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PROGRAMME

Proceedings of the regional technical workshop on Tree Volume and Biomass Allometric Equations in West Africa

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The application of UNDP, UNEP and FAO rights-based and participatory approaches will also help ensure the rights of indigenous and forest-dwelling people are protected and the active involvement of local communities and relevant stakeholders and institutions in the design and implementation of REDD plans.
The programme is implemented through the UN Joint Programmes modalities, enabling rapid initiation of programme implementation and channeling of funds for REDD efforts, building on the in-country presence of UN agencies as a crucial support structure for countries. The UN-REDD Programme encourage coordinated and collaborative UN support to countries, thus maximizing efficiencies and effectiveness of the organizations' collective input, consistent with the "One UN" approach advocated by UN members.

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The UN-REDD Programme, group photo of participants of the regional workshop on volume and biomass tree allometric equations

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Abbreviations

AE	Allometric equation(s)
BCEF	Biomass conversion expansion factor
BEF	Biomass expansion factor
EF	Expansion Factor
IPCC	Inter-governmental Panel on Climate Change
ITTO	International Tropical Timber Organisation
REDD	Reducing emissions from deforestation and forest degradation
REDD+	Reducing emissions from deforestation and forest degradation, sustainable forest management and biodiversity conservation
REDDES	Reducing emissions from deforestation and forest degradation and enhancing environmental services
UNFCCC	United Nations Framework Convention on Climate Change

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1. INTRODUCTION AND OBJECTIVES

Stephen Adu-Bredu[1]

Accurate assessment of forest carbon stocks and carbon stock changes through time does not only allow developing countries to benefit from positive incentives provided by developed countries under REDD+, but also has the potential to simultaneously deliver cost-effective climate change mitigation through sustainable means. Changes in forest carbon stocks through time are best appraised by a combination of remote sensing and field-based measurement. Spatial and temporal variation in above-ground carbon is the largest source of uncertainty in measuring forest carbon emissions (Angelsen, 2008; Chave et al., 2003; Pelletier, Ramankutty, & Potvin, 2011).

Allometric equations (AE) are tools used to predict biomass, volume and carbon stocks from easy to measure tree parameters like stem diameter at breast height and tree height, and measured or available parameters like wood density specific to the tree species. They are of great importance because estimates of biomass and/or volume per unit area can be made at low cost based on inventory data. However, in order to avoid systematic errors in tree AEs, which can propagate to plot and forest levels and consequently impact national estimates of GHG emissions from deforestation and GHG inventory (Chave et al., 2004), these AEs must be built based on accurate data and using sound statistical approaches or techniques. The development of accurate AEs for biomass and volume calculations is a powerful tool for national biomass assessment, as well as for providing accurate tree volume and biomass estimations for forest managers, scientists and all the people involved in the economic sector of timber production.

The Status of AE in West Africa is still not well known and should be assessed in order to support activities on the implementation of the national forest monitoring systems for REDD+. In the West African region, the UN-REDD Programme is supporting Nigeria through a National Programme and in Benin, Ivory Coast and Ghana through target support. Furthermore, several countries party to the UNFCCC are requesting partnership with the UN REDD Programme as well as FCPF, and will need AEs to estimate expansion factors (EF). The most comprehensive overview of existing AE for West African countries can be found in the GlobAllomeTree platform (www.globallometree), a tool jointly developed by FAO and partners to collect and provide access to AEs worldwide.

The GlobAllomeTree database is most likely not exhaustive and much more effort is needed to collate existing models from the region in order to have a better idea of where the gaps are and how to fill them. Furthermore, as almost half of the models deal with volume, wood density tables and exhaustive national tree species lists are of great importance to enable estimations of tree mass from volume.

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The objectives of the regional workshop were to:

- Provide an overview of the status of tree allometric equations in West Africa;
- Provide an overview of the different options for using tree allometric equations to assess national forest volume, biomass and carbon stocks;
- Provide recommendations for national forest monitoring systems;
- Identify the gaps and the needs in terms of allometric equation development;
- Identify existing initiatives on volume and biomass models development;
- Initiate a network of stakeholders involved in the development of tree allometric equations in West Africa;
- Encourage knowledge exchange and transfer to forestry experts in West Africa;
- Identify potential actions to fill the gaps and support national actions.

The proceedings of regional workshop on AEs were structured as: general context based on which the workshop was organized, country experiences and results emanated from group discussions.

2. IMPORTANCE OF ALLOMETRIC EQUATIONS FOR TRANSPARENT FOREST MONITORING SYSTEM AND INTERNATIONAL REPORTING

2.1. Inventory of volume and biomass tree allometric equations for West Africa

Winston Adams Asante[2]

Introduction

The goal of this presentation was to compile and document how national forest volume, biomass and carbon stocks are calculated for the 16 countries in West Africa, based on data officially submitted by the countries to FAO (FAO, 2010). In addition, it identifies the gaps and needs in the estimation of national volume and biomass of forest trees in West Africa.

Methodology

To ensure transparency and consistency over time, FRA reporting by countries to the FAO follows a comprehensive set of guidelines proposed by the IPCC (IPCC, 2006). The guidelines require countries to report on a large number of variables including standing volume, biomass and carbon stocks of all pools at the stand (per hectare) and forest levels. Volume and biomass allometric equations used to estimate these parameters were compiled by reviewing soft copies of the FRA 2010 (FRA, 2010) country reports and the guide for country reporting for all the 16 West African countries (http://www.fao.org/forestry/fra/67090/en/). Equations presented in the GlobAllomeTree database http://www.globallometree.org/ database were also reviewed.

Results

The total number of AEs available in the West Africa Sub-Region is 457, and are unevenly distributed amongst countries, with some having none (e.g. Guinea, Liberia, Gambia and Togo) to very few (e.g. Benin and Niger), despite the importance of the forest cover in these countries. Except for Ghana with 245, no country has more than one hundred AEs. It is obvious that GlobAllomeTree does not contain an exhaustive list of all equations in West Africa, hence the need for more searches in the countries. There seem to be some balance between volume and biomass equations although there is some disparity among countries. For example, in Burkina Faso and Senegal almost all equations are for biomass, while Nigeria and Ivory Coast have mostly volume equations. A review of the FRA country reports indicated that the standard equation for the estimation of volume in forestry was applied to generate volume estimates for all the countries that reported. For biomass and carbon stocks estimation, the FRA process relies on the methodological framework developed by the IPCC and documented in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Almost all countries do not use country specific values, and most estimates are old and focus on volume estimates, instead of biomass. Again, there were no country specific Biomass Expansion Factor (BEF) and Biomass Conversion and Expansion Factor (BCEF).

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Discussion and recommendations

Developing species-specific allometric equations is expensive, as the ecological zones traverse the different countries. Therefore effort and resources should be targeted at developing generalised models using African data.

Conclusion

The use of the volume approach in biomass estimation dominates in all the countries in West Africa, though most of the equations being used are species specific and are therefore not applicable to many species. However, given the diversity of tropical forests, the use of species specific allometric equations as an option is ideal, but too expensive and therefore not worth the effort. The use of generalised allometric equations constructed with African data is therefore recommended.

2.2. Impact of tree allometric equations on forest carbon stocks and stock changes

Matieu Henry[3]

Introduction

Allometric equations are used to estimate volume, biomass and carbon stocks of trees in all land use types, particularly in tropical forests. Five carbon pools have been identified by the IPCC guidelines, three of which are usually estimated using allometric equations (above-ground-biomass, below-ground biomass and dead wood). Allometric equations show the relationship between the relative sizes of the different parts of trees, for example between the diameter and tree biomass. Different types of allometric equations exist based on objectives and the method used to construct them. Equations can have single or multiple inputs such as diameter, wood density, tree height, crown diameter, among others. Output variables can also be biomass or volume and for different tree components, from the bark to total biomass.

Adequate use of allometric equations is crucial to obtain comparable estimates of emission reductions, particularly in the context of REDD+. Many sources of error arise from the use of allometric equations: errors 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 are available (e.g. for a tree species, a climatic zone, a forest type, etc.). Also, there can never be only one possible way 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 choice of allometric equations on carbon stocks and stock changes

Some of the current scientific papers compare the impact of allometric equations on carbon stocks. Calculation of forest carbon stocks requires 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.)

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allometric equations will result in different forest carbon stock changes. To analyse the impact of allometric equations on changes in carbon stocks, we simulated a scenario of deforestation and degradation of three forest types in sub-Saharan Africa. Different allometric equations were selected and compared.

Carbon stocks were significantly different depending on the choice of one equation or another. Differences between results of pairs of allometric equations were significant, sometimes of the order of 2 or 3. Significant differences persisted in a scenario of deforestation. In the case of forest degradation scenarios, the differences were not significant and non-significance could be related to decreases in stocks that may be important. At a regional scale, it appears that the differences in terms of emission reductions can be achieved between 7 and 20%.

Conclusion

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 significant. The selection and use of allometric equations must be done carefully to minimize uncertainty related to forest carbon stock change assessment.

2.3. Assessing forest carbon stocks and stock changes: challenges for the preparation of the GHG inventory for LULUCF/AFOLU in West Africa

Sabin Guendehou[4]

Introduction

Article 4.1 (a) and Article 12.1 (a) of the UNFCCC requires that: “each Party [...] shall develop, periodically update and communicate to the COP, among others, a national GHG inventory using comparable methodologies agreed by the COP”.

Decision 1/CP.16 (Cancun agreement): “non-Annex I Parties should submit their national communications every four years and developing country Parties, consistent with their capabilities and the level of support provided for reporting, should also submit biennial update reports (BURs), containing updates of GHG inventories, including a national inventory report and information on mitigation actions, needs and support received”.

Decision 2/CP.17 (Durban agreement):

- Non-Annex I Parties should submit their first BUR by December 2014; the first BUR submitted by non-Annex I Parties shall cover, at a minimum, the inventory for the calendar year no more than four years prior to the date of the submission, or more recent years if information is available, and that subsequent BURs shall cover a calendar year that does not precede the submission date by more than four years;
- Updates of GHG inventory should be developed using decision 17/CP.8, Revised 1996 IPCC Guidelines, GPG 2000, and GPG LULUCF.

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The IPCC methods for estimating C stocks and stock changes in the forestry sector (Tier 1, Tier 2, Tier 3) including the gain-loss and stock change methods were extensively discussed within the context of the forest types, land use categories and the carbon pools that need to be considered.

A summary of potential challenges pertaining to GHG inventory in forestry in West Africa

- Establish a sustainable national GHG inventory system;
- Put in place a data collection and archiving system;
- Provide definition of forest, other categories, carbon pools, and improve the completeness of the inventory: all categories, pools and gases;
- Apply appropriate method for land identification to develop the LUC matrix;
- Use remote sensing to generate data and fill data gap;
- Availability of funding to develop volume and biomass models for the whole range of tree species in West Africa;
- Quantification of uncertainty (how to combine uncertainties: simple error propagation equations or application of the Monte Carlo simulation)

Discussion and conclusion

The majority of the countries in West Africa do not report on forest soil carbon because they do not have the data. To use equations developed elsewhere, there is the need to test the validity of such equations, but in most cases the countries do not have the data, so it is assumed there is no change in soil carbon, and therefore they do not report on it.

3. COUNTRY EXPERIENCES IN DEVELOPING TREE ALLOMETRIC EQUATIONS

3.1. Multi-specific tree allometric equations for volume estimation in West Africa

Noel Houedougbe Fonton[5]

Introduction

Forest inventories aim at estimating timber resources (volumes, biomass, carbon stocks, biodiversity, etc.). Various models/approaches including allometric equations have been proposed for estimating timber resources. The four common approaches used are the shape coefficient, species-specific volume table, generalized equation for many species and equations by clustering species. Equations by clustering species could be considered as the best alternative for converting forest inventory data into volume/timber biomass and has been used in many scientific investigations. Species clusters are built based on:

- Taxonomic features/clusters (family, genus);
- Ecophysiological features/clusters (light demand, shade tolerance, regeneration requirements, etc.);
- Commercial clusters (utilized/unutilized now; may change with time);
- Clusters based on statistical analysis of similarities among species

Clusters based on statistical analysis of similarities between species: e.g.

- Paired test and modified paired test
- Clustering (hierarchical/partitioning methods)
- Used data on species characteristics (growth rates, height, etc.).

Implications are that data on individual species must be available using destructive methods. The study was undertaken to develop multi-specific tree allometric equations for volume estimation.

Methodology

Volume table for 14 forest tree species: *Afzelia africana, Albizia zygia, Antiaris toxicaria, Burkea africana, Ceiba pentandra, Crossopterix febrifuga, Diospyros mespiliformis, Isoberlinia spp., Khaya senegalensis, Lophira lanceolata, Pseudocedrela kotschyi, Terminalia spp., Uapaca togoensis* and *Vitellaria paradoxa* was used for the study. Sixty (60) trees distributed in six (6) diameter size classes with diameter at breast height of greater than 10 cm.

Volume table with a single (i.e. diameter, D, as the only parameter) and double entries (i.e. using diameter, D, and height, H, as parameters) were used for the modelling. In choosing the best allometric equation per species, the criteria for comparison included:

- Quality of the adjustment:
  - R-square (R^2);
  - Residual standard deviation or Furnival Index (for logarithmic equations);
  - Quadratic mean of the absolute error;

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    - Quadratic mean of the relative error
- Graphical analysis of the distribution of errors
- Mean relative quadratic prediction error

In building clusters with different characteristics, the method involves the use of the:

- hierarchical ascending classification, using the values of the coefficients for the best species-specific equations;
- Distinctive characteristics easily observable;
- Best multi-species allometric equation;
- Simulation of optimum sample size of trees for developing multi-species equations.

Results

The best allometric equation (total volume and stem wood volume) obtained was built using the dendrometrical characteristics of Diameter, Total height and Volume as follows:

$$loge\ V = a + b_1 loge\ D + b_2 loge(H)$$

The fourteen species were clustered into four. Cluster one had four (4) *species: Afzelia africana, Antiaris toxicaria, Ceiba pentandra* and *Diospyros mespiliformis*. Most species in this cluster reach a relatively high height (20 – 30 m) and are mainly timber species. The second cluster with three (3) species: *Isoberlinia* spp., *Lophira lanceolata* and *Albyzia zygia*. These species can generally reach up to 20 – 27 m height. Cluster three was composed of five (5) species (*Burkea africana*, *Crossopteryx febrifuga*, Terminalia spp., Uapaca togoensis and *Vitellaria paradoxa*). Cluster 4 contains two (2) species (*Khaya senegalensis* and *Pseudocedrela kotschyi*).

Conclusion

In developing multi-species allometric equations, height represents the discriminant factor for categorizing species. Multi-species equations prove good fitness characteristics and can be used to estimate wood volumes for clusters of species. Optimum sample size for trees for developing multi-species allometric equations was assessed using the prediction quality which correlated positively with sample size per girth size class.

3.2. Tree allometric equation development for Ghana: from the tree to the national forest biomass assessment

Stephen Adu-Bredu[6]

Introduction

Forests provide economic (e.g. timber, bio-energy) and environmental (e.g. carbon sequestration, watershed protection, biodiversity conservation) services. For countries implementing climate change mitigation policies in the forestry sector (e.g. REDD+), estimation of biomass carbon stock is required. Precision in the estimation of biomass carbon stocks is paramount for commercial uses, national development planning, ecosystem productivity measurement as well as contribution to changes in forest stand to global

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carbon cycle. A key way to ensure precision in the measurement of carbon stocks is the use of allometric equations.

Methodology

Development of allometric equations is crucial in the estimation of biomass carbon stocks. Requirements of tree selection for destructive sampling in the development of species specific allometric equations for planted forests include size class distribution (diameter, height) and age class distribution, across all ecological zones and captured variation in climatic variables on wood density. Generalised allometric equations suitable for natural forests due to higher species diversity, require coverage across all ecological zones, and should include all the prevailing species guild types, in the various diameter classes for accurate modelling.

Results

Species specific (particularly teak) and generalised allometric equations were developed for Ghana using single and multiple variables. The equations obtained for the generalised allometric equation were of the form:

		Ecological zone (Aboveground)										
	Dry			Moist			Red Mangrove			Wet		
Model	**a**	**b**	R^2	**a**	**b**	R^2	**a**	**b**	R^2	**a**	**b**	R^2
$Y=a(D^2)^b$	0.649	0.982	0.752	0.000	1.842	0.970	0.177	1.179	0.890	0.247	1.178	0.960
$Y=a*\rho*(D^2)^b$	0.734	1.055	0.871	0.012	1.542	0.974	0.204	1.225	0.873	0.041	1.433	0.969
$Y=a*(Ht*D^2)^b$	0.014	1.038	0.818	0.000	1.334	0.980	0.190	0.781	0.975	0.062	0.931	0.976
$Y=a*(Ht*\rho*D^2)^b$	0.013	1.110	0.926	0.011	1.113	0.984	0.210	0.807	0.971	0.010	1.119	0.979
$Y=a*\rho*(Ht*D^2)^b$	0.043	1.004	0.924	0.007	1.141	0.985	0.208	0.818	0.970	0.009	1.117	0.980

	Ecological zone (Belowground)											
	Dry			Moist			Red Mangrove			Wet		
Model	**a**	**b**	R^2	**a**	**b**	R^2	**a**	**b**	R^2	**a**	**b**	R^2
$Y=a(D^2)^b$	1.044	0.580	0.315	2.317	0.532	0.428	8.342	0.233	0.204	0.017	1.255	0.926
$Y=a*\rho*(D^2)^b$	3.610	0.451	0.490	0.052	1.214	0.756	9.627	0.280	0.213	0.288	0.938	0.959
$Y=a*(Ht*D^2)^b$	1.393	0.366	0.359	0.575	0.509	0.490	7.585	0.170	0.189	0.006	0.960	0.947
$Y=a*(Ht*\rho*D^2)^b$	1.493	0.389	0.438	0.232	0.659	0.735	7.731	0.176	0.192	0.054	0.786	0.960
$Y=a*\rho*(Ht*D^2)^b$	3.762	0.310	0.534	0.176	0.706	0.652	8.484	0.205	0.190	0.082	0.754	0.958
$Y=a(AG)^b$	1.582	0.636	0.686	2.169	0.610	0.499	9.640	0.252	0.199	0.453	0.847	0.953

The equations obtained for species specific (*Tectona grandis* (Teak)) allometric equations were of the form:

	Tectona grandis		
Model	**a**	**b**	R^2
$Y=a(D^2)^b$	0.0604	1.2462	0.9890
$Y=a*(\rho*D^2)^b$	0.2489	1.1529	0.9929
$Y=a*(Ht*D^2)^b$	0.0171	1.0025	0.9951
$Y=a*(Ht*\rho*D^2)^b$	0.0588	0.9409	0.9975

Where AG = above-ground volume or tree mass, BG = below-ground volume, D = diameter at breast-height (i.e. 1.30 m above-ground), Ht = total height, ρ = density, and a, b are constants.

Discussion

Inclusion of tree density in the allometric equation improves the quality of the model. For example, without density in the equation, *Ceiba* and Mahogany of the same size will give the same mass but that may not be true. Among the climatic variables, amount of rainfall in the dry season and maximum temperature have the most effect on the mass/density,, especially where the species cross different eco-regions.

Conclusion

The Allometric equations developed were applied when reporting on Mapping of Forest Cover and Carbon Stock in Ghana, under the Forest Preservation Programme, and also during the development of Reference Emissions Levels and Measurement, Reporting and Verification System for Ghana.

3.3. Status of tree allometric equations in Niger

Bibata Djibo[7], Assoumane Garba[8]

Introduction

Climate change is a global challenge, which is threatening the world's economies. The causes are anthropogenic with devastating effects on the environment. There is the need for some adaptations to the changing climatic conditions. Several studies on bio-sequestration have been carried out in the humid tropics, but the same cannot be said of the Sahelian region as a result of unavailability of appropriate allometric equations. Across forest or clusters of forest in Niger, modelling accurately remains a challenge not only in terms of technical, human and financial resources, but also the necessary scientific tools.

State of the forests in Niger

In 2012, a diagnostic study on domestic energy sponsored by the Ministry of Energy in collaboration with the Ministry of Water and Environment estimated the potential forests to be 8 million ha of which 1,098,403 ha were potentially developable. The main forest types

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are Forest formations trays, Forests flooded lowlands, Forest formations of sandy plains, Parklands, Gallery forests and Forest Plantations. These forest formations bear the brunt of the consequences of changes and climate variability exacerbated by human activities such as the advancing agricultural front, bush fires and uncontrolled exploitation of wood energy. A 2013 study by CILSS of the period from 1975 to 2013 showed that, forest loss related to the expansion of farming were 4.24 million ha, with an average annual loss of 111,578 ha (an annual rate of regression 3.6% over the period 1975-2013).

Status of allometric equations

The development of allometric equations by researchers in Niger began with three gum producing Acacia species: *Acacia senegal, Acacia seyal* and *Acacia laeta*. Biomass of parts of the trees including stem/bole, branches, twigs, leaves and roots were estimated and modelled as follows.

Acacia senegal

Compartment of dry biomass to estimate	Corresponding allometric equations	Significance of the result of the calculation
Biomass of dry stem/bole (kg)	Y = 0,115C (m) + 4,497	P = 0,000, R^2 = 74%
Biomass of dry branches (kg)	Y = 0,146C (m) + 4,80	P = 0,000, R^2 = 76%
Biomass of dry twigs (kg)	Y = 1,880C (m) + 3,064	P = 0,000, R^2 = 98%
Biomass of dry leaves (kg)	Y = 1,089C (m) + 0,287	P = 0,000, R^2 = 93%
Biomass of dry roots (kg)	Y = 0,257C (m) + 1,891	P = 0,000, R^2 = 90%
Aboveground and belowground plant biomass of dry roots (kg)	Y = 4,502C (m) + 14,379	P = 0,000, R^2 = 78%

Acacia laeta

Compartment of dry biomass to estimate	Corresponding allometric equations	Significance of the result of the calculation
Biomass of dry stem/bole (kg)	Y = 1,031C (m) + 3,748	P = 0,000, R^2 = 64%
Biomass of dry branches (kg)	Y = 0,499C (m) + 4,418	P = 0,000, R^2 = 72%
Biomass of dry twigs (kg)	Y = 0,595C (m) + 3,017	P = 0,000, R^2 = 90%
Biomass of dry leaves (kg)	Y = 0,112C (m) + 1,024	P = 0,000, R^2 = 94%
Biomass of dry roots (kg)	Y = 0,220C (m) + 2,221	P = 0,000, R^2 = 89%
Aboveground and belowground plant biomass of dry roots (kg)	Y = 5,494C (m) + 13,42	P = 0,000, R^2 = 79%

Acacia seyal

Compartment of dry biomass to estimate	Corresponding allometric equations	Significance of the result of the calculation
Biomass of dry stem/bole (kg)	Y = 1,380C (m) + 5,589	P = 0,000, R^2 = 98%
Biomass of dry branches (kg)	Y = 0,531C (m) + 5,958	P = 0,000, R^2 = 96%
Biomass of dry twigs (kg)	Y = 0,522C (m) + 4,543	P = 0,000, R^2 = 94%
Biomass of dry leaves (kg)	Y = 0,234C (m) + 2,346	P = 0,000, R^2 = 98%
Biomass of dry roots (kg)	Y = 0,461C (m) + 6,443	P = 0,000, R^2 = 98%
Aboveground and belowground plant biomass of dry roots (kg)	Y = 5,494C (m) + 25,12	P = 0,000, R^2 = 81%

Constraints

Research in this framework is faced with many challenges, mainly related to logistics, necessary resources, the lack of reliable and systematic intermediate data, and the scarcity of qualified expertise to carry out the development of allometric equations. For gum trees in the area, the main constraints are lack of information on regeneration dynamics, plant biomass productivity, lack of periodic inventory data, and data on biomass losses related to agriculture and pasture (logging, fires, etc.)

Future prospects

Work is underway on four Combretaceae species used for the production of firewood, including *Combretum glutinosum, Combretum micranthum, Guiera senegalensis* and *Combretum nigricans*. Other species of importance to agroforestry are *Acacia albida, Sclerocarya burea, Piliostigma reticulatum, Prosopis africana, Prosopis juliflora, Acacia nilotica* and *Acacia tortulis*.

Conclusion

Development of allometric equations in Niger is in the teething stage. However, currently, concerns about climate change are growing and therefore interest in biomass assessment is great. As a result, a lot of effort is needed to develop local allometric equations in order to derive maximum benefits from the international carbon trade.

4. NATIONAL FOREST INVENTORY: BIOMASS AND ACCURACY ASSESSMENT

4.1. The use of tree allometric equations for the second national forest inventory in Burkina Faso

Sia Coulibaly[9]

Introduction

Development of allometric equations in Burkina Faso between 1980 and 1983 faced challenges which led to over- and under-estimation of tree volumes. It became necessary for new allometric equations to be developed. The study was carried out to develop allometric equations for estimating volumes of wood (firewood, poles and timber), and leaf biomass of trees by phyto-geographical sector: South Sudanese, North Sudanese, South Sahel and North Sahel.

Methodology

Individual equations for the main species, multi-species equations and equations for all species were developed using the destructive sampling procedures. However root biomass was not taken into account in the sampling procedures but soil carbon stocks were estimated.

Work done

Number of trees cubed: 3,893 (97.3%)

In the South Sudanese sector, the following species were converted to lumber: *Anogeissus leiocarpus, Gmelina arborea, Khaya senegalensis, Prosopis Africana* and *Tectona grandis.*

Measurement of carbon in wood: A total of 3,893 trees wood samples in the dry state were used for the determination of density and measurement of carbon.

Results

The dominant species within each sector was established and for each sector individual equations as well as multi-species equations were developed. Within the South-Sudanese Sector, 18 individual equations and multi-equations using 1440 trees were developed. The North-Sahel recorded the least number of 12 individual equations and multi-equations for 720 trees were also developed.

Discussion

Our work should be of interest to Niger, and it will be applicable to other countries as well, for example, fodder biomass and other non-wood forest products. On the development of allometric equations, we should be able to develop multi-species equations. Such allometric equations can help to determine for example the biomass of Shea butter and Baobab trees. Allometric equations used in Burkina Faso between 1980 and 1983 had challenges which led to over- and under-estimations, so it was necessary for new ones to be developed.

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Conclusion

Although the activities involved were too "heavy"; it was necessary investment; because it was one of the pillars of estimates from which policies were built. Dissemination of results at national, regional and international levels is currently underway.

4.2. Overview of the Guinean forest sector and the problem of logging

Layaly Camara[10] / Kadiatou Madi Diallo[11]

Introduction

The forest resource in Guinea covers about 53.6% of the total land area with four vegetation zones namely: mangroves (250,000 ha), rainforest (700,000 ha), dry forest 1,600,000 ha and savanna which covers about 10,636,000 ha. Currently, there are about four policies operating in the forestry sector: the National Forest Policy (NFP/1989); the Policy of Decentralization (1986); the Environmental Action Plan (PNAE 1997) and the Declaration of land policy in rural environment. All these policies aim to guarantee sustainable management of forests in the long term, to reduce pressure on the natural resources and to promote lasting management of the forest. Following the adoption of the national forest policy in 1989 with its action plan for six (6) years, several projects and programs were initiated and implemented with a participatory approach involving the local populations.

Constraints

Falsification of official documents, corrupt managers that restrict government's capacity to deal with illegal logging, lack of collaboration between the different sub-sectors and the absence of forest management plans are some of the challenges confronting the forestry sector.

Recommendation

- National forest inventory needs to be carried out.
- Introduction of allometric equations on a large scale in the framework of climate change within the country.
- Sub-regional integration of forest management is also required.
- More support for Guinea will be required in the form of technical support with implementation of UN REDD projects.

Conclusion

An appeal for technical support was made to enable Guinea to conduct national forest inventory, introduce allometric equations on a large scale in the framework of climate change and to implement UN REDD projects.

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4.3. Uncertainty in tree biomass assessment

Luca Birigazzi[12]

Introduction

Above-ground biomass assessment is crucial for measuring carbon stocks in trees and forests. However, accuracy of the results could be compromised by four types of errors propagated during tree biomass assessment. These are: error due to tree measurement; error due to the choice of allometric model; sampling uncertainty; and size and representativeness of the study plot. Additional sources of error may arise from data entry, definitions and log transformation. Measures to address uncertainties associated with each of these errors were examined.

Methodology

A meta-analysis of data from different studies showed wide variations among diameter, height and wood density measurements resulting from equipment used, skill of the observer, experimental technique, etc. Errors associated with the choice of allometric equations, plot sizes and representativeness of the plots were equally examined using data from Ghana as a case study.

Recommendations

The following measures were recommended to overcome uncertainties associated with aboveground biomass estimation:

- Double-check plots containing many large trees
- Include only plots larger than 0.25 ha
- Avoid biomass models with sample size < 50
- Use equations only within their interval of applicability
- Use model including Wood Density as input variable, if possible
- Include in the estimation also life forms other than trees (if they have diameter >10 cm)
- Investigate landscape-scale variability, e.g.
    - Preliminary reconnaissance to be made to identify the major habitat gradients of the landscape:
    - Geo-hydrologic gradient (swamp, upland etc.)
    - Nutrient based gradient (white sands, other soils)
    - Topographic gradient (sloping, flat, etc.)
    - Improve the precision of the field measurement
    - Calibrate the model to reduce possible bias
    - Improving representativeness of the samples used for model developing

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Discussion

It is important to reduce uncertainties associated with models, but in practice, it is difficult to quantify uncertainties in biomass estimation as it requires a lot of resources. A suitable option for assessing uncertainty and uncertainties propagation can be the use of stochastic simulations such as the Montecarlo method or bootstrapping techniques. Those methods are especially recommended in presence of large uncertainties, complex models and possible correlation among factors, as it is the case in biomass assessment. To this regard, specific tools for assessment of uncertainty and uncertainties propagations are going to be developed by FAO. .

On the number of variables to be taken into account when developing a model, the more input variables you add (always within a certain limit, in order to avoid over-fitting) the more likely is the model estimate to be precise. However, at the moment of the application of the model, an increased number of input variables will also entail additional field measurements, and an increase of costs and time. It should also be taken into consideration that certain dendrology variables, such as height, are, in practice, difficult to measure (especially in tropical rain forests) and if added to the model and inaccurately measured could increase the estimate error. I would recommend to use model including height only whether accurate height measurements (or good local diameter-height relationships) are available.

Conclusion

Uncertainty is rarely evaluated carefully and rarely reported. However, a different kind of error is associated with each step of the process, and the errors add up during the estimate, so care must be taken to address them in order to obtain accurate biomass values.

4.4 Use of models for assessing the potential of carbon sequestration from farm to large scale in West Africa

Mahmadou Belem[13]

Introduction

Climate change mitigation is gradually developing into a larger market involving many developers and investors. Current land management and land-cover in Africa provides many countries with significant opportunities to enter into this market while at the same time working to reach development goals (Walker, Theron, & Moseki, 2008).

Relevant methods are therefore required for accurate estimation of carbon stocks. Although models are being used in West-Africa for carbon storage and sequestration assessment at different scales, its usage is poorly known. In order to improve knowledge about the use of models and to improve carbon dynamics simulation in West-Africa, it is important to assess the relevance of past experiences in relation to carbon sequestration and storage.

Carbon management in developing countries concerns multiple actors (farmers, decision makers, non-governmental organizations, scientists), involves multiple sectors (agriculture,

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environment, forestry, water, energy including climate change, biodiversity loss, poverty, health, food, water and energy insecurity and human displacement) and operates at multiple scales: field, farm, local level, meso, national and international levels. Accordingly, there is the need to consider interactions between the social and environmental dynamics.

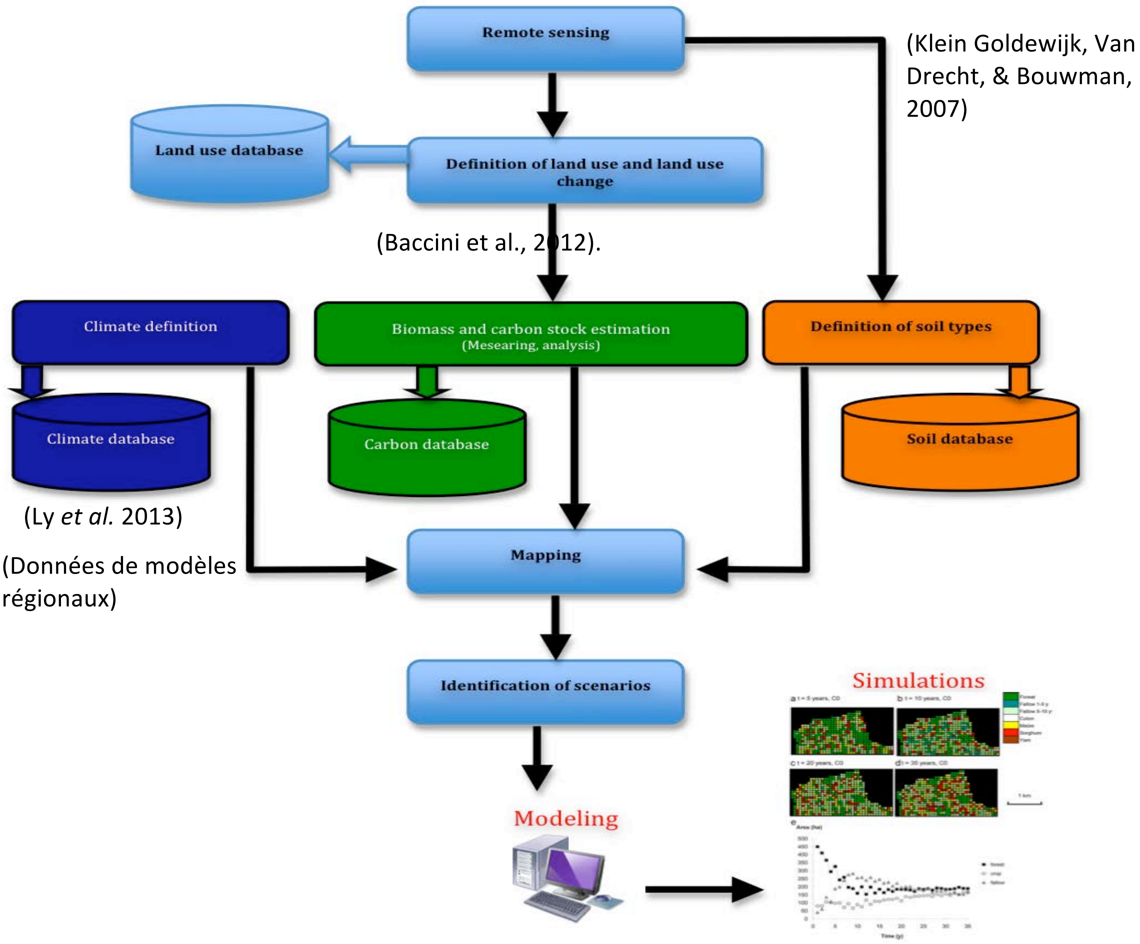
Methodology

Articles focusing on assessment of carbon sequestration with explicit environment spatial data integration applied at least at the farm scale were reviewed. Classification of articles was based on the objective of the study, scale of analysis and the modelling approach. Next, comparison of models to guide the selection of the appropriate model for a specific purpose considered the following criteria: types of user, integration of spatial variability, multi-scale representation, and integration of social, economic, biophysical and policy dimensions.

Results

Integrated Assessment Modelling is an effective tool to achieve the Integrated Assessment.
"A structured process of dealing with complex issues, using knowledge from various scientific disciplines and/or stakeholders such that integrated insights are available for decision makers (Rayner & Malone, 1998)". The WACAM model was developed to assess the potential of carbon sequestration from West Africa. The integrated model consists of different models, sub-models, scheduler and data management components, taking into consideration the social, environmental, economic and policy dimensions.

Toward an integrated approach: WACAM model



Conclusion

There is a high carbon sequestration potential in West-Africa region, and models are relevant tools to complement the direct methods for estimating carbon stock and sequestration. Models reduce financial and temporal cost of carbon stock and change estimation at large scale.

4.5. Assessing commercial volume in Ivory Coast

Casirmir Irie Zobi[14]

Introduction

The significant impact of information technology in many sectors of the Ivorian economy is well known. SODEFOR has volume tables of several tree species generated from projects it undertook. In order to avoid wasting of time, over- and under-estimation of tree volumes, it was necessary to develop a computer program for projecting tree volume increment. In an attempt to address the needs of forest/foresters, the Department FOREN has undertaken a program incorporating several aspects of forest management.

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The overall objective of the study was to develop a computer application program for tree volume estimation which will avoid time wasting and eliminate mistakes in the estimation of the volume of trees. The specific objectives of the software development were: Implementation of software to manage the plantations and natural forests, building a forestry database, and to test the software using the arboretum's inventory data of FOREN Department.

Methods
Data for development of the software were obtained from five forest plantations and three natural forests within the semi-deciduous forest zone, while two plantation forest and natural forest were used within the evergreen forest zone. The tree volume estimation was determined by SMALIAN method.

Results
The application of the study model was developed with three levels of application: conceptual, organizational and operational levels together with the different actors involved and exchange of information between the actors.

Conclusion
Research needs to be conducted regarding increases in Ivorian forest species to integrate its application and also consider the inclusion of wildlife management. Options for mapping and estimating the rate of carbon storage in the development of the application were also to be considered.

5. DEVELOPING ALLOMETRIC EQUATIONS IN DIFFERENT ECOSYSTEM TYPES

5.1. Assessing forest biomass dynamics in savanna woodlands

Louis Sawadogo[15]

Introduction

The major agro-ecosystems across West African Savannas are the open grassland with sparse shrubs, croplands with open woody vegetation, open deciduous shrubland, deciduous woodland and croplands which constitutes over 50% of the land area. The agents of vegetation dynamics includes fire, grazing, tree cutting, mining, land clearing for agricultural activities and urbanisation.

Interest in managing dry forests and woodlands in sub-Saharan Africa for carbon storage and sequestration is gradually increasing due to emerging issues such as REDD. A critical pre-requisite to managing savanna woodland for carbon storage and sequestration is a good knowledge about tree and shrub biomass. Providing accurate measurements of carbon stock is difficult without precise measurements of biomass.

Tree biomass in forests can be estimated either directly or indirectly. Measurements on trees can be directly converted to aboveground biomass using **biomass allometric equations** developed from harvested trees of many species with a large range of diameter in order to estimate biomass per tree. The equations relate diameter (cm) or basal area (cm^2) to biomass (kg $tree^{-1}$). Although time-consuming and the requirement for large sample sizes, measurement of biomass in the field is probably the most accurate method of estimating tree biomass (Henry et al., 2011). The study aimed at development of management tools for better assessment of savanna resources (woody and non woody products) and sustainable use of disturbances (grazing, fire, wood cutting) as forest management tools.

Methodology

Floristic inventories such as scientific name, number of individuals, number of stems of the individuals, height of each stem, diameter at soil level (20 cm) and breast height (130 cm) were taken on all woody individuals in each plot at Tiogo and Laba sites. Measurement, cutting and weighing of trees were carried out in 48 plots per site for 52 species. Every stump (13,405 in Laba and 17,639 in Tiogo) was mapped and followed up every year since 1994 (20th year = 2014). The allometric equations were developed using tree metrics (Db, Dbh, H) data vs. component biomass through regression models.

Results

Fifty two species were felled but due to the gaps among species in terms of tree sizes and architecture, species specific equations were developed for 11 species namely: *Acacia dudgeoni, Acacia macrostachya, Anogeissus leiocarpa, Combretum ghasalense, Combretum glutinosum, Combretum micranthum, Combretum nigricans, Crossopteryx febrifuga, Detarium microcarpum, Entada africana* and *Piliostigma thonningii*.

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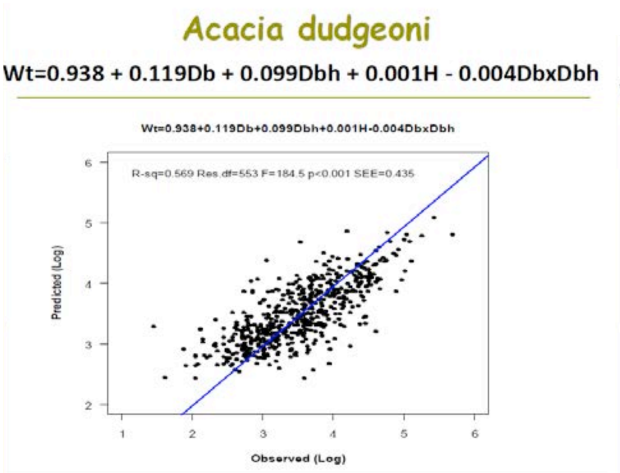
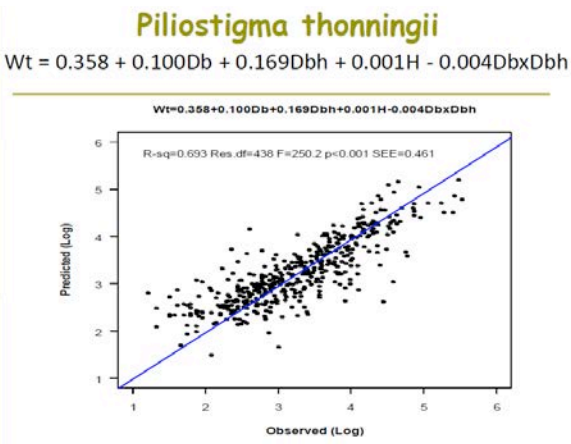
	Tiogo	Laba
Parameters	Mean (±SE (ha^{-1})	
No. of species	79	75
Total number of Stems	8888±743	6549±542
Basal Area Spl (m^2)	11.0±0.9	10.9±0.7
Basal Area 130 cm (m^2)	6.3±0.6	6.4±0.5





Conclusion

Allometric prediction of above-ground biomass of eleven woody tree species in the Sudanian savanna-wooodland of West Africa was developed. Selective cutting of 50 % of merchantable volume of wood with 20-year rotation period, three years protection of the harvested plots against fire and grazing, improvement of natural regeneration by direct seeding with valuable tree species, and implementation of annual early burning on the rest of the area under management could be used for sustainable forest management in Burkina-Faso.

5.2. Assessing plantation growth and dynamics in Ivory Coast

Bi Alphonse Foua TAPE[16]

Introduction

Deforestation continues to threaten the existing forest and with less than three million ha of the forest remaining, it was important to embark on reforestation, and as a result, both the government and private developers responded to the need. Over 185,000 ha of deforested areas have been re-planted since 1929, with both exotic and indigenous tree species.

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However, Teak (*Tectona grandis*) constitutes over 40% of rehabilitated areas. The indigenous species planted include *Terminalia spp., Triplochiton scleroxylon, Milicia spp., Ceiba pentandra, Khaya spp.*. Other exotic species are*, Gmelina arborea, Cedrala odorata, Pinus spp.* and *Eucalyptus spp.*

Method

The study was carried out in three ecological zones, namely, pre-forest (PF), Semi-deciduous forest (SD) and Evergreen forest (SE). Parameters such as diameter, height, density, volume and thickness of heartwood and sapwood were studied. Allometric equations using volumes were developed and image analysis of the variation in the heart/sapwood along the tree was also undertaken.

Results

Results from the case study using *Tectona grandis* showed that the average diameter was highest in the SE (evergreen zone) however, no significant difference was observed between PF (pre-forest) and SD (semi-deciduous) ecological zones. The trend observed in the diameter was similar to the basal area observed across the eco-zones.

The average densities and volumes across the ecological zones did not show any significant difference. The results also confirm earlier studies that the evergreen area has the highest productivity index.

Conclusion and way forward

The following parameters: diameter, height, density, volume, heartwood and sapwood thickness were studied. The study found out that the evergreen zone of the study area had the highest growth in diameter and height, whereas sapwood thickness was higher in the semi-deciduous forest zone. The pre-forest area was the best for the production of Teak in Ivory Coast.

Further studies need to be conducted to determine other areas where Teak will do better. In this era of climate change, carbon sequestration by plantations could be of concern to SODEFOR under the REDD+ process. As Teak plantations are becoming more important, it will be good to look at their impact on biodiversity conservation.

5.3. Developing tree allometric equations for estimating the biomass accumulation and distribution in plant communities: A case study of the above-ground biomass in an age series of Teak (Tectona grandis l.f.) plantations at Onigambari Forest Reserve, Oyo State, Nigeria

E.I. Mbaekwe[17]

Introduction

Tropical forest ecosystems continue to be exploited at alarming rates, resulting in their conversion to secondary forests and many other forms of land use. A high proportion of forests in the tropics are now secondary, mainly as a result of logging, farming and other human activities (ITTO, 2002). With changes in tropical forest ecosystems as a result of

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human disturbance, the ability of secondary forests to accumulate biomass is seriously jeopardized, hence the need to assess biomass levels of primary and secondary forests from time to time (MacKay, Wehi, & Clarkson, 2011). Plantation development is therefore necessary to shore up the biomass of heavily degraded forests. The study was conducted to determine the best-fit allometric equation for estimating the above-ground biomass of Teak plantations in an age-series at Onigambari Forest Reserve in Nigeria.

Methodology

Four plots of ages 5, 8, 11 and 14 years were selected from different locations within the reserve, but not more than 2.0 km from each other. The selected plots were marked out and delimited with pegs. The sample size chosen was 50m x 50m.

In each sampling plot, every living teak tree was numbered with durable red paint and the breast height (1.3m) above the ground level was prominently marked. The diameters at breast height of all the trees were also measured. In selecting the sample trees for destructive sampling, stratified random sampling and the method of uniform sampling intensity were employed. Ten trees were selected from each plot for felling. Other parameters measured included: total heights of the trees taken on the felled trees from the ground level to the tip of the crown, bole height, fresh weights of the leaves, dead wood, living branches and boles, flowers, fruits and seeds.

Results

From the four models used, the allometric model that gave the highest coefficient of determination (R^2), the lowest standard error of the estimate (SEE) and the lowest F- ratio, was selected as the best fit model. The selected model was therefore used to estimate the above-ground biomass of the teak components in an age series (with 95% confidence limit). This also confirms the findings of earlier workers, who used similar allometric model to estimate the biomass of other species.

above-ground total tree dry weight (Y) versus dbh (X) in an age series of teak.

Age	Model	Regression Equations	r^2	S.E.E	F Ratio
5	I	$\log_e Y = -2.6470 + 2.5046*\log_e X$	0.8585	8.34	48.53
	II	$\log_e Y = -0.7210 + 0.2322*X$	0.8555	9.95	47.38
	III	$Y = 103.8034 + - 721.9302*9(1/X)$	0.7584	11.07	25.11
	IV	$Y = -140.8725 + 73.6005*\log_e X$	0.8172	9.63	35.77
8	I	$\log_e Y = -2.9478 + 2.6668*\log_e X$	0.9717	20.41	274.37
	II	$\log_e Y = -1.5784 + 0.1701*X$	0.8820	55.42	59.82
	III	$Y = 262.9199 + - 2254.9150*(1/X)$	0.6745	46.03	16.57
	IV	$Y = -421.5254 + 193.0256*\log_e X$	0.8292	33.35	38.83
11	I	$\log_e Y = -2.1690 + 2.3470*\log_e X$	0.9897	13.02	765.60
	II	$\log_e Y = -2.1784 + 0.1283*X$	0.9425	49.54	131.03
	III	$Y = 334.9153 + - 3466.1850*(1/X)$	0.6811	57.29	17.09
	IV	$Y = -587.3987 + 248.9680*\log_e X$	0.8482	39.52	44.71
14	I	$\log_e Y = -3.0119 + 2.6510*\log_e X$	0.9933	15.85	1181.26
	II	$\log_e Y = -1.7649 + 0.1494*X$	0.9576	53.58	180.75
	III	$Y = 400.8325 + - 3934.8150*(1/X)$	0.6209	88.43	64.75
	IV	$Y = -705.6750 + 299.8054*\log_e X$	0.7967	23.10	31.36

Key: Y = biomass estimate (kg); X = diameter at breast height (cm); *= multiplication sign; SEE = standard error of the estimate; r^2 = coefficient of determination.

There was an obvious trend in the above-ground biomass estimates of the leaves, dead wood, branches 5cm, total branch and total tree; they generally increased to a maximum value by the 5th year, declined to a lower level by the 11th year before increasing again by the 14th year. In general, the increase in the biomass of these tree components was much larger between the 5th and 8th year, while increase from the 11th to the 14th year was considerably low. This implies that the teak growth and biomass accumulation must be taking place more rapidly around the 8th year but the age of the peak growth could not be identified because of the 3-year age interval used. The bole biomass increased steadily with age, while no consistency could be attributed to the biomass estimates of the floral parts and the branches less than 5cm.

The biomass of the undergrowth (stem and leaves) was highest in the youngest plot and highest in the 8 year and 11-year old plots, before declining in the oldest plot.

Conclusion

The log allometric model of the type, logeY = a + b logeX, which was found to be the most suitable allometric model, was used as the predictive model to estimate the above-ground biomass of teak components in an age series. In general, the significance of the regression (based on the F-ratio) increased for the tree components in the order: leaves, branches, boles and total tree, suggesting that the efficiency of diameter as a predictor of biomass of these components also increases in the same direction.

5.4. Assessing forest growth and dynamics in dry woodlands and savanna of West Africa

Maguette Kaire[18]

Introduction

The sustainable use of forest resources, new opportunities from carbon markets, within the context of REDD+ and the establishment of an effective system for monitoring, reporting and verifying (MRV) deforestation, forest degradation and biomass stocks require a reliable assessment of existing forest resources. A monitoring system to regularly report on the status of the forest and on the effectiveness of interventions for Sudano-Sahelian ecosystems where forest data are limited (Mbow, Verstraete, M. Sambou, Diaw, & Neufeldt, 2013) is essential. Current challenges to forest management are related to verifiable, reliable, accurate and cost-effective methods to adequately document forest resource dynamics.

Five vegetation types exist in the Sudanian and Sudano-Sahelian Zone of West Africa namely; Forest formations (dry forests, open woodlands and gallery forests), Savannas (woodlands, tree and shrub), Steppes (wooded, shrubby and grassy), Parklands and Plantations.

Temporary or permanent plots can be used for long-term sampling in estimating changes in tree biomass stocks. Statistically, permanent sampling plots are more effective in the calculation of biomass stocks variations, allow efficient verification by a control (DOE: verify the structure and functioning of monitoring plan of carbon project) but requires marking of the plot (GPS, metal, etc.). In Sahel region, only Burkina Faso (with permanent plots of Laba and Tiogo, Sudanian vegetation) monitored its permanent plots over a long period (over 20 years).

Methodology

The approach for biomass stocks measurement and monitoring process steps was consistent with most known guidance documents (Brown, 1997; Pearson, Walker, & Brown, 2005). The planning process for measurements, delimiting the area (from the site map), area stratification (remote sensing), defining a sampling plan (type, number, size and shape of sample plots), elaborate allometric equations to be used, carrying out the measurements and collection of data (DBH, H, crown diameter, etc.), analysis of data (statistical tools, extrapolations, biomass expansion factors, etc.), calculation of volume and biomass, and interpretations of results all followed standard procedures. Synchronic approach was adopted for modelling biomass growth of woody vegetation in fallows of different ages. Chapman Richards ($Y = K\ [1\text{-}\exp\ (-2rt\ /\ K)]\ ^2$) model was used based on biomass production as a function of age of fallows; with K (maximal production), r (maximal growth rate) and t (age of fallow)

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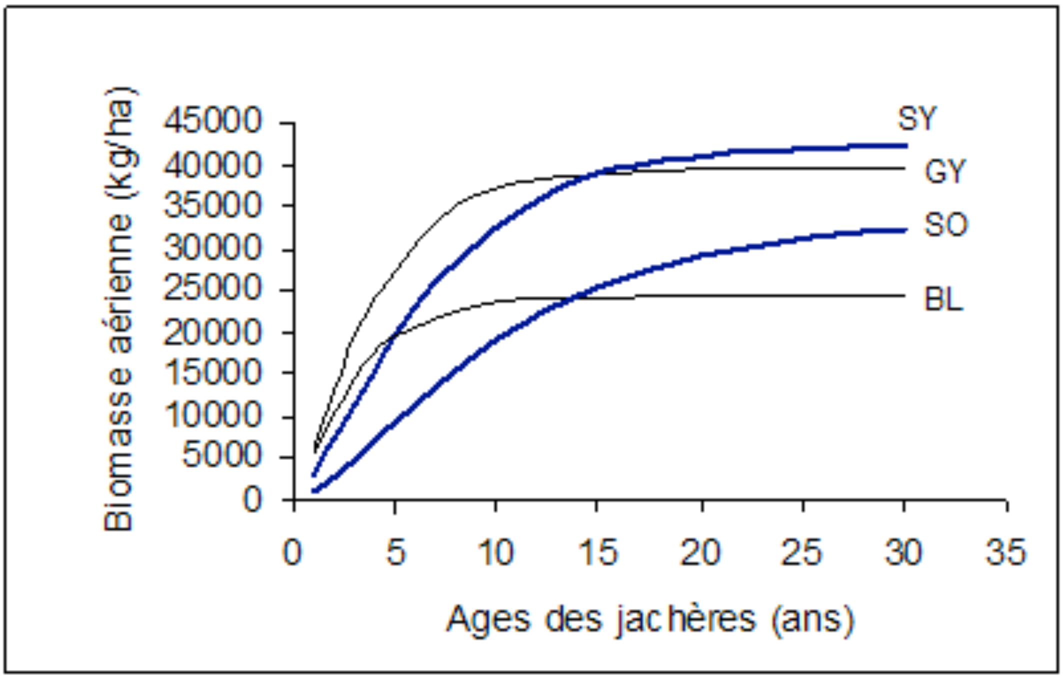
Results

Comparison of the woody vegetation growth of fallow in four sites using the Chapman Richards model, Saré Yorobana (Sudanian with less human pressure) attained the highest biomass (about 45000 Kg ha^{-1}), followed by Guiro Y. Bocar (GY) (Sudanian with high human pressure), Sonkorong (SO) (Sahelo-Sudanian with high human pressure), and lastly Boulandor (BL) (Sudanian with high human pressure: dominance *Guiera senegalensis*) with a biomass of 2000 Kg ha^{-1} (Kaire, 1999 (thesis)), as shown in the figure below.



Conclusion

Efforts should be made in Sudanian and Sudano-Sahelian zone to develop a larger number of allometric equations. Protocols should be harmonized such that same allometric equations can used for comparing biomass between neighbouring areas with the same ecological conditions. Again forest research should work on modelling the growth of forest formations.

6. CARBON STOCK AND OTHER ECOSYSTEM SERVICES

6.1. Impact of selective logging on forest biomass and soil organic carbon

Winston Adams Asante[19]

Introduction

In sub-Saharan Africa, forest degradation is considered to be a main source of land-based emissions (Bombelli et al., 2009). Selective logging is an important factor of forest degradation especially in tropical forested countries such as Ghana (Contreras-Hermosilla, 2000; Treue, 2001). Forest degradation, such as the removal of a few trees per hectare (selective logging) is much more difficult to observe remotely (Murdiyarso, Skutsch, Guariguata, & al, 2008) and field measurements is time consuming (Gibbs, Brown, Niles, & Foley, 2007). These activities affect the canopy cover only minimally but can affect the forest stock significantly (DeFries et al., 2007). Logging studies in Ghana have mostly focused on damage to the residual vegetation and impact on regeneration, but no studies have been conducted on the impact of selective logging on biomass. The present study focused on the impact of selective logging on forest biomass and carbon stocks in three landscape units namely the upper slope, middle slope and the swampy areas or valley bottoms.

Methodology

The experiments were undertaken in Boi Tano forest reserve (latitudes 5°20' and 5°36' North and longitudes 2°34' and 2°50' West) in the Evergreen forest ecological zone of Ghana. One compartment with a total area of 170 ha and three landscape units identified as upper slope, middle slope and swampy area within the compartment were used for the study. Six vegetation classes were differentiated: trees with diameter at breast height (dbh) <20cm, trees of dbh between 20 and 50cm, trees with dbh >50cm, lianas and dead plants. Sixteen plots of one hectare (ha) each were randomly laid within the compartment and all plots were centred on selected trees to be felled.

Results

The average aboveground Carbon stock was 154.2 (±16.2 SD) Mg ha^{-1}. The highest aboveground Carbon stock was found in the middle slope area (185.2 Mg ha^{-1}). The lowest Carbon stock was found in swampy area (121.5 Mg ha^{-1}). The total amount of Carbon extracted by the logging contractor was 549.8 (±98) Mg C and this represented an average of 3.18 (±0.57) Mg C ha^{-1}. The average area impacted by tree fall was 218 m^2 (0.012%), whereas 19.82 ha (11%) were impacted by logging operations, at a logging intensity of 1.5 trees ha^{-1}. In total, 12.62 (±0.45) Mg C ha^{-1} were lost during the logging operations, and this would represent 1.05 (±0.04) Mg C per cubic meter of wood extracted.

Discussion

Logging has an impact on forest biomass. However, the extent of the impact depends on the scale of logging. That is, if too much is removed, there is a risk of losing the forest; and there are examples in Ghana to show. For example, a study conducted in Bobiri Forest Reserve (Djagbletey, 2014) shows that the forest is able to recover biomass after (40 years) of logging.

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Conclusion

Selective logging is difficult to observe remotely and field measurements are time consuming. It affects the canopy cover minimally but can affect the forest stock significantly. Biomass is impacted upon by logging but the extent of the impact depends on the scale of logging.

6.2. Modelling forest biomass growth in tropical rain forest

Ernest G. Foli[20]

Introduction

Woody biomass is the accumulated mass, above and below ground, of the roots, wood, barks and leaves of living and dead woody shrubs and trees. Forest biomass estimation is important for various purposes, e.g., fuelwood/bio-energy production; ecosystem productivity; calculating carbon pools and nutrient flow in forested ecosystems, etc. Once the biomass is determined for different species in different ecological zones, social status, etc., **allometric models** can be developed from the measured tree parameters for estimating biomass in similar conditions. The estimation of tree biomass is based on the simple relationship between **mass**, **volume** and **density**.

There are two methods (Direct and Indirect) for estimating tree biomass. Direct method is achieved by weighing the mass of the samples directly in the field; but this is time-consuming. Indirect method involves the determination of parameters such as stem volume and mass from easily measured parameters such as tree diameter and height. The dry mass of various components are then summed up, from which models are developed for extrapolation to large areas. Usually, above ground tree components include the stump, the trunk, branches and buttresses.

Existing models and the usefulness of their application

Several allometric models exist for tree species in Ghana. But few are related to biomass estimation. Existing models were mostly developed for tree volumes for commercial yield determination; e.g. Wong (1990): $V = 0.004634 \times D^{2.201}$; where V and D are stem volume and diameter at breast height, respectively.

Foli *et al.* (Foli, 1993) developed models relating crown dimensions to stem growth of five species in Ghana from 408 trees. Again, (Foli, Alder, Miller, & Swaine, 2003) found the model $Cd = \alpha + \beta D^2 + \varepsilon_i$ to be a generally satisfactory relationship between tree diameter and crown size for trees in Bobiri forest in Ghana (Cd and D are crown diameter and stem diameter at breast height (dbh), respectively).

Using growing space and increment of species, Alder & Foli (2012) developed projection models for estimating volume increment and carbon yields of planted trees over several years.

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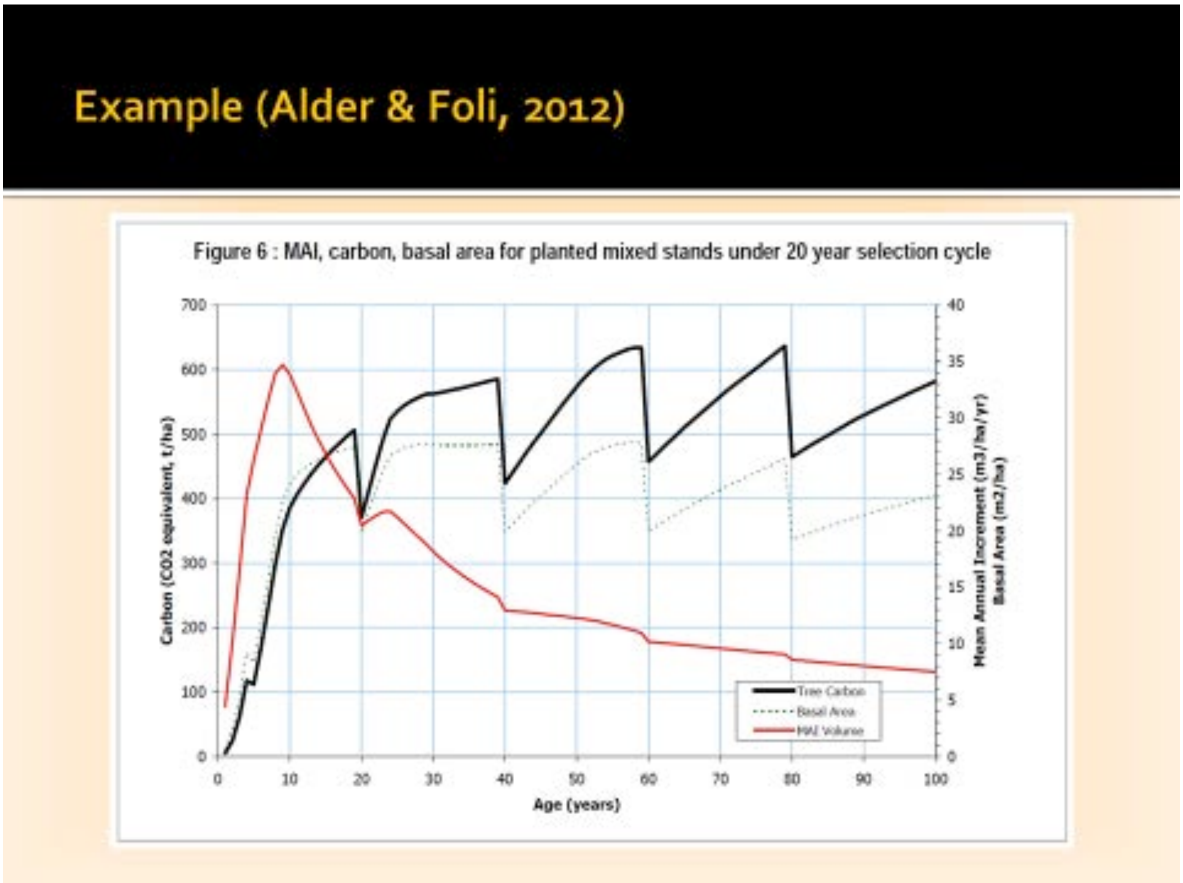

Conclusion

Similar to the development of biomass models, biomass growth models can be developed to simulate stand biomass dynamics. dbh, tree height, wood density and crown diameter have been demonstrated to be useful variables for estimating tree biomass (e.g. (Henry et al., 2010)). Applying tree density to volume growth rates, it is possible to develop biomass growth models or project stand biomass growth over time. For practical purposes, the basic data required for biomass estimation can be used without additional effort at data collection, but increment, recruitment and mortality rates need to be factored into the equation. Generalised biomass growth models can only be useful in practice if site conditions (biomes/ecological conditions, species characteristics, etc.) do not vary considerably. But the more variables there are in the biomass equation, the greater the complexity.

7. PROJECTS TO SUPPORT BIOMASS ASSESSMENT

7.1. The UN-REDD programme and support to national forest biomass assessments

John Fonweban[21]

Introduction

As a result of the significant amounts of GHG emissions from deforestation & forest degradation (17%), policy makers under UNFCCC designed a global mechanism known as REDD+ to provide positive incentives to developing countries through "reward-for-efforts" towards reduction of emissions from forests, and for enhancing and sustainably managing their forests.

In response to UNFCCC Bali Action Plan, a UN Joint Programme was established in 2008 by FAO, UNDP & UNEP to support developing countries build their capacities to "get Ready" to participate in the REDD+ mechanism and support REDD Readiness Process and Development of National REDD+ Strategies or Action Plans. The programme had two levels of support; national and global. The National Forest Inventories (NFI) are key to assessing forest resources, and in the context of REDD+, are crucial for assessing forest biomass, carbon stocks and developing country specific emission factors. The NFI data offer some potential for use in calculating forest carbon stocks and stock changes for various land use types covered during inventories. It is also one of the pillars of the National Forest Monitoring System (NFMS).

Some limitations of NFI include the fact that most inventories are limited to commercial species whereas carbon estimates are concerned with all species in the forest. Again most forest inventories sample down to a minimum diameter limit (for example. 10 cm, 20 cm etc.), whereas carbon inventories sample down to about 5 cm and below. Moreover, inventories only estimate the volume of the main stem, whereas a carbon/biomass inventory is concerned with several "pools"; stem, branches, foliage, roots, deadwood and litter.

NFMS implementation is supported by or based on three technical "pillars " or building blocks: **Satellite Land Monitoring System (SLMS**) for collection and assessment of data on land use / land use change (Activity Data); **National Forest Inventory (NFI)** for collection of information on forest carbon stocks and stock changes, needed to estimate emission factors and **A National GHG Inventory** as tool for reporting on anthropogenic forest-related GHG emissions by sources and removals by sinks to the UNFCCC Secretariat

Conclusion

The UN-REDD Programme support estimation of biomass and Carbon stocks from several "pools" such as standing live trees, standing dead trees, fallen dead trees, understory vegetation, forest floor (Litter) and Soil Organic Matter. Due to high costs involved in the estimations, only "key Categories" or pools should be estimated. The various methods for estimating the 'pools' were also outlined.

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7.2. Initiatives to support biomass assessment in the framework of the ATO-ITTO joint project

Olivier Ahimin[22]

Introduction

An overview of the ITTO was presented with particular reference to ITTO Project PD 123, the reporting systems for forest resources and the utility and use of allometric equations in reporting. The goal of the organization is to promote sustainable development of tropical forests through trade, conservation and best forest management practices. The organization meets every year to discuss issues related to policy and set the agenda for projects, and encourage the active participation of NGOs and industry (who have an interest in trade and the environment). On the ITTO project 124, the principal products were outlined. The seven criteria for reporting systems on sustainable forest management are:

- Conditions for sustainable forest management
- Extent and condition of forest.
- Health of the forest ecosystem
- Forest production
- Biodiversity
- Protection of soil and water
- Economic, social and cultural aspects of forests.

Conclusion

On the use of allometric equations for reporting systems in sustainable forest management, researchers were encouraged to develop allometric equations that make reliable estimates and also to translate them into simple, digestible terms for all actors in the forestry sector. Researchers were also entreated to make simple, understandable and easy to use tools for practitioners, managers and the general public for carbon assessment in stands.

Discussion

In exploring the linkages between ITTO criteria and indicators, vis-à-vis that of FLEGT, UNFCCC, etc., member countries have asked for deferment of the adoption of the seven criteria for sustainable forest management. This is to enable them to make more informed comments. They will, however, require technical and financial support to operate. Experts are putting together final guidelines taking into consideration all concerns raised. It is hoped that all stakeholders will help in the development of the guidelines. ITTO cannot develop criteria and indicators without taking into account the concerns (legal framework) of member countries.

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7.3. CILSS initiatives to monitor forest ecosystems and carbon stock dynamics in West Africa

Maguette Kaire[23]

Overview

The presentation was on climate change issues initiated by CILSS: issues from climate science, environmental monitoring, impact and vulnerability, as well as issues concerning adaptation and mitigation, and also mainstreaming climate change issues and its negotiations, including capacity building. It focused on a Global Climate Change Alliance project being implemented in 17 countries (7 of them in West Africa) with the objective of helping countries implement priority actions for adaptation and mitigation to take up the challenges associated with climate change.

7.4. West Africa GHGs project: technical assistance to seven West African countries?

Sabin Guendehou[24]

Overview

This is a Regional project which is an initiative of the UNFCCC programme in West Africa. The project duration is three years, and the approach of the project is to work with the countries using the IPCC methods in the seven countries. The countries themselves designed the projects and were to identify major gaps within each country. At present, not all the countries are participating fully, however, each country has a focal person around whom the project revolves. The ITTO is providing technical support to member countries in the pursuit of the project.

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8. OUTCOMES: COLLABORATIONS AND ROADMAP FOR NEXT ACTIVITIES

8.1. Developing allometric equations in different forest ecosystems

Allometric Equations show the relationship between the relative increases between the different compartments of trees, for example between the diameter and tree biomass. Different types of allometric equations exist depending upon the objectives and the method used. Allometric equations are very important for estimating volume, biomass and carbon of trees in all land use types. According to IPCC guidelines, at least the above ground biomass, below ground biomass and dead wood must be estimated using allometric equations.

Allometric equations can use one or more input variables such as diameter, wood density, tree height, crown diameter. Climatic variables such as temperature and precipitation may be stated as part of the input variables in all forest types. The age of a stand could also be considered in the input variables when dealing with plantations. Output variables can be biomass or volume and for different tree components, from the bark to total biomass. Other parameters such as biodiversity, non-timber forest product, medicinal plants, carbon stocks etc. may form part of the output variables. In developing specific and generic allometric equations, about 20-30 and 100 trees, respectively distributed across the various diameter classes should be used.

New methods for estimating below-ground biomass and wood density should be less expensive, less destructive and should take into account the biomass of the litter.

Recommendations

- Need to develop local expertise.
- Number of samples must be increased to expand the scope of available equations.
- Allometric equations available in the Region must be collated (complete inventory of Regional allometric equations).
- Partnership between institutions involved in improving the sharing of information on allometric equations must be strengthened.
- Stratification will help to reduce the cost of measurements.
- In order to reduce cost and labour, logging companies and charcoal producers could be followed during their operations.
- Specific allometric equations for dominant species and generic equations for other species should be developed.
- Cross border Regional projects should be encouraged.
- Test as many equations as possible to select the best one and do not use only one equation.

8.2. Designing a decision tree for national biomass assessment

Preparatory, implementation, analysis, reporting and dissemination phases were identified as main stages involved in a decision tree for national biomass assessment. The preparatory phase involve the use of remote sensing and GIS to actually stratify the forest into natural and plantations taking into consideration climatic parameters and fertility index prevailing in the area. The plot type to be established (i.e. permanent or temporal sampling plot) as well as the sampling design (sample size and class) must be decided at this phase. The kind and quality of allometric equations to be used must be considered.

Implementation phase involve actual field measurements which has been clearly set-out at the preparatory phase. Parameters to be measured include dbh, Height, Crown diameter, mortality, recruitment and tree species lists.

Once the field measurement has been taken, other parameters such as tree volume, wood density, tree biomass, allometric equation has to be generated and internally validated in order to create quality database.

Tree species list, genus, and family, basal area, forest structure, carbon stock, growth rate, total above ground biomass and all extrapolations should be accurately reported.

Finally the information should be promptly and correctly disseminated to all stakeholders who may require the data.

Recommendations

A technical and scientific committee should be established to have oversight responsibility during the preparatory phase of the decision tree for national biomass assessment. All stakeholders involved must be aware of the significance of the assessment.

Quality control during data collection and entry must be ensured and validated.

Dissemination of results could be done using the main local languages so that indigenes may have better understanding within the country. Capacity building should be done at all stages of the process.

Statistical Modelling

Models are relevant tools to complement the direct methods for estimating carbon stock and sequestration. They reduce financial and temporal cost of carbon stock and change estimation on a large scale. Softwares such as SAS, R, SPSS and Excel are usually used when developing models for biomass or volume estimation. SAS is not readily accessible due to high cost of license acquisition, which must also be renewed annually. Excel is useful for preliminary analysis and is readily accessible, but not good for model building. R is free, open source software. No license is required. SPSS is more oriented towards social studies; and besides, it is not free. R is recommended, as it is open source, and can ensure continuity in time since there is no need to renew the license yearly.

Log transformation and stepwise regression analysis are the most used which is good for variable selection. However if data points are few, results could be misleading. It requires indepth knowledge of forest ecology. Again non-linear model requires stronger mathematical background than linear models.

Mixed random effect models have not been used in the region. They can probably improve quality of model, but require more data. Log transformation is simpler to use but correction factor should be provided. If capacity is higher, non-linear models should also be tested.

New statistical methods

Bayesian approach is promising for variable selection and model averaging but capacity needs to be built on this topic. Inclusion of climatic variables in the model can improve the accuracy but is very data-demanding. Uncertainty analysis and error propagation is a priority but need further investigation.

Field measurements

The techniques used in field measurement include stratified and non-stratified sampling. Stratified and non-stratified sampling could be done randomly or systematically.

The three main errors encountered during field measurement are:

- Measurement error
- Instrument error
- Human error

Measurement error may stem from presence of buttress, irregular bole, multi-stem, irregular crown shape and the terrain. Fatigue, inexperience and lack of professional training are some of the human errors. Instrument errors may be due to malfunctioning or old instruments.

Modern equipment that are easy to use, efficient and precise such as electronic calliper, laser hypsometer, wood core borer and high precision GPS could help to improve the accuracy of field measurements. However, these equipment are expensive to acquire. In order to build capacity within the region, more training and support such as refresher courses and training of trainers workshops should be implemented.

Allometric equations available in different countries.

The number of allometric equations available in the West African region by countries is shown in the table below:

Row labels	**Benin**	**Cote D'Ivoire**	**Ghana**	**Guinea Bissau**	**Mali**	**Niger**	**Nigeria**	**Senegal**	**Sierra Leone**	**Grand Total**
Biomass						1				1
Biomass		1	160		37	2	5	63		268
Volume	2	1	51	32	42		48	9	8	193
Grand Total	**2**	**2**	**211**	**32**	**79**	**3**	**53**	**72**	**8**	**462**

Source: GlobAllomeTree

A well-developed model must be robust and applicable. Robustness of a model encompasses test of validity, sensitivity analysis, confidence interval, standard error of the model parameters, residual standard error of the model, RRMSE, degree of freedom, significance of model parameters, sample size and representativeness. Applicability involves the agro-ecological (soil and climatic conditions), ecosystems, species, adequacy between the inventory data and the variables of the model (dbh, h) and interval validity.

Limitations

The models developed do not meet all the criteria of applicability such as interval validity which was absent. Again the models do not meet the test of validity as well as errors of parameters of models.

Recommendations

- The models should be documented and should demonstrate the criteria of applicability and robustness in order to increase transparency.
- Major elements to be documented include methods, statistical analysis, results of test of validity, original data, algorithms and reliability.

Knowledge exchange

Barriers to exchange of knowledge:

- Language
- The lack of donor interest
- Forest management does not seem to be a priority for organizations in the Sub-region
- Lack of networking among institutions, NGOs and individuals
- Failure to utilize national data
- The diversity of ecosystems and forest products at country-level

National and institutions that have experience in forest biomass and carbon stocks estimation

National institutions

Ivory Coast

- Société de Développement des Forêts de Côte d'Ivoire (SODEFOR)
- University of Cocody and Abobo-Adjamé
- Polytechnic Institute of Yamoussoukro

Burkina Faso

- Institut de l'Environnement et Recherches Agricoles (INERA)
- University of Ouagagoudou

Ghana

- Forestry Research Institute of Ghana (FORIG)
- Resource Management Support Centre of Forestry Commission

Senegal

- Institut des Sciences de l'Environnement (ISE)
- National Centre for Forest Research (NWRC) at Institut Sénégalais de Recherches Agricoles (ISRA)

Niger

- Institut National de la Recherche Agronomique du Niger (INRAN)
- University of Maradi

Togo

- University of Lome

Guinea

- The forestry center M'Zerokore

Benin

- University of Abomey Calabi
- University of Parakou

Sub-regional institutions

- Permanent Interstate Committee for drought control in the Sahel (CILSS)
- Centre for International Forestry Research (CIFOR)
- World Agroforestry Centre (ICRAF)
- West African Science Service Centre on Climate Change and Adapted Land Use (WASCAL)

How to push the Regional actors:

- Capacity building
- Getting disposal and logistics facilities
- Networking of institutions
- Networking of people
- Networking Databases

Tools to support the exchange of knowledge at regional level

- Platforms for knowledge sharing
- Regional database
- Expert Panel
- Mail List
- Networks, regional workshop

Indicators of success

- Regional and National Projects
- Dynamic Network
- Development of multi-country projects

Action plan or Way forward

- Establish a coordination team
- Choose focal points
- Draft a proposal
- Seek funding
- Establish a knowledge exchange platform
- Create a database
- Capacity building

9. WORKSHOP CONCLUSIONS AND RECOMMENDATIONS

This first Regional Workshop on Tree Volume and Biomass Allometric Equations in West Africa, held at the CSIR-Forestry Research of Ghana, Kumasi, Ghana, brought together 25 experts of different institutions and backgrounds from the West Africa Sub-Region 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.

Whereas some countries such as Ghana and Burkina Faso carried out their first National Forest Inventory (NFI) over two decades ago and can boast of some experience with allometric equation development, other countries such as Togo are yet to conduct the first NFI, with other countries at various stages with respect to experience. Additional discussions focused on current and future methods to improve the construction of allometric models for tropical tree biomass. A significant achievement of this workshop was that it is facilitating important interactions among researchers in the Region 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.

It was clearly demonstrated by some of the presenters that it is not expertise that is lacking in the Region, but rather data. For instance, one presenter highlighted the importance of degradation which is still challenging to obtain from remote sensing, another highlighted the importance of PSPs for modelling tropical forest stand dynamics (growth rates, mortality and recruitment) and presented a stand table projection methodology. With PSP data, a Transition Matrix for projections can be produced. Selection and use of allometric equations, vis-à-vis the use of destructive and non-destructive sampling came up strongly for discussion.

Again, the workshop brought to the fore the desire of international organisations such as the FAO to contribute to the Regional approach in the development of allometric equations, knowing very well the difficulty, given not only the different ecological levels of the various countries; for example high forest in some countries (Ghana, Ivory Coast) and Sahel (Mali , Niger), etc. but also the communication difficulties among the West African countries which can compound the problem. Nonetheless, as scientists, we must strive to overcome, and this workshop should look to continue the development of allometric equations using methods that are not expensive.

The following specific recommendations were made to move the process forward:

- Technical and financial support is needed to put together groups to look at various aspects of the problems, especially as some of the countries are poles apart with respect to expertise and technical know-how.

- Researchers should develop allometric equations that make reliable estimates and also to translate them into simple, digestible terms for all actors in the forestry sector.
- Researchers to make simple, understandable and easy to use tools for practitioners, managers and the general public for carbon assessment in stands.
- Students (PhDs, MSc) should be actively involved in carbon assessment, as well as the link with WASCAL where students are involved.
- There is not much variation in wood density within species across the Region rather, the major issue is the selection of allometric equations.
- Protocols should be harmonized such that same allometric equations can be used for comparing biomass between neighbouring areas with the same ecological conditions.
- Forest research should work on modelling the growth of forest formations.
- It is recommended not to use the coefficient of determination (R^2) for comparison in modelling.
- Data extrapolation introduces errors and as such researchers ought to be careful.
- National forest inventory needs to be carried out, particularly in the countries that are yet to begin.
- Introduction of allometric equations on a large scale in the framework of climate change within each country.
- Sub-Regional integration of forest management is also required.
- Technical support for countries such as Guinea with the implementation of UN REDD projects
- Need to develop local expertise:
    - Increase the number of samples to expand the scope of available equations. Collate all the equations available in the area (complete inventory of regional allometric equations)
    - Strengthening the partnership between the institutions involved in improving the sharing of information on allometric equations available in the area.
    - He noted that good practices are coming up and that accuracy is important. He suggested that we should not be afraid of biases, but that we should be transparent.

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 West Africa. 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 of effort, and limited exposure and dissemination of pertinent research. The workshop also offered an opportunity to evaluate current status of allometric equation development and use among countries in the region, and to anticipate future needs.

Next steps and future actions (data sharing)

Sharing data is critical for Regional cooperation. This can be achieved through a platform for sharing knowledge such as Regional projects, networking, workshops, and expert panel discussions. Notwithstanding the significance of data sharing, the Region is confronted with a number of challenges such as:

- Language barrier
- Lack of networking among institutions, NGOs and individuals
- Forest management does not seem to be a priority for organizations in the sub-region
- The diversity of ecosystems and forest products at the country-level

Some countries within the Sub-Region have institutions as well as established regional institutions working on or with experience in estimation of forest biomass and carbon stocks. For example in Cote d'Ivoire, organisations such as SODEFOR, Université de Cocody et Abobo-Adjamé, and Institut Polytechnique de Yamoussokro; in Burkina Faso: INERA, Universite de Ouagagoudou, in Ghana CSIR-FORIG, etc. have experience in forest biomass and carbon stock estimation. Regional Institutions such as CILSS, CIFOR, ICRAF and WASCAL are also working on forest biomass and carbon stock estimation.

Action plan for regional collaboration

- Establish a team at the Regional level to coordinate activities at the national level
- Choose focal points/persons within each country
- Draft a Regional project
- Seek funding
- Establish a knowledge platform
- Create a database
- Capacity building

10. APPENDICES

Appendix 1. List of participants and their affiliations

No.	Name	Country	Name of Institution (in full)	Address of Institution	Email Address	Telephone Number	Field of Specialization
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13	Winston Adams Asante	Ghana	Department of Silviculture and Forest Management, Faculty of Renewable Natural Resources, KNUST		Waasante.canr@knust.edu.gh		
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25	Victor K. Agyeman	Ghana	CSIR-Forestry Research Institute of Ghana	UP Box 63 KNUST, Kumasi	agyemanvictor@yahoo.com	+233244844171	Forest Management, Forest Policy

Appendix 2. Welcome Address by The CSIR-Forestry Research Institute of Ghana

Dr Victor K. Agyeman[25]

Welcoming participants to Ghana and to CSIR-FORIG, the Director of CSIR-FORIG entreated participants to enjoy the serene environment of the institute. He noted that there was lack of Regional cooperation between Anglophone and Francophone countries within the Sub-Region due to the language barrier and different currencies. He also noted that the number of stoppages when moving from one country to another, among others, does not engender regional cooperation.

He mentioned that slight differences exist in forest management systems being practised among Francophone and Anglophone countries within the Sub-Region. Therefore coming together in a Regional workshop such as this forum helps to break down barriers, foster cooperation and also bring about a uniform system of forest management. One of his concerns was that most of Ghana's data is stored in London (UK) whilst that of SODEFOR is stored in France and these were some of the barriers that have to break down.

He noted that if politicians were not enhancing Regional cooperation, foresters can promote same through proposal writing and information sharing. He noted that, normally researchers come together when there is external funding for projects and that was one of the constraints, as our countries are not willing to put resources together to bring people together and it is important for the various countries to start it.

He also assured participants that the Government of Ghana puts premium on such Regional integration and therefore whatever communiqué that will emanate from the workshop will be communicated to the Sector Ministry for it to be worked on.

Appendix 3. Welcome Address by The Forestry Commission, Ghana

Mr Kofi Affum-Baffoe[26]

Welcoming participants on behalf of the Forestry Commission of Ghana, Mr Kofi Affum-Baffoe acknowledged the contribution of allometric equations to research and development, and noted that Ghana carried out its first national forest inventory in the 1980s, which lasted for almost five and half years. This was because the ground work which was undertaken was not supported by satellite imagery. Again allometric equations for the country had not been developed at the time of the inventory.

However, a decade after the first national inventory, a similar exercise was carried out which lasted for only nine months. This was all because of the power of technology and the development of allometric equations from the first inventory. On behalf of the chief executive of the Forestry Commission, he wished participants fruitful deliberations.

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Appendix 4. Welcome Address by the Food and Agriculture Organisation, Africa Regional Office, Accra

Dr John Fonweban[27]

The Director Forestry Research Institute of Ghana (FORIG)

Representative of the Director of Forestry Commission

Fellow scientists/researchers

On behalf of the FAO, I wish to welcome you to this Regional Technical workshop on allometric equations; jointly organized by FAO and FORIG, with financial support from UN-REDD Programme.

We are all aware that climate change has become one of the most topical and most challenging issues to mankind today, and that the key contributing causal factor to the problem is anthropogenic: resulting from our unsustainable use of the planet's resources.

While the forest sector has always played a key leading role in climate regulation, and the provision of various ecosystem services, its unsustainable management and use, and destruction through various drivers of deforestation and forest degradation have rendered forest ecosystems and forest dependent populations less resilient/vulnerable to the negative impacts of climate change.

Africa (and in particular, West Africa), with its degraded and fragmented forest landscapes is, and is predicted to be the most hardest hit, if trends in global warming continue unabated. Our various countries are conscious of this problem and are committed and determined to undertake relevant adaptation and mitigation measures and to embark on, and transition towards low emission climate resilient development pathways. They are all signatories to various international conventions, including the United Nations Framework Convention on Climate Change (UNFCCC) whose mandate is to reduce/stabilize greenhouse gases (GHG) below critical values.

One of the mitigation measures advocated for by the UNFCCC is the incentive-based REDD+[28] mechanism, and countries are preparing national REDD+ strategies, building forest monitoring systems, engaging various stakeholders and assessing multiple ecosystem services, as part of the REDD+ Readiness process. The United Nations Collaborative Programme on REDD+ (UN-REDD Programme[29]) is supporting developing countries to undertake this readiness process. However, central to this mechanism, and also one of the most challenging, is the national forest monitoring, and the measurement, reporting and verification (M & MRV) aspects of REDD+ that will be useful in the results-based assessment of programme performance, for possible rewards to countries. Within the UN-REDD

[27] Food and Agriculture Organization of the UN, Regional Office, Accra.

[28] **R**educing **E**missions from **D**eforestation, and forest **D**egradation; and the role of conservation, sustainable management of forests, and enhancement of forest carbon stocks in developing countries.

[29] UN-REDD Programme builds on the convening power and expertise of its three UN Organizations: the Food and Agriculture Organization of the United Nations (FAO), the United Nations Development Programme (UNDP) and the United Nations Environment Programme (UNEP)

Programme, FAO is the Lead Agency for the implementation of this forest monitoring component of the programme. It has as main pillars, remote sensing and ground-based forest (carbon) inventories that require the use of allometric equations.

In effect, countries are required to comply with the IPCC good practices of TCCCA (Transparency, Consistency, Comparability, completeness and Accuracy) when reporting to UNFCCC through their national communications (NCs). We all know that most countries are still reporting using the default IPCC (Tier 1) values, which are less precise, less accurate and are subject to large uncertainties. Furthermore, most Country-carbon maps have also been produced (based on remote sensing analysis), but they only provide global biomass/carbon information and are not credible enough to be used for NC reporting. Countries are expected to progressively move to Tiers 2 and 3 (country or regional-based data) which are more precise, accurate and with reduced uncertainties.

Forest biomass/carbon stock estimations are an expensive, time-demanding and are scientifically and technically challenging undertakings. Not only does it require costly destructive sampling, but also expertise in statistical analysis and modelling. Fortunately, once the model is built, it can be applied to easily measurable forest parameters (obtained during inventories), without further destruction of the resources. These models known as Allometric equations, is the object of this regional workshop.

FAO, through its Forestry Department's Forest Resource Assessment and Management (FOM) Division and UN-REDD Programme have been working to enhance capacity building in allometric equations, including the production (with CIRAD and other institutions), the manual of allometric equations, the compilation of allometric equations databases, and undertaking of national and regional workshops in various countries and regions. The Regional technical workshop on allometric equations for West Africa is a continuum to previous ones undertaken in South East Asia and Latin/South America. It is our hope that through the scientific presentations and experience sharing on the development and use of allometric equations we can establish a solid network of expertise in this area, and push the climate change agenda for West Africa forward.

Thank you

11. References

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