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

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

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

The programme is implemented through the UN Joint Programmes modalities, enabling rapid initiation of programme implementation and channelling 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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Contents

1. Introduction and objectives

M. Henry[1]

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

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

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

Spatial and temporal variation in above-ground carbon is the largest source of uncertainty in measuring forest carbon change factors (Angelsen, 2008, Pelletier, *et al*., 2011). Changes in forest carbon, or emission factors, are defined either as the average emission rate of a given GHG for a given source, relative to units of activity, or the average carbon stock increase, in the case of net removals. Estimations of emissions and removals can be obtained in different ways. Therefore, the IPCC has

classified the methodological approaches in three different 'Tiers', which vary according to the growing quantity of necessary information and the degree of analytical complexity (IPCC,2003, IPCC,2006). While Tier 1 is the basic method and can be implemented using the default emission factors provided in the IPCC Emission Factor database , Tier 2 and Tier 3, which are meant to be more accurate methods, use more country specific emission factor depending on the targeted accuracy and complexity of measurement processes and analyses. Allometric equations (AE) used to predict biomass from tree diameter are of great importance because estimates of biomass per area in inventory or calibration plots are estimated as the sum of individual tree biomass across all trees in a plot, and individual tree biomass is estimated from tree characteristics (e.g., trunk diameter, height, and wood specific gravity) using allometric equations.

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

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

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

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

2. Allometric equations: Scope and Applications

2.1 Manual for building tree volume and biomass allometric equations

Laurent Saint-André [2], Picard N., Henry M., Sola G.

Introduction

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

This manual has been designed in answer to a general knowledge deficit and the methodological issues associated with the development of allometric models for estimating tree volume and biomass. Scientists, students, forest engineers and managers as well as forest administrators are not all familiar with the most appropriate and up-to-date model fitting methodologies. R2 is still the most used indicator of the "goodness of fit" and for equation selection, and the biological meaning of the equations is often not taken into consideration.

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

Methodology

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

Results

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

Discussion

The advantage of the manual is that it will provide an exhaustive knowledge on allometric model development, integrating biological sciences with fieldwork experiences and statistical methodologies. The manual contains practical examples to guide and help the reader to acquire knowledge through practice. Although it has been designed for a wide range of users the manual

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does require some understanding of biology and mathematics that might make it not easily readable for politicians and decision makers. A 20 pages summary has been developed to give an overview of the manual main steps.

Conclusions and suggestions

By providing the necessary knowledge and practical examples to develop more robust models, forest volume and biomass estimates can be made more accurate, improving the forest carbon stock and carbon stock changes assessment. Further improvement of allometric equation development would be in a technical capacity, in order to better consider the variability of wood density within a tree - as an important explanatory variable of tree biomass. More generally, integrating approaches to tree allometry for biomass estimates (height-diameter relations, biomass expansion factors, etc.) would lead to a great improvement of forest carbon stock and carbon stock change assessment.

2.2 Tree allometric equation database for south Asia

S. Sandeep[3], M. Sivaram , M. Henry and L. Birigazzi

Introduction

Estimation of volume, biomass and carbon stocks support several applications from the commercial exploitation of timber to global carbon cycle. Especially in the latter context the estimation of tree biomass with sufficient accuracy is essential to determine annual changes of carbon stored in particular ecosystems. Such estimations are the core of carbon sequestration projects (sink projects) that deals with the accumulation and long-term storage of atmospheric carbon in vegetation and soil organic matter. These projects give a better understanding of nature's carbon sinks, and the valuable information and evidence generated therein will help addressing the physical, natural, social and economic aspects of climate change in a more factual way. Though large numbers of tree allometric models have been developed for volume, biomass and carbon stocks estimations in South Asia, their accessibility is very limited as they are mainly confined to scientific articles, reports from private companies and hard copies in institutional or national libraries. The development of new allometric equations is time consuming, laborious and involves destructive harvesting of trees. In order to provide accessibility and facilitate identification of gaps of existing tree allometric models to the national institutions and other stakeholders, it is important to inventory all existing volume and biomass allometric equations.

Methodology

The database has been prepared by extensive and exhaustive literature collected from the region by institutional visits, bibliographic databases and FAO reports. Nevertheless, there will be several lacunae which can be progressively corrected. The collected documents were deciphered into 74 variables grouped into 7 different categories:

1. Plant ecology (Population and Ecosystem)
2. Geographical location where the equation was developed or applied (Continent, Country, Biomes)
3. Equation parameters (variable characters and ranges)
4. Tree vegetation components (Bark, Root, Stump etc.)
5. Taxonomical description (Family – Genus- Species)

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6. Statistical Information (R^2, adjusted R^2, bias correction, RMSE and standard error of mean)
7. Bibliography

Results

The database covers a total of 466 documents on tree allometry (Table 1). 4456 equations on volume, biomass, BEF, carbon and other growth variables in South Asia for 375 species belonging to 96 families and 275 genera are included in the database. The proportion of equations contributed to the database by individual nations in South Asia varied as India > Bangladesh> Nepal > Sri Lanka> Pakistan> Bhutan. We couldn't find any tree allometric equation reports from Maldives. It should be noted that the database is a compilation of available literature and the proportional contributions may not have a bearing on the actual volume of work on tree allometry in these nations.

Table 1. Country wise literature covered in the database for tree allometric equations in South Asia

Country	Total documents collected		Documents covered in the database		Documents not covered for technical reasons	
	Number	%	Number	%	Number	%
Bangladesh	80	14.55	72	15.45	8	9.52
Bhutan	13	2.36	10	2.15	3	3.57
India	371	67.45	316	67.81	55	65.48
Nepal	40	7.27	32	6.87	8	9.52
Maldives	--	--	--	--	--	--
Pakistan	13	2.36	12	2.58	1	1.19
Sri Lanka	29	5.27	24	5.15	5	5.95
Others	4	0.73	0	0	4	4.76
Total	**550**	**100**	**466**	**100**	**84**	**100**

Discussion

The geographical distribution of these allometric equations is highly skewed and conscious efforts should be taken to unearth documents on allometry in the neglected life zones. Vague description of tree components and output terms reduces the quality of allometric equations developed in the region.

Proportionate allocation of allometric models for different species in the collected documents is not homogenous with commercially important ones capturing more percentage share of equations (Eg. Tectona grandis, Populus deltoides etc.). Given the high biodiversity within and among different life zones in South Asia, further scientific analysis of the allometric equations in the database is needed to derive more elaborate results. Efforts to develop allometric equations of neglected species (eg. Melanorrhoea usitata, Zizyphus mauritiana, Ficus benghalensis etc.) should be taken up for a comprehensive assessment of carbon stocks in the region. Though home gardens and trees outside forest contribute much to the vegetation, biomass and carbon storage, these ecosystems remain outside the purview of most tree allometric works .

Among the population, biomass estimates are available for many shrubs and seedlings. However, such estimates are not useful for extrapolation as they lack minimum statistical measures like standard error and thus not found place in the database developed here. Similarly, there are many stand level volume equations developed, most of them are of non-linear nature and hence conceiving a common database for carbon storage estimation appears to be a difficult task.

Conclusions and suggestions

Recently there has been a considerable interest in using site and species specific allometric equations for estimating volume, biomass and carbon stocks in the region. This should be capitalized and conscious efforts should be made so that the published database is used by researchers/ stakeholders for cost effective and accurate biomass, carbon and bioenergy estimations. A capacity building programme on international set of "good practice" guidelines focused on sampling methods, regression methods and inventorying allometric equations is quite essential to improve the quality of works and reporting procedures. It would also be important to periodically update the database so as to provide up-to-date information on tree allometry to all stake holders in the region. This can be achieved by encouraging researchers in the region to provide relevant information to the database as and when developed and by periodic literature surveys. A comprehensive repository of allometric works in South Asia will provide policy makers valuable inputs during REDD+ policy formulations in the region in tune with International standards.

2.3 Impact of tree allometric equations on forest carbon stock changes

M. Henry[4]

Introduction

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

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

Impact of selecting allometric equations on carbon stocks

Most current scientific papers compare the impact of allometric equations on carbon stocks. The differences obtained between allometric may be significant, sometimes of the order of 2 or 3. The calculation of forest carbon stocks then encountered a multitude of allometric equations and the need to draw on the expertise and identify scientific hypotheses to justify an approach. Depending

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on different land transition forms (deforestation, forest degradation etc.), allometric equations will results in different forest carbon stock changes.

Impact of selecting allometric equations on carbon stock changes

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

2.4 Status of forest biomass and carbon stock assessment in South Asia

M. Sivaram[5], S. Sandeep and M. Henry

Introduction

Biomass estimates are useful for the computation of carbon storage and biomass energy values. The forest biomass includes the aboveground and belowground living mass of trees, shrubs, palms, saplings, other understory components, vines, epiphytes, etc., and dead plant mass such as fine litter and wood (Brown, 1997). It is referred to as biomass density when expressed as mass per unit area e.g., tons per hectare. The total biomass for a region or country is obtained from the product of biomass density and the corresponding area of forests.

Methods aiming to estimate the biomass using non-destructive measurements of structural characteristics such as stem diameter and height are referred to as allometric approaches. There are broadly two types of approaches recognized in the literature (Brown, 1997).

Approach 1:

Biomass density can be calculated from volume over bark per hectare (VOB/ha) by first estimating the biomass of the inventoried volume and then "expanding" this value to take into account the biomass of the other aboveground components.

Above ground biomass density (t/ha) = VOB*WD*BEF

where WD=volume-weighted average wood density (oven-dry biomass per unit of green volume)

BEF=biomass expansion factor (ratio of aboveground oven-dry biomass of trees to oven-dry biomass of inventoried volume).

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Approach 2:

Another approach for the estimation of biomass density is derived from the application of biomass regression equations to stand tables. The method basically involves estimating the biomass per average tree of each diameter (diameter at breast height, dbh) class of the stand table, multiplying by the number of trees in the class, and summing across all classes. Biomass regression equations are also developed at tree level. In order to upscale biomass at various spatial scales, the allometric relations are calibrated using LIDAR data and remote sensing images.

South Asian Countries use Approach- 1 discussed above for biomass estimation. In this paper, the forest area, growing stock volume, BCF/BCEF, biomass and carbon in South Asia with reference to the years 2000, 2005 and 2010 have been reviewed. The review considers data quality, calibration, estimation and forecasting methods used to arrive at biomass and carbon estimation for the reference years.

Data Source

The major sources for the review are the country reports of Global Forest Resource Assessment (FRA)-2010 published by FAO (2010) based on the data officially submitted by the countries following the methods suggested by FAO/FRA. The countries were requested to provide the best possible estimates based on National Forest Inventory taking into consideration FAO/FRA categories and definitionsIf national BCF/BCEF is not available, the default BCEF values from IPCC 2006 Guidelines were used for the biomass estimation.

Results

Extent of Forest and Other Wooded Land

The review shows that the use of remote sensing in estimating forest area is not clear with respect to many countries. In order to estimate and forecast for the reference years, the linear extrapolation/interpolation was employed based on annual growth rate. Four out of seven countries viz., Bangladesh, Bhutan, Pakistan and Sri Lanka undertook calibration of forest area in order to comply with FAO/UN Land area statistics. In the case of Nepal, there was no mention about the calibration. With respect to Maldives, only one time information is available.

Growing stock

Growing stock estimates are mostly based on one time national level inventory/partial inventory/ Pre-investment survey/sub-national level working plans. India undertakes forest inventory at regular intervals. Some countries initiated or in the process of undertaking newest forest inventory.

Forest Biomass stock

The growing stock volume estimates available from National Forest Inventory along with BCF/BCEF following FRA 2010 /IPCC 2006/IPCC 2003 guidelines were used for biomass estimation. The BCF/BCEF values are also modified and applied to suit local conditions. In order to obtain biomass and carbon estimates for the reference years, linear extrapolation/interpolation was used with the available data.

Carbon stock

Most countries follow FRA 2010 /IPCC 2006/IPCC 2003 guidelines for converting biomass to carbon values. One or more carbon categories are not estimated in most countries. Carbon in dead wood was not estimated in Bangladesh, Pakistan, Sri Lanka and Bhutan. Soil carbon was not estimated in Bhutan and Nepal. There was no carbon estimates available for Maldives.

Conclusions and suggestions

The countries use the data of National Forest Inventory and other available reports to provide the best possible biomass and carbon estimates. With respect to some countries, the data used for the estimation and forecasting were outdated or related to only one time point. The region/country specific volume and biomass allometric equations, BCF/BCEF and biomass to carbon conversion factor need to be further developed for improving the current estimates. The country needs with respect to financial and technical support should be assessed and supported for periodic national forest inventory. The capacity building programmes on continuous basis would motivate to use the latest technologies and improve the precision of the estimates.

2.5 Data sharing agreements to support national activities and forest biomass assessment

A.Kumar [6]

Introduction

Forest ecosystems with their high complexities brings together errors of measurement, methodological changes related to technological progress, and changes in technical, human and financial capacity (Melson, *et al*.,2011). Data harmonization, whether by interpolation or extrapolation methods, and recalculation ensures consistency of measurements over time (IPCC,2006) but, if not appropriately done, affects measurement accuracy. Despite the earnest efforts of researchers' data collected by measurement campaigns are often lost due to lack of archiving capacities and often leads to work duplication. For successful assessment of forest resources and overcome financial constraints in developing and improving cumbersome allometric equations access to raw data, meta-data and documentation describing the method of data collection by different agencies is crucial. Moreover Principal 10 of the United Nations Declaration on Environment and Development (Rio de janeiro, June 1992), stated that"……….each individual shall have appropriate access to information concerning the environment that is held by public authorities ……. and the opportunity to participate in the decision making process. States shall facilitate and encourage public awareness and participation by making information widely available."

Data sharing involve routine sharing of data sets between organizations for an agreed purpose. It could also involve a group of organizations making an arrangement to 'pool' their data for specific purpose. Data-sharing is an important way to increase the ability of researchers, scientists and policy-makers to analyze and translate data into meaningful reports and knowledge. Sharing data discourages duplication of effort in data collection and encourages diverse thinking and collaboration, as others are able to use the data to answer questions that the initial data collectors may not have considered. Sharing data also encourages accountability and transparency, enabling researchers to validate one another's findings.

Need for data sharing

A data-sharing agreement is a formal contract that clearly documents what data are being shared and how the data can be used. It envisages a strong partnership with clear communication.

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It defines a clear process for sharing well defined contents. It further helps to:

- Reinforces open scientific inquiry.
- Encourages diversity of analysis and opinion.
- Promotes new research, tests alternate hypothesis and methods of analysis.
- Supports studies on data collection methods and measurement.
- Facilitates education of new researchers.
- Enables exploration of topics not envisioned by initial investigators.
- Permits creation of new datasets by combining data from multiple sources.

Types of Data Sets

1. **Open Access Data**

Open access to research data from public funding should be easy, timely, user-friendly and internet-based without any registration process.

2. **Registered Access**

Datasets which are accessible through a prescribed process of registration/authorization by the respective departments/organizations will be available to the recognized institutions/ organizations/ public users through defined procedures.

3. **Restricted Access**

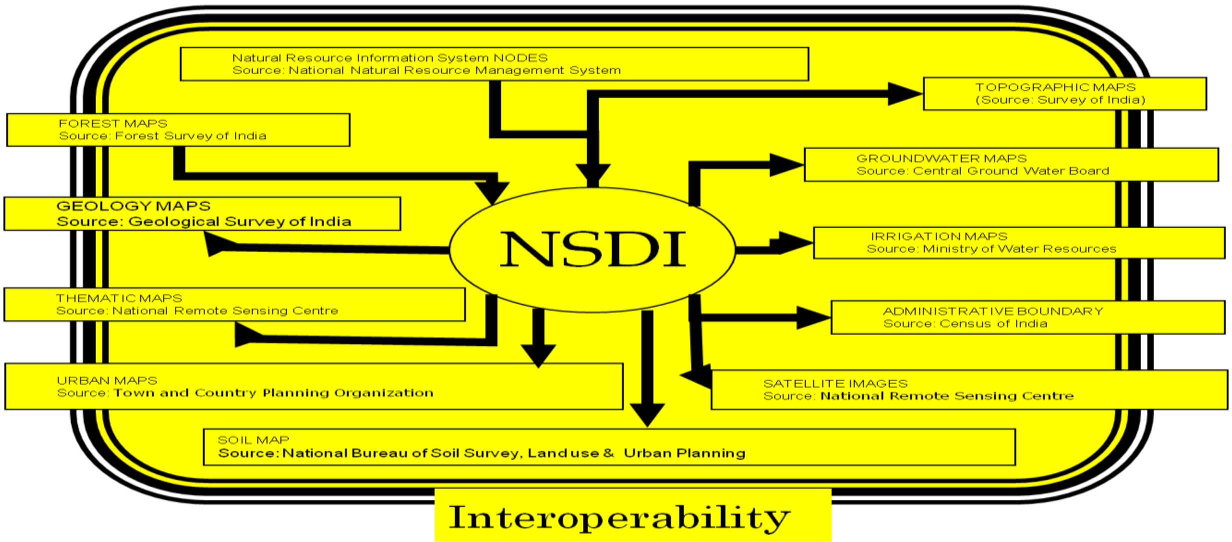
Data declared as restricted by the Government policies will be accessible only through and under authorization. The data users who are accessing/using this data for research should clearly acknowledge the ministry/department in all forms of publications.

Indian scenario

In India, Section 4(2) of the Right to Information Act, 2005 reads "It shall be a constant endeavor of every public authority to take steps in accordance with the requirements of clause (b) of sub-section (1) to provide as much information *suo motu* to the public at regular intervals through various means of communication, including internet, so that the public have minimum resort to the use of this Act to obtain information". Accordingly steps have been taken to share data between stakeholders:

National Spatial Data Infrastructure (NSPI)

Objective of NSPI is to develop a National Infrastructure to make current, accurate and organized geospatial data readily and continuously available at national, state, district and village level. It intends to provide a basis to the economic, environmental and social growth of the country. It also aims at encouraging collection, aggregation and distribution of spatial data on different themes on a common defined set of standard formats by different mapping agencies in India. National Spatial Data Infrastructure Framework is as follows



National Data Sharing and Accessibility policy (NDSAP)

NDSAP, 2012 aims to provide an enabling provision and platform for proactive and open access to the data generated by various Government of India entities. The objective of this policy is to facilitate access to Government of India owned shareable data (along with its usage information) in machine readable form through a wide area network all over the country in a periodically updatable manner, within the framework of various related policies, acts and rules of Government of India, thereby permitting a wider accessibility and usage by public. The Department of Science & Technology, Government of India is the nodal agency for coordination and monitoring of the policy.

Forest Survey of India (FSI)

FSI data sets are being used on a regular basis for allocation of coal blocks, clearance under Forest Conservation Act. Forest cover data was used to assess the extent of illegal mining in the country. Preparation of carbon maps and regular sharing of forest cover datasets during different training programs are regularly undertaken by FSI. FSI has also carried out inventory for Bhutan and Nepal including sharing of technical knowhow. Allometric equations developed by FSI for 160 sp. are in public domain and are being widely used by research organisations and academic institutions.

Benefits of data sharing

1. **Maximizing use**

Ready access to government data will encourage more extensive use of a valuable public resource for the benefit of the community.

2. **Avoiding duplication**

By sharing data the need for separate bodies to collect the same data will be avoided resulting in significant cost savings in data collection.

3. **Maximized integration**

By adopting common standards for the collection and transfer of data more integration of individual databases will be possible.

4. **Ownership**

The identification of owners for the principal data sets enable users to identify those responsible for implementing prioritized data collection programs and for developing data standards

5. **Better decision-making**

Quality information allows to make competent decisions. Avoiding large potential costs. Ready access to existing spatial data is essential for many decision making tasks such as protecting the environment, development planning, managing assets, improving living conditions, national security and controlling disasters.

6. **Equity of access**

A more open data transfer policy ensures better access by all bonafide users.

Conclusion

Data from multiple sources can often be combined to allow comparisons that cross national and departmental lines. The principles on which data sharing and accessibility need to be based include: openness, flexibility, transparency, legal conformity, protection of intellectual property, formal responsibility, professionalism, interoperability, quality, security, efficiency, accountability and sustainability.

3. Regional allometric equations and UN - REDD+

3.1 Forest carbon stock measurement to management in Bangladesh: perspective REDD+

M. Al-Amin[7]

Introduction

Bangladesh has a diverse range of forest ecosystems, including hill forest, freshwater swamp forests and mangroves. The major part of the hill forest of Bangladesh is situated in Chittagong, Cox's Bazar and Sylhet forest Division. Quantification of the organic carbon stock in the hill forest of Bangladesh is impossible without estimating organic carbon storage in these forest areas. Presently, very scanty information is available about the organic carbon storage in these forest areas. The present study is proposing a model of estimation of organic carbon of forest area considering the yield and age classes of the species.

Model

The following empirical organic carbon model used to measure carbon sequestered for any species in woodland

TOC = (TrC + LiC +SoC) x A…………………………..Model 1

where, TOC = Total organic carbon, TrC = Tree carbon stock, LiC = Litter carbon stock, SoC = Soil organic carbon stock up to 1 metre depth, A = Area.

The following models were developed to estimate TrCF, SoCF and LiCF:

Tr C = (AYC x Cm) = [{YCs + $E_{j\,k\,l}$} x Cm]……………………………Model 1a

where, AYC = Adjusted yield class, C m = Carbon stock from Willis-Price (W-P) carbon model (Price, 2001, pers. comm.), YCs = Yield classes of Pyatt (1977) and expert advice, E_{jkl}= Adjustment effects of j = altitude, k = slope, l = exposure to wind.

LiC = AYC x Lics…………………………………………Model 1b

where, Lics = Litter carbon stock with respect to yield classes (extracted from Dewar and Cannell, 1992).

SoC = $(SLOC)_{O\,A\,B\,C}$ x (TLOCS / MOCTL)…………………………Model 1c

where, SLOC = Total organic carbon stock in soil layers (O, A, B, C) of soil classes in the study area, O = 0 to 3 cm depth, A = 4 to 14 cm depth, B = 15 to 30 cm depth, C = 31 to 100 cm depth, TLOCS = Tree and litter carbon stock per hectare for a given species and yield class, MOCTL = Mean of tree and litter carbon stock per hectare for all yield classes concerned.

Finally, Model 1 stands in the following way for any species in woodland:

TOC= [{(YCs + E_{jkl}) x Cm} + (AYC x Lics) + $(SLOC)_{O\,A\,B\,C}$ x (TLOCS / MOCTL)}] x A

Limitation of the model

This is still a conceptual model with few tests. However, this model has a scope to improve applying real data and validation with field observation in Bangladesh.

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Conclusions and suggestions

There is no doubt that the allometric equations are the most easy and authentic way to estimate biomass or volume of tree. However, variables like yield class, species, age, site and exposures to hazard are necessary to consider during generating allometric equations. This will allow more precise estimation of the carbon content of the species and pave the way REDD+ concerns of the country.

3.2 Quantifying forest carbon stock in Bhutanese Forests

P. B Chhetri[8] and S. Katwal

Introduction

Estimation and quantification of biomass is useful in assessing the amount of food, fuel, fodder and fiber and in forest structure and conditions It is equally important for estimation of forest productivity, carbon fluxes and to estimate amount of carbon in wood, leaves etc. Its also useful as an indicator of ecological and economic values. The forest biomasses are often linked to understand the forest dynamics and in differentiating between different forest types. In recent years, the biomass density had been used for tracking cycle between atmosphere and terrestrial biosphere in relation to climate change. The change in biomass results in emission of carbon into the atmosphere when forests undergo certain transformation through deforestation and biomass burning and conversely carbon accumulation occurs in the biosphere.

Methodology

The Department of Forests and Park Services, Bhutan has adopted Randomised Branch Sampling (RBS) as a method to quantify carbon stock in Bhutanese forests. A Total of 2424 Cluster plots laid out in a grid network at the distance of 4 km across Bhutan for National Forest Inventory (NFI). Elbow Cluster Design consisting of three sub-plots is followed. Circular plots of 12.62m (0.05 ha)within which is a smaller circular plot of 3.27 m radius for regeneration is used and for soil assessments 1m X 1m plot is considered.

National Forest Inventory (NFI) and Biomass estimation status in Bhutan

A NFI has been initiated in Bhutan to assess the extent of forest cover in the country and is expected to generate much needed information on forests growing stock,. It does not directly assess the national carbon stock which is essential given Bhutan's commitment to be carbon neutral and the possible benefits that country can benefit through carbon market.

The current NFI activities and status is summarized below:

Activity	Status
Biomass Allometric equation development for 50 important species (Forest types??)	Field and laboratory manual developed for field implementation Two species field data collection
Adopted methodology for assessment of above ground carbon in shrubs, herbs, litter and soil **Bamboo**	Method tested Endorsed by the ministry. Crews Trained Bamboo manual developed
Pre-assessment tool **To develop the Database Management system**	Customized for Bhutan. Working with FAO to integrate NFI data system with OPEN-FORIS Collect
Continuous process of capacity building of the NFI crew and researcher	In-country training being given, seeking funding support for NFI and database management

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Conclusions

The carbon allocation within plant parts can be useful in determining species classification such as shade tolerant or shade intolerant. The international treaty/ convention such as Kyoto Protocol to which Bhutan is signatory requires reliable quantified amounts of carbon stock estimation through reliable scientific method. Presently these estimates are lacking in the country.

3.3 Volume & biomass functions for trees grown under arid conditions in India

V. P. Tewari[9]

Introduction

Volume equations are critical starting points if forest management is to be successful and efficient. Allometric equations for predicting total and merchantable volume play a critical and obvious role in the management of any silvicultural system, and their absence would represent an impediment in developing and implementing management plans geared towards the harvest and utilization of wood products. The importance of volume equations is indicated by the existence of numerous such equations and the constant search for their improvement. Equations that provide accurate predictions of volume without local bias over the entire range of diameter are one of the basic building blocks of a forest growth and yield simulation system. In this article, volume equations developed for the pure even-aged stands of *D. sissoo, E. camaldulensis* and *T. undulata* available in IGNP area of Rajasthan and *Acacia nilotica* and *E.* Hybrid planted in Gujarat have been described. Biomass equations for *Azadirechta India* planted in Gujarat are also reported.

Methodology

Data and field procedure

Thirty sample plots of *D. sissoo*, 35 of *E. camaldulensis* and 22 of *T. undulata* were laid out in the IGNP area of Rajasthan, and 34 sample plots of *E.* hybrid, 22 of *A. nilotica* and 6 of *A. indica* were laid out in Gujarat. The plot size was approx. 0.1 ha and data included a record of age (A), dominant stand height (H), quadratic mean diameter (D_g), stems/ha (N), basal area/ha (BA) etc.

All the trees within the sample plots were measured for diameter at breast height (D) and total tree height (H). Then in each plot trees were stratified into different diameter classes. A sub-sample of trees was felled from the surround of each of the plots representing different diameter classes within the particular plot. These were then measured for D, H and wood volumes. Green weights of stem-wood, branches and leaves and twigs were taken for *A. indica*. A total of 71 sample trees of *D. sissoo*, 91 of *E. camaldulensis* and 75 of *T. undulata* were felled from different plantations in IGNP area of Rajasthan.

Similarly, 160 trees of *E.* hybrid, 80 of *A. nilotica* and 30 of *A. indica* were felled in Gujarat for constructing volume/biomass equations.

The volume was then calculated by dividing the stem and branches into logs of 3m length, measuring the mid-diameters and applying Huber's formula ($V=\pi D^2 L/4$) to estimate individual log volumes. For estimating under-bark volume, the bark thickness at dbh was measured with a bark gauge on one side which was multiplied by 2 and subtracted from the dbh (over-bark) to arrive at the value of dbh inside the bark.

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For biomass, the leaves and twigs were also separated. The green weights of each component were measured in the field. Small representative samples of wood from both the ends of each log and leaves and twigs were collected and their green weights were recorded. Oven dry weights were determined for these samples in the laboratory. Based on these two sample weights, dry weights for each tree were calculated.

Volume equations

The data were divided into two sets by random sampling. The first data set contained 70% of the observations and was used for fitting the volume equations while the latter contained the remaining data and was used for validation.

Model fitting and validation

Linear and non-linear equations were used to model the relationship of total volume with dbh, and total height. A total of 10 volume equations were selected from the literature based on their wide application. To reduce heteroscedasticity in the error structure of volume estimation and to avoid the consequences of violating the distributional assumptions, weighted least squares regression was applied for fitting the multiple linear equations. The bias (B), root mean squared error (RMSE) and the adjusted coefficient of determination (R^2_{adj}) were used to determine the quality of fit:

Bias: $B = \sum_{i=1}^{n} \frac{(y_i - \hat{y}_i)}{n}$

Root mean squared error: RMSE= $\sqrt{\sum_{i=1}^{n} \frac{(y_i - \hat{y}_i)^2}{n-p}}$

Adjusted coefficient of determination: $R^2_{adj} = 1 - \frac{n-1}{n-p} \sum_{i=1}^{n} \frac{(y_i - \hat{y}_i)^2}{(y_i - \bar{y}_i)^2}$

Biomass function

The data from the destructive sampling of *A. indica* trees were used to find allometric relationship for biomass as a function of D and H. Step-wise regression using SPSS package was fitted on the data to select independent variables on the basis of increasing values of F. Best models were selected on the basis of significance of partial regression coefficients at the P-0.05 level, highest F-value, high R^2 and low standard error of estimate (SEE).

Results and Discussion

Total wood volume equations

The equation which performed best in the fitting phase did not perform well during model validation. This emphasises the importance and need of validating a model prior to its use. Hence, based on high R^2 value and low RMSE, a ranking was assigned to all the equations during fitting as well as validation phase. The ranks were then combined and best ranked equation was selected for estimating volume of the particular species. T finally selected single- and double entry volume equations for different species are given below:

E. camaldulensis

$V = 0.000169*D^{2.41298}$ Adj. $R^2 = 0.995$; RMSE = 0.02922

$V = -0.00226 + 0.0000333\ D^2H$ Adj. $R^2 = 0.990$; RMSE = 0.00001

D. sissoo

$V = 0.01328 – 0.00538\ D + 0.000760\ D^2$ Adj. R^2 = 0.961; RMSE = 0.00005

$V = -0.0023 + 0.0000364\ D^2H$ Adj. R^2 = 0.992; RMSE = 0.00006

T. undulata

$V = 0.000088\ D^{2.381398}$ Adj. R^2 = 0.918; RMSE = 0.00803

$V = 0.000066\ D^{2.100121}H^{0.553696}$ Adj. R^2 = 0.924; RMSE = 0.00772

E. hybrid

$V = 0.000076*D^{2.761477}$ Adj. R^2 = 0.978, RMSE = 0.02844

$V = 0.000014*D^{2.141947}H^{1.168588}$ Adj. R^2 = 0.989, RMSE = 0.02054

A. nilotica

$V = 0.000071*D^{2.735778}$ Adj. R^2 = 0.975, RMSE = 0.03015

$V = 0.000018*D^{2.363677}H^{0.938962}$ Adj. R^2 = 0.983, RMSE = 0.02512

where, V is the total wood volumes (m^3) over-bark, D is the dbh (cm) and H is the total tree height (m).

Biomass equations

The green and dry weights of total biomass (stem+branches+leaves+twigs), total wood (stem+branches), stem wood, branch wood, bark and leaves and twigs were regressed on D and H to give the biomass equations for *A. indica*. The equations obtained for various parts of the trees are as follows:

Green weight equations (over-bark):

$Stem=9.61+0.024* D^2H$

$Branch=-0.744+0.692*D^2-0.93* DH$

$Total\ wood=-20.687+0.047* D^2H$

$Leaves\ \&\ twigs=-5.371+0.233*D^2$

$Total\ biomass=1.409+1.382*D^2-1.219* DH$

Dry weight equations (over-bark):

$Stem=5.923+0.017* D^2H$

$Branch=-1.394+0.477*D^2-0.638* DH$

$Total\ wood=8.69+0.036* D^2H-0.36*H^2$

$Leaves\ \&\ twigs=-3.744+0.1.6*D^2$

$Total\ biomass=-13.41+0.04*D^2H$

Green weight equations (under-bark):

$Stem=4.818+0.021* D^2H$

$Branch=-43.027+0.247*D^2$

$Total\ wood=44.789-10.749*D+0.798* D^2$

Dry weight equations (under-bark):

$Stem=3.348+0.015* D^2H$

$Branch=-31.354+0.178*D^2$

$Total\ wood=-12.651+0.026* D^2H$

Bark biomass equations:

$Green=-3.601+0.009* D^2H$

$Dry=-2.719+0.006* D^2H$

Conclusions and suggestions

The equations tested in the study fitted the observed data well. Single-entry and double-entry total wood volume equations have been constructed and validated for *D. sissoo, E. camaldulensis*, *T. undulata*, *A. nilotica* and *E.* Hybrid. These assume importance in projecting the total volume at different stages (thinnings and final harvest) as the plantations mature. Volume equations proposed may be applied on any population of these species available in the study area or in the areas having similar growing conditions. Also, total and component-wise biomass equations are presented for *A. indica*. The volume and biomass equations are extremely useful in estimating above-ground carbon stock and in preparation of carbon tables. The resulting equations should apply only to the region where sample plots were laid out for data collection. The equations could be used more widely, though with caution.

3.4 Use of tree allometric equations for National forest Biomass assessment in India

P. Lakhchaura[10]

Introduction

A robust and verifiable measure of carbon stocks and emissions is termed as carbon accounting. Though the assessment of different parameters of forests have been done for centuries, carbon accounting has gained importance in the recent past due to the role of forests in climate change. This necessitates the growing need to quantify the stocks, sources and sinks of carbon in the context of anthropogenic impacts of climate change.

Methodology

Carbon pools in India are assessed with respect to living biomass (above and below ground biomass), dead organic matter (dead wood and litter) and soil organic carbon. Based on physiography, climate and vegetation India is divided into 14 physiographic zones. From these 14 zones, 60 districts are randomly selected for inventory in a two year cycle. Districts are further divided into grids of 2½ ' X 2½' . Each grid of 2½ ' X 2½' are divided into four sub-grids of 1¼' × 1¼'. From these sub grids two sample plots are randomly selected and thereafter, every alternate 1¼'X 1¼' grid is systematically selected to form two systematic samples. At center of the selected 1¼'X 1¼' sub grid, sample plots of 0.1 ha are laid out. dbh of all tree over 10 cm recorded, litter and soil sample collected, regeneration status, bamboo, land use, legal status, crop composition, etc are recorded. Inconsistency check of sample data is done through software and then processed for generating different estimates

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Preparation of volume tables / equations

Functional / statistical relationship of tree volume with diameter, height and form factor is given as

V = f (D,H,F), where

D= tree diameter at breast height which is again a function of species, density of the crop and site quality where tree is growing; H = tree height and F= form factor are also affected by the factors like diameter stated above.

For preparing allometric equations / volume tables the following concepts are useful:

- Select trees of a species covering wide diameter range (say lowest 5 cm to highest the chosen species generally attain)
- Convert standing trees into logs by felling or otherwise
- Measure log's length and diameter to calculate their volumes
- Measure volume of branch wood
- Fit the best fit line with the data
- Test check/validate the developed Volume equations
- The developed equation should be simple preferably with easily measured dimension (diameter)

Use of volume/allometric equations in India

Allometric equations developed in India are used mainly for assessing

- Quantity of wood contained in the tree
- Prediction of future yield
- Estimate increment
- Estimation of biomass and
- Estimation of carbon stock

Volume equation with India

More than 750 volume equations of 194 tree species have been developed and are used for estimation of growing stock. In FSI these volume equations are based on measurement of trees above 10 cm dbh and exclude volume of main stem below 10 cm and branch wood below 5 cm diameter.

Components of Forest Biomass (Not measured in NFI)

- Biomass of stem below 10 cm dia, branches below 5 cm, foliage etc of NFI trees
- Biomass of all tress below 10 cm dbh,
- Biomass of Shrubs, herbs, climbers etc.
- Biomass of dead wood
- Litter (branches only)
- Biomass of tree bark
- Below ground root biomass

Future work in Allometric equations

Future allometric works in India should concentrate on

- Validation of biomass equations
- Developing more equations for Trees Outside Forests and
- Develop equations for below ground biomass

3.5 Basal Area and Diameter Increment in Long Term Research Sites In Tropical Forests of India

S. N. Rai[11]

Introduction

Some of the oldest Long Term Research Sites (LTRS) in the tropical forests of the world, perhaps exist in India. These sites have different names: Linear Tree Increment Plot, Linear Increment Plot, Linear Sample Plot or Permanent Preservation Plot. The common feature of all these plots is generally their linear shape and the object of their creation was to record periodic diameter or girth measurements of trees. In some sites only commercially important species were monitored, while most in most of them all trees above 10 cm diameter breast height (dbh) were measured. In some cases sites were also created observe the ecological and phenological aspects and to serve as a site for botanizing. In some of these sites trees had classification of crown sizes as Large, Medium and Small and were also categorized into dominance classes as Dominant, Co-dominant, Dominated and Suppressed. These were done to study the differential rates of diameter growth dependent upon crown and dominance classes.

The earliest LTRS were established in the West Coast region for *Hopea parviflora* in 1911. Subsequent to this, during 1930s, there were concerted efforts for establishing such sites in 2 main regions: in northern India in *Shorea robusta* forests of Uttara Khand, Uttar Pradesh, Bihar and West Bengal; and in southern Indian in Tropical Rain forests (TRF) of Karnataka, Tamil Nadu and Kerala. Later on during early 1959s in parts of Karnataka and in early 1980s in parts of Maharashtra more sites were created in Moist Deciduous and Dry Deciduous teak bearing forests, respectively. At present nearly 100 such LTRS exist in India and majority of them are in reasonably good shape, with the exception of Sandalwood plots, which have been practically destroyed.

Results and Discussion

Estimates of Basal Area in Tropical Forests of India

The estimates of Basal area for 93 LTRS has been made (Rai, 1996) as given in Table 1 below.

- The BA in TRF of Assam was 41.9 sq. m/ ha (average of 2 sites) and it was 44.5 sq m/ ha (average of 8 sites) in Karnataka. In Kerala, in the Silent valley area, the BA measured in 10 plots ranged between 40-80 sq m/ ha. In a typical forest in Wynad, Kerala, the BA was 42.8 sq m/ ha. In the Montane Hill forests in Karian Shola at Top slip in Tamil Nadu, it was 44.8 sq. m/ ha. In similar vegetation near Pune in Maharashtra, it was 50.3 sq m/ ha.
- In semi-evergreen forests of Karnataka, it was 35.5 sq m/ ha and in Maharashtra it was 35 .5 sq m/ ha. In another Shola forests at Ootacamund, the BA was 34.8 sq. m / ha.

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- In the Moist Deciduous *Shorea robusta* forests in Uttara Khand and Uttar Pradesh the average of 27 sites gave a BA of 34.5 sq m/ha (range was from 20.2 to 67.6). In West Bengal the average BA of 7 sites was 58.7 sq m/ ha (range was from 27.1 to 75.7).
- In the Moist Deciduous Teak forests of Karnataka, the average BA for 15 sites was 29.7 sq m/ha (range was 21.6 to 47.8).
- In a Non-teak Moist deciduous forest in Maharashtra, the Basal Area was 27.3 sq m/ ha.
- In Dry Deciduous *Shorea robusta* forests in Bihar, the average Basal Area was 27.0 sq m/ per ha.
- In Dry Deciduous teak forests of Maharashtra the average Basal Area for 5 sites was 12.6 sq m/ ha (range was 9.8 to 14.4).
- In Dry Deciduous forests dominated by *Lagerstroemia lanceolata*, *Terminalia tomentosa* and *Anogeissus latifolia* with less of teak the BA was 25 sq. m /ha.

Annual Basal Area Increment and Survival Pattern in Tropical Rain Forests

The rate of Basal Area increment over a period of 36 years for 95 species individually, and for the forest as a whole has been estimated as percentage increase per year (Rai 1983). Based on the habit of growth the species were classified into four categories namely: Pioneers, Canopy, Middle storey and Under storey. The rate of Basal Area Increment per year in these forests for the Pioneer species was 5.3%, Canopy species 3.22%, Middle storey species 2.02% and for Under storey species 1.87%. The overall rate of Basal Area increment for the 4 sites was 2.06 % per year and in terms of real increase it was 0.505 square meter per ha/ per year.

Rate of mortality among various species across the DBH class was also studied. As expected the pioneer species have quicker turn over and over a period of 36 years there was 47% mortality among them. The species which form the top canopy have longer life span; the rate of mortality among them was only 25% over the same period. As opposed to this, the rate of diameter growth and consequently the rate of Basal Area increment for the pioneer species were higher (5.3%) and it was relatively low for the top canopy species (3.22%).

Rate of Annual Diameter Increment

From the analysis of the data following results are reported. The study sites in moist teak zone can be distinguished in 3 different categories; Teak as a pre-dominant associate, teak as an associate and teak absent or rare. On analysis of data it was observed that there was no significant difference in rates of growth between the first two categories. However, variation in the rate of growth was observed depending upon the location of the site. Annual Diameter increment of 64 species is given in table 2. Some details are given below:

- Average annual diameter increment of *Dalbergia latifolia* ranged between 2.0 and 3.0 mm while that of *Xylia dolabriformis* ranged between 2.1 and 3.1 mm (Rai, 1978).
- The rate of diameter growth of *Hopea parviflora* in the West coast of India on alluvial soils was higher (12.5 mm per year) in the trees of 11 to 20 cm diameter class, however, the general rate of growth ranged between 2.9 to 5.7 mm per year (Rai, 1979).
- The rates of diameter growth of *Vitex altissima* and *Lannea coromandelica* which are representative of semi-evergreen forests but also occur sometimes on moist sites in Moist deciduous forests was studied (Rai 1979).

The rate of diameter increment of Sandalwood computed from the old available data gave an increment of around 2.7 cm/per year (Rai and Sarma, 1986). Maximum diameter increment was generally seen in the middle diameter range of 40 – 55 cm for most species.

Conclusions and suggestions

Estimates of Basal Area in Long Term Research Sites of Tropical Forests, Basal Area increment and pattern of mortality in Tropical Rain forests and rate of diameter growth in different forest types is given. Estimates of Basal area ranged around 43 sq m /ha in Tropical Rain Forests to around 30-35 sq m /ha in Moist Deciduous forests and around 13 sq m/ha in Dry Deciduous forests. The rate of Basal Area increment per year in Tropical rain Forests for the Pioneer species was 5.3%, Canopy species 3.22%, Middle storey species 2.02% and for Under storey species 1.87%. The overall rate of Basal Area increment was 2.06 % per year in TRFs of Western Ghats of India. The average rate of diameter increment for species in the Western Ghat ranged between 3 to 3.5 mm per year.

3.6 An overview of allometric equations used for biomass estimation in Nepal

H.B. Thapa[12]

Introduction

The forests have supplied fuel wood, fodder, poles, timber and many other products to meet the requirement of rural communities since long time. The demand of fuel wood, fodder and litter has been increased significantly due to increasing numbers of Forest User Groups (FUGs) in the country. In this context, allometric equations of different tree and NTFP species are necessary to quantify growing stock (biomass) in a particular area for better management of community forests (>18000 CFUGs) including government-managed and private forests.

At present, the biomass studies have been carried out not only for quantifying the fuel wood and fodder in a particular forest, but also for assessment of forest carbon stock. In consideration of forest carbon stock assessment, the biomass studies for tree stands and forest types in the country are equally important in future. Most of the biomass studies are concentrated on a single-tree species.

Involvement of organizations/individuals in biomass studies

Very few organizations and projects have been involved in biomass studies in Nepal since 1980s. The Department of Forest Research and Survey (DFRS) is the main government organization to carry out biomass studies to develop allometric equations in the country.

Types of allometric equations

Based on the available published and unpublished reports, 23 different allometric equations have been reported for 50 trees and NTFP species. In general, the logarithmic transformed model, Ln W=a'+b Ln DBH, was found to be developed for biomass estimation of stem wood, branch wood, foliage, and above-ground wood (green and oven-dry). The tree components used for developing equations differed greatly depending on the purpose of the studies. The three species, Cinnamomum tamala, Shorea robusta and Pinus roxburghii have allometric equations for bark. The equation, Ln (W) = a+b Ln (D2L) has been developed for estimation of foliage, branch and culms of four bamboo species (Bambusa nutans subsp. nutans, Bambusa nutans subsp. cupulata, Bambusa tulda and Dendrocalamus hookeri) in the Terai region of Nepal.

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Species used in allometric equations by physiographic region

Fifty species (tree, NTFP including four bamboo species) have been used for producing a number of allometric equations. Sixteen individual tree and bamboo species have been used in developing allometric equations in the Terai/Bhabar-Terai in Nepal. The biomass studies on three tree species, Ficus semicordata, Bauhinia variegata, and P. roxburghii, have been carried out in the Siwalik. The biomass studies of 34 trees and one NTFP species have been conducted in the Mid-hills of Nepal. P. roxburghii has been studied mostly (four times) in this zone. The biomass studies of two NTFP species, Daphne bholua and Daphne payracea, have been carried out in High Mountains.

Use of predictor variables in biomass studies

In most cases, diameter at breast height, DBH (cm), has been used as a predictor variable in allometric equations. In few cases, diameter at 30 cm for C. siamea, diameter at 50 cm for Bauhinia variegata, crown diameter and height for Ficus semicordata; crown diameter (m) for estimating oven dry pole of Leucaena leucocephala, basal diameter (cm) for estimation of branch (foliage plus branch wood), branch wood, branch bark, and foliage; mean branch length (m) in a whorl and number of branches in a whorl for estimation of whorl (foliage plus wood), whorl wood, whorl bark, and whorl foliage; diameter at breast height (cm), reciprocal of the height to the crown base and crown base diameter (cm) for estimation of total crown, crown wood, crown bark, and crown foliage; diameter at breast height (cm), total height (m) for tree, stem bole, bole wood, and bole bark of P. roxburghii, have been used as predictor variables.

Many researchers have given the causes of using DBH only as a predictor variable for biomass estimation of tree components. Some researchers agree on that allometric equations used for producing single-tree biomass tables to predict the weight of an individual tree from its diameter are reliable for undamaged trees of a number of species of Nepal.

Manuals for biomass studies in Nepal

The data collection procedures have not been clearly documented or reported in most of the studies conducted. There is no clear that how widely and greatly the good practices based on the earlier guidelines have been used in data collection, storing, processing and documentation.

Allometric equations developed since 1980s to 2014 (except Daphne spp.)

The allometric equations have been produced from 21 studies carried out by institutions, projects, and individuals during this period. It is found that 30 tree species have been used for biomass studies in 1980s, while 28 tree species have been used for biomass studies in 1990s. The number of species used in biomass studies is more or less the same in two decades i. e. from 1981 to 1990 and 1991 to 2000.

Allometric equations by green and oven dry weights

In general, allometric equations are produced for oven-dry weights rather than fresh weight, since the latter will vary due to differing moisture content within a tree, between trees of one species, with length of time after cutting and with sites and seasons. Thus, there is no question of importance of oven dry weight equations, however, the green weight allometric equations of different components of a number of tree and NTFP species are larger in number than that of the oven-dry allometric equations in Nepal. Out of 287 allometric equations developed for tree components, fresh stem wood, fresh branch wood and fresh foliage have dominated (143 equations, 49.8%), however only 64 oven dry weight equations (22.2%) have been developed for stem wood, branch wood, and foliage.

Conclusions and suggestions

There are a number of gaps and shortcoming in biomaas studies in Nepal. Destructive sampling is difficult due to the existing Forest Act and Rules of Government of Nepal (no authority to cut trees by researchers). At present, priority of the GoN for release of budget for biomass studies is very low. Obviously, it requires huge amount of money to carry out biomass studies at the national level. At present, coordination among the government, non-government, and Forestry Institutes is very poor in Nepal, so that very few biomass studies have been carried out. A number of biomass studies are based on small trees from a geographically restricted area, which means that the published allometric equations are of local importance only. Standard biomass allometric equations are to a great extent missing in Nepal. There are no allometric equations available for predicting the below-ground-components of tree biomass, i. e. stump and root biomass, based on the data collected by tree species in Nepal However, it is very much essential to estimate carbon stock in the forests of Nepal. Validations of the existing allometric equations are very few.

In the present scenario of carbon trade, both above- and below-ground biomass studies are essential for different species and forest types in five physiographic regions of Nepal. Such studies are very tough due to difficult terrain in the Hills and Mountains. Thus, it needs a concrete government plan and support to carry out biomass studies at the national level. Amendment in existing forest rules and regulations, strong coordination among the institutions (government, non-government and private), mechanism for availability of capable human resources, capacity enhancement and use of standard manuals are other major future priorities for biomass studies to be carried out throughout the country.

3.7 Attempts of modelling forest tree volume and biomass in Sri Lanka

S. M. C. U. P. Subasinghe[13]

Introduction

Forest ecosystems are capable of storing large quantities of carbon as biomass. It is a well known fact that tropical forest trees play a major role in the global carbon cycle by having large stores of carbon in their biomass. Therefore such biomass information can effectively be used to estimate carbon stock and energy content.

Methodology

in Sri Lanka, tree volume and biomass predictions have been done mainly using three different ways, i.e., (i.) using models specifically built for target species, (ii.) using models built for some other species which are different from the target species or target locations, and (iii.) using common or universal conversions of tree parameters to biomass. In addition, some studies were conducted using remote sensing for forest level biomass estimations. However, such studies are not common and also not found for tree level parameter estimations, especially the volume. The following sections describe the first three types mentioned above.

Results and Discussion

Use of models specifically built for target species

Allometric models have been built for most of the common forest plantation species growing in Sri Lanka for this purpose. Due to the lack of precisely re-measured growth data, the common method applied for data collection is the selection of even-aged plantations growing in a range of age classes.

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If there were significant differences of growth parameters due to geographical variations between the selected plantation sites, it was common to include the site quality parameters into those models to mimic the effect of the site variations. An example for such considerations while developing models for *Alstonia macrophylla* is as follows:

A. macrophylla is not a common plantation species in Sri Lanka. However, in the low country of the wet zone of the country, the Department of Forest Conservation and the private sector have established *A. macrophylla* plantations in minor scales mainly due to its faster growth rate and the high adoptability in growing in low nutrient areas. Using the logarithmic stem volume prediction model, two separate models (equations 18 and 19) were built for this species by Subasinghe in 2010). The author also developed GIS maps depicting the site variations for this species in Sri Lanka to cater the easy identification of both site types for the model users.

Site Class I: $\log v = -4.30 + 1.69 \log dbh + 1.18 \log h$

Site Class II: $\log v = -4.18 + 1.89 \log dbh + 0.897 \log h$

Use of models developed for other species

This method is common if species-specific models are not present for the target species and also, if accurate estimations are not required. However, the selection of such models should be based on the similarity of the target species with the species originally used for model construction to minimise the prediction errors. The similarity is based on the structure of the trees and geographical areas or both.

Use of common/universal conversions

Sustainable management of forest resources requires a large amount of supporting information. Especially when managing a forest for production of commercially valuable materials, estimation of present growth of variables which are not possible to measure easily (such as timber volume) and to estimate the growth values in future are essential. If such information is not available for the target species, the decisions have to be taken based on universally accepted norms. For example, CarbonFix Standards (http://www.carbonfix.info/) provides comprehensive details in calculating tree biomass and carbon contents. Their basic model structure is given in equation 21.

$$BM_{above\ ground} = v + BEF + \rho + C\ fraction + C\ to\ CO_2\ ratio$$

where: *BEF* = biomass expansion factor

ρ = wood density

C fraction = ratio of carbon to dry mass

The stem volume has to be estimated using existing growth models or using yield tables. If the density values are not available for the target species, CarbonFix Standards instructs the users to assume wood density as 0.3. It further assumes the ratio of carbon to dry mass as 0.5 and carbon to carbon dioxide ratio as 3.667.

Issues faced in modelling tree volume and biomass

There are contrasts between the data used for modelling and the data available for using the models, especially when these are included in decision-support systems (Amaro, *et al*., 2003). It is very important to define the data characteristics. Often the models are good, as are the decision tools, but the decisions may still not be as good as they should be due to lack of specific quality in the data.

Conclusions and suggestions

Modelling process should clearly be linked with the theoretical knowledge which allows to select the most important candidate variables, explanations of the model structures and estimated procedures. Parameter estimation is a dynamic task: reality is changing and the knowledge of the reality is also changing. All the priority research topics in this area have the same objective: reducing uncertainty in the ultimate model predictions.

3.8 Applications of tree allometric equations for National Forest Biomass assessment in Sri Lanka

W. A. C. Weragoda[14]

Introduction

Several categories of forest types have been identified in Sri Lanka by visual interpretation of satellite imagery. These forest types are Montane forests, Sub- montane forests, Lowland rain forests, Moist monsoon forests, dry monsoon forests, Riverine forests, Mangroves, Sparse forests and Forest plantations. Since the floristic composition and structure of these forest categories are varied each other, different equations have to be used to estimate the tree volume and biomass.

Status of forest inventory in Sri Lanka

A detailed forest inventory has been carried out in 1956 using aerial photographs. One of the objectives was to provide an estimate of the volume of merchantable timber by species and forest types. The total extent of forest was 2.87 million hectares which is 44 percent of the total land area. The merchantable volume of timber was estimated as 4,533,543,000 cubic feet in 1956. Another national forest inventory was carried out in 1982-85 by air photo interpretation and field inventory. According to this survey, the forest extent was 2.45 million hectares which covers 37.5 percent of the total land area and the total gross volume of the country was estimated as 73 million cubic meters. In 1993, an indicative inventory was designed to provide information on the potential supply of wood from allocated natural forests.

Since logging ban in natural forest was imposed in 1994, all natural forests were brought under conservation management. Therefore, there was no necessity to estimate tree biomass and merchantable tree volume of natural forests. However, volume functions have been developed to assess the timber volume of main commercial tree species such as Eucalyptus grandis, Eucalyptus macrocarpa, Eucalyptus microcorys, Pinus caribea and Tectona grandis. They are used for estimation of timber volume of commercial timber plantations. Since these functions have been developed to estimate merchantable timber volume only, there are limitations to use them to estimate total tree biomass.

Conclusions and suggestions

The present situation of forest categories could be identified by analyzing the recent aerial photographs and satellite imageries and thereby the tree volume or biomass could be estimated using newly developed allometric equations.

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4. Recent advances in tree allometric equations

4.1 Carbon stocks, stock changes and accuracy assessment- the importance of forest stratification

R. D. Jakati[15]

Introduction

Forests play an important role in mitigating the adverse effects of climate change by absorbing carbon dioxide from atmosphere. Deforestation and degradation, however, release carbon dioxide increasing its concentration in atmosphere. It is reported that if the average temperature goes up by more than 2.5 degrees the forestry system instead of remaining the 'sink' will become a 'source'. It is, therefore, the responsibility of all stake holders of forestry systems to prevent deforestation, and degradation and maximise carbon sequestration to mitigate the effects of climate change through various management options available. Knowledge of carbon stocks and their changes over time will, therefore, be one of the important forest management requirements under the climate change paradigm. Although wood / biomass oriented forest management is over a century old its association with carbon *per se* is of very recent origin. Many dimensions of carbon sequestration by different forest types under different silvicultural systems and management regimes are yet to be studied. These studies become important under REDD+ programs where not only carbon stocks are to be enhanced but the biodiversity conservation also is to be taken care of.

Methodology

In India, FSI has been carrying out National Forest Inventory since 2002. The basic objective has been to collect the quantitative information of the forest resources of the country. Two 0.1 ha plots are laid out in a grid of 2.5'X2.5'.Growing stock information by species is collected. Volumetric equations of different species in different regions have been evolved through the data collected during this exercise. For getting the carbon stock data by different pools additional studies on assessing the dead wood and leaf litter were undertaken. For assessing the soil organic carbon soil samples were collected and analysed in the laboratories. For the underground biomass default values recommended by IPCC were used.

The data of sample plots falling in different forest types was analysed separately by the three forest canopy density classes (very dense forest-canopy density more than 0.7; moderately dense forest – canopy density 0.4-0.7; and open forest- canopy density 0.1 -0.4) for compiling the carbon stock information.

A forest type represents a definite crop composition within a range of environmental parameters thus representing a different ecological zone. Reporting the carbon stock information by forest types and canopy density classes thus has a better ecological sense than reporting the same by manmade district boundaries.

Results and Discussion

1. The growth of carbon stock with canopy density is different for different forest types and even in the same forest type it is different for different canopy densities. For example the carbon stock builds up very rapidly as the canopy density increases from open to moderately dense forest in case of tropical dry deciduous forests but its growth is less when the canopy density increases from moderately dense to very dense forest. However, in case of subtropical pine

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forest and semi evergreen forests of western ghats the carbon stock builds up slowly in going from open to moderately dense forest category but its growth is more when the canopy density increases from moderately dense to very dense category. These differences become important in deciding the afforestation priorities, for immediate optimum gain, of different forest types and the canopy densities as indicated in the table above.

2. Afforestation of open category of tropical dry deciduous forests is more important, for gain in carbon stock than, afforestation of open moist deciduous forests. These two forest types comprise 42 and 19 percent of the total forest area of the country.
3. The difference in the growth of carbon in different forest types and in the same within the forest type with canopy density may probably be due to interaction of soil moisture content and the temperature which may change with canopy closure.
4. It may be noted that the above curves are drawn with canopy density on x axis and carbon stock on y axis. The time taken to reach different canopy densities and the corresponding carbon stock in different carbon pools may be different for different forest types and cannot be read from these graphs. Separate studies are required to do this.
5. The soil carbon content in all the forest types is substantial compared to the general perception of foresters. It is 40-70 percent of the total carbon content and is as high as the carbon content of the above ground biomass. Within the same forest type the percentage of the soil carbon is more in the lower canopy density. This probably is because of the fact that the soil carbon changes are much slower compared to canopy density changes. The carbon content changes more rapidly with canopy density in tropical dry deciduous forests than in the temperate forests. This may probably be due to the lower rate of carbon release at lower temperature.

Conclusions and suggestions

Given the present climate-change scenario it appears certain that future forest management plans may require being carbon centric with better understanding of crop composition on the part of forest manager. The carbon stock of compartments, the smallest unit of management generally having uniform crop composition, and that of working circles will have to be monitored periodically at the time of every revision of the management plan. The FSI carbon stock data is good for estimation of the stock at national level. Within the same forest type group there may be lot of variation in the carbon stocking depending upon the site quality and other locality factors at different locations. In their submission to UNFCCC Government of India has accepted that by 2017 the sub national level carbon stock information at State and District level will have +_ 20% accuracy. This commitment calls for greater effort on capacity building of the state forestry personnel in updating their knowledge and skills with regard to carbon stock assessment and efforts to reorient management perspective.

4.2 Error propagation in biomass assessment

M. Sivaram[16], S. Sandeep, M. Henry

Introduction

Error is the difference between reality and representation of reality. In statistical jargons, it is the absolute difference between observed and estimated value. The statistical error is also called as

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uncertainty. The error propagation is the effect of variables' errors on the uncertainty of a function based on them.

Error sources

The forest biomass estimation involves measurements using variety of techniques ranging from simple measuring tape to satellite imageries in a hierarchical fashion. The total error in biomass estimates is the sum of errors in its nested sub components. The sources of error in biomass estimates include:

i) Tree level measurements (dbh, height and wood specific gravity),

ii) Choice of an allometric model (in relating height and diameter, the wood-specific gravity (WSG) with taxonomic information and in relating predicted height and predicted WSG to above ground biomass).

iii) Sampling uncertainty: related to the plot size and number of plots and its geographical representation.

iv) LIDAR and satellite imageries.

Conclusions and suggestions

1. Growing stock volume is converted into biomass using BCEFs. The most of the volume equations used for growing stock volume are old and very few equations are developed in the recent past.
2. Tree diversity in tropical forests is very rich. Thus, representativeness of a network of plots across vast diverse forest tropical landscape has been a difficult issue to resolve with the limited resources. Often trade-off is made between the accuracy and resource constraints.

In south Asia, the standard errors of co-efficient of regression equations and R^2 are often taken as indicators for the quality of the biomass equations and biomass estimates. The literature dealing with error quantification of biomass estimates are scarce. Monte Carlo analysis, Pseudo-meta-analysis and Bayesian model averaging have been explored as potential techniques in to tackle the issues of error propagation. Among these Bayesian model averaging seems to be a promising technique .

1. It is suggested to update the existing database of tree volume and biomass allometric equations developed for South Asia by Kerala Forest Research Institute with the support of FAO and undertake Meta analysis for further research.

5. Tree allometric equations: Gaps and mitigation strategies in South Asia

Allometry, generally relates some non-easy to measure tree characteristics from easily collected data such as dbh (diameter at breast height), total height, or tree age and provides relatively accurate estimates. Models for volume, biomass or nutrient content within the trees belong to the same class as methodologies for sampling trees and fitting and using the equations are similar (Picard *et al*, 2012). Despite their apparent simplicity, these models have to be built carefully, using the latest regression techniques. Tree growth parameters varies considerably with species, site quality, location, climatic regimes, altitude etc. and therefore becomes necessary to obtain accurate and precise tree allometric estimates in order to improve understanding of the role of these carbon sinks in global carbon cycle. An unsuitable application of allometric equation may lead to considerable bias in carbon stocks estimations (Henry, 2013).

In the recent past carbon sequestration has received particular attention in South Asia due to global initiatives on climate change and realization of potentials of tropical forests to attract financial resources under Clean Development Mechanisms (CDM) of Kyoto Protocol. Though the market for CDM sinks were limited in the first commitment period of Kyoto, 2008 -12, a huge potential is envisaged for afforestation and reforestation activities in developing countries beyond 2012 (De Koning *et al*., 2005). South Asia with a sizable proportion of tropical forests can harness a good proportion of these global initiatives.

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

Gaps and limitations in knowledge of allometric equations in South Asia

Limitations in the knowledge and use of allometric equations were outlined by the experts participating in the workshop. Being a high diversity region limitations were imposed by the ecosystems themselves while others are linked to methodological or technical issues (lack of biomass expansion factors, limited root:shoot ratios, limitations with wood density, etc.).

Species specific allometric equations

South Asia is a high plant biodiversity area both in number and types of plants. However, majority of the allometric equations developed in the region were for tree populations. Tree populations were followed by stand and shrubs in the number of equations developed in each country. Plantation species such as *Tectona grandis, Populus deltoids, Dalbergia sissoo, Shorea robusta* and *Acacia auriculiformis* has been a top priority for all allometric works in the region. Most of these equations were developed for facilitating extraction/ utilization forestry and in the process non - commercial tree species in natural forests got neglected . Very few equations are also available for trees outside forests (TOF) and hence their quantification in terms of volume, biomass or carbon stocks poses serious problems. Though the coastal lines of India, Bangladesh and Sri Lanka are blessed with a huge cache of mangrove tree species, these ecosystems remain outside the purview of most tree allometric works in the region.

Output parameters

Most available equations focus on tree volume and not necessarily on biomass, and it is not accurate to assess biomass using volume tables or functions. Lack of biomass expansion factors for most species hampers the prospects of using an alternate method for biomass estimation. Though root biomass is as important as shoot in carbon stock estimations, there were very few studies on this aspect and its relation with above ground biomass. There is also a critical need to increase knowledge of how the vegetative components of a tree (*i.e.*, branches, foliage and roots) relate to total biomass. Wood density is another factor not known for all tree species, making inferences and extrapolations among species and within families complicated. Although wood density varies vertically and axially within trees and also responds to differing growth conditions, these differences are not considered when calculating tree biomass.

Skewed representation of ecological zones

There is high unevenness in the geographical distribution of equations developed across different biomes in South Asia. Most of the allometric equations developed in the region were for tree species in tropical rainforests followed by tropical shrubland. Tropical regimes like tropical moist deciduous forest, tropical dry forest and tropical mountain system were also found to have good number of allometric equations. Tropical desert, subtropical steppe and tropical and subtropical mountain systems with low species diversity have less number of allometric equations.

Error propagation

Error is the difference between reality and representation of reality. In statistical jargons, it is the absolute difference between observed and estimated value. The statistical error is also called as uncertainty. The forest biomass estimation involves measurements using variety of techniques ranging from simple measuring tape to satellite imageries in a hierarchical fashion. The total error in biomass estimates is the sum of errors in its nested sub components. In biomass estimation, the standard errors of co-efficient of regression equations (biomass equations) and $R^2$are often highlighted as indicators of quality. The studies on actual quantification of error and its propagation through different nested sub components of biomass are scarce. Monte Carlo analysis, Pseudo-meta-analysis and Bayesian model averaging have been suggested as potential techniques in dealing with the issues of error propagation. Among these Bayesian model averaging seems to be a promising technique .

Restrictions on felling

The development of new allometric equations is time consuming, laborious and involves destructive harvesting of trees. Moreover, felling is banned in many countries and there have been difficulties in obtaining permission to fell sample trees. This discourages the researchers to take up new studies related to developing volume and biomass allometric equations.

Data sharing

Though large numbers of tree allometric models have been developed for volume, biomass and carbon stocks estimations in South Asia, their accessibility is very limited as they are mainly confined to scientific articles, and hard copies in institutional or national libraries. Competition between institutions and individuals limits data exchange and transparency. Researchers are afraid to be excluded from publications resulting from the data they share. In the field of allometric equations, scientists fear that the data are used to develop new models with no real improvement over the original ones. Authors and data owners are afraid of not being able to use their data again if they share it. Formal data exchange agreements are missing to allow appropriate collaborations between research Institutions and national forest inventory holders. Though certain agencies in the region have taken bold initiatives to make all their documents available online, more inter - organizational collaborations and joint research ventures on tree allometry will help to pool the scientific resources (both human and financial) and prevent duplication of works. Developing standard language and elements of potential data sharing agreements would facilitate the exchange of data among researchers, potentially increasing the size of existing datasets and allowing for the construction of more robust allometric equations for a larger number of tree species.

Lack of technical expertise

New technologies for measuring tree volume and biomass non-destructively are being developed in the region. Though these land-based or airborne remote sensing technologies give information on allometry and decrease the amount of destructive measurements needed, these approaches are expensive for widespread implementation in developing countries, and require capacities that are not readily available.

Lack of proper networking

Exchange of knowledge among researchers and data users is needed to strengthen actions to build local and national initiatives to quantify volume and biomass. This will also help to develop common protocols for developing tree allometric equations and help researchers to gain up-to-date information on tree allometry to all stake holders in the region.

National capacities

Financial, Technical, cultural and human capacities may limit data collection, analysis, quality assurance, and sharing of allometric models. Many scientific articles include fees for publication. Not all scientists have the financial capacity to ensure publication of their work and many of the allometric equations are only reported in grey literature making them unavailable to a wider set of audience.

Mitigation strategies and way forward

Streamlining research on allometry

The research gaps in the region should be identified and addressed. The gaps should focus on neglected areas of tree allometry and should be in alignment with national objectives related to REDD+. As development of new models are time consuming and considering the tree felling ban in several of the countries in the region, tree allometric equation development and use can be prioritized as follows:

Case 1: Allometric equations and raw data are not available

In this case, it is preferable to use a generic equation with an interval of validity covering the tree dimensions measured during the forest inventory.

Case 2: Raw data are available

In this case, it is possible to develop a specific equation that considers the different forest types and/or floristic groups that were measured.

Case 3: No raw data but allometric equations are available

In this case, it is possible to simulate a pseudo-population from allometric equations where the sample sizes, the coefficient of determination, root mean square error, AIC, interval of validity of independent variables, and other indicators are indicated. Once the data are simulated, it can be used to develop a generic equation.

Case 4. Raw data and models are available

This is the most advanced case; it is possible to use a Bayesian method to develop a more general model or several models for different types of forests.

Inter institutional data sharing agreements

Inter institutional and inter regional agreements to share data on tree allometry should be promoted in South Asia under the aegis of lead organizations on tree allometry in the region or international organizations like FAO. In such arrangements it is crucial that data authorship, ownership and use of the data are clarified. Beyond the mechanics of data exchange a change in culture is needed among researchers such that data sharing and collaborations are actively sought. A joint initiative should be build up through frequent technical workshops, capacity building programmes and collaborative projects wherein free exchange of ideas and data will take place. Communication of results and publishing of newly developed methods and allometric equations should be encouraged to promote exchange and positive feedback among the scientific community. Even preliminary results should be shared during scientific meetings to increase the interest of additional developers and potential users.

Strengthening regional database

The regional database on tree allometric equations should be strengthened by updating it periodically. The database now available at www. globallometree.org should be broadened to include any left out documents and equations. Meta analysis of the database and ensuring its quality should be taken up on a priority basis. The database should be widened to store raw data and metadata for allometric equations. Such an arrangement will inturn allow management of data sharing among users.

Capacity building

Capacity building is an essential part to create efficient and skilled manpower on tree allometry in the region. New methods to assess forest biomass have a strong technological component. Transfer of knowledge should be considered a key point for improving biomass estimation as the biological and statistical concepts are difficult to understand. Countries should be supported in developing these capacity needs and to develop plans to cover all important areas of forest inventory.

Networking among researchers

It is crucial for scientists in the region to develop professional networks. Such networks can be national and regional and should facilitate interactions, exchange of knowledge and data, and promote research collaborations. Within and among networks, data and document repositories would provide tools for exchanging knowledge and expertise across the region.

6. Workshop conclusions and recommendations

The first Regional Technical Workshop on Tree Volume and Biomass Allometric Equations in South Asia, held at Kerala forest Resaerch Institute (KFRI), Kerala, India brought together 25 Researchers and Senior Foresters to identify gaps in knowledge and needs of information on tree volume and biomass allometric equations in South Asia. The workshop drew from experiences of expert participants to support development of guidelines, technical requirements and actions needed to assess volume, biomass and carbon stocks in South Asia.

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, both country wise and regionally, the challenges of using allometric equations as part of national biomass and carbon assessments were highlighted. Additional discussions focused on current and future methods to improve the construction of allometric models in the region.

Valuable interactions among researchers of multiple institutions and countries in the region was seen as a first step for future collaborations that will help consolidate the development of national and regional research programs to support volume, biomass and carbon quantification *in lieu* with international agreements. Failure to align the research priorities with national forest inventory demands would hamper the prospects of allometric equations developed in the region. There was wide agreement about the importance of this first workshop and the need for widening the network of technicians and policymakers as a means to evolve a strategy of research in allometry and its successful implementation in accordance with current international agreements.

Limitations imposed by the diverse ecosystems themselves in the region as well as methodological or technical issues were identified as roadblocks to future allometric equation development. The lack of formal data sharing mechanisms for exchanging relevant information among researchers within and among countries has led to duplication of works and limited exposure and dissemination of research works related to tree allometry. The workshop also offered an opportunity to evaluate current status of allometric development and use among countries in the region, and to anticipate future needs.

Given the high biodiversity within and among different life zones in South Asia, further scientific analysis (meta analysis) of the developed allometric equations is needed to derive more elaborate results. Studies should be taken up to improve the geospatial distribution of sample plots and thereby include under-represented biomes such as subtropical steppe and tropical desert in the South Asian region. Efforts to develop allometric equations of neglected species should be taken up for a comprehensive assessment of carbon stocks in the region. Though home gardens and trees outside forest contribute much to the vegetation, biomass and carbon storage, these ecosystems remain outside the purview of the most tree allometric works .

Since felling is banned in many countries, there have been difficulties in obtaining permission to fell sample trees. This discourages the researchers to take up new studies related to developing volume and biomass allometric equations. Moreover, most of the existing tree allometric estimates are not useful for extrapolation as they lack even minimum statistical measures like standard error. Lack of minimum publishing standards is another weakness in allometric reporting in the region. Vague description of tree components and output terms also reduces the quality of allometric equations developed in the region.

Recently there has been a considerable interest in using site and species specific allometric equations for estimating volume, biomass and carbon stocks in the region. Regardless of the new techniques we may employ in the future, participants highlighted the need for standardizing protocols used for constructing and reporting biomass equations both in terms of field sampling design and of model construction. A capacity building programme on international set of “good practice” guidelines focused on sampling methods, regression methods and inventorying allometric equations is quite essential to improve the quality of works and reporting procedures. A comprehensive repository of allometric works in South Asia should be developed and expanded which will provide policy makers valuable inputs during REDD+ policy formulations in the region in tune with International standards. Such an arrangement will also allow information sharing among users.

A unified carbon assessment mechanism (surveying and modeling protocols) comprising tree allometry, terrestrial carbon and bioclimatic parameters developed for South Asia will help countries in the region to assess and plan common strategies to conserve forest carbon stocks and manage forests sustainably. A co–ordinated network of researchers working on these aspects of plant biomass and carbon stocks could be established in the region to share information, avoid duplication of works and channelize the available resources to new avenues in an effort to fill the existing research gaps and design meaningful actions. Overall, this workshop provided a much needed opportunity to exchange experiences and knowledge among researchers and users of allometric equations in South Asia.

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