric models for estimating tree volume and biomass. Scientists, students, forest engineers and managers as well as forest administrators are not all familiar with the most appropriate and up-to-date model fitting methodologies. R^2 is still the most used indicator of the "goodness of fit" and for equation selection, and the biological meaning of the equations is often not taken into consideration.

Additionally, dataset structure and outliers are not properly considered and engender a loss of precious information; considering that data collection is expensive and time consuming. The objective of the manual is to present the most up-to-date methodologies for tree allometric model development with the originality of starting from the basics on tree growth biology before dealing with the methodologies used for field and laboratory measurement and ending with model fitting techniques and the use of equations.

Methodology

In order to provide the knowledge and methodology to establish accurate allometric equations, the manual is organized into seven steps: (1) information on the complexity of tree growth and biomass allocation, (2) design of a sampling strategy for field measurement, (3) tree measurements in the field and in the laboratory, (4) data entering and shaping, (5) graphic exploration of the data, (6) fitting allometric equations and (7) validation of the models.

Results

The expected results of the manual's publication are: increased knowledge on tree biology; improved understanding of the importance of data collection and entering (errors made during these activities cannot be corrected afterwards); technical fieldwork advice being applied; more robust models developed (especially models including correction of the natural heteroscedasticity in tree characteristics); and more accurate tree and forest biomass and volume estimates.

Discussion

The advantage of the manual is that it will provide an exhaustive knowledge on allometric model development, integrating biological sciences with fieldwork experiences and statistical methodologies. The manual contains practical examples to guide and help the reader to acquire knowledge through practice. Although it has been designed for a wide range of users the manual does require some understanding of biology and mathematics that might make it not easily readable for politicians and decision makers. A 20 pages summary has been developed to give an overview of the manual main steps.

Conclusion

By providing the necessary knowledge and practical examples to develop more robust models, forest volume and biomass estimates can be made more accurate, improving the forest carbon stock and carbon stock changes assessment. Further improvement of allometric equation development would

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be in a technical capacity, in order to better consider the variability of wood density within a tree - as an important explanatory variable of tree biomass. More generally, integrating approaches to tree allometry for biomass estimates (height-diameter relations, biomass expansion factors, etc.) would lead to a great improvement of forest carbon stock and carbon stock change assessment.

3. Country experiences in developing tree allometric equations

Development of tree allometric equation in tropical rainforests in Costa Rica

Federico E. Alice[7]

Introduction

The Universidad Nacional de Costa Rica has been supporting research aimed at increasing the availability and reliance of forest carbon estimates for tropical forests and tree plantations in Costa Rica. Initially intended to support ongoing efforts to restore degraded lands through carbon financing, it was soon evident that important gaps of knowledge existed for most of the country's ecosystems and carbon pools. Furthermore, for those areas for which local carbon estimates and allometric equations existed, these were based on a few set of data, with limited representation of diametric classes, species, and in most cases, only considering aboveground tree biomass.

Therefore, since then and for the past 8 years, research has focused on filling in these gaps through site and species specific estimates and allometric equations. Now, with the support of the National REDD+ strategy and GIZ, it is expected that the project will continue to provide useful forest carbon data for the rest of the country.

Methodology

For both, forest and tree plantations, temporary sampling plots are used to determine trees that will be harvested and weighed and for which samples will be taken from all tree components (including roots). Sampled plots are also used to determine carbon content for all other pools besides tree biomass (*i.e.* dead wood, litter, herbaceous vegetation and soil).

The only difference from other tree harvesting methods corresponds to the way tree selection is performed in natural forest ecosystems. In these, instead of choosing just one tree with average DBH, trees are divided into diametric classes and for each class, the species with the highest IVI and average DBH is harvested.

Allometric equations are then developed for each tree component, individual tree and at the ecosystem level (C ha^{-1} in all carbon pools), being this last one, the most significant difference from standard allometric equations found in the literature.

Results

So far, more than 500 trees have been harvested and allometric equations, together with carbon fraction, biomass expansion factors and shoot to root ratios have been developed and published. These account for humid tropical forests of the Costa Rican Caribbean Region and approximately 13 species used in forestry and agroforestry systems in the country. As explained before, equations exist also at the ecosystem level, although these do not include soil carbon.

Disussion and Recommendations

As usually discussed, research is time consuming and labor intensive, especially taking into consideration that through our tree selection method, more trees are harvested per sampling plot. However, this slight deviation from standard methods has allow us to obtain estimates from the most representative species found in these ecosystems which still account to a broad range of species (±40).

The results from our research have always supported the need for site and species specific data, especially in tropical ecosystems were significant differences exist when using IPCC default values

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and generic equations. However, faced by the need to provide data for national estimates in a way that is reliable but also accessible to decision makers and those in charge of national forest and carbon inventories, we are confronted to the consideration of grouping data into one country equation. Still, for these to be feasible, efforts will be required to obtain data from a broad range of ecosystems.

Conclusion

For these reasons, we are currently working in those less studied ecosystems which, in the case of Costa Rica, correspond to high altitude forests (above 1000 m.a.s.l.) and tropical dry forests.

Biomass allometric models in Chile

Rafael Rubilar Pons[8], *Eduardo Acuña Carmona*

Chile has approximately 16 million ha of forest land with 2.2 million ha of exotics mainly dominated by *Pinus radiata* and *Eucalyptus globulus* and *E. nitens* exotic plantations. Native forest and exotic plantations have had complete different scenarios development in terms of allometric equations models to estimate individual tree or stand growth and biomass. In the case of exotic plantations, an advanced growth and yield model "Modelo de Simulación Nacional" started in the 90´s (Peters,1989-1992) and has been used as the unique tool to generate estimates of forest production across the land. The model was derived based on a system of permanent and temporal inventory plots with long-term information and considering a growing region "Zonas de Crecimiento" system determined by soil & climate conditions. However, this highly accurate G&Y model and simulation system lacks a system of equations for site specific biomass estimates. Individual biomass models from New Zealand (Madgwick,1994) has been used by Corvalan *et al*. (2011) to estimate age-biomass components fractions, applied to total volume G&Y model estimates and converted to stand biomass estimates. However, overseas models have been found to have bias, particularly for older age stands for which biomass and C sequestration estimates have been rarely generated (Cartes, *et al.,* unpublished). New efforts are being developed to provide accurate biomass allometric models for estimating available biomass for energy purposes after harvesting of traditional exotic stands.

There are no broadly local published or developed equations on belowground biomass components (coarse and fine roots) except for (Gayoso and Guerra,2005, Rubilar, *et al.,* 2005, Rubilar, *et al.,* 2013, Rubilar, *et al.,* unpublished). Additional gaps on individual tree growth and biomass equations are being generated by short rotation forest crops (SRFC) plantations that are being currently subsidized by the Chilean government. Early results on biomass equations for SRFC are being generated for most promising species by Esquivel *et al*. (2011) and Acuña *et al*. (unpublished). In addition lacks of information exist on converting appropriately volume estimates on biomass estimates due to the limited sampling information on specific gravity that may account for site specific estimates.

Native forest occupies 13.5 million ha where *Nothofagus* (54%) and Evergreen forests (31%) dominate. Limited efforts have been carried on developing allometric models for native forests except for some *Nothofagus* species with commercial value (*N. alpina, N. pumilio*). Despite that large number of local thesis and publications have provided estimates for volume equations, Drake *et al*. (2003) presented a compendium of 60 local volume equations at country level from various authors where 80% included Nothofagus species (*N. alpina* 47% & *N. pumilio* 24%), other equations included evergreen species (various species) and sclerophyllus species which included *Quillaja saponaria* (Prado and Aguirre,1987, Leiva,1995), *Acacia caven* (Aguirre and Infante,1988) and *Lithraea caustica* (Prado, *et al.,* 1987). Other studies have included less investigated species such as *Araucaria araucana* (Corvalán,1998).

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Limited information exists on allometric biomass equations in Chile for native forest. Gayoso *et al*. (2001) carried on one of the largest national projects for C accounting where he considered 14 species (2 forest types) from Evergreen and Nothofagus species at 13 sites distributed in the Andes and at the Southern Coastal Range (37 °S – 41 °S). Biomass equations where generated on this project for aboveground and belowground components based on stump, breast height and/or height for major evergreen species (*Aextoxicum punctatum, Amomythus luma, Dasyphyllum diacanthoides, Drimys wintery, Eucryphia cordifolia, Gevuina avellana, Laurelia sempervirens, Laureliopsis philippiana, Persea lingue, Saxegothea conspicua, Podocarpus nubigena and Weinmannia trichosperma*). Detailed estimates (*e.g.* specific gravity) and sampling were considered for aboveground biomass estimates including also forest floor and understory at the site level. More broadly published studies have been not developed for local use.

Allometric equations in Chile, in particular for biomass models, have focused on exotics with high demand for sawn timber and pulpwood, and currently SRFC plantations. In these cases efforts focused initially on C sequestration but now bio-energy needs have increased interest on biomass as a raw material. Native species information is particularly limited to also commercial species with sawn timber or agro-forestry potential, or other species with non-traditional commercial use. A major effort is required to obtain estimates that may provide C sequestration estimates across the land.

Major gaps and needs for allometric biomass models development should focus on its goal and spatial implication of equations (local, regional, country) estimates. This will allow making appropriate considerations on sites, stand characteristics, silvicultural management, and genetics for stand selection strategy. In addition biomass estimates should consider carefully underlying assumptions on ephemeral and non-ephemeral biomass components and the need for nutrient or carbon estimates. Key methodological aspects should consider avoidance of mean tree methods, number of sampled trees, sampling based on diameter or basal area distribution, specific gravity components, testing site specificity of equations and bias correction, and inventory quality to scale up individual tree data to stand level. There are major opportunities & challenges to LIDAR, RADAR and other remote sensing indirect methods to provide biomass estimates. However, all these methods need to be tested appropriately considering the structure of forest type and its variability. Larger opportunities on this regard have been shown for plantations and simple structure forests.

Allometric equations and carbon measurements in forests in Guatemala

Edwin Castellanos[9]

Introduction

Our research center at Universidad del Valle de Guatemala has been making carbon measurements in terrestrial ecosystems for the last 15 years. Measurements have been completed as part of different initiatives with the objective of developing base information for projects related to carbon credits both in natural and planted forests. We have sampled over 100 forest sites completing over 1,600 forest plots to estimate biomass and we have done destructive sampling in various occasions to develop allometric equations to estimate biomass for various tree species.

Methodology

After selecting a particular species of interest, we have identified individuals of different ages and diameters located in similar site conditions to harvest. In all cases, we cut down at least 10 individuals after measuring its standing dimensions. The different components are weighed separately (bole, branches, small branches, leaves) and samples are taken for the laboratory

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analysis. In no case, we have weighed or sampled the root system. In the lab, samples are dried at 50 ºC to constant mass and then processed to be analyzed in for carbon and nitrogen content using a combustion elemental analyzer.

Results

We have developed a total of 17 equations for commercial tree species both for natural and planted trees and for forest and agro-forestry plantations. In addition to this work, we have also sampled 127 forest sites throughout the country completing a total of 1,672 forest plots to estimate forest biomass. The results from all this work was generalized to the forests in the entire country using the different life zones present in Guatemala. The average carbon content per plot was assigned to each life zone and together with the map showing the amount of forest present in each life zone, we were able to create a map showing the carbon content of all forests in Guatemala. The total amount of carbon present in the forests of the country was estimated to be 414 million tons of carbon.

Discussion and Recommendations

Two limitations with the equations developed for Guatemala through our work have been: 1) the small number of trees sampled per equation and 2) the lack of large trees (DBH > 60cm) sampled. These limitations come from limited funding and time available within a single project to complete the harvesting but also from limited permission from communities or private owners to sample trees, particularly large ones.

Conclusion

The work completed so far in Guatemala sets the basis for future development of more robust allometric equations. The trees harvested so far can also be used to test the utility of regional or generic equations developed by other researchers.

4. Country experiences in developing tree allometric databases

Inventory of volume and biomass tree allometric equations for Central and South America

Miguel Cifuentes-Jara[10], Matieu Henry[11], David Morales[12], Luca Birigazzi[13]

Introduction

The quality of the allometric equations being used will determine in large part the uncertainty associated with any landscape-scale estimate of biomass or carbon. In a study in Panamá, for example, Chave *et al*. (2004) found the choice of allometric model was the most important source of error in biomass quantification; reaching up to 20 percent of the final estimate. Thus, to reduce uncertainty in biomass quantification, forestry personnel must be able to gain access to high quality, locally relevant equations. Despite the large number of equations published in international journals worldwide, the choice of an appropriate one for a given location can become a challenge. In order to support assessment of volume, biomass and carbon stocks in South and Central America, CATIE and FAO developed a database containing the largest available tree allometric equation in 20 countries in Latin America and assembling them into a database structure that can be made available internationally. The goal was to compile, systematize and document existing volume and biomass allometric equations for individual trees, sprouts and stands of 20 countries in Central (Belize, Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua and Panamá) and South America (Argentina, Brazil, Bolivia, Chile, Colombia, Ecuador, French Guiana, Guyana, Paraguay, Perú, Surinam, Uruguay and Venezuela). México was not considered in this analysis because recently inventoried by (Birigazzi, *et al.,* 2013).

Methodology

Volume and biomass allometric equations were compiled by obtaining all possible hard and soft copies of articles, reports and other documents containing such equations. We considered peer-reviewed manuscripts, technical reports, theses, dissertations and other grey literature. All equations found within the available documents were then extracted and relevant information related to their application (geographic location; bioclimatic information; equation parameters, units and statistics) entered into an Excel database. Data compilation was performed following Baldasso *et al*. (2012) for data entry. All equations found in the selected documents were extracted and entered into an electronic database. In addition, relevant information related to their application was also entered. This information includes data on the geographic location and bioclimatic variables of the area where the equations were constructed or applied, equation parameters and their units and common regression statistics.

Results

The database currently consists of 1237 unique equations. Almost 89 percent of those are for forest ecosystems. The remaining equations were derived for plantations (10 percent) and other ecosystems with varying degrees of tree cover (*i.e.* agro-forestry and pastures). Tree equations represent close to 87 percent of all equations in the database. Equations for mangroves, palms and tree ferns are the least common; only 3 percent of records in the database correspond to these growth forms. Liana equations represent 10 percent of the total.

Equations were found for 14 of the 20 countries in Latin America (Figure 1). We were unable to locate equations for Belize, Bolivia, El Salvador, Ecuador, Guyana, or Uruguay. This does not imply allometric equations have not been developed for those countries. Most of equations were located in five countries: Brazil (409), Colombia (253), Argentina (177), Chile (114) and Costa Rica (86).

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Plantation equations are available for Brazil, Chile, Colombia, Costa Rica, Nicaragua, Panamá, Perú and Venezuela. Agroforestry equations were found for Colombia, Costa Rica and Nicaragua because of the prevalence of that type of ecosystems in those countries. A set of equations for trees in pasture ecosystems was only found for Costa Rica.

Despite the regional diversity in ecosystems, distribution of equations is highly skewed; over 90 percent of all equations were constructed for 11 life zones and 95 percent of all equations for 15 of all life zones (Holdridge,1967). The subtropical moist forest life zone has the most equations (477) among all life zones, while the tropical dry forest represents has 268. Close to 18 percent of all equations in the database were constructed for the subtropical wet and subtropical dry forests life zones.

Regarding model fitting methods, approximately 40 percent of all equations those have their output log-transformed. The most common transformation (35 percent) was the natural logarithm transformation (Log base e), followed by the Log10 transformation (5 percent). Almost 10 percent of all equations have an exponential (exp) component. From the remainder equations, 34 percent are square polynomials or include a squared term (X^2). Only 1.5 percent of the equations include a cubic (X^3) term.

There are an approximately equal number of volume and biomass equations for the species names in the database (512 and 528, respectively). The 10 genera with the greatest number of associated equations are *Pinus* (185), followed by *Inga* (96), *Vochysia* (83), *Aspidosperma* (80), *Terminalia* (72), *Protium* (59), *Cecropia* (56), *Eschweilera* (56), *Eucalyptus* (56) and *Ocotea* (55). There are 268 equations associated with unknown species (Table 1) This possibly reflects the widespread use of generalized equations across the region and suggest increased uncertainty in the estimates of volume and biomass (and, thus, carbon) being calculated.

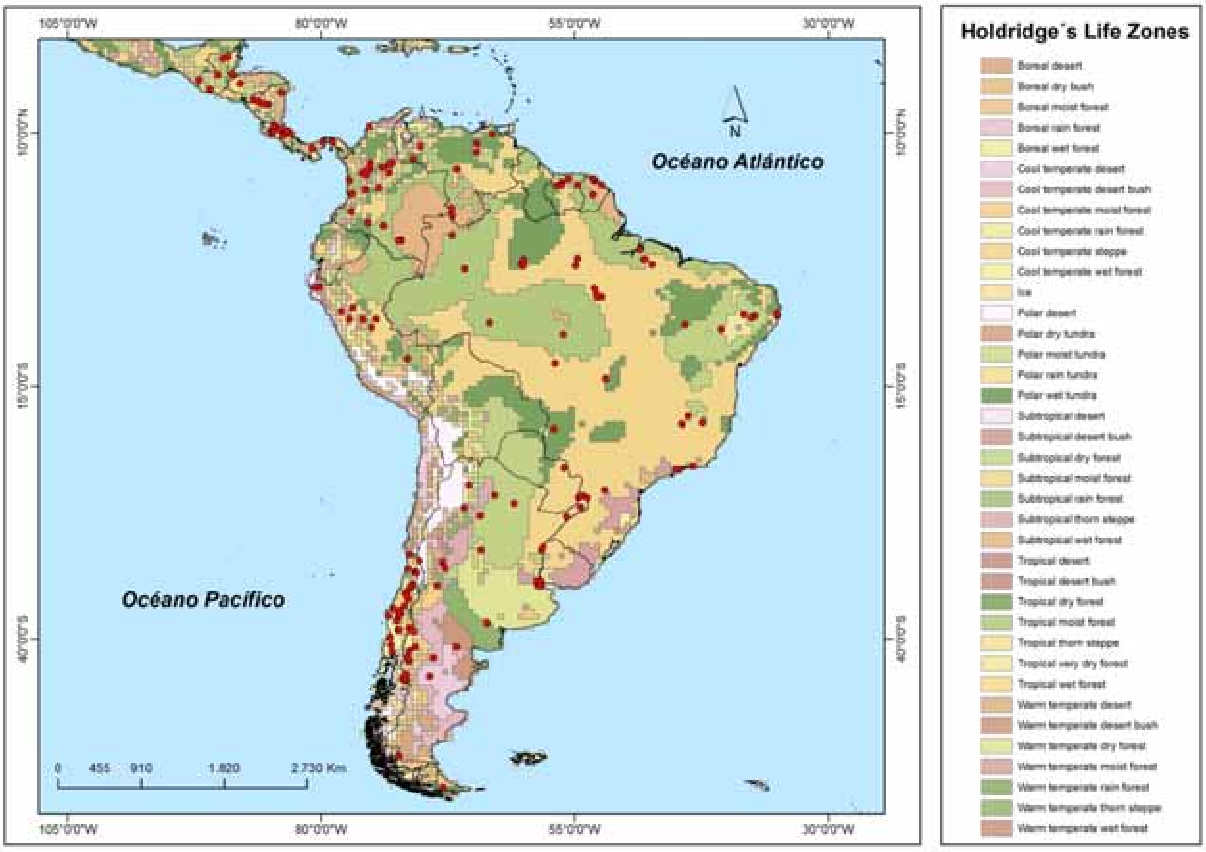

Figure 1: Geographic distribution of allometric equations in Latin America.

Table 1: Distribution of allometric equations among main tree genera in Latin America.

Genus	Number of equations in database
Unknown	268
Pinus	185
Inga	96
Vochysia	83
Aspidosperma	80
Terminalia	72
Protium	59
Cecropia	56
Eschweilera	56
Eucalyptus	56
Ocotea	55

Source: *Cifuentes-Jara et al, (2013)*

Discussion and Recommendations

Lack of completeness is also apparent in other areas. For example, in some instances there is not enough information to properly identify the location of a study site. Only general directions may be given and no geographic coordinates provided to the reader. This complicates retrieving equations that may be applicable to a given region within a country. Having the name of the research site does not a guarantee its exact location either because the same name may be used in two or more regions of the same country.

A critical weakness we encountered was the lack of proper description of the tree components included in any given allometric equation. This is also related to the lack of uniform definitions of tree components and output from allometric equations. For example, a commonly used term in equation reporting is "total aboveground biomass" or "total biomass". However, this may or may not include leaves, dead branches and it seldom includes (0.01 percent of all records) fruits, or explicitly mentions whether the stump of the tree was included in the assessment or not.

Problems with species identification that are common in many tropical forest inventories are also an identified weakness in the data we compiled. To avoid introducing further uncertainty and errors in the database, we remained true to the original sources when it came to plant taxonomy.

The construction of allometric equations is currently biased towards trees in moist and wet forests. Other less common biomes such as dry and very dry forests, cloud forests and other high elevation ecosystems and coastal ecosystems (namely, mangroves), are greatly underrepresented in the available literature. In addition, research is highly biased towards above ground tree components. Currently, the only available large-scale tropical allometric equation available for roots is the one published by Cairns *et al*. (Cairns, *et al.,* 1997). Trees used in agro-forestry systems or growing in silvopastoral systems are grossly under-represented in our sample; 0.6 percent of all records (8 equations). This may be due to the small number of species commonly growing in those systems. Similarly, the d*a*tabase contains equations for only 18 tree species (128 equations, Table 1) used in plantations.

Given the high diversity of species in tropical forests and the logistical barriers to develop a large number of species-specific equations, it is difficult to determine what would be a sensible minimum target number of available species-specific equations for the Latin America.

Conclusion

There is considerable and increasing attention in improving the availability and quality of allometric equations to calculate volume, biomass and carbon in Latin America. Although there seems to be an adequate geographic distribution in the equations catalogued through our efforts, the distribution of equations available per country is skewed, with most of the available equations constructed for a small number of countries and also biased towards trees in moist and wet forests. The lack of allometric equations in other less common biomes such as dry and very dry forests, cloud forests and other high elevation ecosystems and coastal ecosystems (namely, mangroves) needs to be addressed. In addition, increased attention should be devoted to constructing root allometric equations and properly include other relevant but often ignored tree components such as the stump. For countries missing data from the database, additional efforts are needed to locate key local experts and records in each of those countries. Further contacts with local researchers and libraries are thus needed to fully document all available sources of allometric equations.

Geo-referenced database of tree volume and biomass allometric equations for North America

Luca Birigazzi, Matieu Henry[14], Michele Baldasso

Introduction

The quality of tree allometric equations is crucial for ensuring the accuracy of forest carbon estimates. Unfortunately, tree allometric equations are often not easily available especially in developing countries. Since the development of stem volume and biomass equations is laborious and time consuming process existing equations need to be compiled and evaluated to facilitate identification of the gaps in the coverage of the equations. The objectives of this presentation is to provide an overview of the current status of tree volume and biomass allometric equations in North America and to identify the gaps and future needs and provide recommendations for volume, biomass and carbon stock assessment.

Methodology

The literature-survey was conducted on Internet and in specialized libraries and it is mainly based on the two main contributions of Jenkins *et al*. (2004) and de Jong *et al*. (2009). During the data collection, both the hard and soft copies of all the documents cited in the database were collected. Once the documents were collected, the data were organized, geo referenced and slightly adjusted in order to make them consistent with the template database that was being elaborated. As there is not a unique way to define the vegetation components, in order to standardize the information provided by the original sources, an harmonized classification of 11 different tree compartments have been developed. 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. The locations were categorized according to five ecological classifications.

Results

Almost the 70% of the equations were developed in USA, the 18% in Canada and 13% in México. According with the FAO Global ecological zoning for the global forest resources assessment, most of the equations were developed in temperate mountain system (29%), temperate continental forest (28%), and sub-tropical humid forest (24%). The other 13 zones represent less than 18%. 266 species are present in the database, belongings to 116 genera and to 61 families. The families most frequently studied were Pinaceae, representing the 36% of the equation, Fagaceae 14% Aceraceae 8%, Betulaceae 7%, and Salicaceae 6%. The most studied species were *Pseudotsuga menziesii* with the 5% of total equations, *Acer rubrum* 4%, *Populus tremuloides* 2%, *Acer saccharum* 2%, and *Olneya*

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tesota 2%. If comparing these data with Global forest resources assessment 2005, 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 México. On the whole, equations for stem (considering both the equations including and excluding bark) represent about the 41% of the total. The interest in the roots and whole tree biomass (above + belowground) are significantly lower (1.8% and 1.7%, respectively).

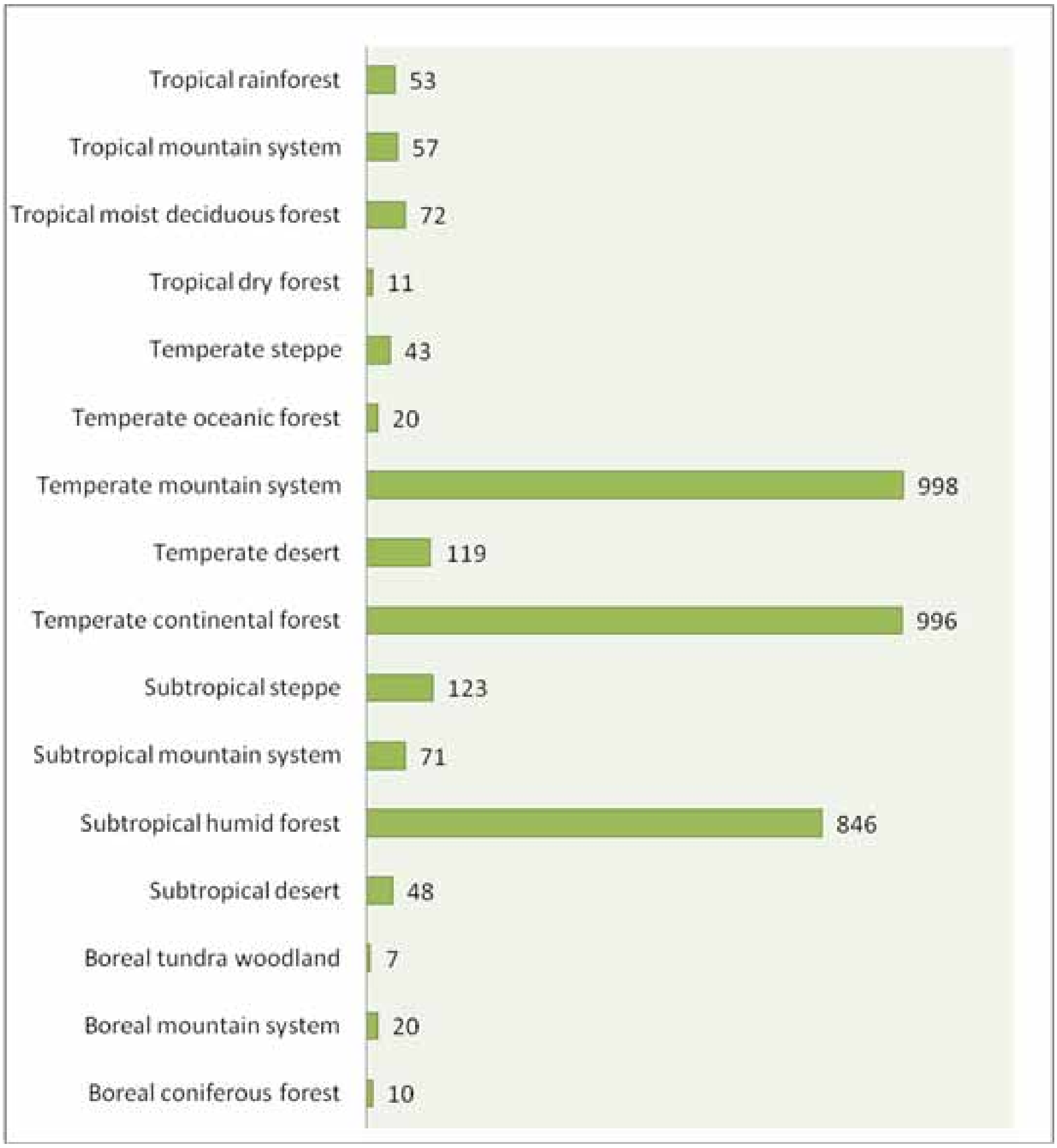

Figure 2: Distribution of tree allometric equations in ecological zones of North America (México, USA, and Canada). Ecological zones as defined by FAO (2001)

Discussion and Recommendations

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 México there is a smaller number of available equations. It appears that three of the 14 ecological zones occurring in North America have more than 80% of the total equations. Important and widespread biomes, such as boreal coniferous forest, tropical rainforest, and 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%.

Conclusion
This database 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. It would be important to update the database by conducting a literature review for USA and Canada for the period after 2003. For México 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. 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 México; 4) to stimulate allometry research for tree aboveground components.

Tree allometric equation database in México

Luis Alberto Rangel García[15]

Introduction
México is advancing in its readiness process for implementing REDD+. As part of this process, the National Forest Commission (CONAFOR), with support from the Strengthening of REDD+ Readiness and South-South Cooperation in México Project, is developing an MRV system. The protocol to estimate carbon stocks and its changes in aboveground biomass is a component of the MRV system. The protocol consists of a series of standard steps and semi-automatic tools based on México's National Forest and Soils Inventory (INFyS) dataset, a taxonomic catalog, a set of allometric models developed for the particular conditions of the country's forests and other complementary datasets (*e.g.* wood density and carbon concentrations) developed by local research centers and published in the scientific literature.

The amount of available information from the INFyS and on allometric equations (AE), and the need to make the most efficient use of it to obtain robust estimates of carbon stocks and carbon stocks changes, required the development of new database tools that ensures a standardized and systematic framework to select allometric equations to estimate national biomass and carbon stocks. Taking advantage of available IT tools, the project's relational database was redesigned so it can be exploited to its full potential. International standards of information handling and communication of large volumes of data among multiple platforms and systems (Matlab, R, SAS, ArcGIS, Business Intelligence, Dashboard, etc.) were followed. The following article describes the portion of the database catalog related to the compilation of allometric models and their relationship with the INFyS database.

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Methodology

A large number of Relational Database Management Systems (RDBMS) are available to manage large volumes of data efficiently under a variety of technologies and applications such as backup and recovery systems, concurrent queries, documentation, security, rights management, data integrity, software development tools, etc. Although it would be possible to use a variety of tools (*i.e.* MySQL, Oracle, DB2, PostgreSQL, Informix, etc.), we decided to use Microsoft SQL Server 2008 because its compatibility of CONAFOR's current database system.

The relational database we developed includes base tables, relational tables and catalog tables. Base tables contain basic information on the allometric models: equation, variables, constants, geographic location (where it was constructed), dasometric information, authors, and statistical information. Relational tables allow us to assign one or more genera and/or species, and/or vegetation type to the model. This allows us to follow any number of decision trees that have been developed: assigning a model depending on the availability of AEs by genus, species (according to the taxonomic catalog), or vegetation type (INEGI, ecological zones, FAO, Hansen, Holdridge Life Zones, etc.). Catalog tables enable us to generate a unique relationship with an ID number, and share the catalog(s) with other sources of information (wood specific gravity, carbon fractions, etc.). This approach allowed us to create a database that is compatible with the INFyS database and flexible enough to be able to adapt to new sources of information.

The catalog is made up of 341 allometric models divided into 281 by species, 48 by genus, and 12 by vegetation type. To further manage this information, a web tool was developed to allow access to the allometric models' information, graph the models, compare estimates among models and enter new models. This tool was developed using PHP5.0 and is available at www.mrv.mx. Using the tool requires having a user name and password.

The most frequent metadata found while reviewing publications and data compilations were: publishing date (81.5%), state within México where the equation was constructed (66.3%), minimum and maximum diameter (61.9 and 60.1%, respectively), minimum precipitation (47.5%), and R2 (36.7%).

Discussion and Recommendations

We recommend the following to design a relational database:

- Use consistent and clearly defined names for tables and columns (metadata)
- Table names in singular
- Variable names must not include spaces
- Use identifiers and indexes
- Manage permissions and authentication
- Data integrity (QA/QC, null values, foreign keys)
- Document through entity-relationship charts
- Use internationally-recognized standards (ISO, ANSI)
- When possible, use standard catalogs

The web tool (*i.e.* the model library) was extremely useful to manage information and graphically compare among equations. The existing database structure allows us to develop tools like this one relatively quickly to rapidly obtain additional gains from the data: on-line access from remote locations, data QA/QC, adding new models to the library, security, simple graphic comparisons of model behavior, real time information if the entry or editing of new models is done by different users and/or locations.

This approach has the drawback of requiring a group of interdisciplinary experts in IT, botanical taxonomy, and allometry.

Conclusion

México has a large number of allometric equations available. Since they were developed with different goals in mind, they have different characteristics, are very heterogeneous at the local and regional scale in terms of species and diameter ranges. Integrating this national database within the MRV system allows us to strengthen the development and generation of official information at the national scale.

Because reporting of models' metadata is commonly incomplete, only 138 of 340 allometric models are being used to estimate the national biomass and carbon stocks. An additional effort must be made to complete as many model parameters as possible. This will increase the quality and amount of information available in the database, which can be used to follow the decision trees developed to choose a suitable allometric equation among many available.

Biomass and carbon database for the Brazilian biomes

Carlos R. Sanquetta[16]

Introduction

Brazil is carrying out its new National Forest Inventory (NFI). The demands for information from NFI are increasing due to the importance of forests regarding climate change, especially in Brazil, a country that has about 13% of the world's forests. On the other hand, there is not a single database regarding biomass and carbon stocks and dynamics for use in NFI. This project aimed to gather all available information already published in the country regarding data and equations on biomass and carbon.

Methodology

The project is supported by the company PETROBRAS, with implementation by the Center of Excellence for Research on Biomass and Carbon of the Federal University of Paraná - BIOFIX and its partners. The methodology includes a literature review of scientific publications, internet, libraries and visits to research centers, as well as interviews with experts. A databank is under preparation taking into account the Brazilian biomes, forest types, both natural and planted forests. The databanks contains the identification of the publication, authors, geographic location of the study, species studied, methods used, biomass compartments analyzed, allometric equations, expansion factors, etc. All data are implemented in the platform ARGIS, which allows us to perform various analysis, including generating a map of biomass and carbon stocks by biome and for the whole country.

Results

The project identified 1,247 citations, 852 for natural forests and 395 for forest plantations. For natural forests, 221 were for the Amazon biome, 521 for the Atlantic Rain Forest, 64 for the Dry Semiarid Savanna, 25 to the Savanna, and 21 to the Wetlands. For the plantations, 356 are in the Atlantic Rain Forest, 18 in the Dry Semiarid Savanna and 21 in the Savanna. The weighted average carbon stocks calculated according to the area of each forest type were: Amazon: 233.31 t ha^{-1} of biomass and 138.24 t ha^{-1} of carbon; Atlantic Rain Forest: 208,62 t.ha^{-1} of biomass and 83.55 t ha^{-1} of carbon; Dry Semiarid Savanna: 30.63 t ha^{-1} of biomass and 12.15 t ha^{-1} of carbon; Savanna: 79.57 t ha^{-1} of biomass and 31.83 t ha^{-1} of carbon, and Wetlands: 89.10 t ha^{-1} of biomass and 35.64 t ha^{-1} of carbon. For the plantations the figures are: Atlantic Rain Forest: 111.50 t.ha^{-1} of biomass and 44.60 t ha^{-1} of carbon; Dry Semiarid Savanna: 78.82 t ha^{-1} of biomass and 38.59 t ha^{-1} of carbon, and Savanna: 105.10 t ha^{-1} of biomass and 42.00 t ha^{-1} of carbon. Further analyzes are being performed and maps produced.

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Discussion and Recommendations

There are lots of publications, but concentrated in certain biomes and regions of the country due to the fact that few institutions devote themselves to the subject. Many forest types are not included and many information gaps exist. There is great diversity in the methodologies employed, and some studies consider only biomass, others only carbon, some fit equations others not. It is necessary to standardize procedures by establishing protocols and mechanisms to use the information in the NFI.

Conclusions

The study will be helpful in the predicting biomass and carbon stocks for the Brazilian biomes, contributing to the NFI and overseas reports, such as the FAO’s FRA. Improvements of the databank are underway, especially regarding the integration techniques for the existing information.

5. National Forest biomass assessment and accuracy assessment

Protocol for estimating carbon stocks in forest biomass of México

José María Michel[17], Lucio Santos, Oswaldo Carrillo, Adriana Rodríguez, Rafael Mayorga, Luis Rangel, Olaf López, Rebeca Aldana, Perla Sinco, Sergio Villela, Miriam Andrade Javier Fernández, Fernando Casanoves.

Introduction

México is advancing in its readiness process for implementing REDD+. As part of this process, the National Forest Commission (CONAFOR), with support from the Strengthening of REDD+ Readiness and South-South Cooperation in México Project, is developing an MRV system. The protocol to estimate carbon stocks and its changes in aboveground biomass is a component of the MRV system. The protocol consists of a series of standard steps and semi-automatic tools based on México's National Forest and Soils Inventory (INFyS), a set of allometric models developed for the particular conditions of the country's forests and other complementary datasets (*e.g.* wood density and carbon concentrations) developed by local research centers and published in the scientific literature.

The development of this protocol will allow CONAFOR to ensure México has estimates of carbon stocks and carbon stock changes that are transparent, precise, consistent, and that support REDD+ implementation and GHG emissions reporting for the LULUCF sector included in México's National Communications to the UNFCCC and any subsequent updates to those reports.

Methodology

Field data used to estimate carbon stocks comes from the INFyS, which is based on a systematic stratified sampling with approximately 26000 sampling units (*i.e.* "conglomerates") measured every five years in sets of 5000 conglomerates. INFyS has completed two re-measurement cycles (2003-2007 and 2009-2012). Tree size data are the main output of the protocol.

To estimate biomass, a total of 340 allometric equations were compiled, together with their DBH range, r^2, MSE, and more than 600 individual wood density values and carbon concentrations for tree species.

The general procedure to estimate biomass carbon is based on the use of allometric equations, wood density values, and carbon concentrations by species, when available. If these are not available, generic allometric equations, or average values for wood density and carbon concentrations are used. Most of México's allometry focuses on generating models for individual species and genera (most of them timber species). The protocol makes the best use of any available information.

Results

The protocol consists of the following 7 steps:

1. *Taxonomic and dasometric depuration of forest inventories:*

Taxonomic depuration consists of a series of steps to ensure the quality of Latin names in the database, including: the initial integration of the original data, detection and correction of typographic inconsistencies, correcting synonyms and family assignments, biological forms, authors, and sources. During the dasometric depuration the INFyS period is chosen, and then variable names, live/dead condition, and taxon selection are verified, variables are standardized, life forms are

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verified, and inconsistent data are flagged. The final output is a database consolidated and validated.

2. *Assigning and running tree allometric equations on individual trees from forest inventories:*

The biomass allometric equation is used according to the tree's DBH. Equations are chosen hierarchically (species – genus – vegetation type) and considering R^2, MSE or geographic location (the area where the equation was derived for). Biomass per individual is estimated and then carbon stocks by conglomerate are calculated.

3. *Stratifying the population of conglomerates:*

This is done to reduce the variability in the estimates of carbon stocks by strata and at the national-level. As a first step, all possible stratification and re-stratifications are identified (vegetation classes in INEGI's series under different levels of aggregation and Holdridge Life Zones, or annual precipitation categories). Then, using Monte-Carlo simulation the uncertainty associated to each stratification and re-stratification options is calculated. The stratification with the lowest uncertainty value is chosen as a last step.

4. *Estimating population parameters:*

Main parameters per stratum are estimated: Carbon stocks per hectare, per strata, and at the national level.

5. *Estimating national-level uncertainty associated to biomass carbon stocks:*

Calculated as the sum of carbon per conglomerate through bootstrapping, sum of the samples, estimating stocks per stratum, and, finally simulating national-level carbon stocks.

6. *Interpolating individual data points to construct carbon maps:*

This step helps to visually validate spatially-explicit data representations.

7. *Estimating carbon stock changes following IPCC's "stock change" method.*

Discussion and Recommendations

The protocol is designed so new data can be added. For example, new allometric equations, more wood density or carbon concentrations data. This ensures progressively better carbon estimates.

Areas of improvement are the calculation of the uncertainty associated to each allometric model, and adding other ecosystem components such as leaf litter and coarse wood debris. New allometric equations for classes under-represented at the national level also need to be developed.

Conclusion

This protocol is a first step needed to institutionalize national-level carbon stocks calculations and support the development of a national REDD+ MRV system. This protocol is robust and allows for improvements as newer data are integrated. Its use can also adapt for use elsewhere with a national or sub-national forest inventory.

Tree allometry and the National Forest Inventory of Brazil

Daniel Piotto[18]

The National Forest Inventory of Brazil (NFI-BR), coordinated by the Brazilian Forest Service, was designed to periodically produce detailed information about the country's forest resources. One of the main goals of the NFI-BR is to use this information to support public policies oriented to the use and conservation of forestlands. The NFI-BR methodology includes the collection of primary

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information from different sources such as biophysical information from field inventory, socio-environmental information from interviews with rural householders, and landscape information from remote sensing. The NFI-BR has approximately 22,000 sample points systematically distributed at 20 km intervals that cover the whole country. These sample points are re-measured every five years to monitor the quantity and quality of forest resources over time.

The biophysical information collected in the field plots represents the main source of information to feed allometric models that estimate timber volume and biomass. In the field plots, the NFI-BR crews collect information on the established vegetation, including overstory trees (dbh ≥ 10cm), midstory trees (dbh ≥ 5cm and < 10cm), and understory vegetation (height ≥ 1.3m and dbh < 5cm). In addition, other qualitative information about the established vegetation is collected in the sample plots such as tree form and health.

Because allometric models are not available for several forest types in Brazil, the Brazilian Forest Service has started an effort to compile existing models developed in the country. The main goal is to identify regions of the country where allometric models are scarce or inexistent and then promote and finance research through a network of national institutions to develop new allometric models.

Another ongoing effort is to create a national repository for allometric models and for raw data used to construct the models. The goal is to concentrate all information on allometry in this repository in order to allow researchers to periodically update allometric models as datasets for forest types get larger which will improve estimates of timber volume and biomass over time.

Applications of tree allometric equations for National Forest Biomass assessment in France

Laurent Saint-André[19], Renaud J-P., Longuetaud F., Hervé JC., Deleuze C.

Introduction

In France, 29.7% of land cover area is forests while the Europe average, including Russia is 32.2%. Forest owners are at 75% private and 25% public. The total standing volume is 2.5 billion m^3 which makes France the 4th European country after Russia, Germany and Sweden. Forest composition is mainly made of pure broadleaves stands (67%) and coniferous stands (22%). Twelve tree species contribute to 80% of the total volume of French Forests. The Institute (IFN) in charge of the national inventory has been embedded into the National Geographic Institute in 2012. This institute delivers yearly assessment of forest inventory (it was every ten years before 2008). Results are provided by administrative departments and by Sylvo Ecological Regions: 91 SER (Sylvo Ecological Region delimited from the determinants of forest growth conditions and habitats) and 12 GRECO (Ecological regions; one GRECO regrouping several SER). They can be freely downloaded on the IGN website[20].

[19] INRA-CIRAD, France. standre@cirad.fr
[20] http://www.ign.fr/

Methodology

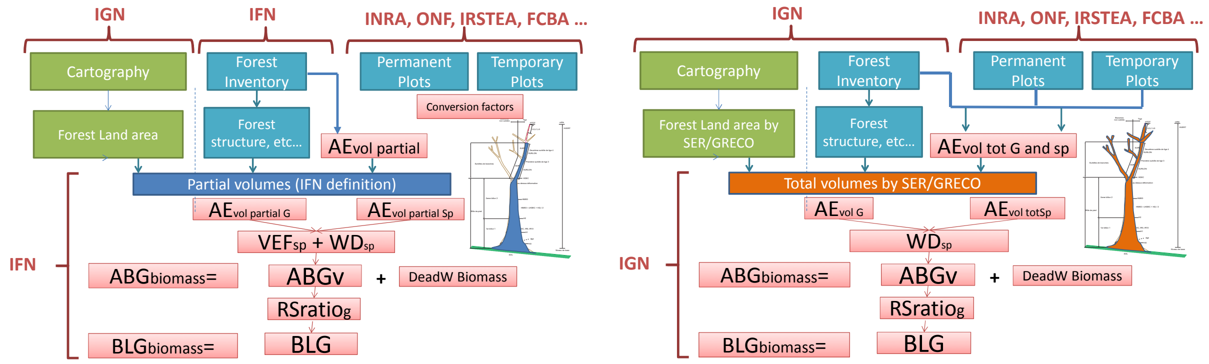

Figure 3: Methodology to assess national forest biomass in France

Before 2004 (Figure 3, left), the carbon stock at national level was calculated from the data coming from IGN (national geographic institute), from IFN (national forest inventories) and partial volume equations elaborated by IFN. Volume expansion factors and wood density data bases (elaborated by research and development institutes) were used to convert volumes to biomass. After 2004, total volume equations have been used (elaborated by Research and Development institutes) at species (6 in all) and pan-specific levels (broadleaves and coniferous) instead of partial ones.

Results

Carbon stocks range between 70 and 80 tC/ha. Total carbon stocks increases regularly since the 80's for two main reasons: an increase over the same period of the forest areas (conversion of abandoned agricultural lands to forest lands) and only 57% of the biological increment is harvested (3/5 for commercial woods, 2/5 for self-consumption energy wood). Higher stocks per ha are found for broadleaves species because of a higher wood density (compared to coniferous species) and a higher proportion of branches.

Discussion and Recommendations

Although it comprised over 4000 trees, the sample used to build the total volume 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 were mainly collected in the northern part of France, data were old (1920-1955) while several factors may have modified the shape of the trees (silvicultural changes, genetic improvement, environmental changes, etc), data have mainly been collected in high forest (half of the forest structure).

A project (ANR EMERGE) was then funded by the French National Research Agency to overcome these limits. It gathers all R&D institute in France. Data have been shared among the 8 institutes through a common database, and a series of common works on this database. It includes 1,106,099 trees from the NFI and 118,505 stems from management and research for volume at 7cm diameter, 20,983 trees with small branches and 31,439 stem profiles from research (old datasheets digitized) for total volume, 6 037 trees sampled for biomass, 1 797 trees sampled for nutrient content and 220 trees have been specifically sampled during the project 2009 et 2010. Improvements of the methodology are the following: the number of specific equations for total volume moved from 6 (+2 general) to 28 (+2 general); volume expansion factors have been modeled for 10 species (+2 general); height-girth relationship have been developed for 36 species (+ 2 general). LiDAR (both terrestrials and airborne) and photogrammetry are at exploratory stages but first results are promising for carbon stocks at both stand and forest levels.

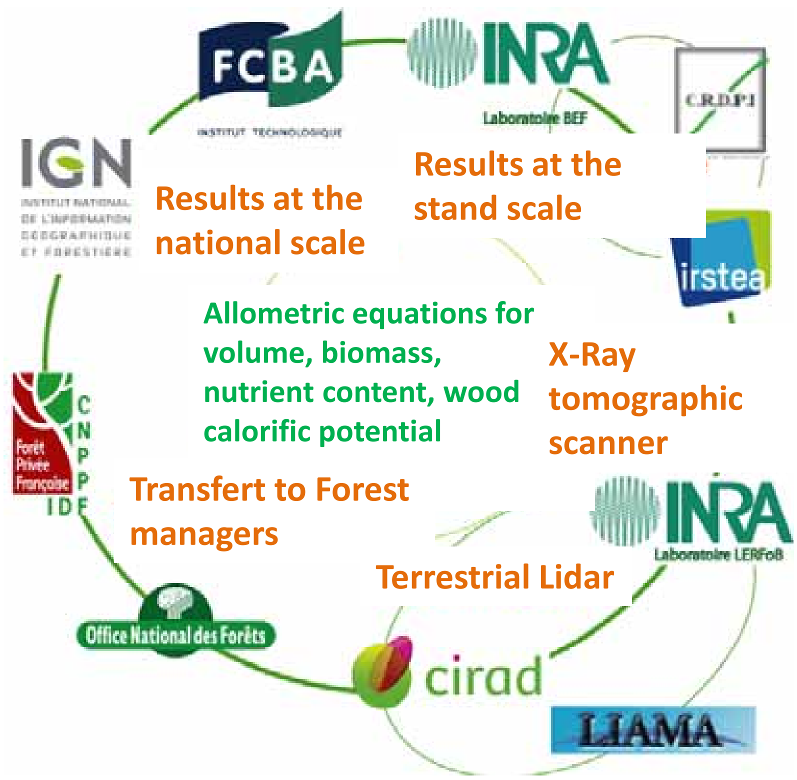

Figure 4: Institutional framework supporting the national tree allometric database in France

Conclusion

The results obtained in the ANR project EMERGE will be soon used by the National Forest Inventory to assess carbon stocks at national level and provide the required figure for the national reporting on GHG. A key success of this project was the common database allowing sharing not only the data, but also the work to be done on this database. Some of these works are still ongoing and the consortium agreed to continue after the end of the project.

Tree aboveground biomass allometric models: how much and when can we trust them? A study case in the Andean mountains of Colombia.

Alvaro J. Duque M.[21]

Introduction

In this study, we used tree-plot inventories to compare the total tree aboveground biomass (AGB) and the correlation between the most employed pan-tropical allometric models developed by Chave *et al*. (2005) and the models recently developed by Alvarez *et al*. (2011) in Colombia. The main goal is to evaluate the likely bias associated with the use of any allometric specific model in relation to the others, in studies that focus on either the rates of AGB change or the total amount of carbon stored in the AGB. In the light of the implementation of projects of reduction of emissions by deforestation and degradation (REDD), these comparisons could inform about the best model to use in each case.

Methodology

I defined the models as CH I and CH II, which represent the models developed by Chave *et al* (2005) with and without height, respectively; and the models Alv I and Alv II, which represent the models developed by Alvarez *et al*. (2012) with and without height as well. Then, I independently applied

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each model to a set of 16 1-ha plots established in the northwest region of Colombia. This region includes the northern tail of the Andean mountains, and some spots on the Caribbean and Chocó regions. First, to evaluate the effect on the main trends in the AGB changes according to the model selected, we used pair-wise Pearson correlations between the total AGB biomass values assessed in each plot by each model. Then, to evaluate the trend in the net differences in the total amount of AGB assessed by each model, we compared the net AGB value obtained in each plot, according to each model.

Results

The Alv I and Alv models, showed the lowest correlation (0.71), while the Ch II and Alv II the highest (0.91). The Alv I model systematically underestimated the total AGB, while the Ch II model always overestimated the AGB, in comparison with the other models (Figure 5).

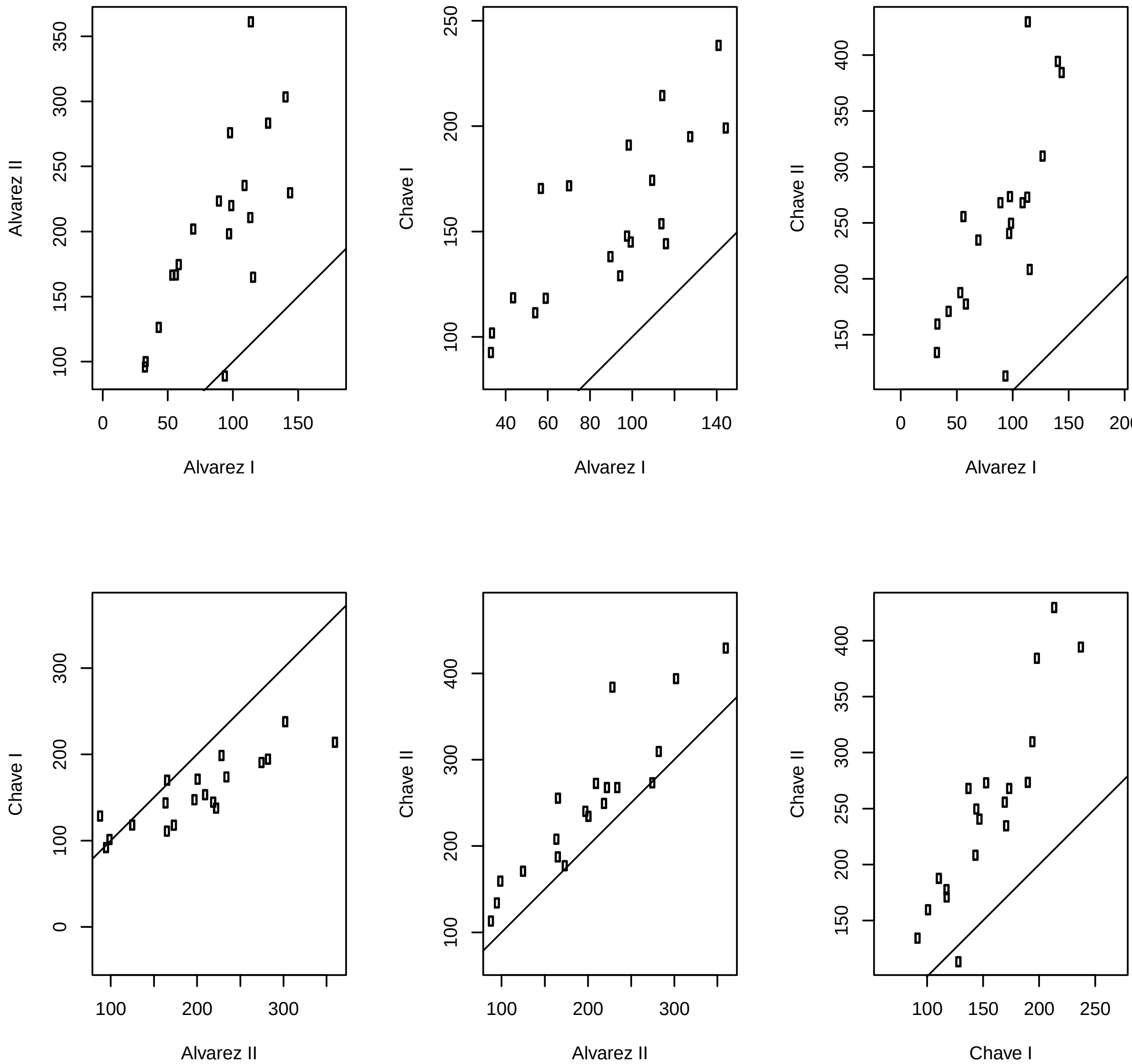

Figure 5: Relationship between the total AGB estimated by the four models. The line shows the 1:1 expected relationship between the two AGB allometric models.

Discussion and Recommendations

Our results proposed that if we aim to assess the general trend of the rate of change of the forest AGB, either the Chave or Alvarez models will produce similar results. However, if we want to quantify the total amount of carbon stored in the AGB, as for instance we do for REDD+ projects, the Ch I model would be desired due to it gives the most rational values. Although the Alv I model was the most conservative model, it seems to systematically and significantly underestimate the AGB. The inclusion of the tree-height in the models showed to be important in determining the main differences in the total AGB assessed by the models. Therefore, improving our understanding of the allometric Height: Diameter relationship could certainly help improving our AGB estimates when the allometric equations are applied to forest inventories. A new systematic generation of harvested trees is needed in order to validate and improve the pan-tropical existing models.

6. Scientific research: New findings on biomass assessment using tree allometric equations

Bayesian methods for estimation of allometric biomass models

Zapata-Cuartas, Mauricio[22], *Sierra, Carlos Alberto*[23]

Introduction

Over the past decades a considerable number of allometric equations have been developed to quantify the amount of aboveground biomass in individual trees and entire forest ecosystems. They relate variables that are easy to measure in the field such as tree diameter and height with the aboveground biomass of an entire tree. However, a major limitation of these equations is that they produce very different results when applied to sites outside the geographical locations where the equations were originally developed; therefore they need to be developed for specific local conditions and species for accurate estimations of forest biomass and carbon stocks. The large amount of information already available on tree biomass equations provides an opportunity to synthesize prior probability distribution among different locations and forest types within a Bayesian inference framework.

Our objective is to propose here a joint prior distribution for parameters values of the simple allometric function between tree diameter and aboveground biomass, and study the performance of the Bayesian approach compared to the classical statistical approach.

Methodology

Information on allometric equations from primary literature over 72 articles were collected and organized in a database. Some summary statistics were done for the values of the parameters *a* and *b* in the following equation: $\ln(M)=a+b\ln(D)$, where M (units in kg) is the dry mass of the tree and D is the tree diameter (units in cm). We choose a prior bivariate normal distribution for parameters *a* and *b*. $N(\mu, \Sigma)$, where $\mu=(\mu_a, \mu_b)$ is a vector of means, and Σ is the covariance matrix. We specified the hyperparameters of μ and Σ from the database of biomass equations selected by forest type (boreal, temperate and tropical). We use the R package MCMCglmm (Hadfield,2010) to construct a function that implement the Bayesian approach with the *a* prior described. To test the performance of the model proposed here, we used a dataset of 257 trees felled and weighed for aboveground biomass determination in a tropical forest of the Porce region of Colombia. A simulation was performed taken random subsamples of predefined simple sizes (200, 150, 100, 80, 60, 40, 30, 20, 15, 10 and 6 trees) from the entire dataset (257 trees). With each subsample, we estimated parameter values using both the classical and the Bayesian approaches, repeating the procedure 1000 times. Also every parameter set estimated in the simulation was used to calculate the biomass of the original sample of trees ($n=257$). This gives a measure of the efficiency of the estimation in terms of the error for the different sample sizes.

Results

A total of 134 biomass equations in logarithmic form were compiled from the literature. The database has a wide geographical distribution, and even though these equations are reported either by species or forest type, the parameters converge in a narrow range within forest type, are normally distributed, and negatively correlated with each other. The simulation showed that the estimates of *a* and *b* using the Bayesian and the classical approach were practically identical when we used the complete dataset of 257 trees. However, as sample size decreased the classical approach produced estimates of *a* and *b* in a wider range compared with the Bayesian. For sample

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size of 6 trees, the standard deviation of the estimated *a* and *b* with classical approach were 186% and 213% higher than the obtained with the proposed method, respectively. The efficiency and significant values in the estimation of the parameters obtained with the Bayesian approach using a sample size of 6 trees was achieved only by the classical approach with a sample size of 20-30 trees. The complete dataset of biomass equations and the function for R is available in Zapata-Cuartas *et al*. (2012).

Discussion and Recommendations

A comprehensive sample of allometric equations gathered from published literature, revealed that the parameters of a simple allometric model can be well described by a bivariate normal distribution. These results provide good support for a widespread applicability of the simple allometric model among different species and biomes, furthermore it is possible to use this information already available to estimate new parameters values for new sites using simple Bayesian techniques and a reduced sample size. This methodology could be expanded to other allometric models, but require a more extensive collection of published equations. We only found a weak relationship between the scaling coefficient (parameter *b*) and latitude, which could be an indication that the combination of biotic and abiotic factors such as temperature, precipitation, growing season length, herbivory, soil development, among others, may contribute to allometric and allocation patterns of trees globally. In future investigations this additional information on biophysical variables can be included in the analysis and develop hierarchical Bayesian models with more accurate priors for new sites. Lastly, in this approach prior information from other studies affects the posterior distribution of parameters values, i.e. the results. Thus, it is important the prior distribution always be based on results from a complete and unbiased compilation of previous studies as presented here, and that it always be clearly reported.

Other techniques like Bayesian Model Averaging (BMA) could be used with equations gathered from published literature for species or biomes to get a new predictive model. It should be a more efficient way to combine calibration and estimation parameters in a regional scale. Future investigations need to test the BMA performance with reduced training data set for biomass estimations and their application in regional and national scale.

Conclusion

In this analysis we found that the parameters of the allometric model $\ln(M) = a + b \ln(D)$ can be well approximated with a bivariate normal distribution. The narrow range of the distribution of these values suggests that scaling rules do exists for the relationship between tree mass and diameter, but the scaling coefficients are better represented as probability distributions rather than as constant values. The methodological approach we present here can largely reduce costs associated with precise quantifications of forest biomass using this distribution as prior information. We therefore recommend the use of Bayesian procedures using existing information for the development of biomass equation for new sites and species.

A new generation of pantropical biomass equations

Jérôme Chave[24], Maxime Réjou-Méchain[25], Alberto Búrquez, Emmanuel Chidumayo, Welington BC Delitti, Alvaro Duque, Philip M Fearnside, Matieu Henry, Angelina Martínez-Yrízar, Helene C. Muller-Landau, Bruce W Nelson, Euler M Nogueira, Edgar Ortiz Malavassi, Casey Ryan, Juan G Saldarriaga, Ghislain Vieilledent

Converting tree diameter measurements into above ground biomass through allometric models is a critical impediment for implementing reliable monitoring, reporting and verification (MRV) protocols

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of carbon storage. In tropical forests, the development of reliable forest biomass estimation methods is challenging given the high diversity of tree species. Local allometric models are often based on only a few destructively sampled trees and even fewer large trees, leading to strong uncertainties in the estimation of local biomass stocks. Previously published pan-tropical allometric models have contributed to resolve this issue by compiling large dataset. These models are widely used by both foresters and ecologists and currently recommended by international authorities such as in the IPCC and REDD guidelines. However, these pantropical models may have two major limits: no harvested trees from Africa were considered in the model construction and relatively few large trees were considered. Another critical source of uncertainty is the use of pantropical models that do not consider tree height because height-diameter relationship is expected to vary significantly along environmental gradients. Here, we analyze a new dataset including new study sites from Africa and a large number of large trees. This dataset is the largest global database of trees directly harvested and weighed at 47 sites in the tropics (n= 2907). We first show that, when tree height is included in the models, a unique biomass equation holds across all forest types. Despite the broad range of forest types and the wide range of climatic and environmental conditions included in the new dataset, we did not find any indication that this allometric relationship varies along bioclimatic gradients. We then compared the accuracy of the local and the pan-tropical models. We found that the accuracy was higher for local than for pan-tropical models on average. However, this difference was mainly due to a few study sites where the pan-tropical model was much less accurate than the local one, the other sites displaying similar accuracy or even higher accuracy with the pan-tropical model. Lastly, as many studies have no access to tree height information, we developed a new model discarding tree height but incorporating bioclimatic variables. As height-diameter relationship may be partly predicted from environmental conditions, this model significantly outperform a model discarding both tree height and bioclimatic information but still remains less accurate than the model incorporating tree height. Overall, this study improves our understanding of the relationship between forest structure, environmental conditions and above ground biomass. We provide new general equations than can be easily used as a new standard all over the tropics.

Estimating uncertainty of allometric biomass equations using a pseudo-meta-analysis approach

Craig Wayson[26], Kris Johnson, Jason Cole, Chhun-Huor Ung

Introduction

Generalizing or aggregating separate equations for biomass estimating from published literature requires detailed fit information (parameters SSEs, R^2, n, etc.) in order to properly propagate errors/uncertainty associated with the original published work. For allometric equations that estimate biomass from tree diameter at breast height (DBH) these problems are compounded by the wide variety of equation forms used, general publishing practices that include little information about the resulting regression and availability of a large enough body of work covering a species' spatial distribution from which to choose studies meeting meta-analytical requirements.

Also, due to complexity, generalizing these individual species allometric equations into functional categories has been used for large-scale forest biomass estimation (regional to global). To date, most of these estimates have not included the error/uncertainty associated with them due to the lack of a defensible process to propagate the errors associated with the aggregation/generalization process. This lack has also led to little investigation into minimizing errors associated with generalizing allometric equations.

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Methodology

The following steps were taken to create a pseudo-data set of points from which an allometric equation could have been generated: 1) Create an original biomass population that could produce a fit with an R-square as seen in published results by inputting the original equation and then creating datasets with low to high levels of variance. 2) Re-fit original equation with pseudo-data to calculate an R^2 of the fit and select the pseudo-dataset with the R^2 most closely matching the published R^2. 3) From each 'population' sub-sample with replacement the same number (n) as used in the original work to bootstrap the error. The approach was tested against a large dataset of raw DBH and biomass numbers from the Canadian ENFOR data. Five species for testing were selected based on *n*, DBH range and distributions and the process of pseudo-data was performed and compared to the allometric equations generated from the raw, and known, data.

Results

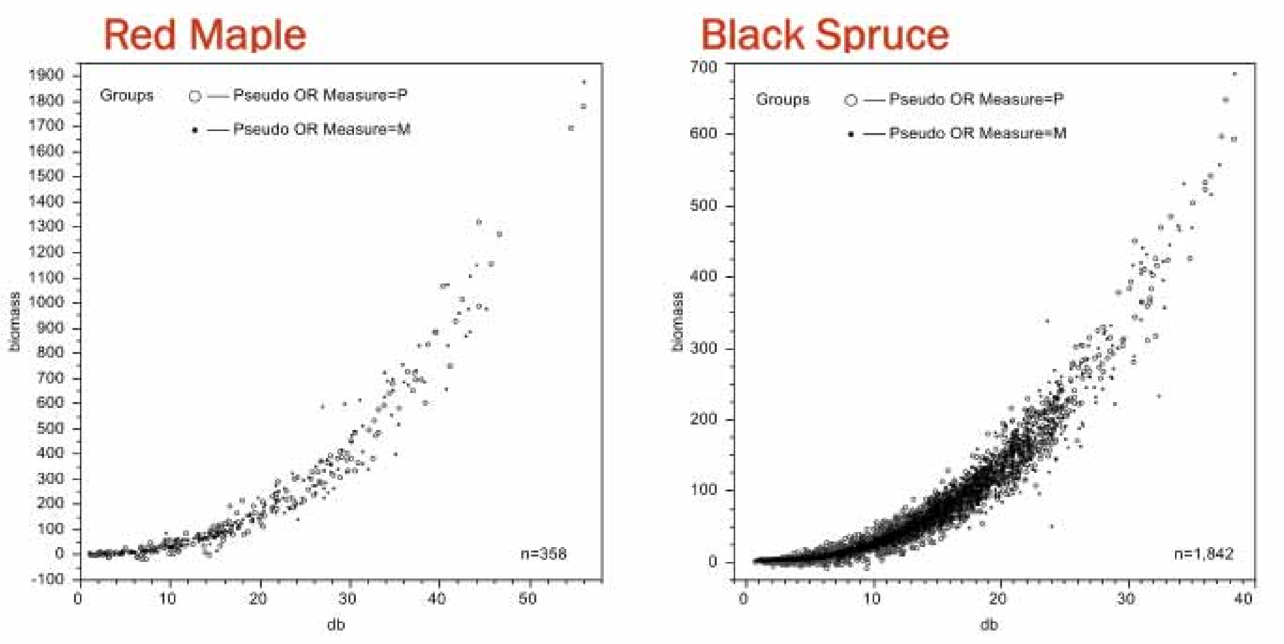

Figure 6: Examples of pseudo-data compared to the original raw data from the ENFOR dataset for red maple and black spruce. Open dots are pseudo-data and closed dots are measured data. The process presented here tends to produce higher levels of variability at smaller DBHs and lower levels at higher DBHs.

Table 2: Summary of results for the five selected species showing the raw data and pseudo-data parameters and R^2 comparisons. The equation fitted was:

$$Biomass = e^{(\beta 0 + \beta 1(\ln(dbh)))}$$

	Measured data			Pseudo data			
Species	*n*	$\beta 0$	$\beta 1$	$\beta 0$	$\beta 1$	*Original* R^2	*Pseudo diff.*
Black Spruce	1,842	-2.117	2.334	-2.124	2.336	0.9765	0.0012
Cottonwood	19	-2.623	2.471	-2.617	2.470	0.9604	0.0050
Aspen	819	-2.063	2.352	-2.031	2.343	0.9700	0.00092
Red Spruce	55	-2.707	2.489	-2.738	2.497	0.9887	0.00032
Red Maple	179	-1.983	2.360	-2.000	2.363	0.9757	0.00059

Discussion and Recommendations

We can create pseudo-populations that mimic the range of possible DBH vs. biomass relationships based on very little information (R^2) and therefore the uncertainty can then be propagated using this information for older equations so that individual allometric equation errors can be aggregated at the plot level and added to sampling errors, etc. The uncertainty using this method is most likely an *underestimate* depending on forest DBH distributions. While these methods are useful for estimating uncertainty, well designed, large-scale field campaigns for generating allometric equations using a standardized approach are critical for reducing errors associated with allometric equation development so that the principle source of uncertainty is from natural variability.

Conclusion

Biomass estimates for large forested regions are important to our understanding of the global carbon cycle, especially now as there is a need to predict as accurately as possible carbon stored in forested ecosystems to improve global models of CO_2 for climate change. Also for mitigation strategies, carbon markets, etc. require knowledge about the uncertainty associated with these estimates. Uncertainty estimates are required to be associated with these values. In order to use existing allometric equations a method like this is a valuable tool for these efforts.

In the future, aggregate allometric equations for functional groups (*e.g.* Jenkins, CRM, etc.) can have robust uncertainty estimations useful propagating errors associated with them. A slight modification to this process would also allow for minimizing errors of functional groups' allometric equations. Through Monte Carlo experiments the groupings can be changed and the effects on uncertainty can be examined. Uncertainty can be minimized *a priori* to select a level of uncertainty to meet and groups can be created accordingly (*i.e.* are 10 groups enough? More? Less?).

Assessing biomass expansion factors for different forest biomes of the world (using tree biomass allometric equations)

Philippe Santenoise[27], Matieu Henry, Laurent Saint-André, Gael Sola, Luca Birigazzi

Introduction

At current status, several biomass expansion factors (BEF) were proposed under the IPCC *Guidelines* and different scientific papers. BEF calculated are mostly not comparable because different methodologies have been used for the assessment of forest biomass and consider different tree compartments. The default BEF proposed in the IPCC (2003) was developed based on few measurements and represents the conversion of merchantable volume to aboveground tree

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biomass. Thereafter, biomass conversion and expansion factors (BCEF) are calculated from the default BEF and basic wood density and used to calculate carbon stocks (IPCC,2006). The downside of these different methodologies is that the use of default conversion factors leads to increased uncertainty. The objectives of this study is to (1) use a minimum of information on tree biomass allometric equations in order to generate pseudo-data that is not statistically different from the one used to develop equations ; (2) calculate BEFs for different forest biomes from pseudo-data generated.

Methodology

The different methodologies used to generate pseudo-data (dependent and independent variables) and calculate BEFs are the following:

1) Select the main independent variable (in general DBH) and simulate values into its interval of validity from a uniform or log-normal distribution;
2) Calculate other independent variables from the first one simulated using mathematical formulas or equations published in scientific papers (Brown *et al*. 1989: relation H_{total}/DBH for tropical forests);
3) Calculate the residual variable using the coefficient of determination of the AE and simulate values of the dependent variable
4) Associate simulated data for different AEs (interval of validity and sample size for each equation) to calculate BEF.

Results

Simulation of biomass for different tree aboveground compartments and calculation of several BEFs (ratio between trunk with bark and aboveground biomass where dead branches and leaves or only leaves are or not considered in aboveground biomass) for different tree species located in 13 forest biomes (temperate continental forest, subtropical humid or dry forest, etc.).

Discussion and Recommendations

With the proposed methods, it is possible to (1) generate pseudo-data from equations published in scientific papers if no raw data are available; (2) elaborate generic equations for different forest biomes using pseudo-data; (3) obtain detailed information on BEFs estimate (per diameter class, tree species, conifer vs. broad-leaved trees).

Among the selected AEs (689 equations) for the calculation of BEFs, 70 equations (10 %) are expressed as a function of DBH and total height (H_{total}). For these equations, H_{total} values are calculated from simulated DBH values using relation H_{total}/DBH in Brown *et al*. 1989 developed for different climate type (moist and wet with rainfall in mm respectively [1500,4000] and >4000). For now, there's no relation H_{total}/DBH for dry climate (rainfall <1500 mm). This relation is important because several AEs are in forest biome where the climate is dry (tropical or subtropical dry forest: 11 equations).

Conclusion

In the next study, it will be possible to calculate an average BEF per diameter class (DBH) for different forest biome using all AEs available (developed at different levels: species, genus, family or biome). Otherwise, it will be interesting to research other relations H_{total}/DBH for tropical forests in scientific papers (Feldpausch, *et al.,* 2012) or elaborate new equations from raw data in order to improve total height estimate as a function of DBH.

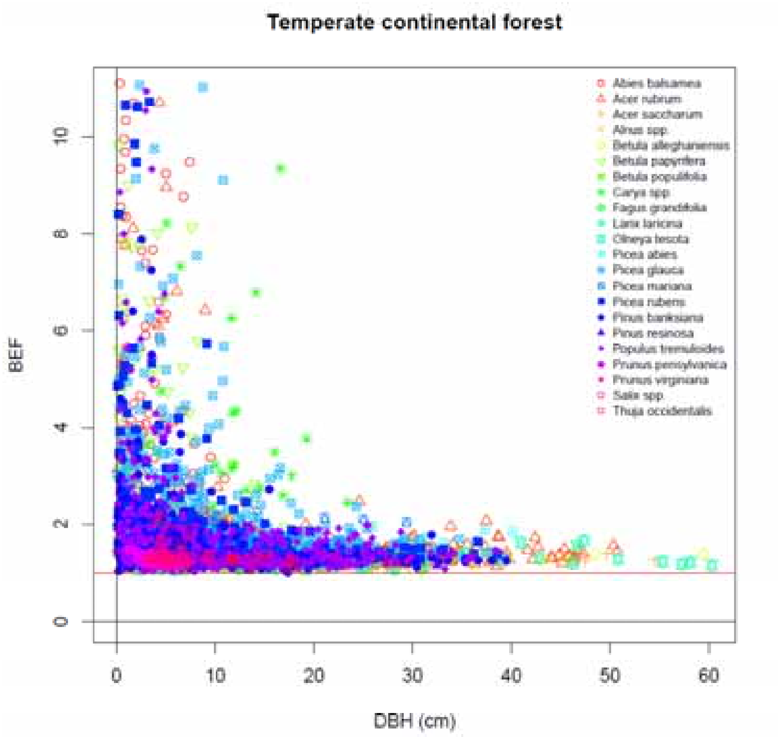

Figure 7. Distribution of BEF per diameter class (DBH) for different species.

7. Scientific research: new findings on biomass assessment using tree allometric equations

FAO and UN-REDD programme support on tree allometric equations and related fields in Latin America

Marklund, LarsGunnar[28]*, Henry, Matieu*[29]

REDD+ has the potential to deliver cost-effective climate change mitigation through sustainable means. To do so, accuracy of assessments of the forest carbon stocks and carbon stock changes is vital. Globally, several allometric models have been developed in the past for a broad range of forests of different continents; however, they are weakly representative of forests in Latin America. Applying such generic models could mean significant uncertainty, resulting in over/under-estimation of forest carbon stocks.

Allometric equations are needed to perform the calculation or verification of forest carbon stocks. Inappropriate use of inappropriate allometric equations can lead to important errors in calculations. The greater the uncertainty, the less credible the reduction of emissions. In order to comply with the United Nations Framework Convention for Climate Change reporting rules principles, the accounting system of emissions reductions in the forestry sector must be as transparent, accurate, consistent, comparable and complete as possible. FAO and the UN-REDD programme[30] support activities at national, regional and global level.

One example of country support is in Viet Nam. One of the activities implemented by the UN-REDD Programme in Viet Nam is to support the development of allometric equations for effective reporting of emission reductions. Back in 2010 the UN-REDD National Programme facilitated, discussions among national practitioners of forestry research, inventory and academic institutions together with the Viet Nam Forestry Administration facilitated. Plans were elaborated to develop tree allometric equations. These plans were then substantiated through a technical seminar to thresh out that identified pros and cons of different approaches and proposed an and an overall work plan emerged for destructive measurements to take place in three key forest types (*i.e.* evergreen broadleaf, deciduous, and bamboo) among five eco-regions of Viet Nam. It was also agreed that the country would benefit if from a single national database could be established that could, consolidating consolidate all of the allometric models, as well as, and as much of the related research data as possible. The tasks which followed, collaboratively implemented by the six research institutes included, i) design of a national manual for destructive measurement for above-ground biomass estimation, ii) collection and entry of existing allometric equation data into a database, iii) conducting destructive measurements in forests of five eco-regions, iv) laboratory and statistical analysis for model development and selection and v) transcribing the results into a report of the developed allometric equations.

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[30] The United Nations Collaborative Programme on Reducing Emissions from Deforestation and Forest Degradation in Developing Countries (UN-REDD Programme) is collaboration between Food and Agriculture Organization of the United Nations (FAO), United Nations Development Programme (UNDP), and United Nations Environment Programme (UNEP). It builds on the convening power of its participating UN agencies, their diverse expertise and vast networks, and "delivers as One UN". Within the partnership, FAO supports countries on technical issues related to forestry and the development of cost-effective and reliable Measurement, Reporting and Verification (MRV) processes for emission reductions.

At regional level, the UN-REDD programme contracted CATIE (Tropical Agricultural Research and Higher Education Center) to develop a database on tree volume and biomass allometric equations for South and Central America. This is part of a global support to improve the knowledge on tree allometric equations and volume, biomass and carbon assessment. Such a database will allow the identification of the gaps and the needs for development of new models based on additional destructive measurements. Several institutions are also currently involved in destructive measurements in several countries. Joint efforts and common understanding will facilitate a cost effective approach to significantly improve biomass and carbon stock assessment in the region.

At global level, a new internet platform named GlobAllomeTree[31] was jointly launched in June 2013 by FAO, CIRAD and UNITUS-DIBAF. This platform allows countries to improve the assessment of forest volumes, biomass and carbon stocks. GlobAllomeTree is the first international, web-based platform designed to help forest and climate-change project developers, researchers, scientists and foresters to improve access to tree allometric equations. This will help national policymakers to make informed decisions regarding climate change mitigation activities and bio-energy development. This new platform enables users to access most of existing calculation tools for various types of trees and ecological zones, import data from their field measurements, select the adequate method for calculation and obtain relevant statistics. The access to the tool is free and users can also develop and submit their own calculation tools.

At current status, the tool covers 61 tree species and 7 different ecological zones in Europe, 263 trees species and 16 ecological zones in North America and 324 species and 9 ecological zones in Africa (Henry, *et al.,* 2013). Databases for South Asia, South-East Asia and Central-South America will be finalized and uploaded to the platform before end of 2013.

Plan to evaluate tree volume, biomass, and carbon in Central America and the Dominican Republic, 2013-2015. REDD-CCAD-GIZ Regional Program

Fabián Milla Araneda[32], Abner Jiménez Galo, Patricio Emanuelli Avilés

Introduction

The monitoring component of the REDD-CCAD-GIZ Regional Program is addressing the need to have local emission factors to report forest carbon stocks and their changes at IPPC Tiers 2 or 3. UNFCCC reporting at Tier 3 is a great challenge because of the large number of tree species (~5000) present in Central America and the uncertainty surrounding biomass derived from indirect volume calculations. Ideally, we would need one allometric equation per species to achieve this level of detail. In addition, allometric equations are needed to help make management decisions beyond the carbon storage service provided by forests. Because of these reasons, the Program will quantify volume, biomass, and carbon across Central America and the Dominican Republic from 2013 through 2015. This will facilitate the generation of required emission factors.

Methodology

We propose using an approach that combines the advantages of the direct (destructive) and indirect (using volume and BEF) to estimate forest biomass. Stratification to distribute 600 sampling points will be done using each country's forest types. This will result in the evaluation of 18200 standing trees. Dasometric information such as DBH, diameters at different heights (measured using a Criterion RD 1000 electronic relascope), and total height will be measured.

At a later, regional, stage of the project, 500 trees will be harvested and their components weighed to determine their total aboveground biomass. Additional samples will be collected to determine

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moisture content and specific gravity for each tree component. Wood cores at 10% and 20% of total height will be extracted to determine wood specific gravity of the species. These trees will be selected from 100 of the 600 sampling points previously measured. In each of the chose sampling points, 5 trees will be chosen based on the relative importance of the species in the site and the observed diameter range. These data will be used to construct models for total biomass, biomass by tree component, and regressions for wood specific gravity and BEF based on DBH.

For all these variables, and provided a minimum sample size of 30 individuals is available, we will derive species-specific equations as well as equations for groups of species (*i.e.* 2 or more species sharing density, morphology and taxonomic characteristics). Where the minimum sample size cannot be obtained we will develop equations by forest type.

Expected Results

The monitoring component of the REDD-CCAD-GIZ Program aims to provide decision makers across Central America and the Dominican Republic with data necessary to calculate CO_2 emissions from deforestation and forest degradation. This implies the development of biomass models for the most ecological and financially important species. Similarly, volume information is needed to support forest interventions that will ensure sustainable forest management operations. The proposed plan will help us achieve those objectives effectively and efficiently.

Discussion and Recommendations

The following recommendations must be kept in mind during field work

- To obtain unbiased estimates of standing volume using the Criterion RD1000 relascope, longer distances (but not greater than the estimated tree height) will be favored from any position where the majority of the stem can be observed (Rodríguez, *et al.,* 2009).
- Wood specific gravity is best determined from cores taken at 10% and 20% of a tree's total height (Omonte and Valenzuela,2011).

Conclusion

This plan will allow countries from Central America and the Dominican Republic to have a set of volume and biomass equations, biomass expansion factors, and wood specific gravity, by species or group of species that would allow them to report CO_2 emissions from deforestation and forest degradation calculated from national forest inventory databases. In addition, an electronic tool (+Funciones) is being developed to systematize allometric equations in countries where the Program operates, thus complementing other databases already compiled.

U.S. SilvaCarbon program provides technical expertise to assist developing countries in monitoring forest and terrestrial carbon

Charles T. Scott[33]

Recent years have seen rapid advancement of science and methodologies to help countries monitor their forest and terrestrial carbon. This includes impressive improvements in satellite data availability and quality, along with improved ground, or in situ, measurements, enhanced modeling capabilities, and increased knowledge through research. Ongoing research and international collaboration is particularly critical now for comparing methodologies and identifying good practices and approaches relevant to a variety of country circumstances. With this in mind, United States federal agencies have joined together to create the SilvaCarbon program to enhance capacity in the tropics for monitoring forest and terrestrial carbon so that countries can better manage it. SilvaCarbon will draw on the expertise of the U.S. scientific and technical community including experts from government, academia, non-governmental organizations, and industry. Working with

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developing countries and other partners, SilvaCarbon will enhance capacity by identifying, testing, and disseminating good practices and cost-effective, accurate technologies for monitoring carbon. SilvaCarbon is a flagship program under United States fast start financing for REDD+ and is a U.S. contribution to the Forest Carbon Tracking task of the intergovernmental Group on Earth Observations (GEO). SilvaCarbon will address technical issues including:

- Sampling protocols and design
- Data capture, processing, archiving, and distribution
- Collection and analysis of in situ data, including involvement of local communities and stakeholders
- Integration of remotely sensed and in situ data
- Classification and mapping of forest cover
- Carbon stock and flow estimation
- Design of monitoring systems for multiple uses
- Land use analysis and planning

Working cooperatively, U.S. federal agencies will draw on their respective strengths to implement SilvaCarbon. Agencies currently involved include: U.S. Agency for International Development (USAID), the U.S. Forest Service within the Department of Agriculture (USFS), the U.S. Geological Survey of the Department of Interior (USGS), the U.S. Environmental Protection Agency (EPA), the U.S. Department of State, the National Aeronautics and Space Administration (NASA), and the Smithsonian Institution. SilvaCarbon will be closely coordinated with international organizations and other governments that are also engaged in the GEO Forest Carbon Tracking task, or in related forest and terrestrial carbon activities.

The SilvaCarbon Portal, www.SilvaCarbon.org, is designed to be the key online focal point for the latest information and updates on the activities of the GEO FCT task. There are a number of intended users for this portal, including:

1. Policy Makers
    - The climate negotiation community, including the UN, UNFCCC, the COP and SBSTA communities
    - National governments, in particular climate and forest departments

2. Data Providing Agencies
    - CEOS space agencies
    - National agencies providing in-situ forest data
    - GEO member agencies

3. National Authorities
    - National agencies who represent their countries in the FCT community
    - Prospective national agencies in countries who may wish to join the FCT efforts

4. Interested Members of the Science and Technical Community
    - Members of the forest modeling, and forest management communities
    - Members of the climate and carbon cycle modeling community

5. The General Public
    - Members of the general public interested in better understanding the role of forests in the carbon cycle

Low intensity destructive sampling to construct allometric equations in Ecuador

Kelvin Cueva Rojas[34]

Introduction

The current initiative to construct allometric equations is part of Ecuador's broader data collection efforts as part of its multi-resource national forest inventory. The quantification of biomass and carbon is an emphasis of Ecuador's national REDD+ Program.

Methodology

We will seek to generate a set of methods to construct allometric equations and biomass expansion factors for different forest types that is adapted to the tropical biophysical (high tree species diversity) and socioeconomic (low income) characteristics present in Ecuador. These methods must meet international standards for precision.

The basic principle is to combine electronic equipment and alternative high precision instruments to measure standing trees (hypsometers, relascopes, laser and sonic range finders, increment core borers and pilodyn to determine wood density and different heights, etc.). In addition, trees chosen based on the Importance Values representative of a given forest type would be harvested and their components weighed. Groups of species may also be used, depending on the number of species present, their common morphologies and wood density.

The comparison between destructive harvests and standing tree estimates will allow us to adopt an innovative and cost-effective procedure to determine biomass of certain species and forest strata.

Results

We will generate allometric equations, biomass expansion factors, and volume equations for species and groups of species with high importance values to estimate biomass and carbon of the forest strata in Ecuador. Our proposed methods will also allow us to compare different methods of constructing allometric equations.

Discussion and Recommendations

Procedures and experiences constructing allometric equations in Ecuador is incipient and limited to only a few tree species and forest remnants in Ecuador. It is necessary to build local capacities and promote cooperation to develop the proposed procedure and institutionalize a long-term research process, taking advantage of current policies and available resources that give priority to climate change mitigation.

Conclusion

The proposed methods will allow Ecuador to increase its precision in estimating biomass and carbon for a wide variety of important forest ecosystems in Ecuador, in combination with locally-available equations, and to progressively rely less on biomass expansion factors and default allometric equations. In addition, this process will enhance human capacities and will also serve to develop an innovative and cost-effective procedure that can be used locally and regionally.

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8. Recommendations for research scientists on the documentation of allometric equations

Introduction

Allometric equations are crucial for estimating volume, biomass and carbon stocks of trees outside forests and in forests, entire trees and its compartments, and also to support policies for bioenergy, commercial exploitation, carbon sequestration, non-timber forest products, etc. (Henry, *et al.,* 2013). According to GlobAllomeTree[35], most allometric equations correspond to just a few families and ecological zones (71 % of equations represent 5 families). When assessing tree biomass for an individual tree, a forest, a country, a region or globally, the calculation process faces many constraints such as: (1) an estimated equivalent number of tree species of about 60,000-100,000, (2) allometric equations for only 1309 tree species are globally available (*i.e.* in GlobAllomeTree), (3) harmonization of data is limited to information available in reports and articles, (4) few raw datasets are available for validation of existing allometric equations, (5) field measurement are very costly and difficult (Picard, *et al*. (2012) (6) mature trees can exceed heights of 50 m and weigh over 50 tons (which requires adequate technologies and protocols to measure properly), (7) the data may be incorrect (23% of erroneous equations appear in sub-Saharan Africa (Henry, *et al.,* 2011)), (8) the equations may not be adapted to data collected in the field, and (9) variation of specific wood gravity within individuals and species, and across locations is poorly documented.

There is a multitude of possible methods for calculating biomass using available equations. The choice of method can cause significant differences in the estimates, which may have an impact on the potential benefits of good management of natural resources. Selecting the best method for calculating biomass is hampered by the absence of a database containing harmonized allometric equations (with the exception of a few countries and GlobAllomeTree), the unavailability of raw data for assessing uncertainty, lacking documentation describing the methods used to develop the equations, and insufficient national capabilities. Because of convenience, users often rely on generic models for calculating biomass and ignore efforts in their country or in similar ecosystems. The platform GlobAllomeTree is the first step towards the establishment of a database to meet the needs of countries and forest managers but is not a substitute for missing information. Many equations in the database lack location, raw data, explanation on the distribution of residuals, information on the statistics of the equation, the method used to adjust the model etc. These missing data limit its harmonization and its use, the accuracy of estimates and, ultimately, the assessment of forest resources. Missing information also limits scientific progress and forest research.

Few articles provide recommendations on the development of forest models. Pretzch *et al*. (2002) propose criteria for the description and evaluation of growth models and simulators and identifies scientific needs. Jenkins *et al*. (2004) provides a list of parameters for the allometric equations for North America. The manual of Ponce-Hernandez (2004) provides recommendations on data collection for estimating carbon stocks and modeling. IPCC guidelines propose recommendations on how to collect and use activity data and emission factors by sector to prepare an inventory of greenhouse gas emissions factors which include forest land (IPCC,2003, IPCC,2006). The Global Terrestrial Observation System (GTOS) provides standards, definitions and methods for the assessment of essential climate variables including biomass (Bombelli, *et al.,* 2009). Picard *et al*. (2012) recently developed a manual for developing allometric equations. However, in the scientific context, no document gives practical recommendations on the necessary criteria and information that scientists should use to develop their models and provide adequate information on them.

[35] www.globallometree.net

This document partly addresses that need by providing recommendations for publishing allometric equations and modeling tree and forest biomass. It aims to ensure that collected information and data used for a scientific article fully contribute to scientific research and advances in forestry research.

Recommended "best practices" for documenting allometric equations

These recommendations should apply in all situations and circumstances and do not aim to become standards. We focus on 6 main areas: information on definitions and concepts, description of the target population and environmental conditions where the study was carried out, sampling details and scope of the study, methods used for data analysis and calculations, metadata and information on raw data, and model fitting and uncertainty.

1. Definitions and concepts:

Authors are encouraged to provide detailed information on the variables and units used in the field measurements, data processing, and for the output from allometric equations.

- Variables: Details on biomass, volume, commercial volume, basal diameter, total height, merchantable height, tree components etc. need to be clearly defined. Appendix 1 provides a list of variables and citations where to find their definition.
- Units[36]: It is preferable to use the international system of units (SI) when reporting values. In case the country where the equation was developed does not use international system of units, it is recommended to provide values using the national and international units. This will allow the data to be used inside and outside country boundaries.

2. Description of the target population and environmental conditions:

Details of the location and environmental conditions of the site where the data were collected help to properly choose and apply allometric equations to additional sites with similar characteristics.

- Geographic location: Latitude and longitude where data were collected should be indicated, including the projection system. If data were collected in more than one location within the same ecological zone or forest type, it is possible to use the centroid of the sampled area polygon rather than listing the geographic location of each tree. Alternatively, location information should be disclosed for all sampled individuals.
- Ecosystem types: Authors should include at least a description of vegetation, stand structure, stocking, basal area, phenology, and seasonality.
- Ecological zone: In case country specific ecological zones are available, it is recommended to also provide information from an international ecological zone classification system such as FAO (2001), Olson/WWF (2001), Holdridge (1967), Udvardy (1975), and Bailey (1989). This will allow the data to be used outside the country boundaries using one of those classification systems.
- Stand age: Stand age should be indicated when possible, particularly for managed forests such as plantations and secondary forests in tropical zones.

[36] Units for tree size (diameter, height) and for biomass –Abbreviations: mm: millimeters (10^{-3} meters), cm: centimeters (10^{-2} meters), m: meters (39.37 inches), in: inches (2.54 cm), lb: pounds (0.4545 kg), g: grams, kg: kilograms (10^{3} grams), Mg: Megagrams (10^{6} grams)

- Management system: Management refers to spacing between trees, tree architecture, and stand structure. It is also advisable to provide information relative to fertilization regimes, rotation, genetics, weed control, and site preparation.
- Soil: Soil influences tree growth and nutrient availability. It is recommended to provide information relative to soil type (texture and depth).
- Climatic variables: These should include at least temperature and precipitation. Including additional variables such as length of dry season, seasonality, climatic water deficit, maximum and minimum values, etc. is advisable.
- Landscape characteristics: Information on the elevation, slope and aspect of the sampling sites should be included.

3. Sampling and scope of the study

Knowledge of how the sample was collected, how large it is, and the tree components included in the resulting allometric equations helps potential users gauge the robustness of models and determine the limits of their application.

- Sample selection: The method used for sample selection should be carefully described to address whether it was based on diameter classes, floristic composition, or other criteria.
- Sample size: The sample size should be adequate to make robust statistical inferences from it. As a matter of consistency, it should also be identical to the number of raw data provided in the database, or provide reasons for any differences.
- Diameter and height interval: Indicates the range of diameter and height for which the equations are valid.
- Tree species and vernacular names: Since common names vary considerably among locations, and taxonomy is being updated constantly, it is desirable to have both lists made available to users, and the reference used for identification should be included. Ideally, vouchers for the species harvested should be deposited in an institutional herbarium.
- Tree components considered: Henry, *et al*. (2011) provides indication on the tree components to be considered when constructing allometric equations: stump, trunk, bark, small roots ($D<5mm$), medium roots ($5<D<10mm$), big roots ($D>10mm$), thin branches ($D<7cm$), large branches ($D>7cm$), dead branches, leaves and fruits.

4. Methods used for data and laboratory analyses, formulas for calculations

Reporting measurement methods, tools, and calculation procedures used help verify the construction of allometric models and replicate their construction with expanded or additional datasets.

- Measurement methods of independent variables: Trees height can be measured using graduated poles, vertex, clinometers, relascopes, or tape measures when on the ground (Chave, *et al.,* 2005). The diameter can be measured using a diameter tape, a caliper or a relascope. Crown diameter can be measured using the projection of the shade or on the ground when felled. Several instruments are used to measure forest variables and it is preferable to indicate them. Brack and Wood provide a description of the various instruments to be used to measure dendrometric parameters (Brack and Wood,1996)[37].

- Methods for laboratory measurements: As described in the manuals developed by Anderson *et al*. (1993) and Picard *et al*. (2012).
- Formulas: Those used for calculating volume, wood density, biomass expansion factors and other variables should be clearly indicated, together with the references used. The manual by Picard *et al*. (2012) provide most of them.

5. Raw data and meta-data

Raw data and its accompanying metadata are necessary to calculate uncertainties, validate models, and construct new ones.

- Volume data by tree components: Volume data are very useful to develop biomass expansion factors. Most countries used volume and biomass expansion factors to assess national forest biomass (FAO,2010).
- Biomass data by tree components: Depending on the objective, biomass has to be estimated for different components. For example, for bioenergy, biomass for trunks and branches up to 7 cm of diameter is generally measured.
- Wood density: Fresh and dry wood values can be used for different purposes.
- Tree species: See previous comments in item 3.
- Metadata: Authors are encouraged to provide information on raw data to facilitate valorization of the work undertaken, continuity of efforts, and build collaborations within the scientific communities.

6. Model fitting, prediction and uncertainty

Statistical parameters are useful to assess the robustness of any given model and aid in comparing among them. Appendix 2 lists basic statistical concepts and their definitions.

- Model type: This information refers to the mathematical form of the models (power, log-transformed, non-linear etc.) and any transformations performed on the data (log- and back transformation).
- Number of variables: Useful in assessing the parsimony of available models.
- Procedures for model fitting: Details about the software (with version), graphical and statistical diagnostics tools, and any scripts and processes used to fit the models.
- Goodness of fit: A description of the statistical parameters used to assess the goodness of the fit: R^2, RMSE, P value, MSE, standard error, bias, etc.
- Model comparison and selection: What were the statistical parameters used for model comparison and selection (SSE, F-Test, AIC/BIC, FI).
- Validation: Information on the data used for validation (sample size, relative average error, etc.).
- Calculation of efficiency factors (Mayer and Butler,1993)

Users are encouraged to present graphics illustrating the relationship between tree diameter versus tree height, diameter versus biomass, crown diameter versus biomass, the resulting model showing the interval of calibration, and predicted values versus observed values.

[37] http://fennerschool-associated.anu.edu.au/mensuration/home.htm

Conclusions

The necessary criteria and information that scientists should use to develop their models and provide adequate information on them had not been considered before in a systematic manner. The recommendations offered in this document are meant to serve scientists and data users as a reference framework to improve biomass and volume allometric equation construction and reporting. These recommendations should apply in all situations and circumstances and do not aim to become standards.

9. Allometric equation databases: data sharing, recommendations and principles

Introduction

Advances in forestry research face the complexity of forest ecosystems whose dynamics are largely longer than human and even larger than a single scientist career. Networks for permanent plots were established at global level and in some countries (Picard, *et al.,* 2010, Picard and Gourlet-Fleury,2008, Beetson, *et al.,* 1992, Hari, *et al.,* 2006). However, it appears that data quality is fraught with errors of measurement, methodological changes related to technological progress, and changes in technical, human and financial capacity (Melson, *et al.,* 2011). Data harmonization, whether by interpolation or extrapolation methods, and recalculation ensures consistency of measurements over time (IPCC,2006) but, if not appropriately done, affects measurement accuracy. Improving estimates and continuity of efforts requires access to raw data, meta-data and documentation describing the method of data collection. However, despite the efforts of archiving and documentation, data lost and data collected by many measurement campaigns are often lost where capacities are not adequately maintained. As part of the assessment of forest resources using allometric equations, access to raw data is crucial for the improvement of models.

Developing countries implementing climate change mitigation policies, will have to submit their updated inventory of GHG emissions every two years and national communications every four years, starting in December 2014 (UNFCCC,2011). Increasing the frequency of preparation of inventories of GHG emissions requires the establishment of an effective national emissions accounting system and access to the data used for completing the inventory (Tulyasuwan, *et al.,* 2012). In the context of the forestry sector, this means access to methods and data used for calculating changes in forest carbon stocks (forest area, forest inventory, allometric equation, wood density, etc.). The calculation of the uncertainty cannot be properly carried out if the original data are not available (Chave, *et al.,* 2004, Molto, *et al.,* 2013). In addition, for allometric equations, sharing data avoids the duplication of expensive and time consuming field data collection. It also increases the size of datasets, which directly enhances the quality of the resulting allometric equations in terms of DBH range, goodness of fit indicators, and range where the equations are valid. The objective of this document is to identify constraints and propose solutions to facilitate data sharing of allometric equations. First we analyze limitations to sharing data among researchers and then propose solutions to those limitations based on 6 main constraints that were identified.

Limitations to data sharing

We identified the following 6 constraints that prevent transparent and useful sharing of data related to allometric equations:

1. Intellectual property: Unless transferred, intellectual property belongs to the institution or the project that funded the research and not the people who collected the data. Where data are collected by private institutions, access to data can be more complicated and can necessitate the exchange of financial services. Under certain government projects, data production can be monitored and the data can be exclusive and confidential. In the context of public research (*i.e.* conducted through public funding), data should be public but often data are not made available by the authors. Intellectual property for data that are collected as part of research funded by the public sector or under the auspice of government projects needs to be further clarified and rules established.

2. Unclear use of the data: data can be used for different purposes including commercial activities. It is important to clarify what the data will be used for to ensure that the work undertaken by the owner(s) and the author(s) is acknowledged and/or compensated.

3. Cultural: Although a culture of collaboration seems to be developing worldwide, scientists are not used to sharing their data. Competition between institutions and individuals limits data exchange and transparency ("my money, my data"). Authors are afraid to be excluded from publications resulting from the data they share. This affects their professional performance because they are mainly evaluated by the number of publications they produce. In the field of allometric equations, scientists fear that data are used to develop new models with no real improvement over the original ones. Authors and data owners are afraid of not being able to use their data again if they share it.

4. Technology: No system is currently available to ensure an adequate system of data sharing. Scientists share their data using their own networks and database formats. There is a clear need to develop a system for data sharing that includes clear rules and standardized procedures and formats for data sharing. This system would need to be trusted by authors and owners alike.

5. National capacities: Technical, human and financial capacities may limit data collection, analysis, quality assurance and control, valorization and sharing. Many scientific articles include fees for publication. Not all scientists have the financial capacity to ensure publication of their work and as much as 47% of all allometric equations are only reported in grey literature (Cifuentes Jara, *et al.,* 2013).

6. Data quality: We need to ensure data quality is adequate among studies (*i.e.* comparing results with other available results). However, there are no agreed upon standards or good practice guidelines that would facilitate this process. Individual researchers have complete independence as to the amount of details they may share about their data. Data and metadata reporting often lacks quality assurance and is only marginally addressed during the peer-review process. There are documented instances of published equations being improperly transcribed or misquoted, and grossly incomplete descriptions of the tree components included in a given equation (Cifuentes Jara, *et al.,* 2013).

Proposed solutions to strengthen data sharing

1. Intellectual property: The intellectual property for the data collected by public and private, national and international projects needs to be clarified. In the context of private data, national policies can support data sharing with national research institutions. In the case of data from the private sector, the data can be strategic and can be shared without geographical location. In the case of public research, it is necessary to inform authors and clarify data ownership, and to ensure the collection and archiving of data. Ideally, this needs to be done at project inception, with clear rules laid out and made public. National capacities on intellectual property rules need to be enhanced adequately.

2. Unclear use of the data: Users should clearly specify how the data will be used and the purpose of data use. Owners, authors, and users have to mutually agree on the terms of fair use.

3. Cultural: Collaboration between research institutions and between authors should be encouraged and facilitated to allow appropriate use of all results (not only those that are published) in a transparent and timely way. Collaborations are also needed to facilitate technical, financial and human support and a more equitable allocation of resources and exploitation of data collected. There is a need to develop a culture of data sharing and to enhance the recognition of researchers' work. Data sharing agreements between researchers need to be facilitated and implemented. Data owners think most of the time that sharing data is a black or white situation, *i.e.* sharing leads to the loss of ownership and not sharing is necessary to keep the ownership. However, as shown by the creative commons license agreement, there is a wide range of possible agreements and negotiations among data owners and users. This type of agreements should be encouraged to promote win-win situations where parties find it advantageous to share their data. The following list of questions represents an initial attempt to help both data owners and potential users think about what they can share and under what conditions:

- Description of the data:
  - What are the vegetation types covered by the data? When were the data collected?
  - What are the indicators and variables collected? (Provide database template with the column names and examples of field forms.)
  - How many trees have been collected per vegetation type?
  - What is the DBH and H range covered?
  - Has the wood density of the collected trees been measured? Does a table of tree wood density exist at species level for the country or region under analysis?
  - Have the collected trees been identified at the species level (vernacular and scientific names)? Do tree species lists exist at the national level?
  - Does the metadata exist?

- Possibilities for sharing:
  - Who owns the data (individuals or institutions)?
  - What are the constraints for sharing data?
  - Which modalities for sharing the data are feasible?
  - For how long would I authorise the use of my data?
  - Would the dissemination of the raw data be authorised or not?
  - What would be the expectations for authorship in future publications?

4. Technology: There is a clear need to develop a structure for data sharing. This entails having standards for data integrity as well as the actual software and tools used to archive and share data. Several networks have been developed to support data sharing agreements for forest inventory data (RAINFOR,2013)[38] and for plant traits 2013; (Cifuentes Jara, *et al.,* 2013, TRY,2013). Such a network and structure for data sharing need to be developed for tree allometric equations as well. These networks and structures include accessibility for metadata depending on the type of data sharing agreement. Currently, authors and owners are encouraged to share their metadata but there are no clear locations to publish those metadata. Appendix and supplementary materials in scientific journals are not made to

[38] http://www.rainfor.org/en

present metadata. It is necessary that such a structure provides information on authorship and ownership. With the increasing availability of cloud storage and readily available on-line database software and tools, the technology barrier is constantly being lowered. The GlobAllomeTree platform[39] is a first step in that direction. It allows researchers to access available tree allometric equations and compare their equations with existing ones.

5. National capacities: National capacities need to be enhanced to facilitate development of national repositories of data, and data archiving systems. National policies should encourage data sharing and provide incentives for it.

6. Data quality: Tools for quality control need to be provided to facilitate quality assurance and control procedures. The emissions factor database of the IPCC is a first attempt to allow researchers to access emission factors and compare it to their results. This would increase the impact factor of journals each time data are used by another article which increases visibility and recognition of the work undertaken. Authors are encouraged to publish their results, including the raw data. This makes calculating uncertainties possible.

Conclusion
It would be necessary to create an online repository to store raw data and metadata for allometric equations. Such a repository should allow management of data sharing among users. A reliable system for the equitable sharing of data is necessary as well. The data repository should promote the establishment of a network of users and facilitate collaboration among researchers. It is crucial that data authorship, ownership and use of the data are clarified in such a system of data sharing. Beyond the mechanics of data storage, metadata, and quality control/assurance protocols, a change in culture is needed among researchers such that data sharing and collaborations are actively sought.

[39] www.globallometree.net

10. Recommendations on using tree allometric equations to assess national forest biomass and assess uncertainty

Introduction

The evaluation of tree volume and/or biomass is crucial to guide management plans and forest policies. The first forest inventories were established in the middle ages in Hungary and they have evolved to meet the demand and provide the necessary information of modern forestry (Tomppo, *et al.,* 2010). Forests provide a multitude of services including bio-energy, biomass, timber, carbon sequestration, biodiversity etc. Allometric equations and volume tables are crucial for evaluating many of those services. In most countries, forest assessments mainly focus on commercial volume. In a few countries, foresters estimate biomass to assess bio-energy availability. In most cases, biomass and carbon stock estimation is performed using volume equations and biomass expansion factors although there are allometric equations developed for different purposes and used in different ways to meet specific objectives.

Few countries have a national database containing available tree allometric equations. Yet, this is the first step to assess data availability and identify the best approach to perform the necessary calculations needed to assess biomass and carbon stocks (both at project and national levels). The fact that few countries possess a national database for tree allometric equations can be explained by various obstacles; access to information and data sharing are probably the most important. Payments for environmental services, particularly for carbon sequestration, are becoming more promising, but require an appropriate assessment of the resources. Under the United Nations Convention on Climate Change (UNFCCC), countries should follow IPCC guidelines to prepare their GHG inventory and should improve the accuracy of measurements as much as possible. This may involve the use of specific methods or default values, depending on the contribution of the inventory categories to the total assets as well as the available national financial, technical and human capacities. There are a multitude of methods for the use of allometric equations to ensure the most accurate results. It is important to note that the desired accuracy should focus on changes in biomass and carbon stocks, not just stocks at a given time.

Decision trees to use allometric equations are based on a set of criteria that will guide selection of models. Criteria that can guide the selection are: variables of interest, statistical parameters, robustness, sample size, species considered, range of validity, geographic location of field measurements, climate zone, date of measurements, quality of equations compared to other equations, transformation of the output variable, mathematical shape, adequate documentation, materials and method used, temporal representativeness, tree components considered, etc. The construction of a decision tree is based on a series of scientific hypotheses to be presented together with the approach. These can be: "The equations having a sample size less than 30 individuals are not robust."; "Species specific equations are more robust than equations for an ecological zone or pantropical distributions"; "Geographical proximity is a good indicator of representativeness of the study area". Identification of the most suitable decision tree requires, in most cases, access to original data. If we sum the total number of individuals for the tree allometric equations available at GlobAllomeTree[40], it follows that 373,419 individuals were measured across a range of forest ecosystems (Database version of June 2013). This figure is significantly higher than the sample size currently available for creating pantropical equations. In addition, while the pantropical equations were developed for trees in unmanaged forest, the GlobAllomeTree database contains individuals from a wide range of forested landscapes.

[40] www.globallometree.net

The objective of this document is to identify recommendations to develop an approach for assessing biomass and volume at the national level that ensures the lowest possible uncertainty. We address how to reduce the uncertainty related to the choice of allometric equations to estimate biomass at the national level. We then discuss adequate sampling approaches to develop tree allometric equations and improving those once national forest inventories are completed. Consideration of national circumstances is then given to the selection of tree allometric equations and their potential use as part of national biomass assessment programs. Finally, we suggest two approaches to assess the uncertainty of volume and biomass estimates, ultimately seeking to improve on the quality of national forest inventories.

Recommendations for assessing biomass and volume at the national level

1. How tree allometric equations accuracy impacts national forest biomass assessments?

The choice of a biomass equation among several available candidates has a significant impact on the carbon stock estimation (Alvarez, *et al.,* 2012, Kuyah, *et al.,* 2012, Nogueira-Lima, *et al.,* 2012). This difference in output among equations tends to decrease when it comes to estimating changes, either for biomass or carbon. Various factors will affect the estimates, both stocks and changes: (1) the mathematical form (linear or non-linear model of a hyperbolic or power relationship); (2) the specificity of the model, *i.e.,* whether it is a model for a particular species, a type of ecosystem or a more general equation; (3) the input and output variables of the equations; whether the input variable is diameter and/or tree height and the output variable is volume or biomass; (4) the interval of validity of the equation; and (5) the representativeness of the model vis-à-vis the population. It will therefore be necessary to test the applicability of the equations under a particular situation (*i.e.* test whether the described tree allometry changes because of differences in soils, elevation, or climate relative to the site where the equation was originally constructed). Many authors argue that including tree height will tend to improve the estimates. However, this implies that tree height is appropriately measured during the field survey. This is particularly difficult in rainforests where tree tops are not easily visible. We must therefore ensure that the equations developed are in line with field measurements made during the national forest inventory. Improper use of allometric equations will obviously introduce a bias in the estimates.

At the national level, there are large differences of estimation of stocks and their changes between different authors (Malhi, *et al.,* 2006, FAO,2010, Saatchi, *et al.,* 2011, Larjavaara and Muller-Landau,2013). For 16 countries in Central and South America, FAO (2010) estimates range anywhere from 0.41 to 4.1 times those calculated by Saatchi, *et al*. (2011). It seems that the main factor influencing these differences is related to varying estimates of land surfaces among studies. This is, in turn, partly due to differences in classification criteria used to define forests and also to different remote sensing technologies and resolutions being used. Errors in land area estimates from national forest inventories should be lower because they are measured in the field.

Using different allometric equations to calculate volume, biomass, and carbon stocks for the same area can also yield differing answers. In a study in Colombia, Alvarez, *et al*. (2012) found differences anywhere from -13.9% to +414% (relative to field-measured biomass) among 8 pantropical models available to estimate above-ground biomass. These differences may be due to one of more of the reasons mentioned before. To identify the available equations and check their consistency with field measurements, it will first be necessary to construct a database containing all allometric equations available for calculating volume and biomass, according to the different tree compartments. Several different decision trees can be constructed, which will result in different volume and biomass estimates at the national level. The most appropriate procedure will be identified according to the chosen objectives. For example, it is preferable to use the equations that directly estimate the biomass if the goal is to obtain a national estimate of the biomass. However, it is not clear whether biomass equations represent all kinds of trees considered in the inventory. In contrast, it is preferable volume equations if the main objective is to obtain commercial volume estimates. The biomass estimation can then be performed with a database on wood densities or expansion factors, as is the case in the U.S. states or France. This database needs not to be exhaustive. A combination of both methods can be used to answer both needs depending on data availability and national capacities. It may be necessary to test several different decision trees and compare among results before choosing the one with the lowest uncertainty relative to direct measurements or field-verified data.

2. What is the adequate sampling scheme to develop tree allometric equations?

Destructive measurement is costly and difficult, so it is preferable to establish an appropriate sampling design to reduce costs and ensure the representativeness of the sample vis-à-vis the population. A good overview of the population is therefore needed. This requires the identification of the species composition, the structure of the population, the size of trees (especially diameters and heights), and its occurrence relative to soil types, altitude, etc. Particular attention should be paid to the selection of trees of different sizes. Large trees, which are more difficult to measure, are often ignored in sampling campaigns, which can lead to considerable bias in the estimates and restrict our ability to accurately calculate biomass and carbon stocks (Saatchi, *et al.,* 2011, FAO,2010). As part of a systematic sample, we thus must be careful to ensure that the sampling effort captures the species and dimensions that are representative of the species, population or ecosystem types under study. One solution would be sampling along gradients where allometry is known, for example by taking into account functional or architectural types. Sampling should be transparent, robust and simple. It will be the result of a compromise between the desired accuracy and the means available to perform field measurements. When data are already available, additional sampling should focus mainly on the parts of the population that have not been covered in the previous sampling (forest type, location, size trees, etc.).

The total error associated to the use of allometric equations is a combination of three types of error. First we have the error associated to the sampling design. It is dependent on the number of trees sampled and the representativeness of those trees relative to the population. This error can be calculated and, given enough resources and time, controlled with relative ease. The second error is due to human error while measuring the forest, entering and checking data. This error cannot be assessed exactly but procedures exist to minimize it. The third error is associated to the model's prediction. The first and third errors are due to the fact that results are based on samples and not on the entire population. These two errors are not avoidable but can be estimated through statistical indicators and reduced as much as possible.

3. How to improve the sampling strategy to develop tree allometric equations when the national forest inventory is completed?

Access to forest inventory data should be given to institutions working on allometric equations, through institutional arrangements. Data from the national forest inventory is crucial to guide sampling and data collection efforts to construct allometric equations. Inventory data such as forest structure and floristic composition helps stratify the population and guides the generation of new equations or the acquisition of additional field measurements. Data collection can be of two types, destructive and non-destructive. Non-destructive measurements may correspond to LiDAR measurements for estimating volume, measuring height and diameter to establish height-diameter relationships, etc. Destructive and semi-destructive measures are needed to construct biomass and volume equations and for calculating expansion factors. Sampling areas used for allometric equations should be located outside the permanent plots used for national forest inventory.

4. Which national circumstances affect the selection and/or use of tree allometric equations?

The main national circumstances affecting the use of allometric equations are (1) data availability;

(2) the biophysical and environmental context; and (3) the human, financial and technical capabilities. The availability of allometric equations depends on the work undertaken to develop and compile the data, but also on the accessibility and transparency of available data. The biophysical and environmental context may be more complex in some countries than in others. A country with a great diversity of flora and climate (*i.e.* along altitudinal gradients) will be more difficult to sample than a country with more homogeneous forests. However, there are practical limits to sampling efforts, as it is not possible to measure all existing variability. In addition, technical and human capacities in some countries are relatively limited, *i.e.* some countries do not have university courses in the field of forestry. In addition, some countries have limited financial capacity to ensure data collection, storage and management; proper use of equations; and improvement of the national system of calculation. The proposed approaches to the use of allometric equations will have to adapt to different national contexts.

5. Taking into account the national contexts, what are the potential options for using tree allometric equations as part of a national forest biomass assessment?

Potential options for using tree allometric equations as part of a national forest biomass assessment depend on the availability of data (raw data, equations, and forest inventory data). Raw data are needed to allow us to validate the estimates and perform accuracy assessments. Although highly desirable, it is not required to have locally-developed equations; available generic models may be used in early stages of the system. Finally, the national forest inventory data can provide national-scale coverage of ecosystems and facilitate the field data required to calculate volume and biomass. Cost issues are also relevant but were not addressed in these discussions.

The following three options for using allometric equations as part of a national forest biomass assessment are possible based on the information available:

- **Scenario 1:** Neither the equations 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:** Raw data and equations are available. In this case, models taking into account tree species, forest types, climate and interval of validity can be considered.
- **Scenario 3:** Raw data, equations and inventory data are available. In this case it is possible to develop new equations for homogeneous population.

A proposed method that would allow inclusion of allometric equations in a national forest biomass assessment would require adapting decision trees to include adjustment methods such as Bayesian model averaging methods (Picard, *et al.,* 2011, Zapata-Cuartas, *et al.,* 2012). Any unique regional model tends to over- or under-estimate estimates for any given location. Bayesian model averaging (BMA) method can group models, *e.g.* by climate zone. The BMA method has the advantage of generating weighted estimates. The weighting can follow the stratification used for inventory or some prior knowledge and improve the estimates to include a greater range of variation in diameters of samples or species. Also, the coefficients used are the result of the weighted average of the information from existing models. This approach is a novel and justifiable method for Scenario 1 and should be a robust (adaptable) alternative to consider when there are information (Scenario 2 and 3).

6. How to perform uncertainty assessments taking into account the different sources of errors and available data?

Two options are proposed for the calculation of the uncertainty. The first method is to validate the results using data obtained from destructive measurements. This can be costly and requires additional field work and coordination with local authorities. The second method uses Monte Carlo methods or Bootstrapping (Molto, *et al.,* 2013). These advanced statistical methods are not field intensive but require advanced skills not readily available in all countries. No assessment of whether field estimation or statistical procedures yield more accurate estimates of the real uncertainty has been undertaken. It is clear that the analysis of error propagation can be achieved when the data are available to allow this.

How can the use of allometric equations improve national forest inventories?
The adequate use and selection of allometric equations and accuracy of estimates contribute to improving national forest inventories (NFI). Allometric equations are critical to improve the precision of volume, biomass and carbon stock and changes. This can be done in different ways: (1) Stratification is valuable, although there will always be the need to sample additional ecosystems or species with particular growth forms. (2) Non-destructive measurements during NFI campaigns can improve adequate measurement of dendrometric parameters. The use of terrestrial LiDAR technology can be used to describe volume, and then related to biomass and carbon stocks. The use of LiDAR technology is still limited by high costs and lack of national capacities to analyze the data. Data such as carbon content or identification of tree species cannot be collected using this technology. (3) Adequate measurement of variables such as wood density, tree diameter and tree heights.

11. New methods to assess forest biomass: recommendations for future research

Introduction
Estimation of forest biomass at national level encounters difficulties related to the complexity of forest ecosystems and to the objectives, sometimes ambitious, of forest policies. Inventories, their methods and analysis, have continually evolved with technological advances. Measurements of diameter, height and distance, once measured from measuring tape, forest compass and relascope are now enhanced with new techniques such as the use of laser. The use of remote sensing has also allowed improved sampling strategies, calculation of forest land area, the location of the inventory plots, and the detection of many variables of interest such as forest fires (Barducci, *et al.,* 2002).

The amount of information collected during forest inventories has risen rapidly to meet the demand of many services such as biodiversity, tourism, interactions between local populations and surrounding forest, carbon sequestration, etc. Similarly, data processing software has evolved from MS-DOS-based computing systems in the 80s (Rondeux,1993), to calculation systems in PostgreSQL or MySQL (Miceli, *et al.,* 2011). Most of the activities related to the management of forest harvesting require a very large amount of data in the field and the capture, storage and analysis of data should be done appropriately.

Statistical analysis has also evolved. Essentially based on the arithmetic mean and the use of default factors, national forest estimates do not take into account many factors that can alter the quality of the results. Estimates of forest resources are influenced by numerous uncertainties: sampling error associated with the inventory (affects precision but not bias as long as the sampling is well designed), measurement uncertainty (can affect both precision and bias), regression uncertainty inherent in any estimated regression relationship (usually only affects precision), and model-selection uncertainty (can affect both precision and bias) introduced by having to choose among multiple, potentially equally applicable regression relationships and conversion factors (Melson, *et al.,* 2011). Although it is necessary to take into account the different sources of error in the calculation of the total error (Chave, *et al.,* 2004) (Molto, *et al.,* 2013), this is rarely done. New methods are being tested in the forestry sector to enable better consideration of the various existing models and improve estimates at the national level (Zapata-Cuartas, *et al.,* 2012, Picard, *et al.,* 2011).

Forest assessment evolves with technology, knowledge and capabilities. Similarly to the development and use of allometric equations, volume tables have evolved in response to different needs. Faced with the need to improve the accuracy of emission factors in the context of quantifying the contribution of ecosystems to balance greenhouse gas emissions, it is necessary to review in this section which technologies and statistical methods are available today and how they can help improve the calculation of volume and biomass at national level.

New technologies to improve forest biomass assessment

Stereoscopy
Stereoscopy (also called 3D imaging) is a technique for creating or enhancing the illusion of depth in an image by means of stereopsis for binocular vision. Stereoscopy is used in photogrammetry and also for entertainment through the production of stereograms. Stereoscopy is not new and has been evolving since the early use of aerial photographs (Spurr,1948, Avery,1996) to more frequent data acquisition techniques (Straub, *et al.,* 2013). Stereoscopy is used with aerial photography for land use surveys, including forest monitoring. Species may be identified and their images measured with

a surprising degree of accuracy. Maps can quickly and accurately be prepared from photographs. Units of vegetation and of land use can be delineated from the photographs and their areas determined with greater accuracy than is possible in the field in any reasonable amount of time. Stereo images can be an alternative to airborne laser scanning data for modeling key forest attributes, even in mixed central European forests with complex structure (Straub, *et al.,* 2013). Stereoscopy can also be used to estimate difficult to measure variables such as forest residues (Ottmar, *et al.,* 1990).

Laser Imaging Detection and Ranging (LiDAR)
LiDAR is a remote sensing technology that is based on laser ranging, which measures the distance between a sensor and target based on half the elapsed time between the emission of a pulse and the detection of a reflected return (Baltsavias,1999). LiDAR systems are classified as either discrete return or full waveform recording (Wulder, *et al.,* 2012), and may be further divided into profiling (recording only along a narrow line directly below the sensor) or scanning systems (recording across a wide swath on either side of the sensor) (Lim, *et al.,* 2003). Full waveform recording LiDAR systems digitize the entire reflected energy from a return, resulting in complete sub-meter vertical vegetation profiles. In contrast, discrete return systems record single or multiple returns from a given laser pulse. We can differentiate four types of LiDAR: Airborne profiling, Airborne scanning, Spaceborne, and Ground LiDAR.

Profiling LiDAR instruments are well suited to applications that seek to characterize forest attributes over large areas by means of sampling (Boudreau, *et al.,* 2008), or that seek to characterize changes in these attributes over time (Wulder, *et al.,* 2007). The Portable Airborne Laser System (Nelson, *et al.,* 2003) is a profiling LiDAR system, built from off-the-shelf components, which has been deployed in research studies over a wide range of forest types and in a number of large area sampling applications. Other profiling LiDAR systems have also been used in a forestry context.

Airborne scanning LiDAR provides a flexible data collection system. High-density LiDAR provides sufficient reflections from the ground to generate accurate digital terrain models under dense conifer forest in mountainous areas (Reutebuch, *et al.,* 2003). Over the past few years there have been considerable advances in LiDAR systems which have resulted in improved LiDAR positional accuracy and increased surface point density. The flexibility of airborne LiDAR, coupled with a high level of positional accuracy and point density, makes LiDAR systems an attractive data acquisition tool for estimating a wide range of tree and forest parameters (Laes, *et al.,* 2011) such as tree height (Andersen, *et al.,* 2006), stem volume (Heurich and Thoma,2008), tree biomass (Li, *et al.,* 2008), and leaf area index (Morsdorf, *et al.,* 2006). The use of LiDAR for estimating forest inventory parameters and structural characteristics is reviewed by van Leeuwen and Nieuwenhuis (2010). Airborne LiDAR can be used by countries to support the national carbon stock estimates, such as in New Zeeland (Stephens, *et al.,* 2012).

The Geoscience Laser Altimeter System (GLAS) was a large footprint spaceborne full waveform profiling LiDAR carried on the Ice, Cloud, and land Elevation Satellite (ICESat) (Wulder, *et al.,* 2012). The main objective of the GLAS instrument is to measure ice sheet elevations, changes in elevation through time, and measurement of vegetation cover. Forest canopy metrics can be generated from the GLAS waveforms (Xing, *et al.,* 2010) and these metrics can, in turn, be used to generate estimates of aboveground biomass (Baccini, *et al.,* 2008) (Boudreau, *et al.,* 2008) and carbon (Nelson,2010). A similar sensor, ICESat2, is planned for 2016 with a GLAS instrument having a smaller footprint than the precedent one. NASA's DESDynI (Deformation, Ecosystem Structure, and Dynamics of Ice) mission, initially targeted for launch in the 2012–2014 timeframe, would have provided global observations of terrestrial biomass to support assessing the impact of human activities.

Several studies have used ground-based LiDAR for forest structural assessments, using simple LiDAR rangefinders (Radtke and Bolstad,2001), discrete-return LiDAR systems (Loudermilk,2007) and Echidna LiDAR (Yao, *et al.,* 2011). The last technique greatly enhances the automated retrieval of DBH and stem count density. Digitizing the full return waveform also provides significant information for the retrieval of leaf area index (LAI) and the foliage profile (foliage area volume density with height) of a stand.

Ground Penetrating Radar

Ground penetrating radar (GPR) is a nondestructive geophysical technique widely used in locating underground objects (*e.g.,* restrictive soil horizons, stone lines, bedrocks, water tables, buried artifacts, pipes, and cables). Applying GPR for coarse root quantification is still in its infancy, but has shown interesting potential in determining coarse root related parameters (Bassuk, *et al.,* 2011). Guo, *et al*. (2013) review the state-of knowledge of coarse root detection and quantification using GPR, and discusses its potentials, constraints, possible solutions, and future outlooks.

Hyperspectral imagery

Airborne hyperspectral imagers are powerful diagnostic tools for remote sensing. (Jusoff,2009). A targeted imager will view smaller specific “target” areas selected by the user. A targeted hyperspectral imager operating from a low altitude flying aircraft will typically provide spatial and spectral resolutions in the order of 0.5-4 m and 5-20 nm, narrow, contiguous over the visible (VIS)-and-near-infrared, respectively. An airborne hyperspectral imager’s ability to detect molecular absorption and particle scattering “signatures” of constituents is its defining advantage, compared with broadband multi spectral imaging sensors such as the Landsat™, SPOT HRV, IKONOS and QuickBird. The finer spectral resolution of an airborne hyperspectral imager, along with an appropriately high signal-to-noise ratio (SNR) in the wavelength of interest, allows detection and inferences of biological processes that are characterized by specific emission or absorption features. In many situations, an airborne hyperspectral imager can unambiguously identify surface constituents and their abundance, and capture the unique spectra, or spectral signature of an object, which can then be used to identify and quantify the material(s) of which it is composed. Hyperspectral systems have made it possible for the collection of several hundred spectral bands in a single acquisition, thus producing many more detailed spectral data. However, with the advances in hyperspectral technologies, practical issues related to increased sensor or imager costs, data volumes, and data-processing costs and times would need to be considered especially for operational modes. The sensor has the effect of measuring the status of the targets such as within field variation and timber inventory for precision agriculture and forestry, respectively. Shafri, *et al*. (2012) reviews the methods for urban classification and Govender, *et al*. (2007) for natural resources using hyperspectral remote sensing data and their applications.

How can new technologies improve forest resource assessments?

New technologies currently available allow improvement of biomass and volume measurements in different ways. Mapping the land and the acquisition of geographical models facilitates calculating the accessibility of field plots, minimizing transport, and preparing the field measurement phase. Remote sensing methods are used to improve calculation of forest land area. Airborne and satellite hyperspectral imagery is being used to improve field accessibility and forest stratification (identification of soil types, floristic composition, seasonality, leaf area index etc.). However, the most significant advances are related to improving the accuracy of field measurements and reducing their cost. As an example, LiDAR samples may be used in a manner similar to field plots, wherein the information generated is used in combination with other spatial data (such as classified optical satellite data) to facilitate stratification, thereby enabling the extension of attributes (*e.g.,* height) across large areas (Wulder, *et al.,* 2012). Alternatively, with forethought and careful planning, LiDAR data can be employed in a sampling design to infer or estimate characteristics of interest (*e.g.,* volume, biomass, carbon) across a larger area or population. The presence of strata within a given population enables the representation of conditions over smaller sub-areas and provides spatial context to aid in model development. Ground Penetrating Radar can be used to predict belowground biomass which is one of the most extensive field variables to measure, particularly if using destructive measurements (Picard, *et al.,* 2012). Most of the time belowground biomass is not considered during field inventory campaigns. Many remote sensing technologies might be a promising field of research and can provide a non-destructive approach to estimate tree volume/wood density and forest biomass. Computerized tomography imaging might be a promising field of research that can provide such data.

Furthermore, development of new technologies is crucial to improve accuracy of field measurement and decrease the cost and improve practicability and feasibility to measure forest variables. New technologies can also decrease the time necessary to collect forest variables in the field.

New technologies allow improving the assessment of forest resources but remain limited
New technologies will help improve the accuracy of measurements, reduce the cost of measurements, and allow the implementation of non- or semi-destructive measurements. However, the adoption, adaptation and feasibility of these technologies face many constraints:

- National capacities must be sufficient to be able to produce and analyze data. The technical staff should be trained to use the techniques and software for the collection, storage, analysis and production of data. The initial cost in terms of training capacity is important and should be anticipated.
- New technologies are often associated with a greater quantity of information and require a suitable archiving data. The institutions responsible for data collection, analysis, archiving, and production of results must thus have sufficient financial capacity to ensure the permanence of a system capable of using the new technologies and their integration into national-level estimation. The financial capacity should also enable the acquisition of equipment and the necessary data.
- Field data are crucial to validate the results obtained by the new technology (but see (Asner, *et al.,* 2012)). Some data such as the relationship between diameter and height cannot be measured accurately in the field. The data acquired by national and international programs should be made available to facilitate and improve the synergy between research and development. For this we need to develop data sharing agreements to make data available among national institutions.
- Results are restricted to limited geographical areas and it is difficult to assess the applicability of the method for larger areas and contexts. The use of certain proxies (*e.g.* LAI) for estimating biomass is limited and only applies in certain specific cases. The use of ground penetrating radar technologies to estimate root biomass or penetration measurements for estimating wood density is also limited by many constraints.
- The results (positive and negative) must be communicated appropriately to policy makers in order to guide appropriate decisions.

New statistical methods
The use of new technologies for data acquisition is only useful if the data are processed and analyzed in an appropriate manner. Traditional forestry statistics are the basic tools of analyzing data. The development of more complex methods can improve our modeling efforts. For example, mixed methods and technologies will produce better ability to identify stratification and gradient, improve model quality, better assess the error, reduce it and provide better indicators. We identify the following recent improvements.

Bayesian models
The use of Bayesian methods is not new in science, but its use in forestry appears to be a new challenge. The use of Bayesian method solves many problems associated with the use of allometric models; some examples follow.

Uncertainty assessment

Standard statistical practice ignores model uncertainty. Data analysts typically select a model from some class of models and then proceed as if the selected model had generated the data. This approach ignores the uncertainty in model selection, leading to over-confident inferences and decisions that are more risky than one thinks they are. Bayesian model averaging (BMA) provides a coherent mechanism for accounting for this model uncertainty. Several methods for implementing BMA have recently emerged (Zapata-Cuartas, *et al.,* 2012).

Allometric model selection

Rather than choosing a single model out of several ones, with the risk of not selecting the best available one, Bayesian model averaging (BMA) offers a way to combine different allometric equations into a single predictive model. Picard *et al*. (2011) used the BMA of deterministic models and combined three existing multispecies pan-tropical biomass equations for tropical moist forests. The resulting model brought a relatively minor although consistent improvement of the predictions of the aboveground dry biomass of trees. The resulting model was able to capture features in the biomass response to diameter that no single model was able to fit. BMA thus is an alternative to model selection that allows integrating the biomass response from different models (Picard, *et al.,* 2011).

Reducing sampling size

A large number of biomass equations have been developed over the years, which provides an opportunity to synthesize parameter values and estimate their probability distributions. These distributions can be used as a priori probabilities to develop new equations for other species or sites. Zapata-Cuartas *et al.,* (2012) propose a method which outperforms the classical statistical approach of least-square regression at small sample sizes. With this method it is possible to obtain similar significant values in the estimation of parameters using a sample size of 6 trees rather than 40–60 trees in the classical approach. Further, the Bayesian approach suggests that allometric scaling coefficients should be studied in the framework of probability distributions rather than fixed parameter values (Zapata-Cuartas, *et al.,* 2012).

Pseudo Data Method
Generalizing or aggregating separate equations for biomass estimation from published literature requires detailed fit information (parameter SSE, R^2, n, etc.) to properly propagate errors or uncertainty associated with the original published work. Often, the level of detail needed to do this in a traditional meta-analysis is not available. Also required is that the regressions used are of all the same form to combine them mathematically.

To combine the different tree allometric equations, it is possible to create pseudo-populations that mimic underlying sample populations. This method allows for the estimating uncertainty needed for error propagation. Pseudo-data can be combined to generate results that are similar to the meta-data provided in the various studies. This method allows for combining different kinds of function forms/studies to limit selection biases.

Other similar methods include non-empirical models, the central limit theorem and meta-data analysis.

Need to improve knowledge and use of statistical methods in the forestry sector

Despite new statistical methods becoming available its use is not widespread. In the few circumstances where they are used to develop new allometric equations, they are tested for relatively small samples, so their application at the national level faces many constraints. Some of these are outlined below:

- The new scientific methods are only accessible through professional networks and reading the scientific literature. Access to both is limited in developing countries.
- National capacities must be strengthened, particularly regarding the use of pseudo-data or Bayesian methods. Gaps in statistical knowledge will impact the use of statistical tools, data production, and quality of the results. A partial way of solving this lack of capacities is to produce multi-lingual manuals and tutorials on the use of new statistical methods in forestry.
- The use of appropriate statistical methods to develop new analyses requires access to relevant data, which are not readily available. In addition, documents describing allometric equations must also contain the statistical data necessary to allow further use and development of models.
- Focus on improving the way sampling of both known and non-understandable variables is done, with new improved methods and tools (*e.g.* tree shape, canopy, form factor for boles and canopy). However, the use of new technological tools in sampling is not necessarily accompanied by an improved use of statistical tools; both should go hand in hand, and dissemination of know-how should include north-south and south-south collaborations.
- The statistical approach selected should consider changes in the magnitude of the variables targeted among different forest biomes, rather than focusing on stocks only.
- Knowledge on the distribution of independent variables (distribution functions of independent variables: normal, log, normal etc. and average and mean values) must be improved.

Proposed approaches to the analysis of national data

In view of new statistical methods and data currently available, the following approaches are proposed for countries wishing to perform volume and biomass calculations at the national level. The proposed approach is flexible and should be able to adapt to all circumstances.

In each of the following proposed approaches, the goal is to reduce the complexity when selecting tree allometric equations, and to improve accuracy depending on different circumstances. When a database on tree allometric equation is available, selection of the appropriate equation will depend on scientific hypotheses that can be more or less robust, particularly for tropical forests, where long term scientific experiments in forestry are rare. The ideal situation, especially when it is not feasible to have species-specific equation, is to obtain an equation by forest type, architectural type or a general equation.

<u>Approach 1: Allometric equations and raw data are not available.</u> In this case, it is preferable to use a generic equation with an interval of validity covering the tree dimensions measured during the forest inventory.

<u>Approach 2: Raw data are available.</u> In this case, it is possible to develop a generic equation that considers the different forest types and/or floristic groups that were measured. It will of course take into account the data from the national forest inventory to ensure the development of a national equation can be applied to all data collected.

<u>Approach 3: The raw data are not available but national allometric equations were developed and more data are being collected.</u> In this case, it is possible to use a Bayesian approach. Allometric

equations are available for most countries and are available at www.globallometree.org. The use of such a method obviously requires adequate statistical knowledge and capacities in forestry statistics.

Approach 4: No raw data but allometric equations are available. In this case, it is possible to simulate a pseudo-population from allometric equations where the sample sizes, the coefficient of determination, root mean square error, AIC, interval of validity of independent variables, and other indicators are indicated. Once the data are simulated, it is possible to use Approach 2 to develop a generic equation.

Approach 5: Data and models are available. This is the most advanced case; it is possible to use a Bayesian method to develop a more general model or several models for different types of forests.

12. Further steps to develop activities and projects on tree allometric equations in Latin America

Introduction

Several ongoing projects are being implemented in the region to support national and sub-national forest biomass assessments. A common need in all assessments is the availability of allometric equations for volume and biomass. Although many allometric equations are available they are poorly documented and disseminated, they focus on a small number of common tree species, and are seldom validated for use in new environments. As the demand for increased accuracy and quantifying uncertainties in the estimation of volume and biomass increases, it has become apparent that additional and improved allometric equations need to be developed.

This paper summarizes discussions among experts convened for the first Regional workshop on tree allometric equation for Central and South America. We review current knowledge on allometric equations and document on-going initiatives to develop allometric equations. We also point out voids in knowledge and propose potential ways to mitigate them in a systematic manner.

1. What are the common gaps in knowledge of allometric equations in Latin America?

Ten areas were identified among all the elements necessary to calculate volume and biomass as the ones with the least information or the greatest uncertainty. Some are related to the limitations due to the ecosystems themselves (high diversity, horizontal structure) while others are linked to methodological or technical issues (lack of biomass expansion factors, limited root:shoot ratios, limitations with wood density, etc.). These issues are later taken into consideration to prioritize the development of allometric equations.

Few tree species are considered: High species diversity in tropical environments brings about a problem of having species-specific models. Thus, current knowledge on tree allometric equations is limited to a few tree species - mostly commercial - and not for all tree species found in any given country. For example, the 10 genera with the most allometric equations are *Pinus*, *Inga*, *Vochysia*, *Aspidosperma*, *Terminalia*, *Protium*, *Cecropia*, *Eschweilera*, *Eucalyptus* and *Ocotea*. Allometric equations are available for less than 17 % of all species found in 13 Latin American countries. Problems with species identification that are common in many tropical forest inventories are also a challenge. For example, 82 % of all allometric equations in an international database recently compiled by FAO (Cifuentes Jara *et al*. 2013) correspond to unidentified species. This possibly reflects the widespread use of generalized equations across the region and suggest increased uncertainty in the estimates of volume and biomass (and, thus, carbon) being calculated. In addition, it is difficult to justify that existing equations are representative of all tree species inside and outside forests when raw data (forest inventory data and destructive measurements) are not readily available for validation across species or species groups.

Species-specific biomass equations are still lacking: Most available equations focus on tree volume and not necessarily on biomass, and it is not accurate to assess biomass using volume tables or functions. The alternative option of using biomass expansion factors to estimate total tree biomass is hampered by the lack of expansion factors for many species. In addition, expansion factors vary with tree size, which complicates their proper use. Furthermore, the relative uncertainty of using biomass expansion factors versus allometric equations to calculate total biomass has not been adequately quantified.

Limited interest and published research in specific tree components and relationships: There is a critical need to increase knowledge of how the components of a tree (*i.e.,* branches, foliage and roots) relate to total tree biomass. This would critically improve accuracy of biomass estimates using volume functions. BEFs can be developed using semi-destructive methods while decreasing the number of destructive measurements. Also, root biomass and relationships between aboveground and belowground biomass are poorly known. Few studies consider belowground biomass, which is one of the carbon pools to be considered as specified in the IPCC. Currently, there is only one pantropical model available for calculating root biomass (Cairns, *et al.,* 1997). In addition, height-diameter relationships are uncommon. It is difficult to measure tree height in tropical rainforests because of their closed canopy, so the use of appropriately developed tree height relationships can be useful to improve biomass assessments based on field inventory data and data obtained using other approaches (*e.g.* LiDAR).

Mismatch between horizontal forest structure and sampling scope: While large trees contribute significantly to total forest biomass, they are often not considered in sampling efforts to construct existing allometric equations. This is mainly because of logistical difficulties related to field harvesting, performing measurements, and the impacts of harvesting large trees on the surrounding forest mass.

Variation of wood density is poorly understood: Wood density is not known for all tree species, making inferences and extrapolations among species and within families complicated. Although wood density varies vertically and axially within trees and also responds to differing growth conditions, these differences are not considered when calculating tree biomass.

Development of non-destructive methods: New technologies for measuring tree volume and biomass non-destructively are being developed. Most use land-based or airborne remote sensing technologies. Measurement of dendrometric variables through these methods would give information on allometry while decreasing the amount of destructive measurements needed. However, these approaches are still being developed, they are expensive for widespread implementation in developing countries, and require capacities that are not readily available worldwide.

Error propagation and uncertainty: Propagation of errors is often not considered when assessing biomass and carbon stocks. There are several sources of error that must be taken into consideration when assessing uncertainty of estimates: sampling efforts, field measurements, equations used, etc. Modern statistical methods (Monte-Carlo, Bayesian, etc.) available to assess uncertainties require advanced statistical knowledge not available in all countries.

Economics of allometric equations: Few studies have compared the different approaches to construct allometric equations, in particular from a financial point of view. This type of studies should be encouraged to help select which approaches may be better adapted to national and sub-national contexts.

2. Which ecosystems and life forms are under-represented in terms of number of allometric equations currently available?

Allometric equation models were mainly developed in forests where commercial timber logging takes place (to calculate volume yields) and as part of scientific research projects in ecology. Since these activities have focused on moist and wet tropical forests that is where most allometric equations available have been constructed. In contrast, several ecosystems have been poorly considered by forestry research related to volume, biomass and carbon stocks estimation: highland forests (>1000 m in elevation) in the Andes and the Central American mountain ranges, dry and very dry forests (*i.e.* thorn forests in Ecuador, *matorrales* in México), mangroves (in Central America, the Caribbean, and South America), swamp forests (*varzeas*, *aguajales*, *cativales*), bamboo forests, and savannas. Certain ecosystem transitions, such as forest-savanna, mixed species wetlands, and the interface between mangroves and upland forests are also poorly represented.

In addition to these natural ecosystems, agroforestry systems or silvopastoral systems have a very limited number of equations available. Only 0.6% of all equations in the GlobAllomeTree database for Latin America correspond to these ecosystems. Similarly, and although the number of tree species used in plantations is likely much higher in Latin America, allometric equations focus only on 18 tree species (Cifuentes Jara, *et al.,* 2013). Finally, certain life-forms such as epiphytes, palms, tree ferns and, to a lesser degree, lianas are not well represented in the literature. Necromass is generally quantified through simple transect intercept methods differentiating different decay status and using a single general equation (Brown and Roussopoulos,1974, Van Wagner,1968).

3. What are the limitations for developing additional allometric equations?

Capacity building is lacking: In many countries there are no forestry schools or courses to build formal capacity on biomass measurement. Transfer of capacities and knowledge is crucial to ensure national ownership of volume and biomass assessment programs. This need is being partially satisfied by strategic capacity building done by local NGOs or research centers such as CATIE, and international organizations such as the USFS and FAO. The latter has produced manuals in three languages (English, French, and Spanish) detailing standard methods to construct, document, and report allometric models (Baldasso, *et al.,* 2012, Picard, *et al.,* 2012).

Access to equations is limited: Most of equations developed before the 21th century have not been digitized and are not readily accessible. They are stored in libraries, forest administrations, research centers, logging companies and might have been forgotten in storage places. It is thus complicated for local technicians to assess the existence of allometric equations to determine their potential use in local projects. GlobAllomeTree is a first step toward improvement of accessibility to tree allometric equations.

Missing metadata and other documentation on published tree allometric equations: Unclear documentation rules for reporting equations result in missing metadata from biomass equation publications. Old equations are not well documented and may have been built for different forest structures. In addition, less robust statistical methods not dealing with heterogeneous variance structures were used in the past, affecting the fit and reliability of those models. The availability of metadata is required to validate equations in sites other than where the equations were first developed. Together with raw data, metadata also determines the feasibility of prioritizing research initiatives or consolidating previously collected tree harvest data with modern datasets to construct new equations.

Data sharing agreements: Data exchange agreements are missing to allow appropriate collaborations between allometric equation developers and national forest inventory holders. This may result in problems with definitions of the variables needed to calculate volume and biomass, and inconsistencies among datasets. Developing standard language and elements of potential data sharing agreements would facilitate the exchange of data among researchers, potentially increasing the size of existing datasets and allowing for the construction of more robust allometric equations for a larger number of tree species.

Networking: Exchange of knowledge among researchers and data users is needed to strengthen actions to build local and national initiatives to quantify volume and biomass. International networks on biomass assessment, however, are not functional and it is difficult for national experts to profit from international expertise and to develop collaborations.

4. Which are the ongoing projects supporting tree allometric equation development and use?

We identified over 20 projects currently developing allometric equations in Latin America (Appendix 3). It is possible to differentiate projects that contribute to (1) national forest inventories; (2) land use and land cover assessment using remote sensing, and (3) testing new technologies and methods. Institutions involved in this research vary from government offices, NGOs, local and regional research institutes, universities, and international organizations such as FAO, UN-REDD, the USFS, and GIZ.

5. How to prioritize generation of new allometric equations?

Development of tree allometric equations should prioritize ecosystems and vegetation types accounting for most of the uncertainty related to biomass changes. Most of the time, those are the same ecosystems that account for most of biomass (*i.e.,* at the species and forest type level). MODIS or Landsat could be used to support identification of forest cover changes and prioritize new field campaigns.

Countries should prioritize efforts where needed and support forest policies and measures. Development of new allometric equations and capitalization of existing knowledge require adequate institutional arrangements and systems for data sharing and knowledge exchange focused on resolving identified gaps. If not, data production will be achieved in a parallel process, creating duplication of information, confusion and discrepancy of estimates. Adequate institutional arrangements are crucial to ensure long-term viability of efforts to measure forest biomass, national forest inventories and allometric equation development.

Where tree species diversity is high, it may be advisable to focus on species that compose 80 % or so of the forest biomass (in the case forest biomass is the main targeted variable). When developing tree equations in certain ecosystem types, data collection should consider the various types of tree's dimensions (including large and small trees), different plant functional types (as well as architecture and morphology), and different tree components (including buttresses, dead branches and roots).

In the context of GHG inventories and climate change mitigation the targeted forest types, ecological zones and tree species should be classified following three criteria: existence of allometric equations, importance in terms of carbon stocks and threat from human activities. Biodiversity indices or identified hotspot may also require specific attention due to their ecological importance.

6. How do we promote enhanced capacities to develop and use new methods to assess forest biomass?

Capacity building should be encouraged to create efficient and well informed task forces in countries. Transfer of knowledge is a key point for improving biomass estimation as the biological and statistical concepts are difficult to understand. As mentioned previously, some international organizations (*i.e.* CATIE, FAO, and SilvaCarbon) are involved in national capacity building. Efforts should be made to match these agendas with needs identified by national programs and south-south cooperation agreements.

Countries should be supported in completing these capacity needs assessments and building plans to build overall capacity to cover all important areas. Potential elements of these plans to reduce knowledge gaps might be the inclusion of topics related to allometric equations in university curricula and in continued education or "training the trainers" programs. As the number of trained people increases, efforts should be made to ensure networking among them.

New methods to assess forest biomass have a strong technological component. Technology developers should thus be involved throughout the process to ensure new methods match the evolution of country needs. The accuracy of models developed following new methods should be tested with inventory data and against previously derived equations. Agreements among data owners should be promoted to facilitate this testing.

Finally, communication of results and publishing of newly developed methods and allometric equations should be encouraged to promote exchange and positive feedback among the scientific community. Even preliminary results should be shared during scientific meetings to increase the interest of additional developers and potential users.

Conclusion

The regional workshop on tree allometric equation for south and Central America was a first step to identify current efforts toward improvement of volume, biomass and carbon stocks assessment for trees inside and outside forests. Based on the issues presented previously, the following recommendations are provided to ensure continuation of current efforts and building on existing knowledge on allometric equations in Latin America:

The development of a regional database for tree allometric equations should be encouraged. The database should include allometric models, relevant documentation and meta-data. It is strongly recommended that the methods by Baldasso *et al*. (2012) be followed to promote standardization with global allometric equation database initiatives. As part of this database, agreements among scientists on standards for QA/QC should be encouraged so data can be fully comparable.

Knowledge gaps should be identified and addressed. Identifying knowledge gaps in certain forest types is useful to guide future measurement campaigns. However, gap identification should focus on the strategy of each country to perform volume and biomass calculations, national objectives related to REDD+, and forest resources and data accessibility. Knowledge gaps should also be addressed by encouraging the development of human and institutional capacities on field and estimations methods. Minimum capacities should address 1) Choosing a model; and 2) Application of a model to calculate country estimates of volume and biomass.

It is important to secure funding for data collection, long-term storage and availability. Data collection should consider country priorities and available resources and synergies among projects and national initiatives. Also, protocols to ensure access to the data should be designed and implemented. Infrastructure and capacities to support these data repositories must be developed by countries, or a joint effort among them sought.

Guidelines and protocols to ensure widespread harmonization of methods should be promoted, while considering local and national circumstances. As part of this harmonization, best efforts should be made to include all tree components when performing destructive measurements. The most expensive steps when developing allometric equations are harvesting trees and collecting field measurements. It is recommended to collect as many samples as possible in an adequate way to avoid using default data and altering the quality of the results. A full set of tree parameters and data can be used for different research purposes (analysis of tree architecture, mineralogy etc.). Root biomass from these complete harvests is also necessary to develop root:shoot ratios In addition to these ratios, complete harvests also allow for the calculation of biomass expansion factors for the different tree components. Both of these variables, which are currently scarce in the literature, can greatly contribute to national scale calculations of biomass from volume estimates.

Testing of new technologies and methods is encouraged to promote the use of non-destructive or semi-destructive methods. This can be very helpful to facilitate the inclusion in datasets of large trees that are difficult to measure using destructive measurement methods. Root biomass assessments can also be achieved by taking into consideration new sampling methods (*i.e.* Voronoï method) and technologies (*i.e.* Ground Penetrating Radar). New methods must include the calculation of uncertainties and error propagation when performing calculations at the national scale.

It is crucial for scientists in the region to develop professional networks. Such networks can be national and regional and should facilitate interactions, exchange of knowledge and data, and promote research collaborations. We encourage workshop participants to share the information from the different discussion sessions with national MRV and UNFCCC focal points. Within and among networks, data and document repositories would provide tools for exchanging knowledge and expertise across the region.

13. Workshop conclusions and recommendations

The first Regional Technical Workshop on Tree Volume and Biomass Allometric Equations in South and Central America, held at CATIE's headquarters in Costa Rica, brought together 30 experts from different institutions and backgrounds to identify the gaps and needs in knowledge related to tree volume and biomass allometric equations in the region. During a series of presentations and group discussions, current knowledge was described and data gaps and strategies to resolve them were identified. Through the analysis of several case studies, the challenges of using allometric equations as part of national biomass and carbon assessments were highlighted. Additional discussions focused on current and future methods to improve the construction of allometric models for tropical tree biomass. A valuable output of this meeting was also to facilitate interactions among researchers of multiple institutions and countries so that future collaborations may consolidate the development of national and regional research programs to support biomass and carbon quantification under current international agreements. The following summarizes the main conclusions and recommendations from the workshop.

There was wide agreement about the importance of this first workshop as a means to initiate a formal dialogue among the many individuals, research groups, and institutions involved in research related to allometric equations throughout Latin America. The lack of formal mechanisms for exchanging relevant information among researchers within and among countries was identified as a roadblock to future AE development. This leads to duplication and limited exposure and dissemination of pertinent research. The workshop also offered an opportunity to evaluate current status of allometric development and use among countries in the region, and to anticipate future needs. Countries like Brazil and México were perceived as having greater technical capacities and could serve as hubs for South-South cooperation initiatives. Expected future collaborations among the group of experts and beyond will be of upmost importance to strengthen the national forest inventory (NFI) processes needed to quantify volume and biomass at the national level.

Allometric equations (AEs) are one of many tools necessary to fulfill Parties' commitments under the UNFCCC. However, there is a remarkable gap between international reporting requirements expected under international mechanisms such as REDD+ and available national capacities to provide reliable country-scale estimates of biomass, carbon and their associated changes over time. Such gap partially relates to the lack of a solid strategy for inventorying and maintaining a national forest inventory (NFI) strategy. It is evident that countries with a more robust NFI strategy (*i.e.* México, Brazil) can show greater progress in the development and application of allometric equations to estimate biomass and carbon stocks. Therefore, the institutional consolidation and long-term stability of NFI processes are fundamental to achieve much better approximations to carbon quantification via the development of AEs.

A second reason for this gap is due to the limited country capacities to construct, validate, and use allometric equations as part of national volume and biomass quantification efforts. Allometric model approaches are common across species, forests structures and sites. However, methodological challenges remain on highly diverse tropical and subtropical forests given the use of common equations for several species and limited sampling capabilities to estimate specific gravity and non-stem biomass components. Although it is recognized that site- or even species-specific AEs may offer more accurate estimates, uncertainties associated with the measurement of wood specific gravity, as it varies radially and along the stem, and tree height need to be resolved to take full advantage of their potential. This additional effort, which many countries may not be able to sustain, supports the use of generalized equations. This is particularly true in countries with limited resources to develop their own AEs. Improvements over generalized equations such as those developed by Chave *et al.* (2005)can increase their applicability over a wide range of forest conditions in Latin America. The debate over which type of AEs (species-specific vs. generalized) are better suited for a particular country remains.

There is an urgent need to improve methodological approaches to quantify biomass given the large uncertainty of estimates. Improvements may consider stand or species structural indices that may be a way to improve equations applied across a range of species. The construction of new generation AEs may incorporate bioclimatic variables. Regardless of the new techniques we may employ in the future, participants highlighted the need for standardizing protocols used for constructing and reporting biomass equations both in terms of field sampling design and of model construction. This can be achieved by socializing technical manuals such those by (Picard, *et al.,* 2012) and from technical workshops such as those conducted recently by FAO in several countries. In addition, sharing raw data and metadata associated with any particular equation should be encouraged as a prerequisite for publication in scientific journals. This would add transparency to AE development efforts, facilitate validation of published equations, and allow researchers to develop new models using larger consolidated datasets. This would also require clear guidelines for data sharing and fair use among researchers.

Several new and potentially new tools and methods were shared during the workshop. New tools such as the terrestrial LiDAR (Hopkinson, *et al.,* 2004) or a stereophotometric approach should be promote and tested in future harvesting experiments. The use of remote sensing techniques needs intensive research in tropical forests but may provide ways to improve individual tree (ground LiDAR) or stand structure (aerial or satellite) estimates. This last use may improve also estimates across the land combined with GIS information on soils and/or key water or nutrient resource limitations that affect stand development and growth. Below ground biomass is a major source of uncertainties as most studies are using a constant conversion factor all over the tropics (Mokany, *et al.,* 2006). The root:shoot ratio is indeed expected to be strongly dependent on environmental conditions, in particular soil and climate conditions. As excavation methods are hard to conduct on the field and hard to standardized, new technologies such as radar technology (Butnor, *et al.,* 2003) should be investigated and tested in the next future. Uncertainties are rarely propagated in biomass assessment studies, despite the requirement to assess and report it. Several approaches are being developed and a Monte Carlo approach, as proposed by Molto *et al*. (2013), or Bayesian methods, as proposed by Zapata-Cuartas *et al*. (2012) may be standardized as methods to propagate uncertainties at the country level.

Concerns were voiced over “good practice” guidelines suggesting the use of a conservative equation (when several ones are available) as this may lead to strong biased estimates at the country level. This is an unfair rule because i) the quality of the models is not taken into account; ii) countries having several biomass equations will be more prone to have a strong underestimation of their carbon stocks. Two possibilities may be offered: 1) the use of the same pantropical models over all countries. This solution would provide a fair rule, as it would be a standardized method over the tropics, but this could also lead to strong biases, especially if tree height is not taken into account; 2) the use of Bayesian approach, such as the approach developed by Zapata-Cuartas *et al*. (2012) or as the approach developed by Laurent Saint-André *et al*. (unpublished), may be a promising approach because it would allow to construct local equations integrating and valorizing all the previous works done locally.

Overall, this workshop provided a much needed opportunity to exchange experiences and knowledge among researchers and users of allometric equations in Latin America and the Caribbean. The analysis of current knowledge and the recommendations for future actions should be taken into consideration by governments, decision-makers, other researchers, and funding agencies to support the development and strengthening of local and national systems to quantify volume and biomass for reporting at the international level.

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15. Appendix

Appendix 1. List of variables and proposed definitions[41]

Variables	Description	Unit	Sources
Aboveground biomass	All biomass above the soil including stem, stump, branches, bark, seeds, and foliage.		(IPCC,2003)
Belowground biomass	All biomass of live roots. Fine roots of less than (suggested) 2mm diameter are sometimes excluded because these often cannot be distinguished empirically from soil organic matter or litter.		(IPCC,2003)
Biomass	1. Mass of living or dead organic matter in an organism, expressed as mass of dry matter. For a tree, this is expressed in kg. By extension, the biomass of an area is the sum of the biomass of the organisms found in the area. This is measured in kg per unit area or, more commonly, in Megagrams per hectare ($Mg{\cdot}ha^{-1}$) 2. The total amount of live aboveground organic matter present in trees including leaves, twigs, branches, main bole, and bark. 3. Mass of live or dead organic matter. 4. Organic material both aboveground and belowground, both living and dead, *e.g.,* trees, crops, grasses, tree litter, roots etc. Biomass includes the pool definition for above- and below- ground biomass.		1. Adapted from Picard *et al*. (2012) 2. (Brown,1997) 3. (Bombelli, *et al.,* 2009) 4. (IPCC,2003)
Biomass expansion factor	A multiplication factor that expands growing stock, or commercial round-wood harvest volume, or growing stock volume increment data, to account for non-merchantable biomass components such as branches, foliage, and non-commercial trees.		(IPCC,2003)
Commercial volume	Commercial volume refers to the volume of tree's part that can be used for timber production. The definition varies among countries and companies. The tree component considered should be clearly described: part of the tree considered and minimum diameter. Definition of commercial volume from Brown *et al* 1997 is volume over bark of free bole, *i.e.* from stump or buttress to crown point or first main branch		(Brown,1997)
Dry matter / Dry biomass	Dry matter refers to biomass that has been dried to an oven-dry state, often at no more than 65 ºC to prevent loss of nitrogen compounds.		Adapted from Picard *et al*. (2012)

[41] When more than one definition is being used, it is recommended to indicate the reference.

Fresh biomass	Biomass measured in the field and not yet oven-dried. A rule of three between fresh biomass measured in the field, fresh biomass of the aliquot, and oven-dried biomass of the aliquot is used to calculate dry biomass from field-determined biomass.		Picard *et al*. (2012)
Gross annual increment	The average annual increment of volume over the reference period of all trees measured to a specified minimum diameter at breast height (varies by country). Includes increment of trees which have been felled or die over the reference period.		(IPCC,2003)
Merchantable stem	Merchantable stem (12-inch stump to 4-inch top); used directly with no alteration.		(Jenkins, *et al.,* 2003)
Minimum diameter outside bark (d.o.b.)	For equations that include a portion of the merchantable stem, describes the minimum diameter outside bark (d.o.b.) of the top of the merchantable stem. Procedures for reporting this variable when authors do not report it are given in Jenkins *et al*. (2003).		(Jenkins, *et al.,* 2003)
MinDiameter and MaxDiameter	Minimum and maximum diameter values (in centimeters) for which a regression is valid. These are the minimum and maximum measurements of the trees harvested to develop the regression.		(Jenkins, *et al.,* 2003)
Sample size	Number of trees harvested or measured to develop a regression.		(Jenkins, *et al.,* 2003)
Stump height	For equations that predict the biomass of any component that includes the tree stem or the stump, this variable lists (in inches) the estimated or measured stump height. Procedures for reporting stump height when authors do not report it are given in Jenkins *et al*. (2003).		(Jenkins, *et al.,* 2003)
Tree components	Ten tree components are proposed in Henry *et al*. 2011: bark, dead branches, large branches (d > 7 cm), thin branches (d < 7 cm), leaves, large roots, fine roots, medium roots, stump, and trunk-underbark.		(Henry, *et al.,* 2011)
Volume	A wide range of allometric equations and formulas exist to calculate the volume of a trunk (cylinder, cone, cylinder multiplied by a form factor) or its components. Volume of logs can be calculated through Smalian, Hubert or Newton formula.		Picard *et al*. (2012)
Wood density	Wood density is defined as the ratio of the oven-dry mass of a wood sample divided by the mass of water displaced by its green volume (wood specific gravity, or WSG). Specific gravity (based on oven-dry weight and green volume) value used to convert stump volume inside bark to stump wood biomass	$g*cm^{-3}$	(Chave, *et al.,* 2005)
BA	Basal area: Stem cross-sectional area at DBH (130 cm height)	cm^2	
BA0	Basal area at height 0 cm: Stem cross-sectional area at the soil	cm^2	

BD	Basal diameter	cm
C	Circumference can be measured at different heights.	cm
Ca	Canopy area	m^2
CA	Crown area	cm^2
Cb	Basal circumference	cm
Cb5	Circumference at 5 cm from soil	cm
CD	Crown diameter	cm
CH	Crown height	cm
CR	Crown radius	cm
CV	Canopy volume	cm^3
D20	Diameter at 20 cm height	cm
D30	Diameter at 30 cm height	cm
DBH	Diameter at breast height (at 130 cm from soil)	cm
H	Height	cm
Hd	Stand dominant height	cm
Hme	Merchantable height	cm
Ht	Height of the trunk	cm
M_DBH	Mean DBH	cm
R	Tree ring	nr
SUMD10	Sum of the diameters at 10 cm from the soil	cm
Vs	Stem volume	dm^3
V.P.	stem volume including bark	cm^3

Appendix 2. Basic statistical concepts

Variable	Definition	Source
Bias correction	Correction factor to compensate for the potential underestimation resulting from bactransforming logarithmic predictions to arithmetic units, as suggested by Baskerville (1972), Beauchamp and Olson (1973), and Sprugel (1983). Published value of CF, to correct for potential underestimation resulting from back-transformation of logarithmic predictions to arithmetic units. As a remedy for bias, it has been proposed that the back-transformed biomass results be multiplied by CF, defined as exp(MSE/2), where MSE refers to the mean squared error of a line fit by least-squares regression.	(Jenkins, *et al.,* 2003)
Coefficient of variation	The coefficient of variation, *vx* is the ratio of the population standard deviation, σx, and mean, µx, where *vx* = *σx*/*µx*. It also frequently refers to the sample coefficient of variation, which is the ratio of the sample standard deviation and sample mean.	(IPCC,2003)
Confidence interval	A confidence interval is the range in which it is believed that the true value of a quantity lies. The level of belief is expressed by the probability, whose value is related to the size of the interval. It is one of the ways in which uncertainty can be expressed. In practice, a confidence interval is defined by a probability value, say 95%, and confidence limits on either side of the mean value x. The confidence limits L1 and L2 would be calculated from the probability density function such that there was a 95% chance of the true value of the quantity being estimated by x lying between L1 and L2. Commonly L1 and L2 are the 2.5 percentile and 97.5 percentile respectively.	(IPCC,2003)
Correlation	Mutual dependence between two quantities. See correlation coefficient.	(IPCC,2003)
Correlation coefficient	A number lying between –1 and +1 that measures the mutual dependence between two variables which are observed together. A value of +1 means that the variables have a perfect direct straight line relation, a value of –1 means that there is a perfect inverse straight line relation, and a value of 0 means that there is no straight line relation. It is defined as the covariance of the two variables divided by the product of their standard deviations.	(IPCC,2003)
Covariance	A measure of the mutual dependence between two variables.	(IPCC,2003)
Error	In statistical usage, the term 'error' is a general term referring to the difference between an observed (measured) value of a quantity and its 'true' (but usually unknown) value and does not carry the (pejorative) sense of a mistake or blunder.	(IPCC,2003)
Lognormal distribution	An asymmetric distribution, which starts from zero, rises to a maximum and then tails off more slowly to infinity. It is related to the normal distribution: X has a lognormal distribution if ln(X) has a normal distribution.	(IPCC,2003)
Mean	The mean, population mean, expectation or expected value is, broadly speaking, a measure of a central value	(IPCC,2003)

	around which values sampled from a probability distribution tend to lie. The sample mean or arithmetic average is an estimator for the mean. It is an unbiased and consistent estimator of the population mean (expected value) and is itself a random variable with its own variance value.	
Median	The median or population median is a value which divides the integral of a probability density function (PDF) or an ordered sample into two halves. For symmetric PDFs, it equals the mean. The median is the 50^{th} population percentile. The sample median is an estimator of the population median. If there are 2n + 1 observations, the median is taken as the $(n + 1)^{th}$ member of the ordered sample. If there are 2n, it is taken as being halfway between the n^{th} and $(n + 1)^{th}$.	(IPCC,2003)
Standard deviation	The population standard deviation is the positive square root of the variance. It is estimated by the sample standard deviation, which is the positive square root of the sample variance	(IPCC,2003)
Variance	The variance or population variance is a parameter of a PDF, which expresses the variability of the population. It is the second central moment of a random variable. The sample variance is defined as a measure of dispersion, which is the sum of the squared deviations of observations from their average, divided by one less than the number of observations.	(IPCC,2003)

Appendix 3: List of projects related to allometric equations in South and Central America.

Countries	Projects	Institutions	Gaps & Needs	Other details	Contact information
Brazil	• Cooperative Program on Forest Enhancement (PCMF) • Thematic Program on Silviculture and Handling (PTSM) • Cooperative Program for Embedding and Eucalyptus Cloning (PECE) • Cooperative Program for Forest Protection (PROTEF) • Cooperative Program for Flux Tower (EUCFLUX) • Cooperative Program on Clonal Eucalyptus Tolerance to the Hydrous and Thermal Stresses (TECHS) • Cooperative Program on Potential Productivity of the Pine in Brazil (PPPIB)	Instituto de Pesquisas e Estudos Florestais (IPEF)	Collaboration between scientists	• Cooperative Program on Forest Enhancement (PCMF): The area is divided into projects, out of which the following are relevant: Enhancement Center Populations, Enhancement Populations, and New Cultivations. • Thematic Program on Silviculture and Handling (PTSM): Adequate scientific and technological basis to take operational decision for forest companies, aiming at increasing *Eucalyptus* and *Pinus* productivity and sustainability. • Cooperative Program for Embedding and *Eucalyptus* Cloning (PECE): Develop protocols for large-scale clonal production of selected subtropical eucalyptus genotypes and their hybrids by means of the mini-stem cutting and micro-stem cutting techniques, with special attention to induction and formation of a morpho-physiologically functional root system. • Cooperative Program for Forest Protection (PROTEF): Integrated management of pests and diseases in forests, implementing systems that take in consideration the insects and natural enemies floating population and adequate monitoring and control forms, respecting technical, economical, social and environmental aspects. • Cooperative Program for Flux Tower (EUCFLUX): Evaluation of carbon, water, nutrients and energy budgets at the landscape level for a full rotation of *Eucalyptus* plantation using an eddy covariance tower, aiming at sustainable forest management. • Cooperative Program on Clonal *Eucalyptus* Tolerance to the Hydric and Thermal Stresses (TECHS): Identifying what are the ecophysiological mechanisms explaining how the different genetic materials can tolerate, with more or less success, hydric stress, which is in general associated with thermal heat stress; core goal is to keep and increase the productivity standards in traditional areas and ensure success of plantations in bordering areas. • Cooperative Program on Potential Productivity of the Pine in Brazil (PPPIB): Study of silviculture and habitat factors in *Pinus* plantation growth in different soil, climate and management.	Instituto de Pesquisas e Estudos Florestais Avenida Pádua Dias, 11 - Caixa Postal 530 - CEP: 13400-970 - Piracicaba/SP

Brazil	NFI – National system of permanent sampling plots	NFI data and compilation of allometric models.	Collaboration between scientists	The Brazilian Ministry of Environment initiated in 2005 the process to establish a nation-wide forest monitoring system based on national forest inventories including systematic field data collection and remote sensing surveys. The Brazilian Forest Service (Serviço Florestal Brasileiro, SFB), created in 2006, is responsible for organizing and implementing the Brazilian National Forest Inventory (NFI). The field inventory will be carried out along a systematic sample grid of clustered plots every 0.18 degrees (10.8 minutes) latitude and longitude, which corresponds to a distance of 20 km by 20 km at the equator. In 2005 a multi-institutional Technical Committee (CT-IFN/BR) was formed by Brazilian and international specialists from governmental institutions, research stations, universities and the civil society to initiate the development of a Brazilian NFI based on systematic sampling for field data collection and remotely sensed landscape mapping.	Daniel Piotto, daniel.piotto@florestal.gov.br Ministry of the Environment, Brazil
Brazil	Biomass and carbon database for Brazilian biomes	BIOFIX/Federal University of Paraná	Project underway. Need to integrate to National Forest Inventory.	Database on all available publications regarding biomass and carbon stocks/equations for the Brazilian biomes	Carlos Sanquetta, sanquetta@ufpr.br, Federal University of Paraná
Central America	REDD-CCAD-GIZ	GIZ in collaboration with CATIE (Costa Rica), TNC (Dominican Republic), ESNACIFOR & ICF (Honduras)	Ecosystem stratification and species selection. Harmonization of methods across the region.	The Program functions under the direction of the Central American Commission on Environment and Development (CCAD), the environmental branch of the Central American Integration System (SICA). The Program receives support from the German Technical Cooperation agency (GIZ), funded by the Federal Republic of Germany through the Federal Ministry of Economic Cooperation and Development (BMZ). The duration will be of six years, through October 2016. The Federal Republic of Germany will contribute 12 million Euros, divided among the following eight countries of the Central American Integration System (SICA): Belize, Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, Panamá and Dominican Republic. On a national level, the project will support dialogue between sectors, the development of national REDD strategies, and the implementation of compensation instruments that have been adapted to the specific reality of each country, including the needs of indigenous and local communities and small farmers, all with a gender-based approach. On a regional level, the project supports processes between countries to develop joint positions and approaches for REDD+, and strategies to keep leakage under control within each country as well as among them.	Abner Jiménez, abner.jimenez@giz.de, GIZ

Chile	Modelo Nacional de Simulación	Instituto Forestal de Chile (INFOR), Universidad de Concepción (UDEC), Universidad Austral	Breadth of species	Growth simulation projects for *Radiata pine* and *Eucalyptus* are driven by the main Chilean forest enterprises. This initiative started in 1989 to support management of *Pinus radiata* plantations. Later, a growth simulator for *Eucalyptus globulus* and *E. nitens* was added. Currently, these tools can predict the development of pine and eucalyptus plantations from planting to harvest, being widely used by forestry companies in the country. In addition to the simulators, has created a series of tools for the management and production of information from forestry trials. In the time period of model development, the private sector has invested more than U.S. $ 6 million supplemented with $1 million public input.	Facultad de Ciencias Forestales. Universidad de Concepción. Victoria 631 Barrio Universitario. Concepción - Chile. Phone: (56) 41 2204983. Fax: (56) 41 2246004. E-mail: simuladores@udec.cl
Colombia	NFI – REDD / Proyecto BioREDD / Proyecto INVEMAR-Carbono & Bosques	Instituto de Hidrología, Meteorología y estudios Ambientales (IDEAM) / USAID / Instituto de Investigaciones Marinas y Costeras (INVEMAR)	Allometric equations are available for only 6 out of 16 Holdridge Life Zones. There are 18 equations total (3 per Life Zones) using DBH; DBH and SG; DBH, SG, and H). Equations for montane forests require more data to increase accuracy. No models are available for palms; only local models.	National biomass/carbon estimates are done using equations constructed by Álvarez *et al*. (2012). LiDAR has been used to estimate biomass in the Amazon region ((Asner, *et al.,* 2012)). There are also equations for the Pacific region (constructed by IDEAM and Juan Saldarriaga), for mangroves (Guandal y Colina - being improved through USAID BioREDD Project, which will also use LiDAR to estimate carbon in 4 areas of the Colombian Pacific). INVEMAR has developed equations for Caribbean mangroves.	Alvaro Duque (UNALMED), Alvaro Duque ajduque09@gmail.com, Universidad Nacional de Colombia Adriana Yepes & Edersson Cabrera (Sistema de monitoreo Bosques y Carbono-IDEAM). Centro de Investigación en Ecosistemas y Cambio Global (www.carbonoybosques.org)
Colombia, Ecuador, Perú	SilvaCarbon	U.S. Agency for International Development (USAID), the U.S. Forest Service within the Department of Agriculture (USFS),	Collaboration among scientists, distribution of results, south-south collaborations	SilvaCarbon is a flagship program under United States fast start financing for REDD+ and is a U.S. contribution to the Forest Carbon Tracking task of the intergovernmental Group on Earth Observations (GEO). SilvaCarbon will address technical issues including: • Sampling protocols and design • Data capture, processing, archiving, and distribution	Charles "Chip" Scott ctscott@fs.fed.us, US Forest Service

		the U.S. Geological Survey of the Department of Interior (USGS), the U.S. Environmental Protection Agency (EPA), the U.S. Department of State, the National Aeronautics and Space Administration (NASA), the National Oceanic and Atmospheric Administration within the Department of Commerce (NOAA), and the Smithsonian Institution.		• Collection and analysis of in situ data, including involvement of local communities and stakeholders • Integration of remotely sensed and in situ data • Classification and mapping of forest cover • Carbon stock and flow estimation • Design of monitoring systems for multiple uses • Land use analysis and planning	
Costa Rica	National REDD+ Strategy	FONAFIFO	Constructing national allometric equations.	Building 10 allometric equations for 3 bioclimatic zones in the country (moist, wet, high elevation forests).	William Fonseca, Escuela de Ciencias Ambientales, Universidad Nacional de Costa Rica, Campus Omar Dengo, 86-3000 Heredia, Costa Rica, e-mail: wfonseca@una.ac.cr
Costa Rica	National REDD+ Strategy	FONAFIFO	Developing technical capacities	Forest strata are being determined and sampling for allometric equations construction is starting	Alexandra Sáenz (asaenz@fonafifo.go.cr) & Javier Fernández (javfernandezvega@gmail.com) FONAFIFO
Ecuador	National Forest Inventory	FAO, Ministry of the Environment	Only for two forest types		Kelvin Cueva, Kelvin.Cueva@fao.org, FAO Ecuador
Ecuador	UN-REDD programme and FAO - National Forest Evaluation	FONAG, Distrito de Quito with support from FAO.	Tree allometric equations under development	Developing 3-4 models for high elevation montane forests	Kelvin Cueva, Kelvin.Cueva@fao.org, FAO Ecuador

Guatemala	Implementing National MRV System, Proyecto REDD-CCAD-GIZ	Instituto Nacional de Bosques (INAB), Consejo Nacional de Áreas Protegidas (CONAP)	Improving local equations/validating international equations	Current project with funding from USAID and other sources in cooperation with government institutions.	Edwin Castellanos ecastell@uvg.edu.gt - Universidad del Valle de Guatemala
Honduras	Permanent plots in *Pinus* and broadleaf forests	P. ECOSISTEMAS (Sico-Paulaya; from February 2011), CATIE –FINFOR y SINFOR (Permanent plots) PANACAM (from March 2011)	Forest Dynamics	Plantations. Establishment of Permanent Monitoring Plots / Carbon	Johnny Perez japerezn@yahoo.es
México	El Salto, Durango	INIFAP (Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias)	Subnational, not linked to the national forest inventory		
Panamá	Carbon sequestration across secondary forests in Central Panamá	U. Stirling, UK, INDICASAT & Smithsonian Tropical Research Institute (STRI)	Biomass sampling across the chronosequence. No AE exercise has been carried, just forest height by LIDAR (Mascarano paper). However wood density data has been obtained throughout the chronosequence	The sites are between 20 to 100 years old forest in surrounding BCI area established in 1994 through good aerial photo record and are now being included in a LIDAR survey by the Asner Lab group.	Omar Lopez (Co-PI), olopez@indicasat.org.pa, INDICASAT, Daisy Dent (PI) U. Sterling

Panamá	Forest Dynamics of coastal swamp forests (mostly monodominant)	Instituto de Investigaciones Científicas y Servicios de Alta Tecnología (INDICASAT) & Smithsonian Tropical Research Institute (STRI)	Biomass sampling of monodominant species. No AE exercise has been done for these forests, but some volume/biomass sampling has been done by Golley 1968-69, some by ANAM and some in Colombia	The sites are located in seasonally and permanently flooded forest dominated by *Prioria copaifera* and *Campnosperma panamensis* with some small plots in *Rapier* palm forests	Omar Lopez (PI), olopez@indicasat.org.pa, INDICASAT
Panamá	Soils, diversity and forest Dynamics of cloud forests in Chiriquí, Panamá	U. Illinois, UNACHI & Smithsonian Tropical Research Institute (STRI)	Not completely under STRI. Great collaboration potential. No allometric equations developed.	The plots go from 800 up to 1200 m.a.s.l. with wide variation in species diversity in relation to soils type.	Jim Dalling (PI) U. Illinois, Omar Lopez (collaborator) INDICASAT, olopez@indicasat.org.pa
Panamá	Long term projects	Smithsonian Tropical research Institution (STRI)		The Smithsonian Tropical Research Institution (STRI) in Panamá, is a bureau of the Smithsonian Institution based outside of the United States, is dedicated to understanding biological diversity. Scientists are currently working on using terrestrial LIDAR on 15 circular plots of 30 meters diameter. The experiment will test linking airborne LiDAR to Terrestrial LiDAR.	Charles "Chip" Scott ctscott@fs.fed.us, US Forest Service
Panamá	Biomass Sampling	Smithsonian Tropical Research Institute (STRI) /McGill University (UMcGill)	A potential project	Mid elevation forest on the Caribbean slope of Panamá	Helene Muller - hmullerlandau@gmail.com, STRI

Panamá, Paraguay, Argentina, Colombia, Perú, Ecuador, Chile, Costa Rica, Guatemala, Guyana, Honduras, México.	UN-REDD programme	FAO, UNEP, UNDP	Accessibility to raw data, data sharing and documentation of data collection.	Several activities are being implemented to support implementation of forest monitoring system in the context of REDD+. Activities include design and implementation of national forest inventory, database management and analysis, capacity building. development of satellite forest monitoring system, tree allometric equations etc.	Lars Marklund LarsGunnar.Marklund@fao.org, FAO
Perú	Proyecto REDD+	Ministerio del Ambiente (MINAM)		MINAM is responsible for developing and coordinating national strategy on climate change and adaptation and mitigation measures and monitoring their implementation. MINAM is leading the process of preparing the country for the implementation of REDD+. As part of preparedness actions for REDD +, MINAM has been implementing the project "Strengthening of technical, scientific and institutional arrangements for the implementation of REDD + in Perú" funded by the foundation Gordon & Betty Moore and the project "Support to the implementation of the REDD mechanism in Perú", financed by the KfW. The project will support the following actions: 1) Capacity building and dissemination, financial and economic mechanisms, 2) REDD, 3) legal and Institutional, 4) methodological frameworks and baselines (MRV), 5) Economic viability and promoting REDD and 6) Communication and safeguards.	Renzo Giudice Granados rgiudice@minam.gob.pe
Perú	National Inventory Sustainable Forestry and Forest Management to Climate Change	Inventario Nacional Forestal-Ministerio de Ambiente	Allometric equations are not available.	The Ministries of Agriculture and Environment, with the technical support of FAO in Perú and the cooperation of the Government of Finland, launch the project "National Inventory Sustainable Forestry and Forest Management to Climate Change in Perú. The Ministry of Environment is developing the Carbon Forest Map for Perú, which is linked to the NFI methodology. The sub-populations of interest are linked to forest carbon needs. Next year is planning a pilot of field data collection for allometric equations. National Forest Inventory data. Complete the compilations of allometric equations from unpublished data.	Berioska Quispe, INF-Ministerio de Ambiente, Carla Ramírez FAO-Perú, carla.ramirez@fao.org