SAARC Training Workshop on Measurement and Estimation of Carbon Stock in Mangrove Forests of South Asia

November 19 – 24, 2011

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Abbreviations

AFOLU	Agriculture, Forestry and Other Land Use
AGB	Above Ground Biomass
ALM	Agricultural Land Management
ARR	Afforestation, Reforestation and Revegetation
ASTER	Advance Spaceborne Thermal Emission & Reflection
AVHRR	Advanced Very High Resolution Radiometer
AWG-LCA	Ado-hoc Working Group on Long term Cooperative Action
BA	Basal Area
BBD	Belowground Biomass Density (Mg ha^{-1})
BCEF	Biomass Conversion and Expansion Factors
BMV	Brasil Mata Viva
CAR	Climate Action Reserve
CCB	Climate, Community and Biodiversity
CCX	Chicago Climate Exchange
CDM	Clean Development Mechanism
CER	Certified Emission Reductions
CI	Confidence Interval
COP	Conference of Parties
CVS	Current Vegetation Survey
DBH	diameter at breast height
DCCF	Deputy Chief Conservator of Forests
DEM	Digital Elevation Model
EU ETS	European Union Emissions Trading Scheme
FCSI	Forest Carbon Standard International
FHM	Forest Health Monitoring
FIA	Forest Inventory and Analysis
GCF	Green Climate Fund
GEF	Global Environment Facility
GHG	Green House Gas
GIS	Geographic Information System
GOFC-GOLD	Global Observation of Forest and Land Cover Dynamics
GPS	Global Positioning System
IFM	Improved Forest Management
IPCC	Inter-governmental Panel on Climate Change
IRS	Indian Remote Sensing Satellite
LDC	Least Developed Countries
LULUCF	Land Use, Land Use Change and Forestry

MODIS	Moderate Resolution Imaging Spectroradiometer
MRV	Monitoring, Reporting and Verification
MSAVI	Modified Soil Adjusted Vegetation Index
NDVI	Normalized Difference Vegetation Index
NFI	National Forest Inventory
NGO	Non Governmental Organization
NIR	Near Infra Red
NZ ETS	New Zealand Emission Trading Scheme
OTC	over the counter
PES	Payments for Ecosystem Services
PKSF	Palli Karma-Sahayak Foundation
QMD	Quadratic Mean Piece Diametre
RED	Reducing Emissions from Deforestation
REDD	Reduction of Emission from Deforestation and Degradation
RMSE	Root Mean Square Error
RMUs	Removal Units
SAARC	South Asian Association for Regional Cooperation
SAR	Synthetic Aperture Radar
SE	Standard Error
SR	Simple Ratio
SRF	Sundarbans Reserve Forest
TM	Thematic Mapper
UNFCCC	United Nations Framework on Convention on Climate Change
VCS	Verified Carbon Standards
VCU	Voluntary Carbon Units
VER	voluntary emission reduction
WSG	wood specific gravity

ANNEXURES

ANNEXURE 1 : Data Forms for Carbon Assessment/Forest Inventory : **Plot Description**

ANNEXURE 2 : Data Forms for Carbon Assessment/Forest Inventory **: Understory & Canopy Cover** (Seeding, Herbaceous vegetation & large shrubs)

ANNEXURE 3 : Data Forms for Carbon Assessment/Forest Inventory **: Understory & Canopy Cover** (Sapling)

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ANNEXURE 7 : Data Forms for Carbon Assessment/Forest Inventory **(Destructive Harvest)**

(Bamboo)

ANNEXURE 8 : Data Forms for Carbon Assessment/Forest Inventory **(Destructive Harvest): Non Woody Palms**

ANNEXURE 9 : Data Forms for Carbon Assessment/Forest Inventory **(Destructive Harvest): Large Shrubs** (Crown diameter, height)

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ANNEXURE 11 : Data Forms for Carbon Assessment/Forest Inventory **(Destructive Harvest): Small Shrubs**

ANNEXURE 12 : Data Forms for Carbon Assessment/Forest Inventory **(Destructive Harvest): Seedlings**

List of Participants

Sl No.	Participants
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11	**Bangladesh:** Mr. S M Ahsanul Aziz, Deputy Director, Department of Environment, Bangladesh
12	**Bhutan :** Mrs. Sonam Choden, Forest Officer, Dept of Forests and Park Services, Ministry of Agriculture & Forests, Royal Government of Bhutan.
13	**India :** Dr. Rajiv Pandey, Scientist, Ministry of Environment and Forests, NewDelhi, Government of India.
14	**India :** Dr. Syed Ainul Hussain, Wildlife Institute of India, Dehradun.
15	**India :** Dr. Subrat Mukharjee, Field Director, Sundarban Tiger Reserve, West Bengal, Government of India.
16	**India :** Mr. Prakash Lakchaura, Deputy Director, Forest Survey of India, Dehradun, Government of India.

17	**Maldives:**	Mr. Hussain Faisal, Senior Forest Officer, Ministry of Fisheries & Agriculture, Republic of Maldives.
18	**Maldives:**	Mr. Ibrahim Fayaz, Agricultural Field Officer, Ministry of Fisheries & Agriculture, Republic of Maldives.
19	**Maldives:**	Mr. Ali Suaadh, Environmental Protection Agency.
20	**Pakistan:**	Mr. Taj Mohammad, Conservator of Forests Planning, Balochistan Forest and Wildlife Department, Quetta, Pakistan.
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23	**Sri Lanka:**	Mr. M.L Abdul Majeed, Colombo Regional Dy. Conservator of Forests
24	**Sri Lanka:**	Mr. K.T Premakantha, DFO Kurunegala District
25	**Sri Lanka:**	Mr. N. Ratnaweera, DFO Kegalle District

List of Trainers/Resource persons

Sl No.	Resource Persons
1	Mr. Ishtiaq Uddin Ahmad, Chief Conservator of Forests, Bangladesh
2	Dr. Fazle Rabbi Sadeq Ahmed, Climate Change Specialist, PKSF, Dhaka
3	Dr. A T M Emdad Hossain, Ex Divisional Officer, Soil Science Division, Bangladesh Forest Research Institute, Chittagong
4	Dr. Ram A Sharma, Deputy Chief of Party, Integrated Protected Area Co-management Project, Dhaka
5	Mr. Imran Ahmed, Deputy Conservator of Forests, Forest Management Wing, Dhaka
6	Mr. Zaheer Iqbal, Deputy Conservator of Forests, RIMS Unit, Dhaka
7	Dr. Sukumar Das, Ex Divisional Officer, Inventory Division, BFRI, Chittagong
8	Mr. Md. Towfiqul Islam, Assistant Conservator of Forests, Sundarban West Forest Division, Khulna
9	Mr. Md. Mizanur Rahman, MS student, Forestry and Wood Technology Discipline, Khulna University **(Field Training Assistant).**

SAARC Forestry Centre

1. Dr. Sangay Wangchuk, Director
2. Mr. Pasang Wangchen Norbu, Sustainable Forest Management Specialist
3. Mr. Ugyen Thinley, Inofrmaition & Knowledge Management Specialist


SAARC Training Workshop on Measurement and Estimation of Carbon Stock in Mangrove Forests of South Asia
19-24 November, 2011, Dhaka, Bangladesh
Bhutan and Bangladesh Forest Department

Key Note Address by the Chief Guest
By Mr. Md. Mesbah Ul Alam

Secretary, Ministry of Environment and Forest, Bangladesh
Bismillah-hir-rahmanir-rahim
Dr. Sangay Wangchuk, Director, SAARC Forestry Centre;
Mr. Md. Ali Kabir Haider, DCCF Education and Training
Participants and colleagues;
Distinguished guests;
Ladies and gentlemen;

Honorable Chairperson of the Inaugural session of the training workshop Mr. Md. Ali Kabir Haider, Deputy Chief Conservator of Forests, Education and Training Wing, Forest Department, Bangladesh,Honorable Special Guest Mr. Ishtiaq Uddin Ahmad, Chief Conservator of Forests, Forest Department, Bangladesh, Honorable Keynote speaker Dr. Sangay Wangchuk, Director, SAARC Forestry Centre, Bhutan,Distinguished Participants along with SAARC member countries, Representative from Electronic and print media, journalists, dear colleagues, distinguished guests, ladies and gentlemen;

Assalamualaikum and good morning,

Ladies and gentleman;

This is my immense pleasure to be here with you as chief guest in such an international training workshop on 'Measurement and Estimation of Carbon Stock in Mangrove Forests of South Asia'.

You know that mangrove forests grow in tropical and subtropical tidal zones and they are among one of the most productive and biologically important ecosystems in the world. Mangroves occur in Asia's south coast, throughout the Indian subcontinent, in all Southeast Asian countries and on islands in the Indian Ocean, Arabian Sea, Bay of Bengal, South China Sea and the pacific.

Within the SAARC region, mangroves are found in Bangladesh, India, Maldives, Pakistan and Sri lanka. In our country, Sundarbans is the largest single tract of natural mangrove forests in the world. Sundarban is a unique ecosystem of about 6017 sq. km. It has rich biodiversity. This is a landmark of ancient heritage of mythological and historical events that bestowed with magnificent scenic beauty for its internationally recognized wide mangrove variety both on land and water which led immense scientific, anthropological and archaeological interest.

Distinguished Guests;

Carbon dioxide is the major source of global warming. Forest degradation and deforestation is an important contributor to global warming. IPCC describes that out of total emission of greenhouse gases forest's contribution is about 20% through forest degradation and deforestation. On the other hand, forest itself is the victim of climate change impacts. Forests must be protected from deforestation and degradation if we want to reduce emissions to the levels needed to protect the planet against the worst and most expensive global warming impacts.

Distinguished Ladies and gentlemen;

Bangladesh is aggressively looking forward to access carbon markets. Despite the striking deforestation scenario, Bangladesh is endowed with natural resources of global standing. The Sundarbans Reserve Forest - the largest mangrove forest in the planet-is a World Heritage Site. The Government is committed to preserve the forest because the forest saves millions of people from natural disasters and supports the lives of millions of poor people with its resources. We are working to present this heritage forest to the world for carbon funding under REDD, REDD+ mechanism and voluntary carbon markets. Carbon stock of forests is needed if the carbon accounting is to be in accordance with the articles of the Kyoto Protocol.

Distinguished Participants;

This six days training workshop will create a new arena of best professional as well as experts working together on mangrove forest management and climate change in the SAARC region, effective network and contact developed knowledge, experience and technology shared. The participants from SAARC member countries will be trained in the techniques for measuring and estimating the carbon stock of mangrove forests and are able to take the lead role in estimating forest carbon stock of their respective countries. Common techniques for estimating carbon stocks for mangrove forests for use by the member states will be developed. So it's a valuable and potential training workshop.

In this regard, I would like to thank to the authority of SAARC Forestry centre for giving financial assistance in arranging such a training workshop in Bangladesh.

I believe through the arrangement of such an event the forest department will be honored with excellence.

I offer my heartfelt thanks to the organizer of the SAARC Training Workshop on Measurement and Estimation of Carbon Stock in Mangrove Forests of South Asia for their excellent initiative and wish this training programme a grand success.

Thank you so much again.

Allah hafez.

Welcome Note

Mr. Ishtiaq Uddin Ahmad
Chief Conservator of Forests, Bangladesh

Bismillah-hir-rahmanir-rahim
Mr. Mesbah Ul Alam, Secretary, Ministry of Environment and Forests;
Dr. Sangay Wangchuk, Director, SAARC Forestry Centre;
Mr. Md. Ali Kabir Haider, DCCF Education and Training
Participants and colleagues;
Distinguished guests;
Ladies and gentlemen;

Assalamualaikum and a very good morning.

On behalf of Bangladesh Forest Department, I welcome you all to the SAARC Training Workshop on Measurement and Estimation of Carbon Stock in Mangrove Forests of South Asia. Bangladesh Forest Department is proud of getting the opportunity to arrange such an auspicious event.

The ability to accurately and precisely measure the carbon stored and sequestered in forests is increasingly gaining global attention in recognition of the role forests have in the global carbon cycle, particularly with respect to mitigating carbon dioxide emissions. Changes in forest cover have been, and are currently, net sources of carbon dioxide, the main greenhouse gas (GHG), to the atmosphere.

Land-use change and forestry is one sector for which a national inventory of sources and sinks of GHGs must be developed. With reference to forests, the inventory must include estimates of carbon emissions and removals caused by changes in forest biomass stocks due to forest management, harvesting, plantation establishment, abandonment of lands that regrow to forests, and forest conversion to non-forest use. **All these changes imply that measurements of carbon in biomass stocks must be made.** Many of the Articles in the Kyoto Protocol on forestry refer to the emissions and removals as being real, measurable, and verifiable changes in carbon stocks. Carbon stock of forests is needed if the carbon accounting is to be in accordance with the articles of the Kyoto Protocol.

Since five of the Member States have mangrove forests, carbon accounting will not be complete for these five member States if measurement of carbon stock of mangrove forest is not taken into account.

Carbon inventory is a growing science. Upon successful completion, the participants of this training workshop will be benefitted both personally as well as nationally. The lessons learnt in this workshop may be disseminated through the participants to their fellows and thus help building capacity of their respective countries.

At the end I would like to thank SAARC Forestry Centre to choose Bangladesh for arranging the workshop. Our forest officials will try to give the best to the participants. I wish all the participants coming from different countries a nice and comfortable stay in Bangladesh and enjoy the hospitality. I wish every success of the workshop.

Thank you all.

REDD and Priorities in International Negotiations

By Fazle Rabbi Sadeque Ahmed, Phd
Climate Channge specialist, Palli Karma-Sahayak Foundation (PKSF)

Introduction: Deforestation and forest degradation, through agricultural expansion, conversion to pastureland, infrastructure development, destructive logging, fires etc., account for nearly 20% of global greenhouse gas emissions, more than the entire global transportation sector and second only to the energy sector. It is now clear that in order to constrain the impacts of climate change within limits that society will reasonably be able to tolerate, the global average temperatures must be stabilized within 2^0C. This will be practically impossible to achieve without reducing emissions from the forest sector, in addition to other mitigation actions1.

Reducing Emissions from Deforestation and Forest Degradation (REDD) is an effort to create a financial value for the carbon stored in forests, offering incentives for developing countries to reduce emissions from forested lands and invest in low-carbon paths to sustainable development. “REDD+” goes beyond deforestation and forest degradation, and includes the role of conservation, sustainable management of forests and enhancement of forest carbon stocks[1].

In 2005, Parties to the United Nations Framework Convention on Climate Change (UNFCCC) began discussions on the scope of REDD at the COP 11 (Conference of Parties) in Montreal in the year 2005[2]. Discussions were initially limited to reducing emissions from deforestation (RED), but expanded to include forest degradation (REDD). As part of the Bali Action Plan (BAP), the discussion broadened further in 2007 and the parties to the UNFCCC called for: “Policy approaches and positive incentives on issues relating to reducing emissions from deforestation and forest degradation in developing countries; and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries”[2]. Ado-hoc Working Group on Long term Cooperative Action (AWG-LCA) supposed to take decision on various aspect of REDD-plus in COP 15 in Copenhagen, Denmark. There was no COP decision about REDD-plus in Copenhagen. However, in Copenhagen Accord the following two notes were adopted[3]:

- “We recognize the crucial role of reducing emission from deforestation and forest degradation and the need to enhance removals of greenhouse gas emission by forests and agree on the need to provide positive incentives to such actions through the immediate establishment of a mechanism including REDD-plus, to enable the mobilization of financial resources from developed countries”.

- “We decide that the Copenhagen Green Climate Fund shall be established as an operating entity of the financial mechanism of the Convention to support projects, programme, policies and other activities in developing countries related to mitigation including REDD-plus, adaptation, capacity building, technology development and transfer”.

Decisions during COP16 (Cancun)

During COP 16 at Cancun, the following COP decisions were taken about REDD+[4]:

"*Affirming* that, in the context of the provision of adequate and predictable support to developing country Parties, Parties should collectively aim to slow, halt and reverse forest cover and carbon loss, in accordance with national circumstances, consistent with the ultimate objective of the Convention, as stated in Article 2,

Also affirming the need to promote broad country participation in all phases described in paragraph 73 below, including through the provision of support that takes into account existing capacities,

68. *Encourages* all Parties to find effective ways to reduce the human pressure on forests that results in greenhouse gas emissions, including actions to address drivers of deforestation;

69. *Affirms* that the implementation of the activities referred to in paragraph 70 below should be carried out in accordance with appendix I to this decision, and that the safeguards referred to in paragraph 2 of appendix I to this decision should be promoted and supported;

70. *Encourages* developing country Parties to contribute to mitigation actions in the forest sector by undertaking the following activities, as deemed appropriate by each Party and in accordance with their respective capabilities and national circumstances:

    (a) Reducing emissions from deforestation;

    (b) Reducing emissions from forest degradation;

    (c) Conservation of forest carbon stocks;

    (d) Sustainable management of forests;

    (e) Enhancement of forest carbon stocks;

71. *Requests* developing country Parties aiming to undertake the activities referred to in paragraph 70 above, in the context of the provision of adequate and predictable support, including financial resources and technical and technological support to developing country Parties, in accordance with national circumstances and respective capabilities, to develop the following elements:

    (a) A national strategy or action plan;

    (b) A national forest reference emission level and/or forest reference level6 or, if appropriate, as an interim measure, sub-national forest reference emission levels and/or forest reference levels, in accordance with national circumstances, and with provisions contained in decision 4/CP.15, and with any further elaboration of those provisions adopted by the Conference of the Parties;

(c) A robust and transparent national forest monitoring system for the monitoring and reporting of the activities referred to in paragraph 70 above, with, if appropriate, subnational monitoring and reporting as an interim measure,7 in accordance with national circumstances, and with the provisions contained in decision 4/CP.15, and with any further elaboration of those provisions agreed by the Conference of the Parties;

(d) A system for providing information on how the safeguards referred to in appendix I to this decision are being addressed and respected throughout the implementation of the activities referred to in paragraph 70 above, while respecting sovereignty;

72. *Also requests* developing country Parties, when developing and implementing their national strategies or action plans, to address, inter alia, the drivers of deforestation and forest degradation, land tenure issues, forest governance issues, gender considerations and the safeguards identified in paragraph 2 of appendix I to this decision, ensuring the full and effective participation of relevant stakeholders, inter alia indigenous peoples and local communities;

73. *Decides* that the activities undertaken by Parties referred to in paragraph 70 above should be implemented in phases, beginning with the development of national strategies or action plans, policies and measures, and capacity-building, followed by the implementation of national policies and measures and national strategies or action plans that could involve further capacity-building, technology development and transfer and results-based demonstration activities, and evolving into results-based actions that should be fully measured, reported and verified;

74. *Recognizes* that the implementation of the activities referred to in paragraph 70 above, including the choice of a starting phase as referred to in paragraph 73 above, depends on the specific national circumstances, capacities and capabilities of each developing country Party and the level of support received;

75. *Requests* the Subsidiary Body for Scientific and Technological Advice to develop a work programme on the matters referred to in appendix II to this decision;

76. *Urges* Parties, in particular developed country Parties, to support, through multilateral and bilateral channels, the development of national strategies or action plans, policies and measures and capacity-building, followed by the implementation of national policies and measures and national strategies or action plans that could involve further capacity-building, technology development and transfer and results-based demonstration activities, including consideration of the safeguards referred to in paragraph 2 of appendix I to this decision, taking into account the relevant provisions on finance including those relating to reporting on support;

77. *Requests* the Ad Hoc Working Group on Long-term Cooperative Action under the Convention to explore financing options for the full implementation of the results-based actions referred to in paragraph 73 above and to report on progress made, including any recommendations for draft decisions on this matter, to the Conference of the Parties at its seventeenth session;

78. *Also requests* Parties to ensure coordination of the activities referred to in paragraph 70 above, including of the related support, particularly at the national level"

Considerable progress has been made in the UNFCCC negotiations and there is consensus on a number of areas regarding the scope of REDD-plus. The immediate priorities are deforestation and forest degradation and there is consensus that a future REDD mechanism could be implemented in a phased approach that could perhaps integrate conservation and carbon stock enhancement activities at later stages. There are also proposals that REDD should be incorporated into a broader agriculture, forestry and other land use programme. There is agreement that only developing countries can participate in REDD, and participation should be on a voluntary basis.

Consensus achieved regarding general principles of REDD+

Up to now the following consensus has been achieved regarding general principles of REDD-plus:

- Parties concur that REDD-plus could form an important part of the mitigation efforts of those developing countries that have mitigation potential in this area.
- There is convergence on the view that as part of the implementation of these actions, co-benefits, broad participation and sustainable forest management should be promoted, and the issues of permanence and leakage should be addressed.
- There is also convergence on the view that policy approaches should be performance based, so that support for implementation is based on results.

As much as there has been a significant convergence of views over the scope of REDD during the past three years, there are a number of outstanding issues that have implications for both the effectiveness of the REDD-plus scheme and the participation of countries. Several areas where consensus has not yet been reached:

- Whether there should be a primary set of measures for deforestation/degradation, and a secondary set for other forest-based mitigation options.
- Whether the legal nature of actions (voluntary and non-binding or binding) should be different for different groups of countries (these would be identified according to a set of criteria reflecting countries' economic development and capacity).

Financing and Benefits Distribution:

Financing and benefits distribution has been a major area of discussion in the negotiations and remains a key area where resolution is needed to move forward. Whatever funding mechanism is adopted, it will probably have to be integrated into the overall financing provided under the UNFCCC as part of the agreement that will come in Durban.

Parties concur that an effective financial framework is needed for the provision of financial resources and investment to support enhanced action on mitigation, adaptation and technology cooperation. This framework would require clear and focused mandates and responsibilities, and would help in the planning, coordination, monitoring and review of verifiable manner, in the case of mitigation activities. International REDD finance should complement domestic funding by developing countries in accordance with their respective capabilities, taking into account pre-existing national efforts and expenditure on sustainable forest management, forest protection and forest inventories.

There is convergence on the need for various sources and options to scale up the generation of new, additional and adequate financial resources. An approach based on a REDD Fund is considered to be more appropriate for capacity building and readiness activities. **There is also convergence among Parties on the underlying principles for the generation of financial resources, namely[6]:**

- Resources should be new and additional, adequate, predictable and sustainable;
- Generation of resources should be based on the principles of equity and common but differentiated responsibilities and respective capabilities.
- Parties are converging on the view that positive incentives and support should be provided for actions under REDD-plus.
- On the subject of which elements should receive support, there is convergence on supporting readiness activities (including capacity building, institutional strengthening, technical assistance, improving governance and enforcement), as well as on initiating national programmes and demonstration projects.

Convergence among parties

There is convergence among Parties that the overall governance of a possible financial framework should[6]:

- Be under the guidance and authority of the COP;
- Ensure full transparency, efficiency, effectiveness, openness, and the equitable and balanced representation of all Parties;
- Provide coherence and coordination among various sources of financing. There is

convergence among Parties on the principles for delivery of new and additional financial resources, to guide access to these resources and their disbursement. These principles include:

- All developing countries should be eligible to access financial resources, with emphasis on the needs of vulnerable countries in the context of adaptation;
- The delivery of resources should preferably take a programmatic approach, but use a project-based approach where national circumstances require it;
- The delivery of resources should be measurable, reportable and verifiable;

Parties and Observers have provided ideas and proposals for approaches to the generation of financial resources for REDD-plus. These comprise policy approaches, positive incentives, the use of non-market approaches, and a combination of market and non-market approaches. Proposals include the following options for generating new and additional financial resources[6]:

- An assessed contribution from developed country Parties as a percentage of their gross national product or gross domestic product;
- An assessed contribution from all Parties, except LDCs, based on a predefined set of criteria, including GHG emissions, respective capacity and population;
- Auctioning of assigned amounts or emission allowances at the international and/or domestic level;
- A uniform global levy on CO_2 emissions, with exemption for LDCs;
- Levies on emissions from international aviation and maritime transport;
- A tax on air travel;
- A share of proceeds from market-based mechanisms under the Kyoto Protocol;
- A global levy on international monetary transactions.

There is a range of views on the roles of the public and private sectors in generating financial resources to support enhanced action. Further consideration is required on how public finance could leverage private finance effectively and ensure coherence among different sources of funding. Further clarification is also needed on the subject of enabling environments to foster investment and financial flows, including the issue of support needed to establish enabling environments in developing countries. Market-linked approaches can use revenues generated through the auctioning of allowances or from emissions trading within a dual market. In an auctioning process, emissions reductions from REDD would be additional to existing developed country commitments.

Support for implementation of actions under REDD+

Further consideration is also needed of ways and means to support implementation of actions under REDD-plus. Parties have proposed a number of approaches:

- A performance-based approach that rewards emission reductions, supported by non-market positive incentives;
- A performance-based approach that rewards successful actions, supported by nonmarket positive incentives [7,8]
- Financial support provided through a comprehensive set of modalities and mechanisms, including an increased level of official development assistance, loan funding and non-repayable financial flows, assessed contributions by developed countries and carbon credits from the global carbon compliance market;
- Financial support provided to fund alternative, sustainable development plans that address the drivers of deforestation. The payments would be based on the cost of implementing these development plans[9];
- A two-track approach that includes support provided by market-based mechanisms for deforestation and forest degradation, and fund-based support for a broad range of land use activities such as conservation;
- A performance-based approach supported by diverse funding sources where emissions reductions could be allocated in international markets. There are also a number of general considerations of governance and institutional arrangement for managing financial resources and delivery of these that will impact the REDD negotiations. **Options for institutional arrangements for implementation of the financial framework include the following:**
- Making efficient and effective use of current institutional arrangements, including funds;
- Reforming the existing institutional arrangements, including funds, such as the Global Environment Facility (GEF), an operating entity of the financial mechanism of the Convention, and creating new institutional arrangements including funds, if needed.
- Parties have proposed the creation of a single umbrella body, as an institutional arrangement under the authority and guidance of the COP, to coordinate the activities of different specialised bodies in providing financial resources including resources for REDD actions. Therefore, creating new windows in the proposed Green Climate Fund (GCF) for REDD-plus
- Further consideration is also required of proposed institutional arrangements of specialised national and international funds and mechanisms to generate, manage

and deliver financial resources from private and public sources for mitigation, including REDD-plus actions. Equitable distribution of funds is another area that requires further consideration. The proposals of most Parties and Observers do not offer opportunities for redistribution of benefits and some countries are strongly against it. Thus, the majority of proposals reward historically high emitters and exclude low emitters.

Equitable distribution of funds

Others have proposed alternative models for equitable distribution of funds[9]:

- Transferring funds directly to national government accounts (e.g., UNFCCC Adaptation Fund).

- Establishing special agencies or accounts in-country to handle funds (e.g., Brazil's Amazon Fund, USA's Millennium Challenge Accounts).

- Implementing projects through multilateral and bilateral aid structures, such as the World Bank or UN agencies (e.g., Global Environment Facility, the Multilateral Fund for the Implementation of the Montreal Protocol).

- Disbursing funds directly to multiple recipients in-country, including governments, NGOs and the private sector (e.g., The Global Fund to Fight Aids, Tuberculosis and Malaria). There are a number of proposals around how financing could flow to support REDD schemes.

Several Parties have endorsed the idea of a 3 phased approach. Overlap between phases within countries may be necessary and even desirable as the boundaries between the phases are transitions, not clear breaks. Phase 1 finance will be limited in scale and can be contributed on the basis of voluntary pledges from countries bilaterally or via multilateral organisations. As soon as the financial instrument for Phase 2 funding has been established, the international funding for capacity building could be converted into a window of the Phase 2 instrument. Capacity building funds would remain separate as they cannot be tied to particular performance or results, but they could be administered jointly with other Phase 2 funds. In particular, for the transition from Phase 2 to Phase 3, modalities are required to ensure that there is no double counting.

For Phase 3, a REDD financing instrument would provide direct rewards for provision of climate benefits based on a GHG metric. A REDD mechanism could foresee the conversion of emissions reductions or enhanced removals from REDD-plus actions into REDD units that

could then be sold to industries or governments for compliance with quantified emission reduction obligations. Alternatively, the compensation mechanism could rely on direct, nonmarket payments for emission reductions/removals.

Monitoring, Reporting and Verification (MRV):

A number of issues related to MRV are under discussion, many of which will have an impact under a REDD-plus scheme. The most pressing issue is the scope of MRV in REDD. Much progress continues to be made on aspects related to carbon accounting. However, MRV of the

'safeguards' outlined in the preamble of the draft decision continues to be contentious, as many developing countries are opposed to monitoring and reporting on these. The recently proposed eligibility criteria[10] would likely trigger monitoring of most of the safeguards. However, the establishment of required levels of satisfactory performance in these areas will await the modalities negotiations if this proposal is retained. One of the key issues is whether all actions should be verified by national entities and in accordance with national procedures, or whether verification should occur at the international level (e.g., under the auspices of the UNFCCC) and involve an independent review process. A possible solution explored by Parties is for verification to be carried out at the national level, but in accordance with internationally agreed guidelines or procedures, for nationally funded actions, and at the international level for actions implemented with external support. There is a need to consider whether verification requirements should differ for different groups of countries or different types of action.

Parties agree that measurement and reporting of voluntary actions by developing countries in climate change mitigation need to include:

- Information on the implementation of voluntary mitigation plans, programmes and actions themselves (including REDD-plus);
- The reduction in GHG emissions achieved by the action in relation to the national GHG trajectories (e.g., at a national or sectoral level);
- The incremental cost of the action, and the support needed;
- The sustainable development benefits and co-benefits. With respect to a REDD-plus scheme, Parties have converged on the view that monitoring, reporting and verification of actions should take the following main elements into consideration:
- Reference emissions and reference levels need to be established and verified, taking into account national circumstances;
- A common methodology should be used for all policy approaches, based on remote sensing and verification on the ground;
- Robust national forest monitoring systems and verification are both necessary. There appears to be convergence on the view that measurement, reporting and verification systems in this area should be based on:

- National forest inventories, existing or to be developed;

- Unbiased, periodic reviews (possibly organised under the auspices of the UNFCCC) to assess the application of agreed modalities, including review of data.

Few of the issues related to MRV have been resolved, but the question of what to monitor must be resolved before the discussion can proceed. There is ongoing discussion about monitoring of safeguards and monitoring of financial flows; such discussions have become more contentious since Copenhagen and then in Cancun. Safeguard monitoring is advocated by many developed countries, indigenous peoples' groups and a large number of Observers as a means of ensuring that REDD-plus protects local community rights and generates development benefits for countries hosting these activities. It is opposed by many developing countries, particularly the African Group, because of fears that this requirement would be the basis for excluding countries with significant governance issues. Recent additions to the text include specific eligibility criteria as part of the preamble. Monitoring of financial flows is tied up with negotiations on NAMAs and adaptation financing. There are unlikely to be separate agreements on MRV issues for REDD financing. Developing and developed countries are divided over the nature of the issue. Developing countries want monitoring to focus on whether or not developed countries are meeting commitments, whereas developed countries want monitoring to focus on effectiveness of financing with respect to outcomes.

Stakeholder Involvement:

Protection of the rights of local communities (LCs) in a REDD mechanism has been one of the major areas of contention in the REDD-plus negotiations. The effective participation of local stakeholders will be important to environmental effectiveness of the programme. There is consensus that local community rights must be respected and protected within the REDD-plus mechanism.

Environmental and Social Co-benefits:

There are a number of benefits that a properly designed REDD-plus scheme could generate:

- Social co-benefits associated with sustainable development and poverty reduction;

- Governance benefits associated with improved protection of human rights and improvement in forest governance;

- Environmental co-benefits, particularly enhanced biodiversity protection, soil and water conservation, and ecosystem restoration.

There is divergence on whether and how social (at national and community levels) and environmental co-benefits should be mandated in the design of the international REDD-plus regime. Some favour keeping REDD-plus simple and not encumbering it with additional requirements. Among those who favour inclusion of REDD in a climate change regime, some argue that because the main aim of REDD is mitigation, not poverty reduction, the appropriate standard should be 'do no harm' to the poor. Others favouring a 'pro-poor' approach argue that failure to specifically include co-benefits objectives in REDD-plus design will ensure failure of the programme.

Challenges and Research Needs:

Baselines. Setting the reference emission levels or baselines is among the more challenging aspects of implementing REDD-plus projects in developing countries. One key area for research to support a REDD-plus programme is in developing methods and approaches for the integration of historical deforestation data with knowledge of drivers of deforestation to construct scenarios and provide reasonable estimates of future emissions.

Carbon accounting.

Unavailability of country- or region-specific factors for these GHG accounting equations is a limitation that could largely be overcome with a concerted research effort, and significant progress could be made within 10 years. Several groups have developed REDD accounting methods. However, in many tropical forest ecosystems, more than half of the carbon can actually be below ground. Research needs to focus on providing appropriate factors for the equations that could improve project- and national-level carbon accounting,

Linking national and project-level carbon assessments.

There is a need for research to address methods for linking national and subnational monitoring, estimation and accounting. This is a multifaceted area of research that includes:

- Developing approaches for community participation in project-level accounting exercises to increase transparency and community ownership of projects;
- Developing methods for linking project baselines and performance with national baselines and performance benchmarks to facilitate project implementation;
- Developing institutional innovations that will be required to implement a national REDD-plus scheme—in particular, there is a need for knowledge to support rural institutional development for integration of community participation into carbon accounting and linking rural institutions with institutions at the national level that are responsible for carbon monitoring and reporting.

Conclusion: Forestry is one of the important elements of climate change negotiation. Till now REDD-plus is the cheapest option for mitigation. It is an excellent adaptation option as well. Parties are now seriously engaged with the final out come of REDD-plus negotiation. Side by side REDD preparedness is going on satisfactorily in some developing countries. Some multilateral as well as bilateral funding sources is also available for REDD preparedness, capacity building and implementation. We are facing some challenges ahead on procedural and carbon accounting rules, funding mechanism and MRV issues. These challenges should be solved immediately to save our mother earth. Developed countries should take the lead to solve the financial issues for successful implementation of REDD projects. Together developing and developed country parties should take care of our forestry and this is needed for our survival and existence.

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SAARC Forest Carbon Concepts, Markets and Standards

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Abstract

SAARC countries offer good cases for forest restoration and conservation in gainful partnerships with local community stakeholders who depend on neighboring forest resources for meeting their subsistence needs including conservation-linked livelihood. Some of these countries have densely populated coasts with predominantly natural resources-based agrarian economy, and so their vulnerability to climate change is high. Their natural resources including cultivable land, forests and wetlands are getting degraded due mainly to heavy biotic pressure brought by huge population, concentrated in comparatively small geographic area. However, tropical forests in general and the coastal mangroves in particular are ensuring substantial sequestration and storage of carbon both in the forest biomass and forest soils of the SAARC countries. Avoiding the release of carbon dioxide resulting through deforestation and forests degradation is even more important phenomenon that is currently occurring in many SAARC countries.

In addition to afforestation and reforestation, avoided deforestation and forests degradation is included as a third category of forest-based activity, qualified for conservation financing under compliance and voluntary forest carbon markets. Reduction of emissions from deforestation and forests degradation (REDD+) is one such emerging carbon finance mechanism that is particularly suitable for the forests including the mangroves of the SAARC countries. Avoided deforestation offers an excellent opportunity for achieving national environmental goals by mitigating Green House Gas emissions while conserving biodiversity and alleviating rural poverty. Greening of the SAARC countries through community conservation activities necessary for reducing deforestation and degradation will result in empowering local communities. Many of the community forests conservation activities are labor-intensive, cost effective, efficient and equitable with large employment and income gains expected to accrue to neighboring poor community. Local surplus labor resources can be utilized in restoring the degraded forest landscapes of the SAARC countries while generating substantial forest carbon credits.

A number of carbon forestry concepts, markets and standards have been discussed in this paper. Introductory section on carbon forestry concepts provide explanation on : carbon forestry objectives, climate change mitigation and adaptation, eligible carbon forestry activities, forest carbon sequestration and storage, carbon forestry in poverty alleviation, carbon forests protection, forest carbon pools, data types, forest carbon assessment tiers, forest carbon assessment, forest carbon monitoring, temporal assessment of deforestation and forests degradation, and monitoring, reporting and verification system. Carbon markets have been discussed in the next section by analyzing and focusing on carbon forestry markets. The last

section of the paper deals with main standards that can be applied while designing carbon project, and planning and estimating forest carbon credits.

Key words : CDM, A/R, ARR, IFM, ALM, REDD+, LULUCF, AFOLU, PES, climate change, resilience, mitigation, adaptation, green house gases, protected area, improved forests management, VCS

1. Introduction

All the eight South Asia Association for Regional Cooperation (SAARC) countries (Bangladesh, Nepal, Bhutan, India, Maldives, Sri Lanka, Pakistan and Afghanistan) are low-carbon emitting countries due mainly to their predominantly agrarian economy with low level of industrialization. But being located in a densely populated natural disaster prone region, their vulnerability to climate change is high; for instance, a sea-level rise of 1-2 meter would inundate the substantial area of coastal countries including Bangladesh, Maldives, Sri Lanka, India and Pakistan, thereby adversely affecting a large poor coastal population. The per capita carbon dioxide (CO_2) emission in the SAARC counties (estimated to be as 0.2 ton/year in Bangladesh, for instance) is much lower when compared to 15-20 ton/year in some developed countries. However, the consumption of fossil fuels in some of the SAARC countries is growing fast and increasing motor traffic in big cities such as Dhaka, Kathmandu and Delhi is causing environmental pollution.

Land-based natural resources including mangrove forests are degrading in the SAARC countries due mainly to heavy biotic pressure brought by huge population, concentrated in comparatively small geographic area. Their remainder forests (including man-made plantations) in general and the mangrove forests in particular can ensure substantial sequestration and storage of carbon dioxide, generating forest carbon credits. Avoiding the release of carbon dioxide resulting through deforestation and forests degradation is even more important as a large proportion of the total carbon is released due to deforestation activities that are currently occurring in the SAARC countries. In addition to afforestation and reforestation, avoided deforestation and forests degradation is included as a third category of forest-based activity qualified for conservation financing under compliance and voluntary markets. Reduction of emissions through deforestation and forests degradation (REDD+) is one such emerging mechanism that is particularly suitable for the forests of the SAARC countries.

2. Carbon Forestry Concepts

The neglect of existing natural forests due to lack of funding and inadequate management resulted in natural forests degradation in many SAARC countries. Anthropogenic pressures including increased commercial extraction of forest produce, brought by manifold increase in human population, led to widespread shrinkage and deforestation of natural forests. Keeping in view of deforestation that took place earlier, the Governments of most of the SAARC countries promulgated wildlife acts and gazetted some natural forests as Wildlife Sanctuaries and National Parks mainly to conserve dwindling wildlife and degraded forests. The people-oriented Forestry Policies which were enacted by most of the SAARC countries *inter-alia* emphasized peoples' gainful participation in the sustainable management of government forests. Accordingly, the emphasis of forests management during 80s and 90s gradually shifted from timber production to meeting bonafide consumption needs of local people. Community forestry and social forestry were included in the revised Forest Acts to implement the policy recommendations in most of the SAARC countries.

2.1 Carbon Forestry Objectives

Overall aims of a carbon forestry program could be to achieve, through avoided deforestation and degradation, afforestation and reforestation, and improved forest management activities, carbon sequestration and storage with livelihoods improvements through community participation in forestry activities as well as conservation of flora and fauna species through measures including habitat protection and improvement The emissions reductions can be achieved through avoided deforestation and avoided forests degradation in selected forests areas subjected to biotic interference. A typical carbon forestry project in a SAARC country may have the following three objectives:

1. Climate: to mitigate greenhouse gases (GHG) through both emissions reductions and enhanced removals of carbon dioxide from the atmosphere. That is, to slow or reverse documented deforestation and forest degradation, and generating higher carbon intensities per hectare across more hectares through improved forests management (IFM), and afforestation, reforestation and revegetation (ARR).

2. Community: to assist local communities living within an identified zone of influence (may be referred to as the reference region or interface landscape zone) upon the project area by providing alternative livelihood options and conservation-linked value chain development to reduce forest dependency for daily needs and to ensure awareness raising and education facilities for adults and children to increase motivation about the importance of forests for climate change mitigation and adaptation.

3. Biodiversity: to conserve the habitat for biodiversity including endangered floral and faunal species, and flagship species such as tiger, elephant, hollock, dolphin, macaque, and other important species of bird, fish, reptile, and other wildlife.

2.2 Climate Change Mitigation and Adaptation

Climate change mitigation would involve either not releasing GHG in atmosphere by improving the technology or/and sequestering released GHG and storing so that adverse climate change impacts do not occur. However, in case GHG is already released and as a result climate change happened then both the concerned community and ecosystem should have resilience and adaptation capacity in order to be able to tolerate adverse impacts of climate change. In other words mitigation is an avoidance phenomenon for unmanageable climate change activities whereas adaptation refers to managing the unavoidable climate change resulting from development activities including industrialization, agriculture, deforestation, etc. For example, controlling release of GHG by avoiding deforestation and forest degradation or sequestrating carbon dioxide through afforestation and reforestation can be categorized as climate change mitigation, whereas improving ecosystem productivity or building capacity of local community in order to make them resilient to climate change can be categorized as an adaptation activity.

Land-use sectors (e.g. forests, agriculture, wetlands) provide low cost opportunities to combat climate change either through reduced GHG emissions or through improved land-use management practices or through carbon sequestration of GHG as sinks. Climate change adaptation of ecosystems can be achieved by enhancing their resilience and productivity. Similarly local community can be better prepared in order to be resilient to climate change.

2.3 Eligible Carbon Forestry Activities

A carbon forestry project activity cycle would include project design, validation/registration, implementation, monitoring, verification/certification and issuance of carbon credits. Only some specified activities have been allowed to be able to generate carbon credits. Eligible activities fit within one of such categories may for instance include afforestation and reforestation (A/R) under CDM, and should have completed all requirements like verification and board approval. Global warming has adversely affected earth's climate, with significant consequences for natural resources including water, soil, forests and air. Land Use, Land Use Change and Forestry (LULUCF) has been identified as an important land-based activity that mitigates climate change as defined in the Climate Conventions. Forestry, broadly included under LULUCF sector, provides low cost mitigation opportunities to combat climate change either by increasing the removal of GHG from the atmosphere through forests/plantations as carbon sinks or by reducing GHG emissions through avoided deforestation and forests degradation. Till now only reforestation and afforestation are two eligible activities under the Article 12 for non-Annex-I countries including the SAARC countries. Avoided deforestation and forests degradation have now been focused as per the decision taken in the Bali Conference, 2008; Copenhagen, 2009 and Cancun, 2010.

Eligibility of A/R projects would include key requirements including additionality, permanence and leakage. Additionality criterion ensures emission reductions or removals that would not happen in the absence of the project; for example, an A/R project under CDM would require a document that the area under the project was deforested prior to 1990. Ensuring permanence would focus on activities demonstrating that the carbon credits generated from the project are permanent. Project activities must demonstrate that non-permanence is being addressed for issuing of either tCERs or ICERs.

2.4 Forest Carbon Sequestration and Storage

By conserving forests and developing plantations, landscape degradation can be halted, biodiversity and water conserved *in-situ*, and community biomass needs met by utilizing surplus labour. Besides, sustainable forests management opportunities would have significant potential to transfer investment funds and technology, and upgrade institutional capacity of FD field staff and local community organizations for biodiversity conservation, forests landscape restoration and bio-energy. The revenue generated by carbon credits sale can be used to re-vegetate the degraded landscape through *in-situ* biodiversity conservation.

The role of forests in carbon cycle is vital as they account for approximately 80% of CO_2 exchanged between land and atmosphere through the process of photosynthesis. As trees grow, the carbon is stored in biomass by converting CO_2 and water (by using solar energy) into sugars and oxygen (released through the leaves). Forests also release CO_2 during the process of respiration. However, a forest that is growing (i.e. increasing in biomass) will absorb more CO_2 than it releases. So the sequestration and storage potential depends on growing and sustaining forests.

Sustainable forests management in densely populated regions such as the Indian subcontinent would have high socio-environmental benefits for local communities, who are mainly subsistence farmers and laborers. The development and sustainable management of forest carbon sinks will benefit local community by contributing to poverty alleviation through their enhanced income generation and better quality of life. There is substantial economic potential of carbon forestry for the mitigation of global GHG emissions over the coming decades, that could offset the projected growth of global emissions or reduce emissions below current levels.

2.5 Carbon Forestry in Poverty Alleviation

Although climate change, as a public good, is global in its causes and consequences, its adverse impacts are being borne inequitably in different regions and communities of the SAARC countries. Riparian countries such as Bangladesh, Sri Lanka and Maldives, very near to sea level, and coastal poor, dependent on neighboring biodiversity, are being particularly affected adversely. Avoided deforestation and degradation offer an excellent opportunity for achieving global environmental goals by mitigating GHG emissions while conserving biodiversity and alleviating rural poverty locally. Greening of the SAARC countries through community conservation activities will result in empowering local communities, thereby contributing in improved environmental governance. Many of the community conservation activities are labor intensive, cost effective, efficient and equitable with large employment and income gains expected to accrue to neighboring poor communities. In the process, local surplus labor resources can be utilized in restoring degraded forest landscapes of the SAARC countries and also will generate substantial carbon credits.

Avoiding deforestation and forests degradation is in line with the poverty reduction strategies of the Governments of most of the SAARC countries. Scaling up flows of carbon finance to the SAARC countries to support effective policies and programs for reducing emissions would accelerate the transition to a low-carbon economy. Avoided deforestation will sequester GHG emissions, and generate global and local environmental benefits and would conserve biodiversity and alleviate rural poverty locally.

2.6 Carbon Forests Protection

In some of the densely populous and poor SAARC countries, effective protection of dispersed and mosaic forests is not possible without gainful partnerships of local community. Climate change mitigation from forests conservation is important in addition to controlling deforestation. Participatory management initiatives have proved successful in many SAARC countries, thereby proving that conservation of forests is necessary for the forests landscape restoration by involving local community. The forests can be sustainably co-managed locally by sharing benefits accrued as a result of enhanced forests productivity. It should be possible to equitably distribute forests benefits to participating community as naturally regenerating forests would require canopy opening through silvicultural interventions, thereby providing yield as a byproduct. As regenerating forests (either through natural regeneration and/or aided regeneration) sequestrate more carbon than mature standing forests, it may be necessary to take recourse of silvicultural thinning by following selection system for encouraging natural regeneration in mature forests.

2.7 Forest Carbon Pools

Carbon gain-loss method estimates net balance of additions to and removals from a carbon stock (based on annual growth rates), whereas the carbon stock change method estimates the difference in carbon stocks at two periods. Temporal inventories for mangrove forests can provide time series data on growing stock, particularly for trees, and in such a case the later method is suitable for carbon monitoring and reporting. The following carbon pools can be estimated depending on the forest type where carbon inventory is to be designed and implemented:

a) Above-ground carbon (tree, sapling, seedling, bamboo, cane, crown foliage, branches)

b) On-ground carbon (woody debris, dead trees, leaf litter, grass)

c) Below-ground carbon (soils, roots)

2.8 Data Types

Forest carbon inventorying needs the collection of activity data and information for estimating emission factors. Activity data refers to landscape coverage of different land-use that might be present in the forest area to be inventoried, and can be collected through remote sensing and field surveys. Emission factors refer to changes in various carbon pools of forest and can be estimated based on ground data collection.

2.9 Forest Carbon Assessment Tiers

Forest carbon information can be collected at 3 tier levels. Tier 1 uses Inter-governmental Panel on Climate Change (IPCC) default values which are based on simplified assumptions and so are generic. Tier 2 employs country-specific data for key factors that can be used locally for a project area. Tier 3 is the most precise and uses detailed inventory of key forest carbon stocks and temporal assessments by collecting and analyzing data collected by field crew from the project area.

2.10 Forest Carbon Assessment

It is important to develop an appropriate methodology for objectively assessing enhancement of forest carbon stocks as a consequence of conservation and sustainable management of natural forests in the SAARC countries. Forest carbon assessment methods as approved internationally would require updating in view of local forests situations in some of the SAARC countries. The carbon inventory protocol as circulated among the workshop participants includes suitable carbon inventory methods for assessing forests carbon pools (above-ground carbon, on-ground carbon and below-ground carbon, forest soil carbon). Scientific data showing the increment of carbon stocks in forests will be required and more work may be needed in some countries, particularly for the temporal assessment of forests stocking that will include an accurate assessment of deforestation/forests degradation rates. Suitable modalities and procedures for transparent and verifiable assessment of forests changes need to be developed by Forest Departments. This also will require developing a suitable common strategy, approach and modality for assessing positive and negative forests changes over a period of time.

Species specific volume equations and specific gravity may be estimated for carbon stock and historical deforestation and degradation rates can be assessed either by employing temporal inventory data and/or temporal analyses of imageries such as LANDSAT/IRS. Maps can be generated by using remote sensing facilities and base maps at 1:50,000 scale will be helpful in generating these maps. However, it is important to know that carbon inventory and mapping pose some challenges as forests inventory are generally characterized by uncertainty and data limitations. Emission factors may not be available for some of the SAARC countries and land-use changes may happen rather at a faster rate due to heavy biotic pressure. Therefore Forest Departments will require being equipped with the latest equipments and technology, and manned with trained staff.

Measuring of soil carbon as well as below- and above-ground carbon and biomass can be carried out through permanent sample plots determined by systematic random sampling. The dominant pools of biomass and carbon stock (i.e., trees) may be measured every five years, along with periodic independent verification. Measurement of pools that comprise a less significant portion of the overall carbon stock or that are likely to change more slowly, such as soil carbon, may be measured less frequently, for instance every ten years. Best practices such as remote sensing and field methods can be employed to inform the land use categorizations that are used in measuring and monitoring changes in biomass and carbon. Similar to the case of the project parameters, carbon stock monitoring can be carried out largely by the local community with the FD providing guidance on field inventory protocols. To ensure they are equipped with the necessary knowledge and skills for carbon stock monitoring, NGOs and other relevant institutions can be brought in to provide training-of-trainers to FD field staff as well as the local community on the use of remote sensing and field inventory technologies. Targeted follow-up training will be offered, particularly if technologies used changes.

2.11 Forest Carbon Monitoring

Several aspects of a carbon project may be monitored to ensure that project activities are successfully carried out and adhere to conservation principles. Monitoring of both project parameters and carbon sequestered may be conducted in order to gauge the effectiveness and impacts of project activities; to measure forest carbon; and to inform any adjustments needed to ensure the efficacy of methodologies, implementation activities, or the monitoring plan itself. Key aspects of the project to be monitored include: project boundaries; forest protection; forest management; carbon stock changes; and leakage. It is envisioned that local community, together with the FD field staff, can play a central role in participatory monitoring, with assistance from relevant local NGOs in the areas of administrative, managerial, and financial monitoring.

Periodic monitoring of the boundaries of the project areas may be conducted through the use of appropriate technologies such as remote sensing as well as through monitoring and ground-truthing in the field. Maps can be updated regularly to ensure that monitoring is based on the most current situation. The capacity of institutions such as local community and the FD field staff to understand and utilize monitoring technologies and techniques will be strengthened through targeted training.

2.12 Temporal Assessment of Deforestation and Forests Degradation:

Deforestation is long-term or permanent conversion of land from forest to non-forest uses. Forest degradation is reduction in forest cover, tree density, or tree biomass (and thus carbon stock) that do not qualify as deforestation. International negotiations on forest reference levels, agreed levels for transition point, long-term responsibility, definitions, incentives, etc. are continuing in response to the decisions taken in the Copenhegan and Cancun COP conferences in view of the Bali decision that refers to incremental changes and enhancement of stocks linked to sustainable forest management and conservation in line with the additionality principle. National baselines and emission reference levels, forest stock changes and time series analyses will be required for assessing historical trends of de-generating and/or re-generating forests. Forests under conservation and sustainable management will need to be assessed, inventorized and accounted for at the national and sub-national levels using inter-governmental panel on climate change (IPCC) guidelines in order to be assigned REDD credits for carbon trading. Monitoring of forests carbon stocks and assessing leakage and permanence would be required regularly. Access to remote sensing technology will be helpful but needs to be supplemented by ground truthing to be conducted regularly both at national and local levels.

Increment of carbon stock can be assessed by using scientific data collected from the identified permanent and temporary sample plots. Technology transfer particularly from relevant tropical countries would be helpful in carrying out not only national inventory and carbon credit assessments but also sustainable management of natural forests that have degraded severely due to lack of resources. Some SAARC countries do not currently have a regular forests inventory mechanism and so developing national forests inventory institutions for objectively assessing baseline scenarios and emission reference levels are necessary.

2.13 Monitoring, Reporting and Verification (MRV) System

Main elements of a feasible monitoring, reporting and verification (MRV) system can be identified. Mangrove forests form important bio-geographical zones in the coastal SAARC countries. and shall thus form a stratum when a national MRV system is designed and implemented. In the identified Forest Divisions and Forest Ranges, sample plots (temporary and permanent) can be laid out by estimating appropriate sampling design, sampling intensity, number and location of sample plots on a grid. A two year cycle inventory can be carried out in the sample plots laid out as per the grid by marking them in the field. Mangrove forests can be typically categorized in the following 4 categories:

- Dense forests (more than 70% crown density)
- Moderately dense forests (40-70% crown density)
- Open forests (15-40% crown density)
- Scrub forests (less than 15% crown density)

However, country- and region-specific MRV systems may be necessary in different SAARC countries.

3. Forest Carbon Markets

Developing appropriate conservation financing mechanisms and frameworks is necessary for carrying out forests-based climate change mitigation and adaptation activities. Initiatives such as Payments for Ecosystem services (PES) have developed over the period as a mechanism for valuation of the functions and services from forest ecosystems and compensation to losers from those who benefit. Suitable incentives are being discussed and worked out for payments to the communities and countries which are able to protect their forests beyond an agreed cut off period. Similarly, conserving forests on a progressive sustained yield basis should be well compensated through financial incentives that can be ploughed back in forest restoration, achieved by employing participatory management initiatives/activities. As carbon credit market develops in the SAARC countries, it may be necessary to develop climate change trust funds such as National REDD+ Trust Funds exclusively for addressing forests-based climate change mitigation and adaptation issues. For example, currently there two such funds are in operation in Bangladesh: the climate change trust fund set up by the national government and the climate change resilience fund set up different donors and being managed by the World Bank.

Forest carbon markets can be categorized into two broad types : compliance or regulatory markets such as Kyoto Protocol's Clean Development Mechanism (CDM), and voluntary carbon markets such as the voluntary over-the-counter (OTC). Project-based markets (e.g. compliance under CDM, voluntary under informal OTC or formal Chicago Climate Exchange, or donor-driven under BioCarbon Fund managed by the World Bank or other donor carbon finance) cater to different projects which result in the generation of carbon credits through project implementation in developing countries (for example, CDM projects implemented in developing countries with buyers of carbon credits from developed countries) or in a developed country (for example, Joint Implementation (JI) mechanism under CDM) with buyers from another developed country. CDM, established under Article 12 of Kyoto Protocol, has been operationalized in 2003 with the unit of trade as Certified Emission Reduction (CER) credits. Most of the credits under CDM have been bought by private companies based in European Union with UK being the largest buyer of credits from a vast majority of projects (mainly in energy efficiency, hydropower and wind) in China, India and Brazil.

Allowance-based markets include the European Union Emissions Trading Scheme (EU ETS) set up by European Parliament as the largest carbon market in the world. Other allowance-based markets include : i) Chicago Climate Exchange (CCX) that trades both allowances and offsets with membership consisting of a wide range of industries including agriculture and forest, ii) Regional Greenhouse Initiative which is a consortium of 10 northeastern and mid-Atlantic US state governments using regulations to force compliance particularly in power sector, iii) New South Wales Greenhouse Gas Abatement Scheme for power sector, and iv) New Zealand Emission Trading Scheme (NZ ETS).

Compliance markets support country and industry compliance with the targets as fixed under Kyoto Protocol as legally binding commitments to reduce GHG emissions on time. CERs are sold in carbon markets, with each CER representing one metric ton carbon dioxide equivalent (tCO_2e). CERs are further classified as temporary CER (tCER) and long-term CER (ICER). In the voluntary markets selling unit is voluntary emission reduction (VER) credit. Removal Units (RMUs) are obtained from LULUCF activities such as afforestation and reforestation. Projects generate credits from eligible activities and companies buy offsets in carbon markets (CCX, ETS and others serve as trading platform) to meet company targets.

Over-the-Counter markets involve a wide range of transactions by many players engaged in many markets. Such markets are called voluntary because they are not subject to emission caps. Project catering to OTC markets are carbon offset projects and are outside of allowance systems. Market drives the prices and transaction volumes in OTC carbon markets. Many private companies are increasingly entering OTC markets based on corporate social responsibility and public relations. Of late REDD has emerged as a major source of credits as a result of strong international support and emerging compliance markets that were strengthened in Bali and Copenhagen conferences. A number of methodologies have been developed, which cater to the development and implementation of REDD projects. As a result, in 2010, REDD surpassed the volume supplied by any other project type.

4. Forest Carbon Standards

Forest carbon standards provide a practical tool to evaluate carbon projects in the early stages of project design and development. Standards enable investors and project managers to identify quality projects by avoiding implementation roadblocks in order to ensure timely delivery of their stated products and outcomes. This helps in the generation of credible carbon credits. There are nearly 30 standard types, which can be categorized into two main types : carbon standards ensuring the quality of carbon product (credits0 and project design process standards ensuring positive community and biodiversity benefits. Main forest carbon standards are presented as below:

- CDM Standards and Methodologies
- Verified Carbon Standards (VCS)
- Gold Standards (supported by World Wide Fund for Nature)
- Climate Action Reserve (CAR) Standards
- Plan Vivo Standards
- American Carbon Registry Standard
- Brasil Mata Viva (BMV)
- Forest Carbon Standard International (FCSI)
- Climate, Community and Biodiversity (CCB) Standards

For forestry projects, the CDM, VCS and CCB standards are particularly suitable and are so employed by most of the projects that have come recently in forest carbon markets. VCS, founded in 2005 and operational since 2007, for voluntary offset markets for Agriculture, Forestry and Other Land Use (AFOLU) projects, facilitate robust, global standards for approval of credible voluntary offsets for projects under REDD, ARR, IFM and Agricultural Land Management (ALM). They have recently included wetlands and grasslands for which new standards are under development. Voluntary carbon units (VCU) are issued by following a rigorous evaluation process.

CCB standards go beyond CDM or VCS requirements by generating positive community and biodiversity benefits by following 15 required criteria and 8 optional criteria, classified under General, Climate, Community and Biodiversity sections. Gold Standards are managed by a company called APX for a non-profit foundation of 60 NGOs. Climate Action Reserve was established in California for US compliance market and has protocols for forestry, livestock methane and landfills. An Edinburgh (UK) based foundation manages Plan Vivo Standards mainly for small community-based forest and agroforestry projects. American Carbon Registry

Standards are forestry related standards that were released in 2009 by Winrock International, USA.

5. Conclusion

Given favourable and enabling environment, many SAARC countries offer good cases for forests restoration and conservation in gainful partnerships with local community, who depend on neighboring forests for meeting their subsistence needs including livelihoods. Coastal countries in the SAARC region are particularly prone to negative consequences of global climate change that need to be mitigated by protecting and conserving forests through carbon forestry initiatives that generate forest carbon credits. This workshop would go a long way in developing required capacity, particularly for FD both for climate change mitigation and adaptation of local ecosystems and community.

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A Review on existing methods of Above Ground Biomass Estimation

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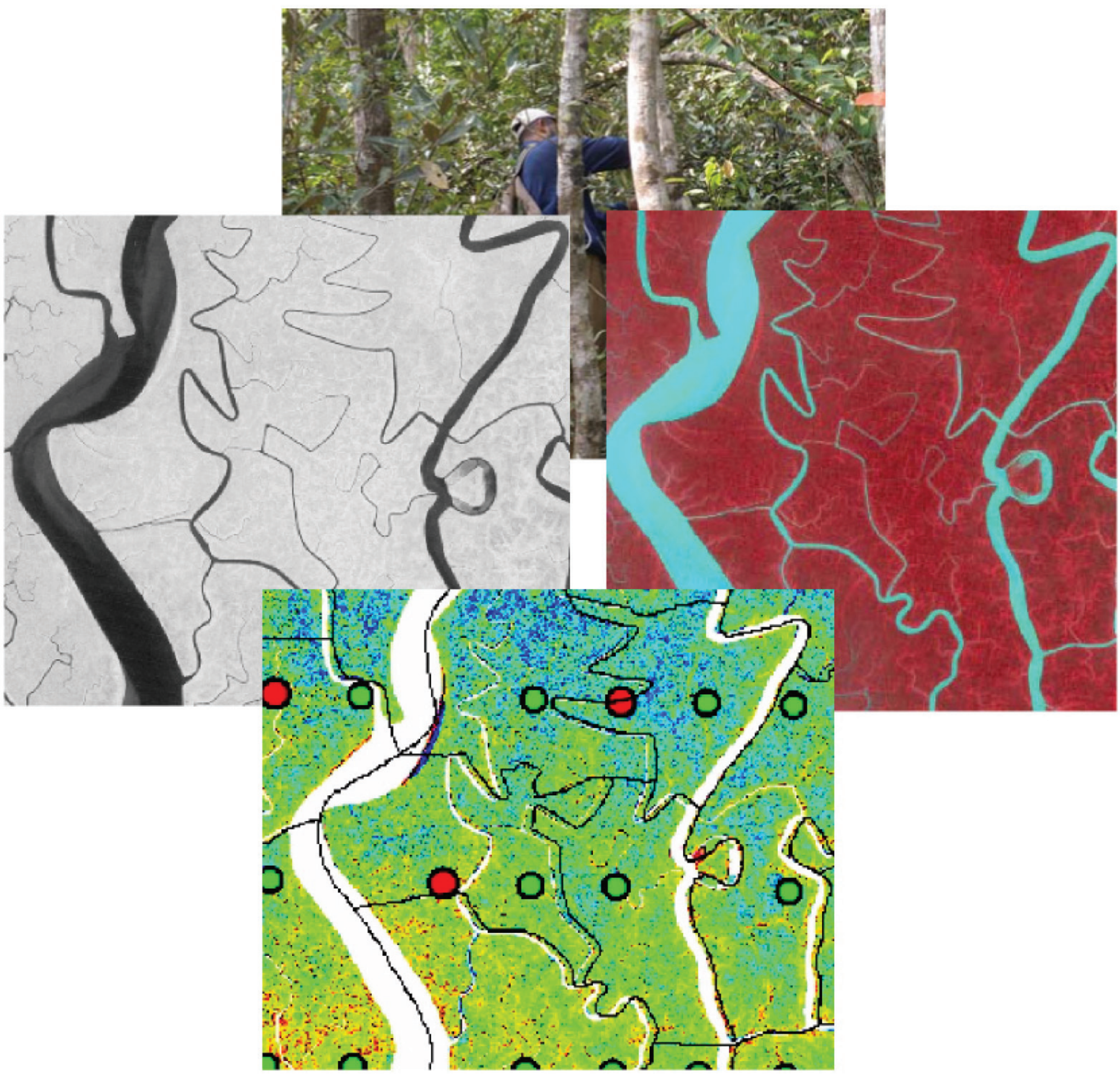

1 Background

Tropical forests cover about 15% of the worlds land surface and contained about 25% of the carbon in the terrestrial biosphere. But they are being rapidly degraded and deforested. Deforestation alone is probably responsible for 18% of the world's greenhouse gas emissions (Stern 2006). Clearing of tropical forest also destroys globally important carbon sinks that are currently sequestering CO2 from the atmosphere and are critical to future climate stabilization (Stephans et al. 2007). Quantifying carbon in forests is increasingly important for monitoring and reporting requirements in order to plan/know the productivity, nutrient allocation, fuel accumulation, carbon cycle etc. in terrestrial ecosystem (Ryu et al. 2004).

Forest ecosystems are the living biomass includes the above-ground and below-ground mass, such as trees, shrubs, vines, roots and the dead mass of fine and coarse litter associated with the soil. Biomass governs the potential carbon emission that could be released to the atmosphere due to deforestation. Accurate delineation of biomass distribution at scales from local and regional to global becomes significant in reducing the uncertainty of carbon emission and sequestration.

Due to the difficulty in collecting field data of below-ground biomass, most previous research on biomass estimation focused on above-ground biomass. Only above-ground biomass (AGB) is measurable with some accuracy at the broad scale. While below-ground biomass stores a large part of total carbon stocks, it is rarely measured (GCOS 2003, Gibbs et al. 2007).

Biomass is commonly estimated by applying conversion factors (biomass expansion factors) to tree volume (either derived from field plot measures or forest inventory data) (Kurz et al. 2002) and AGB, where the latter is determined from trees that have been dissected, oven-dried and weighed (Brown 1997, Chave et al. 2005). Mani and Parthasarathy (2007) have been reported relationships between biomass and other inventory attributes (e.g., basal area). Fournier (2003) has been explored the use of existing forest inventory data to map large area tree AGB and conversion tables were developed to estimate biomass from attributes contained in provincial forest inventory data, including species composition, crown density and dominant tree height. Somogvi et al. (2007) was provided guidance on the selection, development and application of appropriate biomass factors and allometric equations for large-scale biomass estimation.

There are different approaches based on field measurement, remote sensing and GIS modeling has been applied for AGB estimation (Geotz et al. 2009, UNFCCC 2008, Lu 2006). AGB estimation using remotely sensed data has been explored during the past decades. This paper emphasizes more to elaborate the approaches for AGB estimation using of remotely sensed data.

2 Existing measurement methods of AGB

2.1 Field/In situ measurements

The most direct way to measure AGB is harvesting trees, drying them and then weighing the biomass. Other includes sampling measurements that do not require harvesting trees, such as height and trunk diameter and uses allometry to extrapolate biomass. These measurements of forest biomass can be aggregated for a small sample area or extrapolated to wider levels using allometric equations. In situ measurements are critical to the monitoring of terrestrial carbon stock as they are labor-intensive, expensive and difficult to implement, especially in remote areas (Lu 2006). There also have several problems related to the measurement are incomplete data, inconsistent parameter definitions, inconsistent spatial and temporal scales and sampling bias in measurements (IGOS 2004).

2.2 Remote sensing measurements

Remotely sensed data, such as in repetitivity of data collection, a synoptic view, a digital format that allows fast processing of large quantities of data and the high correlations between spectral bands and vegetation parameters, make it the primary source for large area AGB estimation, especially in areas of difficult access. Therefore, remote sensing-based AGB estimation has increasingly attracted scientific interest.

2.2.1 Remote sensing data used in the studies for AGB estimation

Many studies have demonstrated that remote sensing data is successfully used for estimating AGB at various scales depending on study purpose and scope. A variety of remotely sensed data sources continue to be employed for biomass mapping including fine spatial-resolution data, such as IKONOS (Proisy et al. 2007) and QuickBird (Leboeuf et al. 2007) images are used for forest biomass estimation.

The most frequently used medium spatial-resolution data is the Landsat data, which have become the primary source in many applications, including AGB estimation at local and regional scales (Sader et al. 1989, Steininger 2000, Foody et al. 2003, Zheng et al. 2004, Lu 2005, Zheng et al. 2007, Barrett 2009). Data from other moderate spatial resolution sensors have also been used, including ASTER (Muukkonen and Heiskanen 2007) and Hyperion data (Kalacska et al. 2007).

Coarse spatial resolution data such as SPOT-VEGETATION and AVHRR (González et al. 2006, Tan et al. 2007) and MODIS (Baccini et al. 2004, Feng et al. 2007, Zhang and Kondragunta 2006, Muukkonen and Heiskanen 2007). To facilitate the linkage of detailed ground measurements to coarse spatial resolution remotely sensed data (e.g., MODIS, AVHRR, IRS-WiFS), several studies have integrated multi-scale imagery into their biomass estimation methodology and incorporated moderate spatial resolution imagery (e.g., Landsat, ASTER) as an intermediary data source between the field data and coarser imagery (Tomppo et al. 2002, Zheng et al. 2007, Muukkonen and Heiskanen 2007).

Numerous studies used Synthetic Aperture Rader (SAR) data to map AGB (Kasischke et al. 1997, Tatem 2008). Lucas et al. (2004) and Kasischke et al. (2004) reviewed SAR data for AGB estimation in tropical forests, temperate and boreal forests respectively. Sun et al. (2002) used multi-polarization L-band SAR data for AGB estimation of forest stands in mountainous areas. Light Detection and Ranging (Lider) has only been widely used for a little more than a decade. Several studies used lider data for stand attributes and then used these attributes as input for allometric biomass equations (Lefsky et al. 2005, Bortolot and Wynne 2005, Popescu 2007, McRoberts and Tomppo 2007). Several benefit and limitation of the remote sensing data related to AGB estimation is listed in table 1.

2.2.2 Methods/techniques used to predict/estimate AGB from different studies

Stand level biomass is frequently calculated from linear regression and nonlinear regression models established by species/type with field measurements. These models are accurate for at tree, plot and stand levels. They are limited when considering spatial pattern analysis of AGB across the landscape. In order to scale AGB estimate to the landscape level, the estimates have to be linked with various vegetation indices or reflectance derived remote sensing data. Numerous models have been developed to estimate AGB for different regions using remote sensing data. Some of are discussed bellow.

Zheng et al. (2004) used Landsat ETM+ imagery for northern Wisconsin for AGB estimation. They used reflectance of six ETM+ bands to generate five vegetation indices including i) ratio of blue and red ii) Normalized Difference Vegetation Index (NDVI) iii) Simple Ratio (SR) iv) Modified Soil Adjusted Vegetation Index (MSAVI) v) corrected NDVI for statistical model development. Field data collected from different cover types and age groups (mature, intermediate, young) and then AGB was calculated. Incorporating stand age as a predictor with the reflectance and the vegetation indices statistical models was developed for the cover types to calculate AGB from ETM+ imagery.

AGB = 48. 8*(NIR/red)+2. 3 *Age-454*MAS VI-3 8, $r2$ 0.82 (for overall--mixture of shrub, sparse trees)

AGB = 111 *(NDVIc$^{10.3}$/ (NDVIc$^{10.3}$ +.0.351 0 . 3), $r2$ 0.86 (for pine)

AGB = 23.2*NIR+2.7*Age-71, $r2$ 0.95 (for Hardwood)

They found, Hardwood forest AGB was strongly correlated to NIR reflectance and strong age using a linear model. AGB for pine forests was strongly related to NDVIc using a sigmoidal model. They also found, classification system developed using age groups for separating the AGB was more successful which was difficult through traditional classification system. Error in AGB calculation in this study could be associated with the accuracy of land cover map, sampling error, soil color reflection, species composition and model utilization they mentioned.

Mani and Parthasarathy (2007) estimated AGB in the ten permanent sample plots of inland and coastal areas of tropical dry evergreen forests of peninsular India. Two linear regression equations one using basal area (BA) and the other using BA and height were employed to estimate AGB of all trees in these areas. Murali et al. (2005) developed AGB calculation equations from the destructive harvest survey for the area were used by the study.

$$AGB = -12.05+0.876(BA),\ r2\ 0.98 \quad (1)$$

$$AGB = 11.27+6.03(BA)+1.83(H),\ r2\ 0.94 \quad (2)$$

They found the relationship between BA and AGB obtained a positive correlation for all sites of inland and coastal areas of the forest. The methods used for AGB estimation yielded a little variation between them with the exception of four sites that yielded greater values by using Method 2, which can be assigned to the relatively taller forest of these sites than the others they mentioned. BA values of this study provide an effective estimate of AGB in tropical dry evergreen forests in comparison to the other related studies they mentioned.

Muukkonen and Heiskanen (2007) utilized ASTER and MODIS datasets for three 8-day periods for estimating AGB in boreal forest of southern Finland. They employed non linear regression models developed by Muukkonen and Heiskanen (2005) for the area. Stand wise forest inventory data and stand wise averages of ASTER data were used for trees and all forest vegetation for AGB estimation. The models based on small study area which were utilized with MODIS data for large area.

$$AGB(trees) = exp(26.80).(1+RED)^{-2877.39}.NIR^{7.09}\ X\ exp(2739.64.RED).exp(-42.73.NIR),\ r2\ 0.56$$

$$AGB(allvegetation) = exp(26.29).(1+RED)^{-2907.02}.NIR^{6.09}\ X\ exp(2739.64.RED).exp(-42.73.NIR),\ r2\ 0.56$$

Using red and NIR reflectance as predictor, regressions were applied to the MODIS reflectance data in order to estimate AGB. They found three 8-day MODIS composites demonstrate the differences in the estimation accuracy are relatively large comparison with the National Forest Inventory (NFI) stand volume measurements. The estimation errors are considerably lower when using the average of three composites instead of the single datasets. The inaccuracy in radiometric correction of the atmospheric effects between the datasets is the probable reason for the differences they identified.

Zheng et al. (2008) used Landsat ETM+, MODIS and forest inventory data to estimate forest AGB across six states of New England, USA. Raw bands of Landsat.

was converted to reflectance and used to generate three vegetation indices i.e. NDVI, SR, NDVIc. To calculate AGB values within ETM+ scene were directly coupled with reflectance in six bands (blue, green, red, near infrared, and two middle infrared channels), three vegetation indices, DEM and recorded stand ages for the plots. Spectral calibrations were conducted between ETM+ and MODIS 1 km resolution data to minimize the spatial and spectral differences between two sensors. Unlike the other studies they found good relationship between AGB observation and simple ratio of the reflectance in NIR and red bands. They used AGB means derived from forest inventory plots to adjust MODIS based AGB estimates with a ratio map. A multiple regression model was developed using stepwise regression approach for AGB calculation and employed to the mask areas of forest from MODIS. They found stand age, NDVIc and blue reflectance are the best combination for estimating AGB in the study area.

$$AGB = 392.11*NDVIc+1.27*AGE+1173.35*BLUE-260.95, (r = 0.619)$$

They found small errors at the state level which is desirable information for large scale related studies and well represented in comparison to the forest inventory data.

Several researches has demonstrated that it is more effective to generate relationships between field measures and moderate spatial resolution remotely sensed data (e.g., Landsat, ASTER) and then extrapolates these relationships over larger areas using comparable spectral properties from coarser spatial resolution imagery (e.g., MODIS). Following this approach alleviates the difficulty in linking field measures directly to coarse spatial resolution data.

Lu (2005) employed Landsat TM imagery in five study area (Altamira, Pedras, Bragantina , Machadinho, Machadinho) of eastern and western Brazilian Amazon for AGB estimation. This study aimed to explore the textures and spectral responses for improvement of AGB estimation performance based on different biophysical environments in the Brazilian Amazon.

This study analyzed the complexity of the forest stand structure using different parameter, such as tree height, diameter at breast height (dbh) and crown size. It is found that two of the study area belongs to the extremes in the complexity of forest stand structure and soil conditions. AGB is used to compare the complexity of forest stand structures between successional and mature forests to explore the impacts of different complexity of forest stand structures on AGB estimation.

Textures are found weakly correlated with successional forest biomass, but some textures significantly correlated with mature forest biomass. Conversely, TM spectral signatures are significantly correlated with successional forest biomass, but weakly correlated with mature forest biomass of the study area.

Filed sample data were linked to image variables to extract the mean value for each sample. After the image values for these samples were extracted, Pearson's correlation coefficient was used to analyze relationships between AGB and remote sensing derived variables, including TM spectral signatures, vegetation indices, and textures. Field AGB, remote sensing variable and a stepwise regression analysis was used to develop AGB estimation models. Several combinations of spectral responses and textures are explored based on various biophysical conditions.

Spectral responses

Altamira 249.892 - 2202.045 ND54, *R*2 0.404

Pedras 95.196- 25.852 TM5, *R*2 0.683

Bragantina 68.116-21.832 TM4, *R*2 0.701

Machadinho (Successional forest) 66.772 -21.392 TM4, *R*2 0.746
Machadinho (Mature Forest) 102.414 - 25.496 TM5, *R*2 0.158

Textures

Altamira 89.4612151.495 VARtm2_9, *R*2 0.708

Pedras 35.10926.455 KUtm3_5, *R*2 0.493

Bragantina 21.03823.766 VARtm5_15, *R*2 0.304

Machadinho (Successional forest) 16.46220.227 VARtm4_15, $R^2$0.232

Machadinho (Mature Forest) 13.457 + 1.929 CONtm5_19, *R*2 0.392

Combination of spectral and texture

Altamira 122.28821.078 KT12128.913 VARtm2_9, *R*2 0.772

Pedras 65.239210.189 TM723.816KUtm3_5, *R2* 0.748

Bragantina 64.03721.651 TM4+ 1.405 SKtm4_9, *R2* 0.780

Machadinho (Successional forest) 48.08220.806 TM420.098 VARtm4_15, *R2* 0.755

Machadinho (Mature Forest) 75.33 124.321 TM5+ 1.789 CONtm5_19, *R2* 0.498[2]

Although no validation or accuracy assessment of the AGB estimation result is conducted, the author found the result is satisfactory after visually checking the spatial distribution of the AGB estimation.

Comparing the spectral responses used in the eastern Amazon, the AGB estimation has best performance in Bragantina with relatively simple stand structure and poorest in Altamira with complicated forest stand structure. Conversely, comparing the textures used in this study, the AGB estimation has best performance in Altamira and poorest in Bragantina. Considering the AGB estimation performance between successional and mature forests in the western Amazon, the spectral signature provides better AGB estimation performance for successional forest than for mature forest, but the converse for the textures. A combination of spectral and textural features improves the AGB estimation performance. The role of textures in improving the AGB estimation performance is more important in Altamira than in Bragantina, also texture is critical for mature forest biomass estimation, but relatively less important for successional forest biomass estimation.

This study demonstrates that Landsat TM image is more successful for AGB estimation in successional forests than in mature forests. Textures play an important role in improving AGB estimation performance, especially for those sites with complicated forest stand structure. A combination of spectral responses and textures improves AGB estimation performance comparing pure spectral responses or textures.

Labrecque et al. (2006) used polynomial and multiple linear regressions of raw Landsat bands and derived vegetation indices to predict aboveground biomass in Newfoundland, Canada. They found that for a single regression equation for all forested areas, the model that explained the most variation was the one that incorporated only the raw Landsat bands. For three study sites, Foody et al. (2003) found that multiple regressions with raw Landsat TM bands explained at least as much and generally more of the variation in tropical forest biomass as did derived vegetation indices. In Yellowstone National Park, Jakubauskas and Price (1997) found that multiple regression models of biomass from derived spectral indices did not greatly improve predictions of aboveground biomass over models using only raw Landsat TM bands. In contrast, many studies have demonstrated that the inclusion of derived spectral indices and biophysical variables, in addition to raw spectral bands, can improve biomass predictions. Hall et al. (2006) used Landsat ETM+ data to model aboveground biomass in Alberta, Canada, and found that the additions of modeled stand height and crown closure as predictor variables significantly improved model error over spectral-only models.

In Sweden, Fazakas et al. (1999) used a k-NN approach to model tree biomass using raw Landsat TM bands, and found that the RMSE was inversely related to the scale of the validation data. In one application of Gradient Nearest Neighbor (GNN), Ohmann and Gregory (2002) found that ancillary biophysical data, such as elevation and climate data, can aid in the prediction of vegetation variables across large study areas with strong biophysical gradients. In another application, Pierce et al. (2009) found that GNN was accurate for predicting large groups of forest structural attributes at the regional scale and maintaining covariance among the response variables.

Blackard et al. (2008) used a regression tree approach to develop a national aboveground biomass map using MODIS imagery and ancillary data for the conterminous U.S. Several recent studies have demonstrated the utility of Random forest (RF) regression approach for prediction of forest attributes, including successional stage (Falkowski et al. 2009), tree species distribution (Prasad et al. 2006).

Table 1. Benefits and limitations of available methods to estimate national-level forest carbon stocks.

Method	Description	Benefits	Limitations	Uncertainty
Optical remote sensors	• Uses visible and infrared wavelengths to measure spectral indices and correlate to ground-based forest carbon measurements • Ex: Landsat, MODIS	• Satellite data routinely collected and freely available at global scale • Globally consistent	• Limited ability to develop good models for tropical forests • Spectral indices saturate at relatively low C stocks • Can be technically demanding	High
Very high-res. airborne optical remote sensors	• Uses very high-resolution (~10–20 cm) images to measure tree height and crown area and allometry to estimate carbon stocks • Ex: Aerial photos, 3D digital aerial imagery	• Reduces time and cost of collecting forest inventory data • Reasonable accuracy • Excellent ground verification for deforestation baseline	• Only covers small areas (10 000s ha) • Can be expensive and technically demanding • No allometric relations based on crown area are available	Low to medium
Radar remote sensors	• Uses microwave or radar signal to measure forest vertical structure • Ex: ALOS PALSAR, ERS-1, JERS-1, Envisat)	• Satellite data are generally free • New systems launched in 2005 expected to provide improved data • Can be accurate for young or sparse forest	• Less accurate in complex canopies of mature forests because signal saturates • Mountainous terrain also increases errors • Can be expensive and technically demanding	Medium
Laser remote sensors	• LiDAR uses laser light to estimates forest height/vertical structure • Ex: Carbon 3-D satellite system combines Vegetation canopy LiDAR (VCL) with horizontal imager	• Accurately estimates full spatial variability of forest carbon stocks • Potential for satellite-based system to estimate global forest carbon stocks	• Airplane-mounted sensors only option • Satellite system not yet funded • Requires extensive field data for calibration • Can be expensive and technically demanding	Low to medium

Source: Gibbs et al. 2007

2.3 GIS-based modeling

GIS-based modeling using ancillary data exclusively, such as climate normal, precipitation data, topography, and vegetation zones is another approach to biomass estimation (Brown et al. 1993, Brown 1997). Some studies have also used geostatistical approaches (i.e., kriging) to generate spatially explicit maps of AGB from field plots (Monserud et al. 2006, Sales 2007) or to improve upon existing biomass estimation (Rahman et al. 2005). More commonly, GIS is used as the mechanism for integrating multiple data sources for biomass estimation (e.g., forest inventory and remotely sensed data) (Feldpausch et al. 2006, Meng et al. 2007, Cihlar 2007). MODIS, JERS-1, QuickSCAT, SRTM, climate and vegetation data have been

combined to model forest AGB in the Amazon Basin (Saatchi et al. 2007). Similarly, a combination of MODIS and ancillary data (precipitation, temperature, and elevation) has been used to model AGB over large areas (Baccini et al. 2004).

3 Consistent tropical forest biomass measurements

A key technical challenge for successful implementation of mechanisms such as REDD is the reliable estimation of AGB and carbon stocks in tropical forest biomass. Reliable estimation of AGB depends on a number of sampling factors, including sampling of spatial variability, determination of forest structural allometry and knowledge or determination of tree wood density (referred to in the literature also as 'wood specific gravity' (WSG)). Wood specific gravity is an important factor in converting forest volume data to biomass (Fearnside 1997).

Sampling a sufficient number of trees to represent the species and size distribution in a forest (particularly in a highly diverse tropical forest) to generate information on local or regional WSG is a time consuming and costly exercise. For tropical regions, however, published data on WSG are frequently limited to a relatively small number of commercial timber species that often only represent a fraction of the forest biomass. WSG data on other species are very scarce or completely lacking.

Height and diameter are the most common dependant variables to develop allometric equations to calculate AGB. However, height is relatively difficult to measure for individual trees in tropical forests and the most practical allometric models for tropical forestry are generally based on tree diameter alone (Williams and Schreuder, 2000; Alder and van Kuijk, 2009).

From above described studies, we know there is little consensus on which statistical method or set of predictor variables is the most robust across a range of forest conditions. Model transferability is a major concern after models are developed but, in reality, it is often difficult to transfer one model developed in a specific study area to other study areas because of the limitation of the model itself and the nature of remotely sensed data (Lu 2005). Foody et al. (2003) discussed the problems encountered in model transfer. Many factors, such as uncertainties in the remotely sensed data (image preprocessing and different stages of processing), AGB calculation based on field measurements, the disparity between remote sensing acquisition date and field data collection date and the size of sample plot compared with the spatial resolution of remotely sensed data, could affect the success of model transferability (Lu 2006). Each model has its limitation and optimal scale for implementation.

It is realized that most biomass models or regressions were developed for specific locations, therefore application of these models at other location rather then their originals could generate errors in biomass estimation.

Chave et al. (2004) provide an overview of error propagation for tropical forest biomass estimates.

They identify four types of uncertainty associated with AGB estimates:

- error due to tree measurements

- error due to the choice of an allometric model relating AGB to other tree dimensions
- sampling uncertainty
- representativeness of small plot networks across the vast forest landscape

They find that the most important source of error is related to the choice of allometric model. Also the methods tends to underestimate carbon stocks in tropical forests where optical satellites are less effective due to dense canopy closure and has been unsuccessful in generating broad or transferable relationships (Gibbs et al. 2007).

Most studies on tropical forest AGB have been conducted in the Brazilian Amazon and in South-East Asia. There is an urgent need for improved and more accurate methods of determining tropical forest biomass and its spatial distribution in general.

4 Conclusions

Satellite based methods are very important for quantifying the AGB and reliable for mapping carbon stocks over large area. Commonly used methodologies and approaches has been discussed but there are a number of other approaches exist.

Traditional techniques based on field measurement are the most accurate ways for collecting biomass data. A sufficient number of field measurements are a prerequisite for developing AGB estimation models and for evaluating the AGB estimation results. However, these approaches are often time consuming, labour intensive, and difficult to implement, especially in remote areas; also, they cannot provide the spatial distribution of biomass in large areas.

Remote sensing techniques have many advantages in AGB estimation over traditional field measurement methods and provide the potential to estimate AGB at different scales. The user's need, the characteristics of remotely sensed data, the scale of the study area and the availability of economic support have important influences on the design of an AGB estimation procedure. Fine spatial-resolution data, such as airborne aerial photographs and space borne IKONOS images, may provide accurate AGB estimation at a local scale. Medium spatial-resolution data, such as Landsat TM, provide the potential for AGB estimation at a regional level, but the mixed pixels problem in AGB estimation in those sites with complex biophysical environments. The coarse spatial-resolution data, such as AVHRR or MODIS, may provide AGB estimation at a national or global scale, but have not yet been used extensively because of the difficulty in linking coarse spatial-resolution data and field measurements. A combination of multi-scale remotely sensed data, from coarse, to medium, to fine spatial resolutions, may improve AGB estimation accuracy at the national or global scale.

Remote sensing-based AGB estimation is a complex procedure in which many factors, such as atmospheric conditions, mixed pixels, data saturation, complex biophysical environments, insufficient sample data, extracted remote sensing variables, and the selected algorithms, may interactively affect AGB estimation performance.

GIS-based methods using ancillary data are also difficult because of problems in obtaining good quality ancillary data, indirect relationships between AGB and ancillary data and the comprehensive impacts of environmental conditions on AGB accumulation. Hence, GIS-based approaches have not applied extensively for AGB estimation.

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Methodology/Protocol for Measurement & Estimation of Carbon Stocks in Mangrove Forests

(Adopted from the Carbon Assessment Protocol for Sundarbans Mangrove Forest of Bangladesh)

Purpose and Scope

This document outlines the rationale, design, field measurement, analysis, and reporting required for forest carbon assessments. The focus is on mangroves but, with minor adaptations, the approaches generally apply in other wetland forests as well. Further, most of the general principles and approaches presented here apply to any forest type.

Although there are a number of suitable methods for measuring forest carbon stocks, the focus here is to adapt international standards as per guidelines of the Intergovernmental Panel on Climate Change (IPCC) and relevant sourcebooks. The aim is to provide instruction on field measurements and computations that will support entry into regulatory or voluntary carbon markets at a high tier. However, it should be noted that the technical aspect of quantifying forest carbon is but one of several elements of carbon accounting schemes. These other important elements include social, political, and economic factors—for example, addressing permanence, leakage, governance, etc.—and are not covered here. Definitions and information on those topics can be found in the IPCC guidelines and associated sourcebooks.

Essential Sources

Several sourcebooks provide the specific field methods and computations presented here, including GOFC-GOLD (2009), Pearson et al. (2005), Pearson et al. (2007), and the IPCC Good Practice Guidance for Land Use, Land-Use Change, and Forestry (2003) and IPCC Guidelines for National Greenhouse Gas Inventories (2006). These sources are relied on heavily here and several passages are inserted directly from them. Nevertheless, modification of these guidelines is necessary in some cases due to the uniquely challenging nature of sampling mangrove forests.

International guidelines and standards for carbon inventories evolve over time. Many of the relevant sourcebooks are 'living documents' that change as guidelines and standards change. Moreover, these documents contain significantly greater detail on options and rationale for carbon monitoring methodologies. These large documents have been distilled here based on the authors' experience of quantifying carbon in Asian-Pacific mangrove forests. Therefore, it is important for project personnel to read and keep updated on these guideline documents (see References for detailed citations).

Introduction

The general principle of a forest carbon project is to reduce greenhouse gas emissions (e.g., carbon dioxide, or CO_2) from the forest sector. Forests store carbon, and deforestation and forest degradation in developing countries currently account for nearly 20% of global greenhouse gas emissions. Thus, reducing these trends may help mitigate climate change, in addition to conserving other ecosystem services provided by forests.

Carbon markets, in which payments are made to governments or other organizations for conserving forest carbon, are considered a promising mechanism where objectives include reducing deforestation and degradation. These markets come in various forms (e.g., regulatory versus voluntary), but most have some basic principles in common. Most relevant to this protocol is that carbon storage/emissions over a project area must be quantified for three time periods: the **past**, the **presen**t, and the **future**.

The past rate of carbon loss from the project area is estimated (e.g., for the past 10-20 years), the current carbon stock is estimated, and the future trend in carbon storage is projected based on the historic deforestation/degradation rate. The carbon project implements conservation measures that, ideally, reduce the rate of carbon loss compared to the historic rate, or the 'baseline.' Over time a monitoring program evaluates whether there has actually been any reduction in the rate of carbon loss. This difference, or 'additionality,' is the value traded in carbon markets.

This protocol emphasizes field methodologies for assessing current forest carbon stocks. However, the same analysis techniques apply to assessing past and future carbon stocks, thus allowing the use of ground data in support of all phases of a carbon project.

For the proposed carbon (C) assessment in the mangroves of South Asia, this document aims to provide a general conceptual background as well as specific, detailed instructions for the collection and analysis of field C data. Specific suggestions for overall sampling design, plot layout, and measurements are provided based on the authors' experience measuring C in Asian-Pacific mangroves. Other options are available and may well be perfectly adequate; these are mentioned in brief in this document. Project personnel may choose to adapt the specific methods according to their local knowledge, resource constraints, other data collection needs, or the evolving nature of IPCC and related sourcebook guidelines.

Conceptual basis

Tracking C Stocks, Deforestation & Forest Degradation

Carbon stocks are the combined storage of carbon in terrestrial ecosystems. In simplified terms, forest carbon accounting tracks changes in carbon stocks due to conversions between intact forests, non-intact (or degraded) forests, and other land uses (Figure 1). Relevant definitions are found in GOFC-GOLD (2009); the most important are repeated here from that source:

Forest is generally defined as having a minimum area of 0.05 – 0.1 hectare (ha), canopy height of 2 – 5 meters (m), and minimum tree crown cover of 10 – 30%. There is some flexibility in how countries define forest, depending on local circumstances.

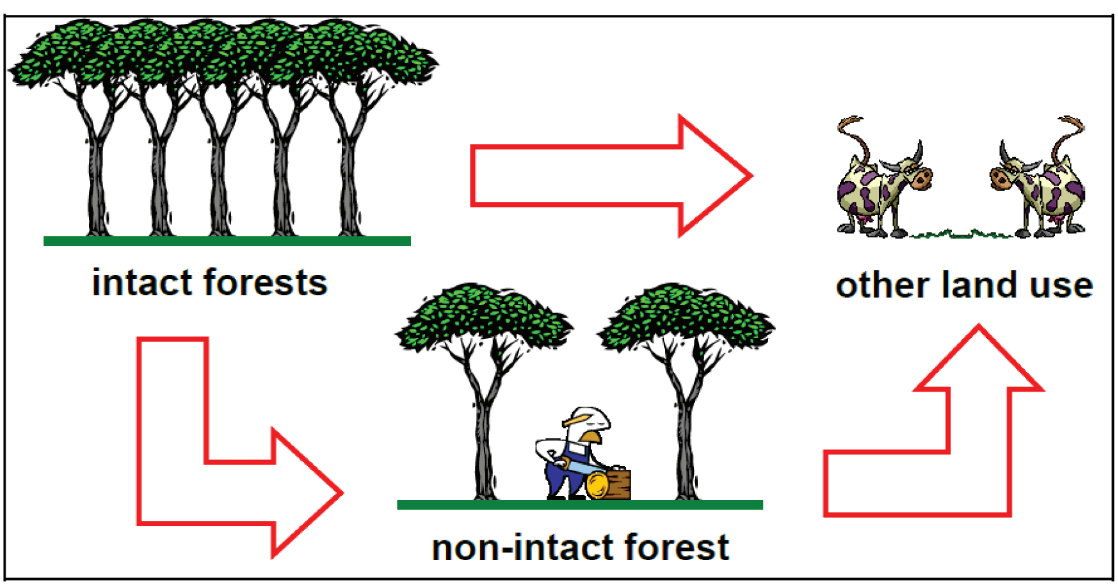


Figure 1. *Forest conversion types considered in a carbon accounting system. Adapted from GOFC-GOLD (2009). See text for definition of terms.*

Intact Forest: Fully stocked forest, undisturbed by timber extraction activities. Patches of forest that are not damaged or immediately surrounded by small clearings; forests without gaps caused by human activities.

Non-Intact Forest: Forest that meets at least the minimum criteria for 'forest' (see above), but is degraded by any of the following: canopy gaps created by logging operations, log landings where logs were stored and bare soil is exposed, logging roads which may be 3-5 m wide, etc. Not fully stocked.

Non-Forest (Other Land Use): Land not meeting the minimum criteria for forest cover.

Deforestation: Long-term or permanent conversion of land from forest to other non-forest uses.

Forest Degradation: General term for reductions in crown cover, tree density, or tree biomass (and thus carbon stock) that do not qualify as deforestation.

Two types of data:

Carbon inventorying requires two types of data namley, activity data and emission factors. Activity data refer to the landscape coverage of different land uses, such as forest, agricultural land, grassland, or settlements, and the degree of transfer between them. For example, activity data may show that, during a certain time period, X number of hectares were converted from forest to agricultural land (deforestation). Activity data usually rely heavily on remote sensing analyses to classify land use types and to track changes between them over time. Activity data are not a primary focus of this protocol.

Emission factors refer to changes in various carbon pools of a forest. Changes may occur due to conversion between different land uses (e.g., deforestation from forest cover to agricultural land), or due to changes within a land use type (e.g., forest degradation due to selective logging). The methods in this document support the quantification and monitoring of emission factors based on ground data on carbon pools.

Generalized Steps to a Forest Carbon Accounting System

1. Establish the baseline (historic rate of reduction in forest carbon stocks due to deforestation and degradation)

2. Quantify current forest carbon stocks

3. Project future forest carbon stocks/emissions based on baseline rate (business as usual)

4. Monitor actual forest carbon stocks/emissions over time with conservation measures implemented; compare to baseline

This system requires both activity data and emission factors for past, present, and future time periods. Activity data is derived from remote sensing and other land cover information.

Emission factors are derived from broad assumptions on carbon pools and their changes, or from field data on carbon stocks/emissions. Field data, which are the focus of this protocol, support higher tier (more precise, higher value) carbon assessments.

Tiers of Carbon Assessment

Carbon stock information can be assessed at different Tier levels (Table 1). Tier 1 uses IPCC default values (i.e., biomass in different forest biomes, etc.) and simplified assumptions; it may have a large error range of +/- 50% or more, or +/- 90% for the variable soil carbon pool. Tier 2 requires some country-specific carbon data for key factors. Tier 3 requires highly specific inventory-type data of carbon stocks in different pools, and repeated measurements of key carbon stocks through time, which may also be supported by modeling.

Table 1. *Summary of tiers that may be used to assess carbon (C) emission factors. Adapted from GOFC-GOLD (2009).*

Tier	Requirements
1	IPCC default factors
2	Country-specific data for key factors
3	Detailed inventory of key carbon stocks, repeated measurements of key stocks through time or modeling

In general, higher tiers increase the accuracy and precision of estimates. The IPCC recommends that countries should aspire for Tier 3 where possible, and that it is a good practice to use higher tiers for the measurement of key carbon stocks/sources/sinks. Higher tiers produce more credible estimates and may support higher rates of carbon payment. On the other hand, Tier 3 is more costly to implement up front and is not always possible.

Tier 3 assessments may be most appropriate for the mangroves of South Asia. The measurements required for a typical forest resource inventory and a Tier 3 carbon inventory are generally quite similar.

Carbon assessments aim to estimate decreases in forest carbon stock, which is equated with emissions of CO_2 to the atmosphere. The two main approaches to this estimation are the stock-change approach and the gain-loss approach. The stock-change approach estimates the difference in carbon stocks at two points in time, while the gain-loss approach estimates the net balance of additions to and removals from a carbon stock. The stock-change approach is used when carbon stocks in relevant pools have been measured and estimated over time, such as in forest inventories. Thus, Tier 3 assessments often use stock-change methods. The gain-loss approach is used when annual data such as biomass growth rates and reliable data on wood harvests are available; these are more often used in Tier 1 and 2 assessments. However, in reality a mix of the two approaches may be part of any Tier assessment.

Note that, even if Tier 3 monitoring is not practical in the future due to financial constraints, establishing a credible benchmark estimate of carbon storage in a project area will allow future assessments to be conducted on at least a Tier 2 rather than Tier 1 level.

Project Design Aspects

Inventory and Reporting Principles

Good practice in carbon inventorying includes five general principles which should guide the estimation and reporting of forest C stocks and emissions: Transparency, Consistency, Comparability, Completeness, and Accuracy (GOFC-GOLD 2009).

Transparency – All assumptions and methodologies used in the inventory should be clearly explained, well justified, and appropriately documented, so that anybody could verify its correctness. All data should be well managed, tracked, and documented with meta-data (information explaining the data) to ensure transparency.

Consistency – The same definitions and methodologies should be used over time. This should ensure that differences between years and categories reflect real differences in emissions. Under certain circumstances, estimates using different methodologies for different years can be considered consistent if they have been calculated in a transparent manner. Thus, allowance is made for improvement of methods over time. The principle of consistency should be considered when assessing data available for the baseline, current C stocks, and future monitoring.

Comparability – Methods should be similar among countries. International standards as outlined in IPCC guidelines and relevant sourcebooks should therefore be followed.

Completeness – Estimates should include—for the relevant geographical area—all relevant pools. When gaps exist, all relevant information and justification on these gaps should be documented in a transparent manner.

Accuracy – Estimates should be systematically neither over or under the true value, so far as can be judged, and uncertainties should be reduced so far as is practical. Appropriate methods should be used to promote accuracy in inventories and to quantify uncertainties in order to improve future inventories. The subprinciple of *conservativeness* is an important part of accuracy; it means that reductions in forest C emissions should, if anything, not be overestimated, or at least the risk of overestimation should be minimized.

For guidelines on reporting in a manner consistent with these principles, it is strongly recommended that Chapter 4 of GOFC-GOLD (2009) be read thoroughly and its suggestions followed, particularly the guidelines for reporting tables and inventory reports on pages 4-175 through 4-178.

Sampling rationale

Because not every tree or land parcel in a project area can be measured, sampling must be employed. Sampling is the process by which a subset of points or plots is studied in order to allow generalizations about the whole area of interest. Values attained from measuring a sample are an estimation of the equivalent value for the entire area. In order to evaluate how close the estimation is to reality, statistics are used (Pearson et al. 2005).

The two most relevant statistical concepts to know are accuracy and precision (Figure 2):

Accuracy is how close the sample measurements are to the true value. Good Practice Guidelines state that carbon estimates must strive for the highest accuracy possible, such that estimates are neither over- or underestimates (i.e., bias is avoided). For this reason, location of sample points must be effectively random within the study area.

Precision relates to the level of agreement among repeated measurements of a quantity. This is represented by how closely grouped the results are from various sampling points or plots. In other words, precision reflects the level of variation around the mean estimate. High precision (low uncertainty) is an objective of carbon assessments. Determining the number of sample points is a crucial step since precision usually increases with the number of sample points. Precision and uncertainty are treated in quantitative detail in later sections.

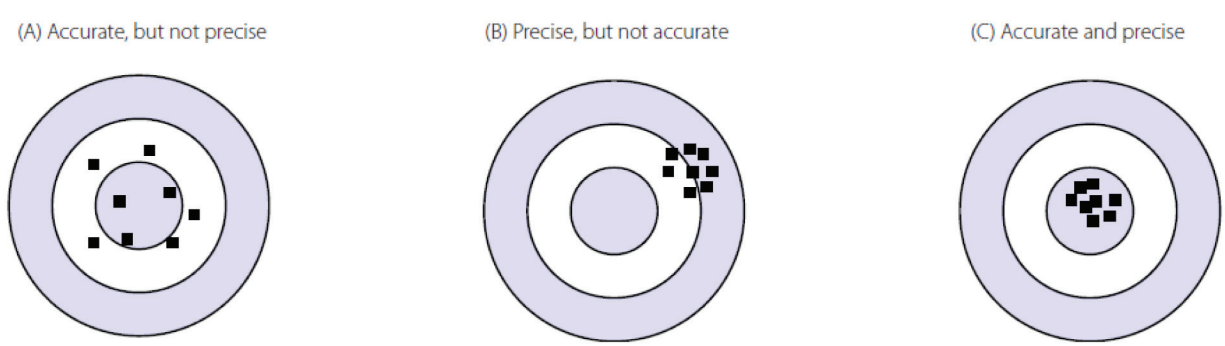


Figure 2. *Bull's eye target example of accuracy and precision. From Pearson et al. (2005).*

Developing a Measurement Plan

The steps to preparing a robust measuring plan can be summarized as in Figure 3. Each of these steps should be done in a transparent, consistent, well-justified manner.

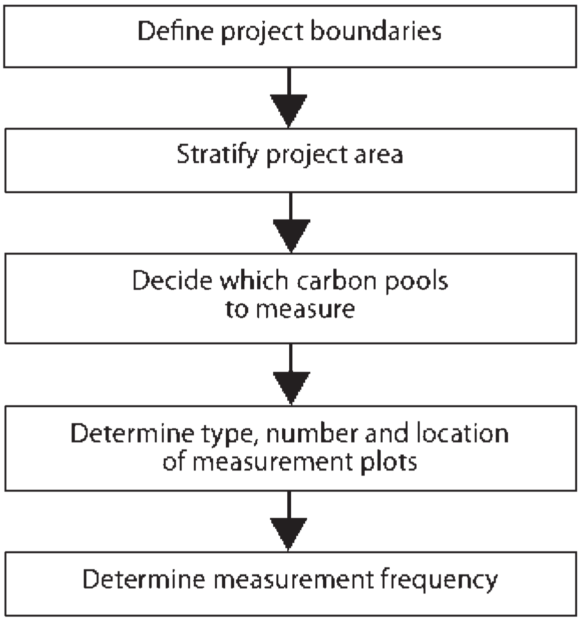


Figure 3. *Steps to preparing a measurement plan. From Pearson et al. (2005).*

1) Define the Project Area Boundaries

Spatial boundaries of the land under consideration need to be clearly defined and properly documented from the start to aid accurate measuring, accounting, and verification. Use GPS coordinates and/ or a map to achieve this. The specific requirements of this aspect may vary depending on the market mechanisms being sought. Some markets may only require a project-level carbon assessment for a specific land area as small as several hectares. Other markets, particularly emerging regulatory versions, may require national-level C assessments. In the latter case, a carbon assessment for mangroves would be one component of a larger national effort.

The aquatic portions of mangrove forests – the rivers and sea channels—are not considered with respect to carbon storage under current regulations or markets. Carbon accounting and markets are currently focused on terrestrial carbon stores only, particularly forests. This means that, for example, although the total area within SRF is ~601,700 hectares, only the ~412,000 hectares of actual land area are currently eligible for carbon accounting and carbon markets. This means that total carbon stocks in SRF need to be computed over the 412,000 hectares of land, not the 601,700 hectares of total area.

2) Decide on Stratification of the Project Area

In some cases it may be desirable to stratify the project area into subpopulations, or 'strata,' that form relatively homogenous units. Because each stratum should have lower variation within it, fewer plots may be needed to achieve the same level of precision. Useful tools for defining strata include ground-truthed maps from satellite imagery, aerial photographs, and maps of vegetation, soils, or topography. Stratification could be based on, for example, land use or vegetation type, but should be carried out using criteria that are directly related to the variables to be measured—for example, the carbon pools in trees (e.g., only stratify based on differences in tree species dominance if those differences relate directly to biomass/carbon stocks).

For Sundarbans, it is recommended that stratification should not be employed, for several reasons. First, an existing systematic sampling grid is already in place, with historic data available from those ground points. This will allow past, current, and future data to be evaluated in a consistent manner. Second, as long as a systematic sampling grid was started from a random point (which the SRF inventory grid was), that sample layout is considered the most rigorous and intuitive. Third, Sundarbans is a dynamic region, with short- and long-term changes in forest cover and biomass occurring due to changes in hydrology, sedimentation, disease, and human factors. Thus, a stratification employed today may not make sense in the future as vegetation communities and lands shift spatially.

3) Decide Which Carbon Pools to Measure

Most international standards divide forests into roughly five carbon pools: 1) aboveground and belowground biomass of live trees, 2) non-tree vegetation, 3) dead wood, 4) forest floor (litter), and 5) soil. Not all pools are required to be measured in every project; decisions can be made at the project level to streamline the effort involved in carbon assessment. A pool should be measured if it is large, if it is likely to be affected by land use, or if the land-use effects or size of the pool are uncertain. Small pools or those unlikely to be affected by land use may be excluded.

Trees are always included since they are relatively easy to measure, good scaling equations exist, and they are heavily affected by land use. The importance of non-tree vegetation varies depending on ecosystem; it may be important where shrubs, leafy palms, or bamboo are a large biomass component. Dead wood is often an important pool in mature forests. Forest floor varies but may be an important pool in mature forests. Soil organic carbon is difficult to measure and may be slow to change with land use, but it should be considered because it can be a very large pool and one susceptible to land use. Mangroves such as Sundarbans, in particular, often have deep organic-rich soils resulting in large carbon pools; these are technically mineral soils rather than peat soils in most cases. Thus, either stock-change or gain-loss methods may be applied for soil C.

For the SRF carbon assessment, final decisions for which pools to measure should be made by project personnel with knowledge of the ecosystem. An initial recommendation here is to measure trees, non-tree vegetation, dead wood, and soil. Trees are the most susceptible to land use activities, and soil may be the largest and most uncertain carbon pool in mangroves. Dead wood and non-tree vegetation may be a significant biomass component in SRF and may change significantly with logging activities. Forest floor is usually a minor or even negligible biomass component in Asian-Pacific mangroves; as SRF is similar, this pool has been excluded. In the case other mangrove in this region if it is similar to SRF then the pool may be excluded.

4) Determine Type, Number, and Location of Measurement Plots

Type— Permanent or Temporary:

Sourcebooks describe options for 'permanent' sample plots, in which all trees within plots are tagged and tracked through time, or 'temporary' sample plots, in which trees are not tagged. [Note that the latter plots are called 'temporary' even if they are permanently marked and revisited over time.] In the latter method, trees are treated like other C pools and are tracked at the plot level over time, rather than as individuals. Each method has its advantages and disadvantages (see sourcebooks for more detailed discussion), and the decision for approach is ultimately up to project personnel. In the interest of reducing time and logistical constraints imposed by mangrove field work, it is recommended here that trees are not tagged. Measurement and analysis guidelines in the remainder of this document follow this pattern.

Plot Shape:

The shape and size of sample plots is a trade-off between accuracy, precision, time, and cost for measurement. Plots can either be one fixed size or 'nested,' meaning that they contain smaller sub-units for various C pools. Nested plots are generally more practical and efficient in forests with a range of stem diameters and densities. The number of nests depends on the distribution of stem sizes in a given forest type. Plot nests can take the form of nested circles or rectangles (Figure 4). Circles have the advantage that the actual plot boundaries need not be measured. Only the center point need to be located correctly. There after, the plot boundary can be measure by used of a reliable distance measuring equipment.

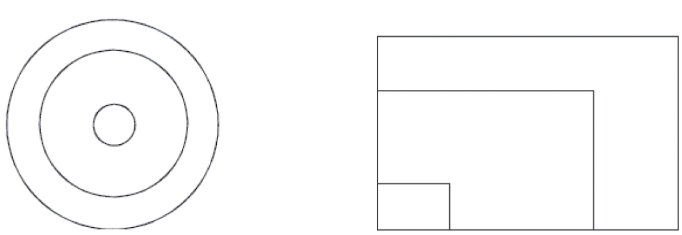


Figure 4. *Examples of circular and rectangular nested plots. Adapted from Pearson et al. (2005). High-frequency C pools (e.g. small trees) are measured in inner nests, while lower-frequency pools (e.g. large trees) are measured in outer large nests.*

Clustering:

Another consideration is whether, at a given plot, multiple sample units are clustered together, or if a single sample unit is employed. Many well established forest inventory programs, such as the United States' Forest Inventory and Analysis (FIA) program, use clustered sample units, commonly referred to as 'subplots.' Clustered plot designs tend to capture more microsite variation in vegetation, soils, etc., thereby reducing among-plot variation (increasing overall precision). Examples of clustered plot designs are shown in Figure 5.

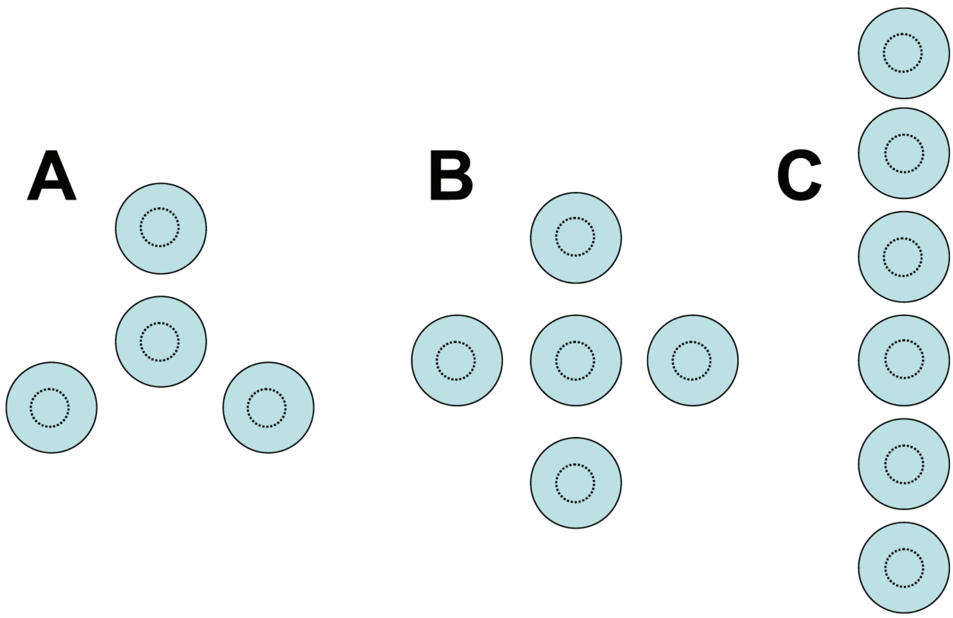


Figure 5. *Examples of clustered plot designs. The 'plot' is composed of a series of 'subplots' (blue circles). (**A**) and (**B**) are from the United States' Forest Inventory and Analysis (FIA), Forest Health Monitoring (FHM), and Current Vegetation Survey (CVS) programs (e.g., USDA 2008)—used for efficiently assessing larger ground areas and increasing overall precision. (**C**) is from the Indo-Pacific Forest C Study (Donato and Kauffman unpubl.)—used for assessing directional gradients, reducing species contagion, and increasing precision.*

For the SRF carbon assessment, a clustered plot composed of five circular subplots arranged as in option B in Figure 5 is recommended, thus taking advantage of the increased precision of clustered sampling, and the fact that this plot design was employed during the previous forest inventory for SRF. However a wide array of plot designs may be perfectly adequate depending on local knowledge and needs. Country specific clustered sampling for mangroves may be followed.

Number of plots:

It is important that sampling is carried out with statistical rigor. A key step is identifying the number of plots required to reach the desired precision level. An online tool for calculating the number of plots is available at: http://www.winrock.org/Ecosystems/tools.asp.

Typically the desired precision level is to target within 10% of the true value of the mean at the 95% confidence level. [95% confidence intervals are defined and treated quantitatively later in this document.] To estimate the number of plots required, some prior knowledge of the variation in carbon pools within the project area is needed—e.g., from a previous inventory if available, or from a preliminary sample of 6-10 plots. The variation in the tree pool captures most of the variation, so this can be used if that is the only available data (Pearson et al. 2007). Soil may be an exception, having its own variance that can be very large.

At the simplest level, the number of plots required should be calculated by:

Equation for number of sample plots

Minimum number of sample plots (n) = $\left(\frac{t^{*}s}{E}\right)^2$

n = the number of sample plots,
t = the sample statistic from the t-distribution for the 95% confidence interval; t usually is set at 2 as sample size is unknown at this stage,
s = standard deviation expected or known from previous/initial data,
E = allowable error or the desired half-width of the confidence interval. Calculated by multiplying the mean carbon stock by the desired precision, i.e., mean * 0.1 (for 10 percent precision)

Other, more complex equations are also available to estimate the minimum number of plots; see Pearson et al. (2007) for treatment of these options. Note that, if stratification of the project area is employed, the determination of number of plots must be conducted for each stratum.

The minimum sample size should be increased by about 10 percent to allow for plots that cannot be relocated or are lost due to unforeseen circumstances.

As an example, assuming the standard deviation is very high, perhaps 60% of the mean, or 180 Mg ha^{-1} (a conservative approach since it is likely not that high), the above equation can be solved with an objective of 10% precision:

Minimum number of sample plots for Sundarbans (n_{SRF}) = $\left(\frac{2 * 180}{0.1 * 300}\right)^2$

= 144 plots

Example values are used only here, based on rough estimates and a conservative approach. This estimate may be refined based upon analysis of past inventory data.

Increasing this by 10 percent to allow for unforeseen circumstances yields an estimate of 158 plots. Thus, even if variation is very high, this number of plots should yield adequate precision for SRF.

Location:

Plot locations can be selected randomly or systematically (plot grid with random origin). Both approaches are defensible and tend to yield similar precision. However if some parts of the project area or strata have higher carbon content than others, systematic selection usually results in greater precision than random selection. Systematic sampling is also easily recognized as credible (Pearson et al. 2007).

Initial Recommendation for SRF:

The last SRF inventory, conducted in 1997, sampled approximately 1200 plots situated on a systematic grid at 1-minute intervals of latitude/longitude. Therefore, it is recommended here that the sampling grid be utilized, but using a systematic subsample. This approach should strike an acceptable balance between area coverage, precision, and practicality, while allowing past data to be leveraged. Moreover, the grid origin is an ecologically arbitrary point in lat/long space, so this grid can be considered a random, statistically rigorous sample. Out of 1200 sample plots of 1997 Sundarban inventory, every alternative plots towards longitudinal direction and every 2nd alternative plot towards latitudinal direction were selected. Thus a total of 155 plots were recommended for SRF and FD completed measurement accordingly in 2010.

Based on logistical constraints communicated by Bangladesh FD personnel, approximately 100-150 plots is the maximum number that can be sampled in a given census effort. This is still likely adequate for the C assessment (see above calculation) given local circumstances, and is similar to plot densities in difficult-access roadless areas that has been used by the United States' Forest Inventory and Analysis program. FD personnel have also expressed that ~300 plots may be needed to complete the forest resource inventory; this would be accomplished by either hiring additional crews or extending the census to a second dry season.

To facilitate these options, the original plot grid can be subsampled by selecting every second plot in both the x and y directions. This yields 295 plots (the full option). To attain a lower plot density, every second row of this new grid can be sampled; this yields 155 plots. Figure 6 and Table 2 illustrate these options, along with some smaller scale options. Thus, given limited resources, sampling can be conducted as a progression through the following options as resources allow (see Table 2):

- C assessment and inventory in one small pilot area.
- C assessment and inventory in one large pilot area.
- C assessment and inventory of entire SRF, 105 plots, all with soil samples.

- C assessment and inventory of entire SRF, 155 plots, all with soil samples.
- C assessment and inventory of entire SRF, 295 plots, half with soil samples.

Note that if the new subsample grid contains 'holes' where insufficient plots are located, plots could be added in a given area in a transparent, systematic manner.

Table 2. Options & resources needed for C assessment and forest inventory in SRF.

	1 small pilot study area	**1 large pilot study area**	**SRF combined inventory, low density**	**SRF combined inventory, med. density**	**SRF combined inventory, high density** (soil in only ½ of plots)
# plots	12	30	105	155	295
# plots in which soil is sampled	12	30	105	155	155
# soil samples to be analyzed	24	60	210	310	310
time needed	1 month	1 - 2 months	4 months	4 - 5 months	4 - 5 months
# crews	1	1 – 2	2	2 - 3	4
# crew members (not incl. guards)	6	6 – 12	12	12 - 18	24

5) Determine Measurement Frequency

Frequency of monitoring is a cost-benefit analysis and should be determined by the magnitude of expected change in carbon pools. Thus, the carbon dynamics of land use activities and measurement costs should be considered. Given the dynamics of forest processes, they generally are measured at intervals of 5 years (Pearson et al. 2005, 2007). For carbon pools that respond more slowly, e.g., soil, even longer periods can be used – perhaps 10 or even 20 years between censuses (sampling events). Note that a disadvantage of long periods between censuses is the risk of natural or anthropogenic disturbance, the effects of which may by missed with widely spaced monitoring intervals (Pearson et al. 2007). Also, in some cases, it may not be possible to claim market credits for pools not measured with at least a 5-year frequency (Pearson et al. 2005).

To determine that plots are representative of the entire project area, periodic checks should be made to ensure that the overall activity is performing in the same way as the plots. Field indicators of carbon stock changes or high-resolution satellite imagery can be used to accomplish this task (Pearson et al. 2007).

For Sundarbans and other mangroves, 5-year monitoring intervals for aboveground C pools, with soil sampling every other census (i.e., every 10 years) may be sufficient.

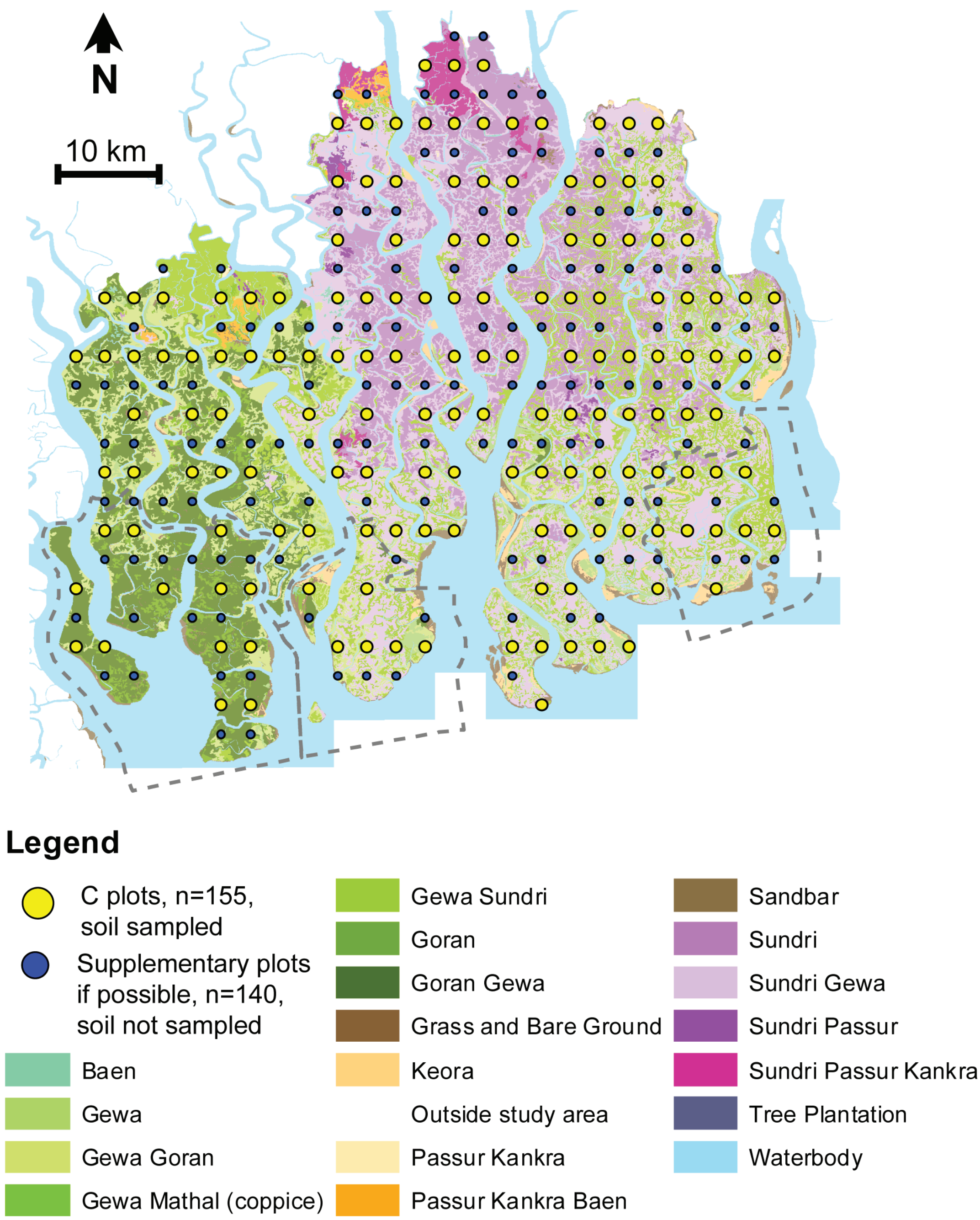


Figure 6. *Proposed sampling scheme for Sundarbans carbon and forest inventory. A systematic grid is employed, with 295 plots spaced at regular intervals of latitude/longitude.*

Gaps in the grid are due to watercourses. These plots are a systematic subsample of an existing inventory grid of ~1200 plots that were measured in the 1997, thus enabling past inventory data to be utilized for baseline comparisons.

Field Procedures

Unique considerations for measuring C in mangroves

Tides

Most mangroves are subject to semi-diurnal tidal cycles. Sampling of certain carbon pools, primarily the soil and surface materials, are only practical when the soil surface is exposed to the air. Thus, most stands must be sampled when the tide is low.

The "Rule of Twelfths" provides insight into the length of time available to sample. The change in water level during the tide changes in a predictably nonlinear pattern:

- During first hour after high water the water drops **1/12**th of the full range.
- During the second hour an additional **2/12**th.
- During the third hour an additional **3/12**th.
- During the fourth hour an additional **3/12**th.
- During the fifth hour an additional **2/12**th.
- During the sixth hour an additional **1/12**th.
- This pattern repeats as the tide rises again.

The sampling window generally last about 4 hours, in the time span bracketing the low tide (Figure 7). This short window necessitates an efficient sampling protocol.

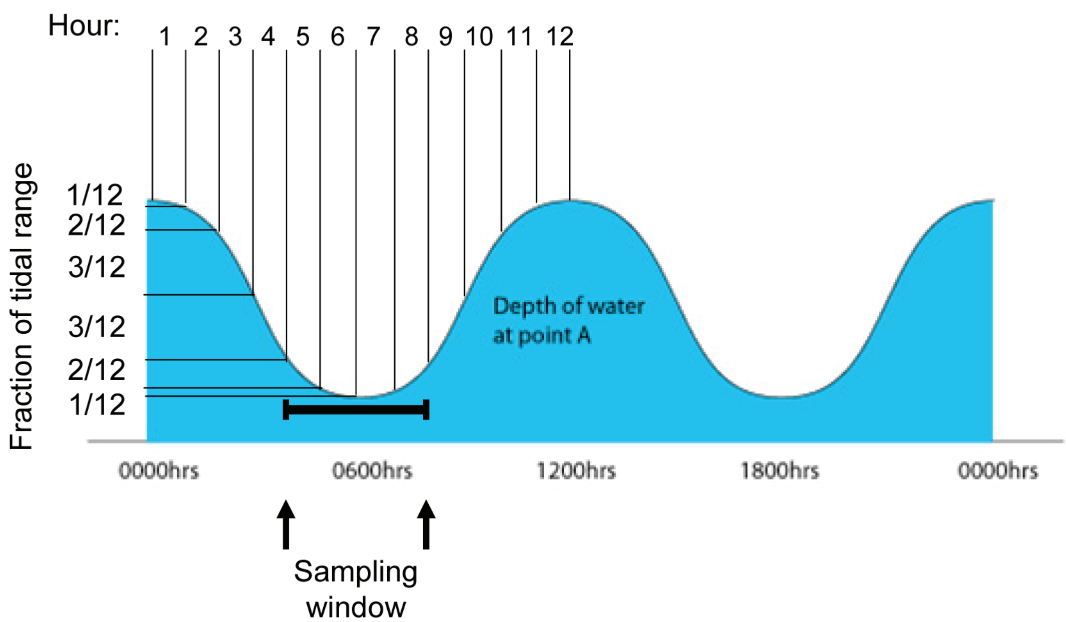


Figure 7. *Tides and the "Rule of Twelfths." A period of minimal change in water level occurs for ~2 hours on either side of low tide, creating a 4-hour sampling window.*

Plot Establishment and Layout

The plots are situated in a systematic grid across the Sundarbans Reserve Forest, at regular intervals of latitude and longitude (Figure 6). There are some gaps in the proposed sampling grid; these are a carry-over from the previous inventory and largely reflect where large water channels preclude forest measurements. If a grid point was not measured in previous inventory (gap in grid), it should not be measured now. Upon arriving at a mapped point, if it is in an open water channel for more than 200 m in every direction, do not establish a plot. If there is land within any part of the plot (i.e., any subplot), do measure the plot. Record the percentage of each subplot occupied by water canals on the understory/canopy cover datasheet.

Plot Layout

The plot consists of 5 circular subplots, oriented as a center subplot with four more subplots oriented in cardinal directions from the center (east, west, south, north) (Figure 8). Different forest components are measured in different size circles ('nests'), co-located at the center of each subplot.

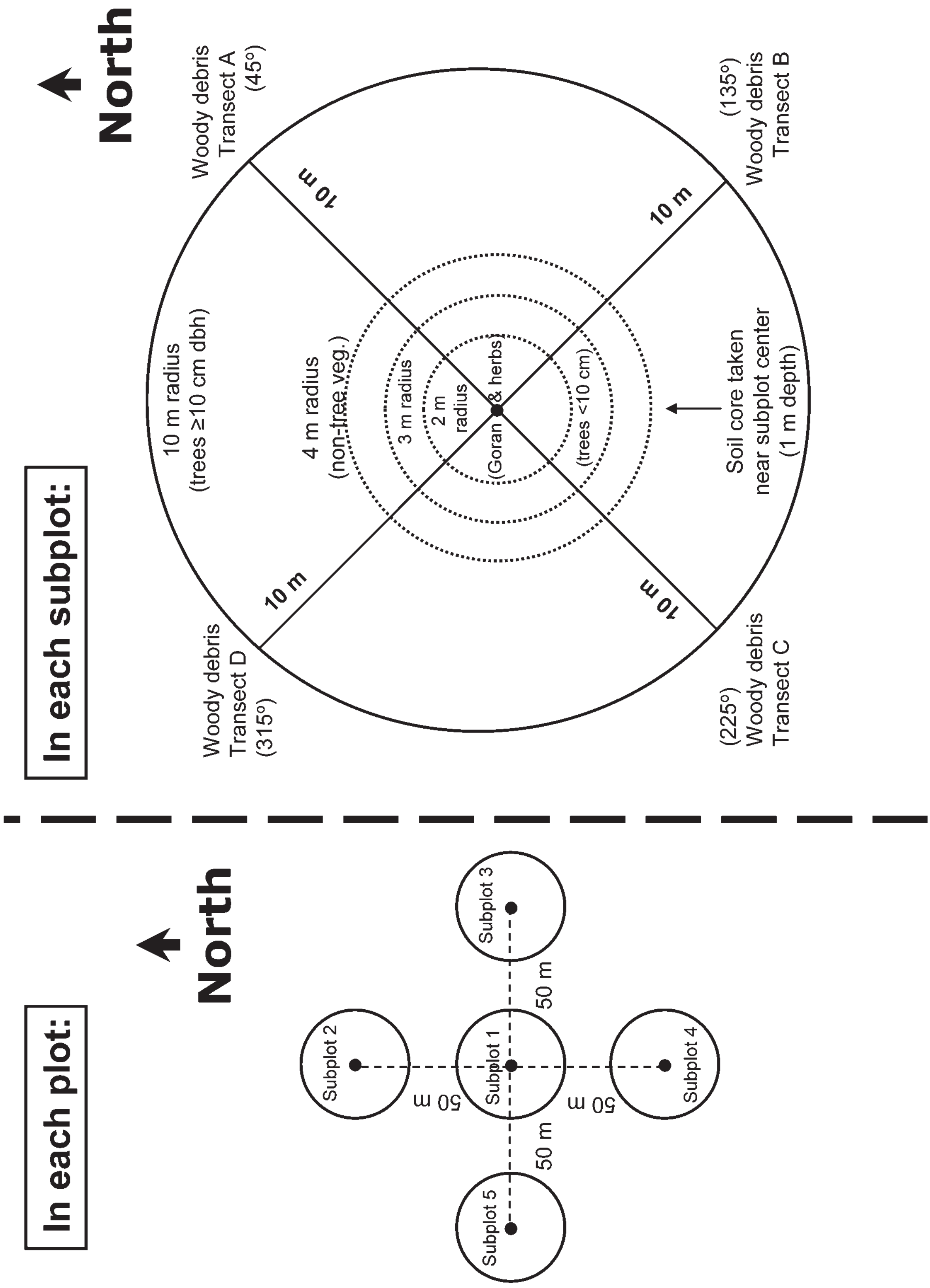


Figure 8. Schematic of plot layout.

General information at each plot

At the start point of each plot (subplot 1 center), record the following information on the general plot datasheet:

- Plot number
- Date
- Crew members present
- Range, Compartment, and Block number
- GPS coordinates in latitude/longitude (dd.ddddd°), and precision (± X m)
    - Mark a waypoint in the GPS; file name is the plot number.
    - Make sure the appropriate datum is used (e.g., India-Bangladesh or WGS84, depending on what is normally used in SRF).
- Notes on directions to plot (include waypoints of access points/boat mooring if applicable)

The following information should be recorded by circling the appropriate choice on the data form.

- Site category: Forest, Scrub (<5 m height), Grass/Bare Ground, or Other (if other, describe)
- Forest condition: Intact, Degraded, or Deforested (see above definitions)
- Topography (microrelief): Flat, Depression, Levee, Slope (if sloped, record %)
- Soil description: Loose Sand, Hard Clay, Soft Mud, or Fluid Mud
- Disturbance evidence:
    - Cyclone damage: Not Evident, Light, Moderate, or Severe
    - Heritiera fomes top-dying: Not Evident, 0-30% (trees affected), 30-70%, or 70-100%
    - Timber harvest: Not Evident, Low (<30% basal area), Medium (30-70%), or High (>70%). Also describe the harvest.
    - Other disease/disturbance: Not Evident, Light, Moderate, or Severe. Also describe the other disease/disturbance.

The bottom of every data sheet provides room to document quality control activities. At the end of every field outing, all data sheets should be reviewed by the recorder for completeness, legibility, and accuracy. Once satisfied by the quality of data recorded, the recorder (or other data reviewer) should write their name and the date of the review, along with any notes on issues that were noticed during the check so that they can be prevented in the future. Similarly, when data is entered into a computer program, such as Microsoft Excel, each data sheet should be compared to what was entered into the computer to ensure accuracy in data entry. Once the person entering data has compared the computer entry to the data sheet and fixed any errors, they should write their name at the bottom of the data sheet and the date of data entry. Any issues should be noted so that they can be corrected in the future. In addition, a sub-sample of the data sheets should be compared to the computer entry by someone other than the person who entered the data (minimum 10%, the exact number is dependent on the QA/QC plan and the amount of errors found—more errors warrant more data reviews). The data reviewer should also write their name and the date of the data review, along with any notes on issues that were apparent or corrections that were made. It is important that all issues that are noted on the data sheets are brought to the attention of the field supervisor so that preventative measures can be taken.

Plot Photos

From plot center (subplot 1 only), take 4 digital photographs—one in each cardinal direction (N, S, E, W). In each photo, hold a small sign with the plot number, photo direction, and date in the lower corner of the frame. Use the back of a datasheet and a permanent marker to make the sign. Make sure most of the photo is of the forest, not the sign or the ground. Once photos are downloaded onto a computer, the photo names should be changed to "plotnumber_direction_2009-10" (e.g., 738_N_2009-10). Once the photo names have been changed, their new names should be recorded on the datasheet, with the storage location. Photos should be stored electronically with other project data in a photos folder with separate plot folders.

Measurements in subplots

Tree Survey

Trees dominate the aboveground carbon pool and are the best indicator of land-use change. It is essential to measure trees thoroughly and accurately. The basic concept is that measurements of stem diameter are used in allometric equations to compute biomass and carbon stocks.

What counts as a tree

- All live woody stems having a diameter at breast height of 10 cm or greater. Diameter at breast height (dbh) is the stem diameter 1.3 m above the ground.
- Any dead woody stem (snag or stump) with diameter ≥ 10 cm, provided its angle from true vertical is less than 45° (Figure 9).

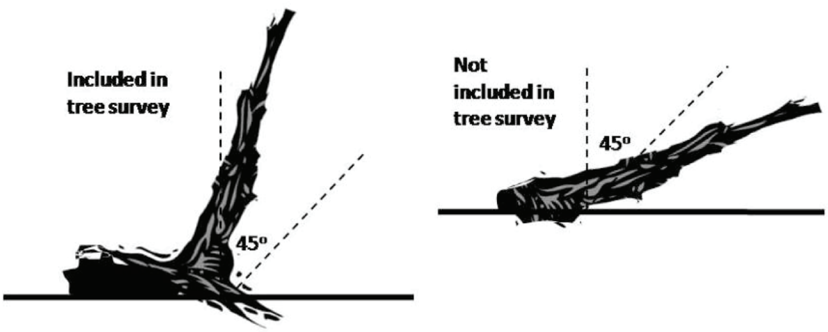


Figure 9. *If a dead tree leans more than 45º from vertical, it is not included in the tree survey.*

The subplot

- Subplot is a circle with radius 10 m. To check if trees are in the subplot, use the laser rangefinder, the linear side of a 10-m diameter tape, or the woody debris transect tapes.
- A tree is included in the survey if at least 50% of the stem is inside the subplot perimeter. Alternately include and exclude individuals too close to call.
- Take care to measure every tree once and only once.

Measurements

- For each tree, record species and dbh using a diameter-tape (to nearest 0.1 cm)
- If the tree is dead, record “y” in the dead column of the datasheet. Record other data as normal. If species is unknown, record “unk” in species column. Record dead trees’ decay status as follows (see Figure 10):
    - Status 1: Retains small branches and twigs; resembles a live tree except for absence of leaves
    - Status 2: No twigs/small branches; may have large branches or stem only
        - For status 2 dead trees, also record diameter at base of tree, and total tree height using laser tool or clinometer.
        - Record whether status 2 dead trees were cut in the remarks column.
        - Stumps (status 2 dead trees not reaching dbh, cut or natural) are recorded in this survey, provided they have a top diameter ≥ 10 cm—i.e., they would be large enough for the tree survey if not cut/broken. If a stump does not reach breast height, only record base diam. & ht.

Figure 10. *Examples of dead tree decay status. Class 1 trees retain twigs and small branches. Class 2 is a broad category including trees with no twigs or small branches; these may have large branches, or stem only. Adapted from Walker et al. (unpubl.).*

- If the tree is a Heritiera fomes and top-dying is present, record whether greater or less than 50% of the crown is affected.
- Height of 3 co-dominant trees: For the 3 co-dominant trees closest to each subplot center, measure tree height to nearest 0.1 m using the laser tool or clinometer.
    - A co-dominant tree is one forming the main overstory layer, receiving sunlight on top of crown only. It is not emergent above the main layer, nor is it completely shaded below (Figure 11).

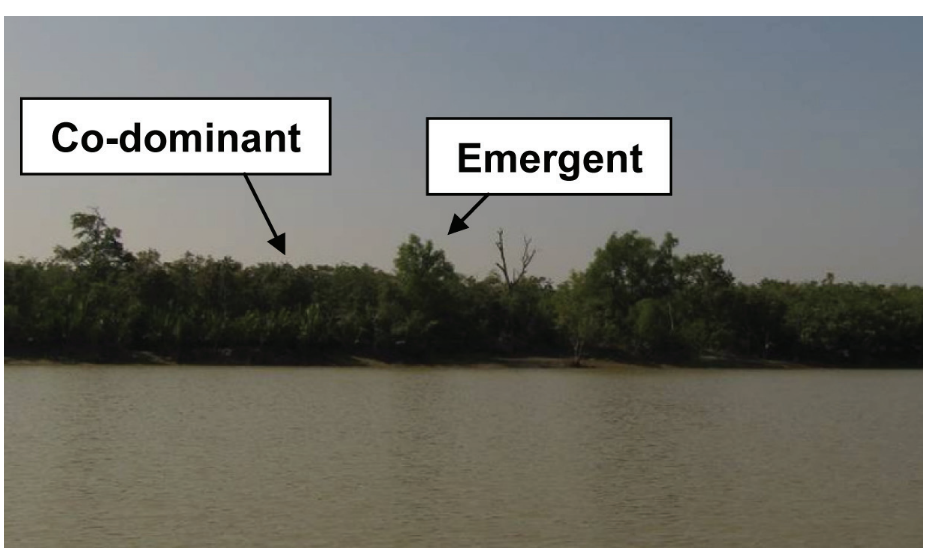


Figure 11. *Example of co-dominant versus emergent (dominant) canopy position.*

Notes:

- Be sure to use the diameter side of the dbh tape, not the linear side.
- If there is any slope, measure dbh as 1.3 m from the uphill side of the tree.
- Trees are considered alive if any green leaves are present.
- For trees that fork into multiple stems at or below dbh, measure below the fork. If impossible to measure below, then measure as multiple trees. (Although traditional forestry dictates that forked stems be measured as separate trees, for biomass computations it is more accurate to measure as one tree.)
- For leaning trees, wrap dbh tape perpendicular to stem, not parallel to ground.
- Measure lianas just as trees, but record dbh only and "liana" for species. Take care that the same liana is not measured more than once.
- Palms with woody trunks are measured in the tree survey. No dbh measurement is required, only height. Species is recorded if known; otherwise "palm." Note that all palms reaching dbh height are recorded in the tree circle, even if their dbh is less than 5 cm.
- For trees with buttresses/prop-roots above 1.3 m, measure the dbh 0.5 m above the highest buttress/prop-root (see, e.g., Komiyama et al. 2005).
- If laser rangefinder is unavailable, use a clinometer to measure tree heights (to nearest 1 m). In this case, in the height column record percent slope to top and bottom of tree, and the distance the clinometer was from the tree.
- Note that, if desired, trees can also be tagged using aluminium tree tags and nails. This leads to a much different approach to tracking changes in tree carbon over time ('permanent' plots). Because of sampling constraints when working in mangroves, it is recommended here that tree tagging is not employed for this assessment. If desired for this or future surveys, or for other forest inventory purposes, see Pearson et al. (2005) and Pearson et al. (2007) for how to conduct C monitoring calculations using tagged trees.

Sapling and Seedling Survey

What counts as a sapling

- All live trees reaching breast height (1.3 m), but having a dbh < 10 cm.
- Any dead tree having dbh < 10 cm, provided its angle from true vertical is less than 45^{o}.

What counts as a seedling

- All live trees not reaching breast height (1.3 m).
- Any dead tree not reaching breast height and having a top diameter < 10 cm, provided its angle from true vertical is less than 45°.

The subplot

- Subplot is a circle with radius 2 m (concentric with tree survey circle).
- Saplings and seedlings are included in the survey if at least 50% of the stem is inside the subplot perimeter. Alternately include and exclude individuals too close to call.
- Take care to measure every individual once and only once.

Measurements

- For each sapling, record the tree species and dbh (to the nearest 0.1 cm), using a caliper or diameter tape.
- If the sapling is dead, record "y" in the dead column.
- Live seedlings are recorded as a simple count of individuals. Record dominant seedling species.
- Dead seedlings are recorded as a count. Include small stumps (< 5 cm diameter and not reaching breast height) in this count.

Notes:

  - Notes from the tree survey apply to the seedling/sapling survey.
  - Palms with woody trunks, but not reaching breast height (<1.3 m height), are counted in the seedling tally.
  - For woody shrubs with vertically oriented stems (e.g., *Hibiscus*), measure their individual stems as saplings if they reach breast height, and seedlings if they do not. One shrub individual may therefore contain many sapling stems and many seedling stems.

Canopy cover

Canopy cover measurements may aid in leveraging remotely sensed data to track forest degradation.

A spherical densiometer is used to estimate canopy cover. It should be held 30-40 cm in front of your body and at elbow height, so that your head is not visible in the mirror. Level the instrument using the level bubble. In each square of the grid, imagine that there are four dots, representing the center of quarter-square subdivisions of each of the squares (Figure 12). Systematically count the number of dots NOT occupied by canopy (where you can see sky at that dot). Record this number on the datasheet. Make four readings per location – facing north, south, east, and west.

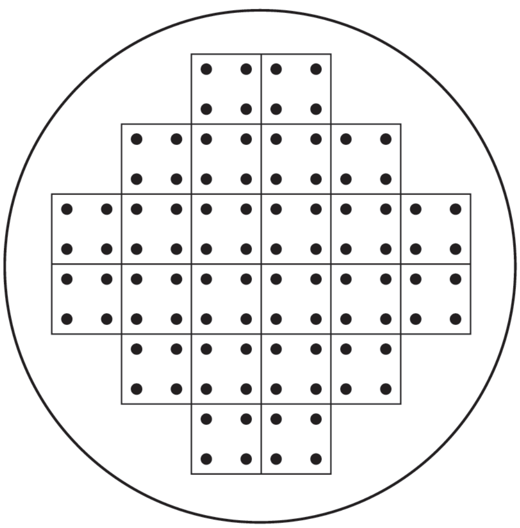


Figure 12. Schematic of densiometer mirror, with the 4 dots depicted in each square. Count the number of dots NOT occupied by the canopy, in the 4 cardinal directions at each subplot.

Water Canal Cover

For each subplot, record the percent of the subplot area occupied by water canals that are void of vegetation. Also record an ocular estimate of the canal width to the nearest meter.

Non-Tree Vegetation Survey

Non-woody palms (e.g., *Nypa fruticans*), Ceriops decandra (goran), and herbaceous vegetation should be measured in the inner nested subplots. Options for these include destructive harvests in each sample plot or non-destructive sampling using allometric relationships. Non-destructive sampling is preferred for the efficiency required of mangrove plots; this employs a one-time destructive harvest to construct the appropriate allometries (see relevant section below).

What counts as non-tree vegetation

- Any vegetation not meeting the requirements of the tree or sapling/seedling survey.

The subplot

- Non-woody palms, ferns, etc. are measured in a circle with radius 4 m (concentric with tree survey circle).
- Ceriops decandra and herbaceous vegetation (grasses and herbs) are measured in a 2-m radius inner circle.

Measurements, 4-m radius circle

- *Non-woody palms* (e.g., *Nypa*): count the number of stems rooted in the subplot (not individuals or clumps, but separate stems).
- *Pandanus*: Record the number of clumps (bunches of leaves) in the subplot.
- *Tiger fern*: Record the number of clumps (bunches of stems) in the subplot.
- *Woody shrubs*: Measure their individual stems as part of the sapling/seedling survey (see sapling/seedling survey notes, above).
- *Other*: When other vegetation is encountered, field personnel will need to make decisions on reasonably efficient and accurate methods for biomass estimation.

Measurements, 2-m radius circle

- Ceriops decandra is simply tallied (counted) by the number of stems in each of 4 size classes. The size classes are the same as those for woody debris (0-0.6 cm, 0.6-2.5 cm, 2.5-7.6 cm, >7.6 cm). The diameter is measured at the base, above the collar. For branching stems, record the lower ‘parent’ stem diameter, not each branch. No distinction is necessary between live and dead stems (however make a note if >25% of stems in subplot are dead).
- *Herbaceous vegetation*: Visually estimate and record percent ground cover of herbs and grasses separately. Record to the nearest 1% if below 10, and to the nearest 5% if between 10-100%.

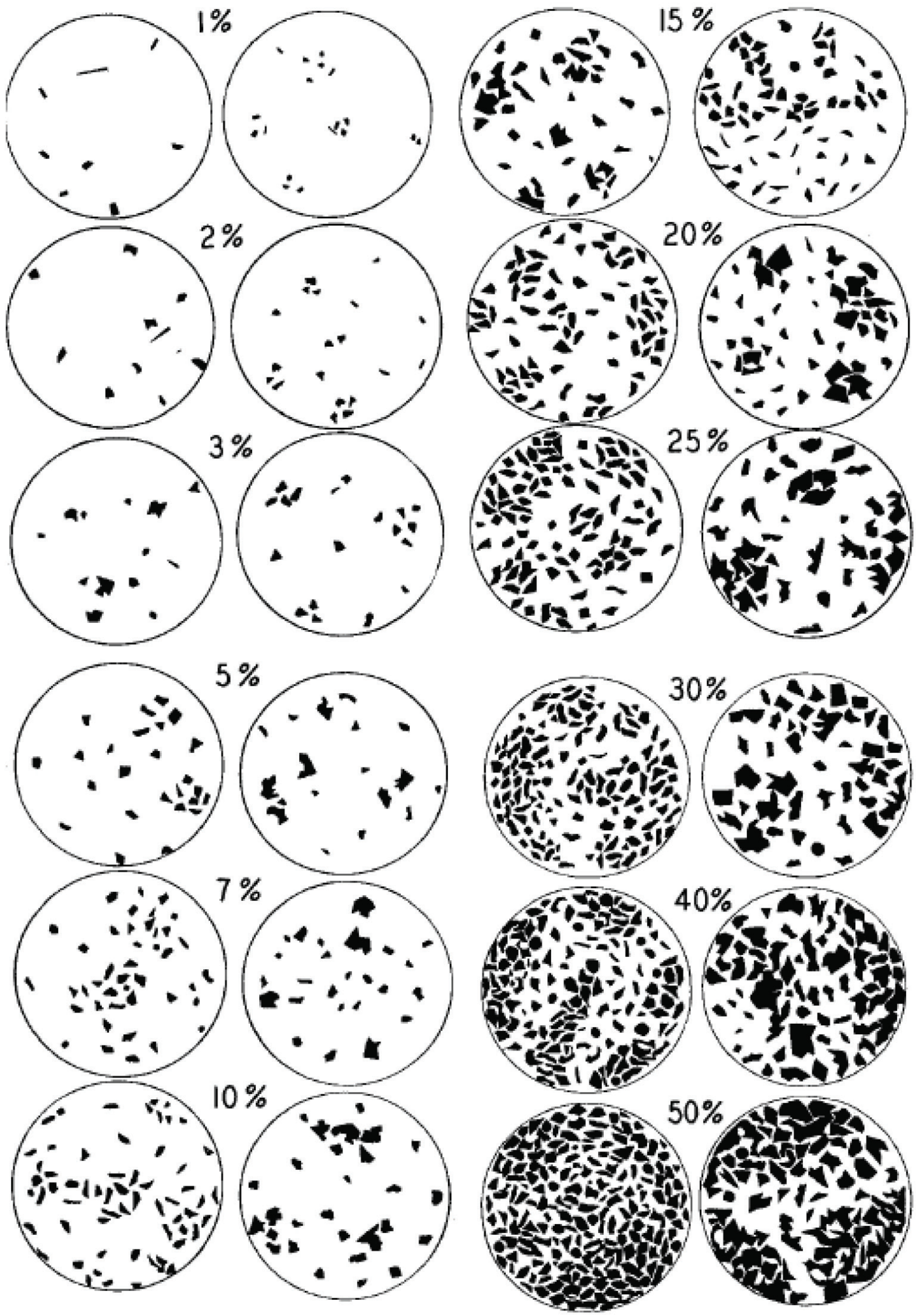


Figure 13. Reference scatter plots for estimating percent cover. From Terry and Chillingar (1955) as cited in USDA (2008).

Forest Floor (Litter)

- The forest floor is defined as all dead organic surface material on top of the mineral soil. In mangroves, the amount (and therefore carbon stock) of this material is usually negligible due to the effects of tides, seasonal river flooding, and the activities of fauna such as detritus-consuming crabs. Therefore, in accordance with sourcebook recommendations, we recommend not measuring this pool.
- However, litter sampling is briefly described below in the event that project personnel decide that it is a significant carbon pool.
    - To the extent possible, sample litter at the same time of year at each census to avoid any seasonal effects.
    - Using the folding ruler, lay a 30 cm x 30 cm square sampling frame down on the soil surface, located on the outer edge of the 4-m radius subplot. Collect all organic surface material, excluding woody particles, which are already measured in a separate survey. Use a blade to cut litter pieces that fall on the border of the frame.
    - Collect the material in a sturdy bag or container, clearly labeled with “SRF C project”, date, plot, and subplot. Oven-dry to constant mass, and record the final dry mass (minus bag or container mass).
    - If sample bulk is excessive, record the fresh (wet) mass in the field, then take a well-mixed representative subsample of manageable size (~80-100 g). Discard the remainder. Record the wet mass of the subsample, dry to constant mass, and use the ratio between the subsample’s wet and dry mass to estimate the dry mass of the total sample.

Woody Debris Survey

- Woody debris (down, dead wood material) can be a significant component of aboveground biomass and may be affected by land use change.
- The planar intersect technique involves counting intersections of woody pieces with a vertical sampling plane (transect).
- A survey tape is run out from subplot center for 10 meters in each of 4 directions, oriented at 45-degree angles from the main transect line. Use a compass to run the transect tape on a straight line.
    - transect A: 45°
    - transect B: 135°
    - transect C: 225°

- transect D: 315°

- Woody debris intersecting the transect plane is recorded, up to a height of 2 meters above the forest floor.

Figure 14. *Example of a woody debris transect tape in a mangrove (left), and using the down-wood gauge to classify pieces by size (right). The upper right piece is a medium class; the lower right piece is small class.*

- The slope of the actual survey tape can be different from slope of the overall plot. For example, a transect laid out diagonally down and across a slope will have a gentler slope than the actual hillside. A perfectly sidehilling tape would have a slope of zero. Most mangrove transects have negligible slope, but when there is a slope, record the % slope of the actual survey tape in the “transect” column under the letter.

- Woody debris is categorized into 4 size classes: Small, Medium, Large, and Extra-Large. These size classes are regularly used in forest inventories, and convenient measurement tools exist to streamline field sampling based on these cutoffs. Use the aluminium down-wood gauge to determine the size class of each piece encountered.

- Size classes are:

Small	0 – 0.6 cm
Medium	0.6 – 2.5 cm
Large	2.5 – 7.6 cm
Extra-Large	≥ 7.6 cm

- Small, medium, and large pieces are tallied as the number of pieces that cross the transect tape. They are tallied separately for each size class. No diameter measurement is needed.

- Extra-large pieces require more data to be taken. For each piece crossing the transect, record its true diameter at line intercept using a ruler. Also record the decay status: sound (machete bounces off or only sinks slightly when struck) or rotten (machete sinks deeply and wood is crumbly with significant loss).

- Small and medium pieces can be very abundant, so to save time they are only sampled along sub-sections of each transect. These sub-sections start from the distal end of the transect (meter 10). Small pieces are only tallied for 2 meters of transect (from meter 10 to meter 8). Medium pieces are only tallied for 5 meters of transect (from meter 10 to meter 5). Large and extra-large pieces are recorded along all 10 meters. See Figure 15.

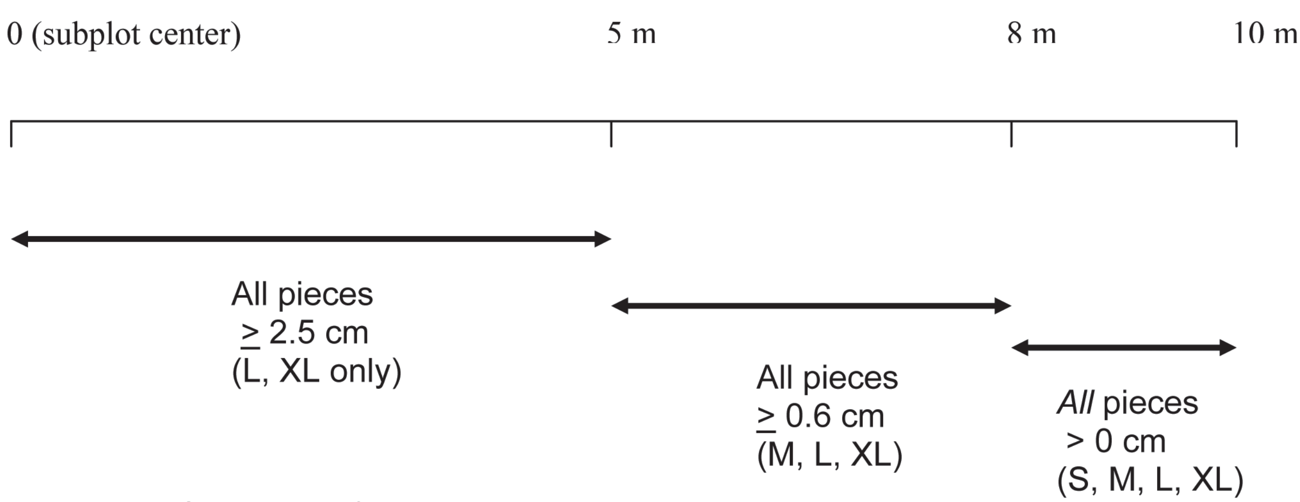


Figure 15. *Schematic of wood debris transect*

- What counts as woody debris?
  - Any downed, dead woody material (twigs, branches, or stems of trees and shrubs) that has fallen and lies within 2 m of the ground. Dead trees that lean at an angle of > 45° from true vertical also count.

- The transect tape must intersect the central axis of the piece for it to be counted. This means that if the tape only clips a corner at the end of a log, it does not count.
- Any piece can be recorded multiple times if the tape intersects it more than once (e.g., a curved piece, or at both the branch and the stem of a fallen tree).
- Count wood slivers, bark and irregular chunks; visually mold these pieces into cylinders for determining size class.
- Count *uprooted* stumps and roots not encased in soil. Do not count undisturbed stumps or roots still in contact with soil.
- The piece must be in or above the litter layer to count; it does not count if its central axis is buried in soil at the point of intersection.
- Dead branches and stems still attached to standing trees or shrubs do not count.

Soil Sampling

- To accurately quantify the soil carbon pool, three parameters must be evaluated: 1) soil depth, 2) soil bulk density (BD; mass per volume), and 3) organic carbon concentration (%OC).
- Notes on adaptation of common guidelines:
    - *Soil Depth*: For many C assessments, sampling is generally to a fixed depth of 30 cm, since most soil C is in the top horizons and this is the most vulnerable to land-use change. However, mangroves and peat swamps often have deep organic-rich soils with little vertical differentiation (see, e.g., IRDP of Sundarbans RF, vol. 1), and land-use may have effects on deeper layers due to drainage, oxidation, etc. Therefore, it is recommended that the top 100 cm are sampled for this assessment. The soil profile should be sampled from 0-30 cm depth, plus an additional sample representing the 30-100 cm depth range.
- Measuring soil depth: A 'bottom' of the soil profile is unlikely to be reached in the deep sediments of Sundarbans, so measuring soil depth is not necessary. [In mangroves over coral sands or bedrock, or in peat swamps, measuring soil depth with a probe such as a bamboo pole is important.]
- Obtaining soil samples for bulk density and %OC: A core sample is taken near the center of each subplot with a 1-m long open-faced peat auger. The goal is to obtain a sample as undisturbed as possible. Move 1 meter from subplot center in a random direction. Remove any organic litter from the surface of the sample point. Then steadily insert the auger vertically into the soil until the top of the sampler is level with the soil surface. If the auger will not penetrate to full depth, do not force it, as this may be a large root; instead try

another location. Once at depth, twist the auger in a clockwise direction a few times to cut through any remaining fine roots. Gently pull auger out of soil. If an undisturbed sample has not been obtained, clean the auger out and try another location.

- Once an undisturbed soil core is extracted, use a serrated knife to gently cut and remove the soil from the auger face, to obtain a smooth surface on the core, level with the auger edges. Work around coarse roots if necessary.

- Use a ruler and blade to mark the 30-cm depth line. From the mid-point of the 0-30 cm interval, take a 5-cm long sample from the soil core, using the ruler and blade. Avoid coarse roots (>2 mm diameter). The exact location of the sample may need to be varied to avoid coarse roots.

- Place sample in a numbered soil container; take care to avoid any loss of sample. Record container number. This sample will be used to determine %OC.

- Take another 5-cm long sample, immediately adjacent to the previous sample that was removed from the core; place in another numbered container. Record container #. This sample will be used for bulk density determination.

- Repeat this process for the 30-100 cm interval of the core, taking two 5-cm samples from the midpoint (~65 cm depth).

- If soil is especially dense/hard, it may be necessary to first obtain the 0-30 cm sample, then re-insert the auger into the hole to obtain a deeper sample.

Figure 16. *Collection of soil samples from open-face auger. A: Cutting the soil away from auger face. B: Cleaned, flat surface of soil core. C: Measuring and marking the depth intervals. D: Cutting a sample. E: Removal of sample from auger. F: Collection of sample in numbered container.*

- If open-face auger will not work: The open-face auger is designed for mucky soils with high organic content. Sometimes it will not work, for example if the soil is not well consolidated (e.g., sand). In this case, use the slide hammer and dutch auger to obtain samples. If this decision is made, it must be done consistently across all 5 subplots within a plot. NOTE: Always record on datasheet which tool was used.

    - Clear away the surface litter.
    - Insert sampling sleeve(s) into slide hammer's aluminium bit; screw bit onto slide hammer.
    - Insert bit into the soil and use the hammering mechanism to get to depth. Only go down until the top of the bit is flush with the surface. Going deeper will compact the soil, resulting in over-estimation of bulk density.
    - Retrieve the bit from the soil, unscrew bit from hammer, and extract sampling sleeve. Cut sample so it is flush with the open ends of the sleeve.
    - Push soil out of sleeve and into a numbered collection container. Record the container number.
    - If possible, use the second sleeve within the bit to obtain a second sample from that depth interval (for nutrient sample). If not possible, a second hole will need to be sampled (see last step below).
    - Using the dutch auger, bore into the original soil hole to a depth of ~60 cm (a mark on the auger rod may help). Clear the hole to the extent possible.
    - Re-insert the slide hammer (with aluminium bit and sample sleeve re-assembled) into this deeper hole until the bottom is felt.
    - Hammer down approximately 10 cm. Again, do not go too deep.
    - Repeat the sample extraction and collection process for the 30 – 100 m sample as for the surface sample.
    - If necessary, repeat entire process for the nutrient sample.

- Pre-laboratory processing of soil samples: Samples must be dried as much as possible before storage and transport to the laboratory.

  In the field:

  - Air-dry the samples by opening the containers, keeping the numbered lid with the container (on underside), and place in the sun during the day. Re-close the containers at night to avoid dew condensation. Repeat over multiple days.

- When the samples are dried, combine the five %OC samples from the 0-30 cm depth interval for each plot into one plastic whirl-pak (or two if necessary). Have the whirl-pak(s) pre-labeled with “SRF C project”, “Nutrients”, date, plot, and depth interval. Repeat for the 30-100 cm depth interval.

- Repeat the above step for the bulk density samples from each plot (whirl-pak labels should read “SRF C project”, “Bulk Density”, date, plot, and depth interval).

- Take the samples to the drying oven facility as soon as possible.

Oven-drying

- Remove the soil samples from the whirl-paks; save the labeled whirl-paks for future use.

- Keep the combined samples together (5 from each plot for 0-30 cm interval stay together, and 5 from each plot for 30-100 cm interval stay together). Place combined samples in oven-safe containers. Aluminium foil can be used to form containers if needed. Keep careful track of which samples are from which plots; label the oven containers as needed. (Note: the plastic field containers are only rated to 100 °C maximum; never put those containers in an oven above that temperature.)

- Bulk density samples should be dried to constant mass in oven-safe containers at 105 °C.

- Nutrient samples should be dried to constant mass *in a separate oven* at 50 °C. The temperature is lower because higher temperatures may reduce the carbon in the sample.

- *Drying to constant mass*: Dry samples for at least 48 hours, then check samples for dryness. Samples that are dry to look and feel should be weighed (with container) on a digital scale; record the value on the soil datasheet. Take care to avoid any loss of sample. Return samples to oven, let dry for at least another 12-24 hours, then re-weigh, recording the mass on the datasheet. Keep checking and re-weighing at 12-24 hour intervals until the mass does not change from previous weighing, indicating that no more water has left the sample. Record and circle the last dry mass value.

- *Bulk density samples:* Once samples have been completely dried and weighed, wipe any residual soil dust out of containers with a clean rag. Weigh the empty containers with and record this mass on the datasheet. Once the data are entered electronically and backed up, these samples can be archived for future reference or discarded.

- *Nutrient samples*: Once the samples have been completely dried and weighed, return the samples to the appropriate labeled whirl-paks and send to the laboratory for analysis.

Equipment maintenance

Mangroves are extremely harsh on equipment. Corrosion is a major factor due to exposure to salty water and soil, and can happen within hours. Strive to rinse all equipment with fresh water after every day in the field. This is especially important for steel equipment with screw-on threads; these must be unscrewed and rinsed every day. Also, take care to protect the screw-on threads during equipment transport.

When equipment will not be used for an extended period (more than ~3 days), coat the metal parts with a light oil as a protectant.

Mark all equipment with permanent marker—project name, organization, etc.—so that it remains with the inventory project.

Destructive harvests for allometries and wood densities

For some forest components, region-specific allometric equations may not yet exist. For these components, a one-time destructive harvest will be needed to scale plot measurements to biomass and carbon. These components include shrubs, ferns, non-woody palms, seedlings, and possibly others. Decisions can be made by field personnel to add new allometries as the data require.

Non-woody palms:

- These are palms such as *Nypa fruticans* and similarly built species, which only have large leaves aboveground. Because these are only recorded by count in the plots, a mean biomass must be used to scale to carbon pool.
- Select 25-30 palm fronds from different individuals, outside of any sample plot. Include all common species in this sample.
- Cut frond at ground level and weigh it; record on datasheet.
- Take a manageable subsample from each frond and weigh. Record on datasheet. Clearly label with frond number.
- Oven dry subsamples at 50 °C or higher until a constant mass has been reached; record final dry mass. Use the ratio between subsample wet and dry mass to estimate dry mass of entire frond.
- Calculate the mean dry mass of palm fronds in kg. This value will be applied to scale up counts of palm fronds in plots.

Tiger ferns and similarly built species:

- These are small to medium sized, non-woody ferns and similarly built species. Because these are only recorded by count of clumps in the plots, a mean biomass is necessary to scale to carbon pool.

- Select 25-30 fern clumps from different individuals, outside of any sample plot. Include all common species in this sample.
- Cut clump at ground level and weigh it; record on datasheet.
- Take a manageable subsample from each clump and weigh. Record on datasheet. Clearly label with clump number.
- Oven dry subsamples at 50 °C or higher until a constant mass has been reached; record final dry mass. Use the ratio between subsample wet and dry mass to estimate dry mass of entire clump.
- Calculate the mean dry mass of fern clumps in kg. This value will be applied to scale up counts of fern clumps in plots.

Pandanus:

- Collect and analyze samples in the same manner as for *Nypa*. Each sample should be a clump of leaves and the stem leading to it.

Seedlings:

- These are trees that do not reach breast height (1.3 m). Because these are only recorded by count in the plots, a mean biomass must be used to scale to carbon pool.
- Select 25-30 seedlings from outside of any sample plot. Include all common species in this sample.
- Cut seedling at ground level and weigh it. Record on datasheet.
- For each seedling, separate wood and foliage and weigh separately. Record on datasheet.
- Take a manageable subsample from each cut seedling (of wood and foliage separately) and weigh. Record on datasheet; clearly label seedlings with number.
- Oven dry subsamples at 50 °C or higher until a constant mass has been reached; record final dry mass. Use the ratio between subsample wet and dry mass to estimate dry mass of entire seedling.
- Calculate the mean dry mass of seedlings in kg. This value will be applied to scale up counts of seedlings in plots.

Ceriops decandra*:*

- One time during the field season, measure the actual base diameter of 30 stems for each of the 4 Ceriops decandra size classes. The 30 stems should come from different individuals. Calculate the quadratic mean diameter of each size class (see formula in woody debris harvest below).

Herbaceous (forbs and grasses):

- Obtaining biomass of these components is not a priority since they are generally quite small. However, if desired during this or future surveys, allometric equations can be constructed relating percent cover to biomass per m^2. To do this, a one-time destructive harvest is necessary. Establish 20-25 temporary 2-m radius circular plots (similar to, but outside of, the actual survey plots), seeking a full range of percent covers. Make sure the low range of percent cover values (1-10%) is well represented. In each of these allometry plots, record the percent cover value, then clip all the herbaceous vegetation at ground level. Oven-dry at 50-70 °C to constant mass. Using a graphing or statistical program, create an allometric equation relating percent cover to biomass in kg per 12.6 m^2 (accounting for area of 2-m radius plot circle).

Woody debris densities:

- Field measurements are entered into equations that yield woody debris volume per area. To convert volume to biomass and carbon estimates, densities of woody debris are needed. Once during the field season, representative woody debris samples should be collected for each of the 5 categories: small, medium, large, extra-large (sound), extra-large (rotten). Collect 20-25 pieces of each size class, capturing a representative range of sizes within each class, and the full range of species to the degree recognizable. As a rough guideline, samples should have a mass of between ~0.5 and 50 g. Collection of pieces should be random/arbitrary, and not inside sample plots.

- Small, medium, and large collected pieces should be measured for diameter at mid-point. Calculate the quadratic mean piece diameter (QMD) for each size class separately. QMD is obtained by squaring each diameter (d), summing the products, dividing by sample size (n), and taking the square root:

$$QMD = \sqrt{(\sum d_i^2)/n}$$

- All pieces from the five woody debris classes should then be measured for specific gravity (density).

    - To obtain specific gravity, first obtain piece volume. Fill a glass beaker ~2/3 full of water (enough to submerge each wood piece), zero the scale, then dip each piece one at a time into the water (while holding the piece with fine tweezers or blade tip; do not let the piece touch the bottom or sides of beaker). Because the specific gravity of water is 1 g cm^{-3}, the resultant increase in mass shown on the scale is the volume displaced by the particle. Record each piece volume. Do so immediately after dipping the piece in the water, as water absorption by the piece can make the volume readout drift downward.

- Next obtain the oven-dry mass of each piece. Oven-dry at temperature of at least 50°C to constant mass, then record and circle the final dry mass values.
- To obtain specific gravity, divide mass by volume for each piece. Calculate the mean specific gravity (g cm^{-3}) for each of the five woody debris classes. These mean values will be used in later computations of biomass/carbon.

Laboratory and Data Analysis

Laboratory Processing of Soils

Soil samples should be sent to a professional laboratory for analysis. It is recommended the selected laboratory be checked to ensure they follow commonly accepted standard procedures with respect to sample preparation (for example mixing and sieving) and carbon analysis methods.

Bulk density samples

If bulk density has not already been determined in the field, the laboratory should dry the bulk density samples at 105 °C for a minimum of 48 hours. Record the final oven-dry weight, minus the container weight.

NOTE: In the event that soils go to the lab in the hard-sided polypropylene collection containers, soils must be transferred to containers that are rated for high oven temperatures. The hard-sided polypropylene containers will melt at 105 °C.

NOTE: Do not dry the samples that will be used for %OC at any temperature greater than 50 °C; the extra drying in the lab is only for bulk density samples.

Rock fragments: If the sample contains rocky fragments (>2 mm diameter), these fragments should be retained and weighed separately, and these weights should be recorded.

Nutrient samples: % organic carbon (%OC) determination

Sample preparation: Sieve sample through a 2-mm sieve and then thoroughly mix. Grinding of the sample may be necessary. Make sure all 5 samples from a given depth interval in a plot are combined during this process.

Analysis: The dry combustion method using a controlled-temperature furnace (for example, a LECO CHN-2000 or equivalent□) is the recommended method for determining total soil carbon (TC), but the Walkley-Black method is also commonly used (Pearson et al. 2005).

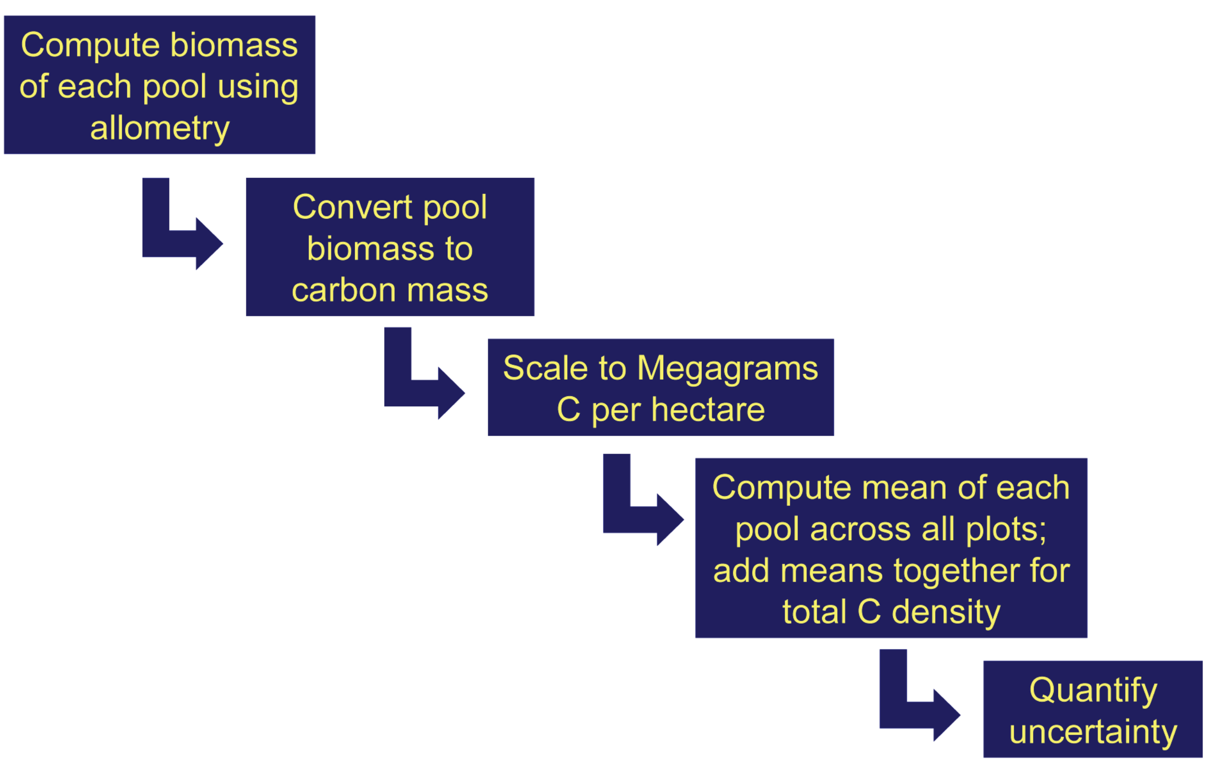
If resources permit, separate the inorganic and organic fractions and report each. The organic fraction can be isolated by pre-treating the sample with HCl or H_2SO_4 to remove carbonates (inorganic C) before analyzing. Alternatively, a gravimetric technique can be employed to estimate the organic fraction through lower-temperature (400 °C) combustion. In either case, inorganic carbon is then estimated as the difference between total carbon (TC) and organic carbon (OC). There are also methods for direct determination of inorganic carbon. Each of these methods has advantages and disadvantages. See Schumacher (2002) for detailed discussion of these methods.

If this separation is not possible, use the total carbon value for soil C computations instead of organic carbon.

NOTE: Although %OC samples are not oven-dried at 105 °C, %OC must be reported on an oven-dry basis (based on the bulk density sample).

Steps to Calculating Carbon Stocks

In basic form, the steps to calculating carbon stocks are:



Carbon Content of Biomass

Most calculations first determine the biomass of a given forest component, then convert to carbon pool. Since forest biomass is generally half carbon by mass, it is common practice to convert biomass to carbon by multiplying by 0.5:

$$\text{Carbon mass} = 0.5 * \text{Biomass}$$

NOTE: If local values for carbon content are available, these should be used instead of 0.5. In the future, calculated local values may be required.

Finally, soil is an exception to this conversion since soil carbon is measured directly. No conversion from biomass is necessary for soil.

Live Trees

Biomass equations relate dbh to biomass. Equations may be for individual species or groups of species, but this literature is inconsistent and incomplete. Before applying a biomass equation, consider its original location because trees in a similar functional group can differ greatly in their growth form between geographic areas. Also note the maximum diameter from which the equation was derived, as applying the equation to larger trees can lead to significant errors (large trees overestimated).

First, select a biomass equation. For mangroves, two widely applicable equations make this selection relatively easy. Chave et al. (2005) and Komiyama et al. (2008) each have general equations that can be used for mangrove trees across many regions. Each has advantages based on geography, diameter range, etc.; however we recommend the mangrove equation from Chave et al. (2005, page 93) because it agrees well with other mangrove equations and also handles larger diameters better (biomass estimates are less inflated for large trees). The equation is:

Equation for aboveground tree biomass:

Aboveground biomass (kg) =

$$p * \exp(-1.349 + 1.980 * \ln(dbh) + 0.207 * (\ln(dbh))^2 - 0.0281(\ln(dbh))^3)$$

p = wood density (g cm^{-3})
-1.349 = constant
1.980 = constant
0.207 = constant
0.0281 = constant
dbh = tree dbh (cm)

Wood densities for live trees (which may be different from woody debris densities) are required for many biomass equations, including the general mangrove equations. These can be applied by species (preferable) or as a site-average wood density based on the species composition of dominant trees. Wood densities may be known by local forest agencies; if so, use these values. Otherwise, good sources for wood density include the World Agroforestry Database http://www.worldagroforestry.org/sea/Products/AFDbases/WD/Index.htm), which reports densities in units of kg m^{-3} (divide by 1000 to obtain g cm^{-3}) or the primary literature. Two useful primary literature sources are Hidayat & Simpson (1994) and Simpson (1996; see Table C3, column G_b, values are in g cm^{-3}). A table of wood density for common Sundarbans tree species is given in Table 3.

Table 3. Wood densities of common tree species of Sundarbans and other mangroves

Scientific name	Four-letter species code	Common name	Wood density (g cm^{-3})	Available in
Avicennia officinalis	AVOL	Baen	0.74	BAN, IND,
Bruguiera gymnorhiza	BRGY	Kankra	0.97	BAN,IND,PAK,SL,
Ceriops decandra	CEDE	Goran	0.96	BAN, IND, SL,PAK
Excoecaria agallocha	EXAG	Gewa	0.49	BAN,IND,SL,MLD
Heritiera fomes	HEFO	Sundri	0.73	BAN, IND
Sonneratia apetala	SOAP	Keora	0.70	BAN, IND
Xylocarpus granatum	XYGR	Dhundul	0.70	BAN, IND
Xylocarpus mekongensis	XYME	Passur	0.72	BAN, IND
Rhizophora mucronata	RHMU	Jhana-garjan/ Kumri	1.02	BAN, IND, PAK,SL,MLD
Avicennia marina		Timmer/	0.81	SL,PAK,IND
Rhizophora apiculata			1.05	PAK,SL,IND
Acanthus ilicifolius				IND,SL
Sonneratia caseolaris.		Choila	0.81	PAK,SL
Lumnitzera racemosa		Kripa	0.88	SL,IND
Bruguiera Cylindrica			0.90	SL,IND,MLD
Ceriops tagal			0.97	PAK,SL,MLD,IND
Hibiscus tiliaceus			0.55	MLD
Site average of above values	na	Mean density	0.815	

Note: These values are from the World Agroforestry Database (see text). If more site-specific values are available, use those instead.

To calculate tree biomass and carbon:

- Plug the dbh and density of each tree into the biomass equation (default is mangrove equation from Chave et al. 2005, page 93). If species or wood density is unknown, use site average wood density in Table 3.
- Divide the resulting number by 1000 to convert to megagrams (Mg).
- Multiply by 0.5 to obtain Mg of carbon contained in the tree.

Example: Heritiera fomes tree with dbh of 22cm and wood density of 0.730 would be entered as follows:

Biomass calculation:

Aboveground Biomass (kg) $= \rho * \exp(-1.349 + 1.980*\ln(dbh) + 0.207*(\ln(dbh))^2 - 0.0281(\ln(dbh))^3)$

[Where ρ is wood density in g cm^{-3}, dbh is in cm]

Aboveground Biomass (kg) $= 0.730 * \exp(-1.349 + 1.980*\ln(22) + 0.207*(\ln(22))^2 - 0.0281(\ln(22))^3) = 271.6$ kg

Convert to Mg:

Aboveground Biomass (Mg) = 271.6/1000 = 0.2716 Mg

Convert to carbon:

Aboveground C mass (Mg) = 0.2716 * 0.5 = 0.136 Mg C

Lianas: Calculate liana biomass using a specific allometric equation for lianas, based only on dbh. See Appendix 2 for equation. Once biomass is calculated, convert to Mg C by multiplying by 0.5.

Palms with woody stems (e.g., hental): Calculate biomass using a specific allometric equation for woody palms, based only on height. See Appendix 2 for equation. Once biomass is calculated, convert to Mg C by multiplying by 0.5.

Finally, add all the individual tree C masses together within each plot (including all trees, lianas, and woody palms), to obtain total tree aboveground C mass in each plot. Scale to aboveground tree C mass per hectare by dividing by the plot area, which for trees is $5*\varpi(10^2)$, and multiplying by 10,000 to convert m^2 to hectares. This yields aboveground tree C density in Mg ha^{-1}.

Example of tree C computation:

Heritiera fomes	0.136 Mg C	Scale to Mg per hectare:
Excoecaria agallocha	0.125 Mg C	
Liana	0.082 Mg C	[0.444 Mg C / (5*3.14*10^2)] * 10,000
Heritiera fomes	0.101 Mg C	
Plot Total =	0.444 Mg C	= 2.83 Mg C ha^{-1} of trees

Note on slope correction: In upland forests, a correction factor for plots on sloping ground is implemented so that all per-hectare carbon values are reported on a horizontal projection. This slope correction is an important step for scaling up to per-hectare values. See Pearson et al. (2005) for a description of these corrections. For mangroves, which are generally flat, slope correction is unnecessary.

Alternative allometries and historic data

Note: If comparing current data with historic data, it is best to use consistent formulas among censuses, to the extent possible. Selection of allometric equations should be as consistent as possible for past, present, and future censuses.

There are also methods for converting stand tables or stock tables of merchantable volume to biomass, which may be useful if that is the only data type available from past inventories. These are called biomass conversion and expansion factors (BCEF) and are considered adequate but less accurate than direct biomass equations. BCEF's are explained in sufficient detail on pages 2-56 through 2-57 of the GOFC-GOLD sourcebook; see also Pearson et al. (2007). Similarly, allometric equations for merchantable volume of individual trees, which already exist for Sundarbans forests (Chaffey et al. 1985), can be used, followed by multiplying by wood density and a factor of 1.2 to account for branches and leaves. This method is considered less accurate than direct biomass equations.

Below ground Biomass of Trees

The most efficient way to obtain belowground root biomass is to apply widely accepted general models (Pearson et al. 2005). Unlike the aboveground equation, the belowground equation is not applied at the individual tree level. Instead it is applied at the plot level. Belowground biomass density of trees in the plot is a function of their aboveground biomass density in the plot:

Equation for tree belowground biomass density:

BBD = exp(-1.0587 + 0.8836*ln(ABD))

BBD = belowground biomass density (Mg ha^{-1})
-1.0587 = constant
0.8836 = constant
ABD = aboveground biomass density (Mg ha^{-1}). Obtain ABD by multiplying aboveground tree C density (Mg ha^{-1}) by 2.

Multiply BBD by 0.5 to obtain C mass.

No scaling is necessary since the aboveground biomass value is already scaled to the hectare.

Example of belowground tree computation:

Aboveground C density = 120 Mg ha^{-1}
Aboveground Biomass Density (ABD) = 120 * 2 = 240 Mg ha^{-1}

BBD = exp(-1.0587 + 0.8836*ln(240))
BBD = 44.0 Mg ha^{-1}
Belowground C density = 44 * 0.5 = 22 Mg ha^{-1}

Standing Dead Trees

Standing dead trees are estimated for biomass in two different ways, corresponding to the two decay status categories.

Decay status 1 trees (recently dead) can be estimated for biomass in similar fashion as live trees:

- Insert the wood density and dbh into the same equation as for live trees.
- Subtract out the biomass of leaves (2.5 percent of aboveground biomass).
- Divide by 1000 to obtain Mg.
- Multiply by 0.5 to obtain C mass.

Decay status 2 trees (no twigs/small branches) may be calculated in a number of ways. We recommend the following method for its relative ease. Using the basal diameter measurement, apply the taper equation to estimate the diameter at the top of the dead tree:

Taper Equation:

$$d_{top} = d_{base} - \left[100 * ht * \left(\frac{d_{base} - dbh}{130} \right) \right]$$

d_{top} = estimated diameter at top of tree (cm)
d_{base} = the measured basal diameter (cm)
ht = tree height (m)
dbh = tree dbh (cm)

Then estimate the volume by assuming the tree is a truncated cone:

Equation for volume of decay status 2 trees:

$$\text{Volume } (cm^3) = \left(\frac{\pi * (0.01*ht)}{12} \right) * (d^2_{base} + d^2_{top} + (d_{base} * d_{top}))$$

ht = tree height (m)
d_{base} = the basal diameter (cm)
d_{top} = the diameter at the top (cm) estimated from the taper equation (if taper equation results in negative number, use 0 for d_{top}).

Next, use species-specific or average wood density (Table 3) to convert volume to biomass. Sound wood density can be used because the wood must be reasonably sound to support the standing tree (Pearson et al. 2005). The conversion equation is:

Dead tree biomass (g) = volume (cm^3) * wood density (g cm^{-3})

- Because the biomass is in g rather than kg, divide by 1,000,000 to obtain Mg.
- Multiply by 0.5 to obtain C mass.

Finally, add all the dead tree C masses together within each plot. Scale to dead tree C mass per hectare by dividing by plot area ($5*\varpi*10^2$) and multiplying by 10,000 m^2 ha^{-1}. Refer to example box for tree C computations above.

Live Saplings and Seedlings

Saplings:

- Insert the dbh and wood density of each sapling into the dbh-density biomass equation (default is dbh-density mangrove equation from Chave et al. 2005, page 93). If species or wood density is unknown, use site average density in Table 3.
- Include small (<5 cm dbh) lianas in these calculations. Use the liana allometric equation in Appendix 2.
- Divide the resulting number by 1000 to convert to megagrams (Mg).
- Multiply by 0.5 to obtain Mg of carbon contained in the sapling.

Seedlings:

- Multiply the count of seedlings in the plot by the average biomass per seedling (determined by destructive harvest, see above).
- Convert to megagrams (Mg).
- Multiply by 0.5 to obtain Mg of carbon contained in all the seedlings.

Sapling/Seedling aboveground C density:

Finally, add all the sapling C masses together, then add in the total seedling C mass. Scale to sapling/seedling C mass per hectare by dividing by plot area, which is $5*\varpi*3^2$, then multiplying by 10,000 m^2 ha^{-1}. Refer to example box for tree C computations above.

Belowground Biomass of Saplings and Seedlings

Repeat the process as for trees. Belowground biomass density of saplings and seedlings in the plot is a function of their aboveground biomass density in the plot:

Equation for sapling/seedling belowground biomass density:

$$BBD = \exp(-1.0587 + 0.8836*\ln(ABD))$$

BBD = belowground biomass density of sapling/seedling (Mg ha^{-1})
-1.0587 = constant
0.8836 = constant
ABD = aboveground biomass density of sapling/seedling (Mg ha^{-1}). Obtain ABD by multiplying the sapling/seedling aboveground C density by 2.

Multiply BBD by 0.5 to obtain C mass.

No scaling is necessary since the value is already scaled to the hectare.

Refer to example box for tree C computations above.

Dead Saplings and Seedlings

Dead saplings can be estimated for biomass in similar fashion as live saplings:

- Insert the wood density and diameter into the same equation as for live trees.
- Subtract out the biomass of leaves (5 percent of aboveground biomass).
- Divide by 1000 to obtain Mg.
- Multiply by 0.5 to obtain C mass.

Dead seedlings can be estimated for biomass in similar fashion as live seedlings:

- Multiply the count of dead seedlings in the plot by the average biomass per seedling (determined by destructive harvest, see above).
- Subtract out the biomass of leaves (10 percent of aboveground biomass).
- Divide by 1000 to obtain Mg.
- Multiply by 0.5 to obtain Mg of carbon contained in all the dead seedlings.

Finally, add all the dead sapling C masses together, then add the total dead seedling C mass. Scale to dead sapling/seedling C mass per hectare by dividing by plot area, which is $5*\varpi*3^2$, then multiplying by 10,000 m^2 ha^{-1}. Refer to example box for tree C computations above.to example box for tree C computations above.

Non Tree Vegetation

Non-woody palms, ferns, etc.:

- Multiply the count of stems of *Nypa* in the plot by the average biomass per frond (determined by destructive harvest, see above).
- Divide by 1000 to obtain Mg.
- Multiply by 0.5 to obtain Mg of carbon contained in all the *Nypa* fronds in the plot.
- *Repeat* for tiger fern (by clump), *Pandanus*, and any other species recorded.

Add all these together within each plot. Scale to non-tree vegetation C per hectare by dividing by plot area, which in this case is $5*\varpi*4^2$, and multiplying by 10,000 m^2 ha^{-1}.

Ceriops decandra:

- Enter the quadratic mean diameter of each size class (determined during a one-time field measurement, see above) into the allometric equation for Ceriops decandra biomass, which was developed during the 1995 inventory:

$$\text{Biomass (kg)} = 1.337 - 0.8816*D + 0.3876*D^2$$

Multiply the resulting biomass by the count of stems in each size class.

- Divide by 1000 to obtain Mg.
- Multiply by 0.5 to obtain Mg of carbon contained in all the Ceriops decandra in the plot.
- Scale to Ceriops decandra C per hectare by dividing by plot area, which is $5*\varpi*2^2$, and multiplying by 10,000 m^2 ha^{-1}.

Note: If herbaceous vegetation biomass is of interest in the future:

- Calculate forb biomass by entering % cover value into allometric equation to obtain biomass per 12.6-m^2 subplot (the area of the 2-m radius nest). Add the five subplot values together within the plot. Convert to units of Mg, convert to carbon mass.
- Repeat for grasses.
- Convert to C mass per hectare by dividing by plot area and multiplying by 10,000.

Forest Floor

Forest floor (litter) is unlikely to be collected for this project. However, if this decision is changed in the future and it is to be quantified, apply the following steps:

- If subsamples were taken to determine moisture content for some plots, multiply the original sample wet mass by these subplot-specific dry:wet ratios. The result will be the estimated dry mass of the original sample.
- Add total dry mass of all 5 litter collections from each plot.
- Convert to Mg. Multiply by 0.5 to obtain Mg C mass.
- Scale to litter biomass per hectare by multiplying by expansion factor 10000/(5*0.3*0.3) = 22 222

Canopy Cover

To obtain canopy cover estimates from the densiometer readings:

- Multiply the recorded counts by 1.04 to obtain the percent of area not occupied by canopy. This is because there were only 96 dots to count, instead of 100.
- Subtract the resulting value from 100 to obtain canopy cover in percent.
- Average the 4 values from each subplot (N, S, E, W) to provide a mean estimate of canopy cover at each subplot.

Finally, average the 5 subplot means to obtain a plot-average canopy cover.

Woody Debris

Small, medium and large size classes:

For small, medium, and large classes, these data were collected as counts only. Therefore, use the quadratic mean diameter for each class. The volume equation for these classes is:

Equation for volume of small, medium and large woody debris classes:

$$\text{Volume } (m^3\ ha^{-1}) = \pi^2 * \left(\frac{N_i * QMD_i^2}{8 * L} \right)$$

N_i = the count of intersecting woody debris pieces in size class i
QMD_i = the quadratic mean diameter of size class i (cm) (see destructive harvest)
L = transect length for that class (m).

For size class small:	L = 2 m
For size class medium:	L = 5 m
For size class large:	L = 10 m

<u>Extra-large size class:</u>

For extra-large woody debris classes, volume per hectare is calculated by the formula:

Equation for volume of extra-large woody debris classes:

$$\text{Volume } (m^3\ ha^{-1}) = \pi^2 * \left(\frac{d_1^2 + d_2^2 + d_3^2 + \ldots d_n^2}{8 * L} \right)$$

d_1, d_2, etc. = diameters of intersecting pieces of dead wood (cm)
L = the length of the transect line for a given class (m). For size class extra-large (sound, rotten), L = 10 m

Next, convert volume to biomass for all 5 classes of woody debris using class-specific wood densities. These densities were obtained via the one-time destructive harvest of woody debris (see destructive harvest above). Calculate separately for each class:

$$\text{Woody Debris Biomass } (Mg\ ha^{-1}) = \text{Volume } (m^3\ ha^{-1}) * \text{Wood density } (g\ cm^{-3})$$

Finally, add the 5 classes together to get a single value for total woody debris on each transect. Multiply biomass by 0.5 to obtain woody debris C mass per hectare on each transect. *Average* all 20 transects across the plot.

Soil

First obtain the bulk density of each soil layer within each plot. This is determined by dividing the oven-dry soil sample by the volume of the sample. The bulk density equation is:

Equation for soil bulk density:

$$\text{Soil bulk density } (g\ m^{-3}) = \frac{\text{Oven dry mass (g)}}{\text{Sample volume } (m^3) - \left(\frac{\text{Mass of rock fragments (g)}}{2.65 \times 10^6\ g\ m^{-3}} \right)}$$

Where $2.65 \times 10^6\ g\ m^{-3}$ is the default density of rock fragments (Pearson et al. 2005).

- If rocks (mineral particles > 2mm diameter) were present in the sample, these should have been separated and weighed in the laboratory. A correction factor is then included in the equation:

Equation for soil bulk density when rocks are present:

Where 2.65×10^6 g m^{-3} is the default density of rock fragments (Pearson et al. 2005).

- *Sample volume*: If soils were collected using the open-face peat auger, the sample volume is obtained by the following calculation:

Equation for soil sample volume using open-faced peat auger:

$$5 * \text{Sample length collected} * \left(\pi * r^2 - \left(\frac{r^2}{2} * \left(\frac{\pi}{180}\theta - \sin\theta\right)\right)\right)$$

Where the factor of 5 accounts for five subplots
sample length collected (in m) = the length of the soil sample that was collected from the auger and taken from the field
r = the radius of the auger (in m)
θ the angle (in degrees) indicated in the figure below

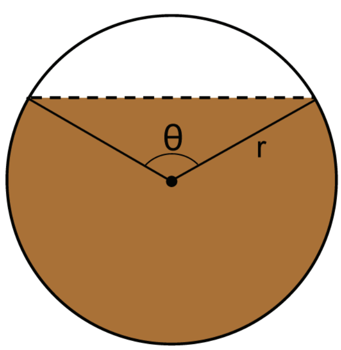


Figure 17. *Cross-section of open-face soil auger.*

For the auger used in this survey, sample length collected = 0.05 m, r = .0275 m and □ = 119.5°. The resulting sample volume is:

$$5 * 0.05 * \left(\pi * 0.0275^2 - \left(\frac{0.0275^2}{2} * \left(\frac{\pi}{180} * 119.5 - \sin(119.5)\right)\right)\right)$$

This results in a sample volume of 0.0003833 m^3.

- If soils were collected using the slide hammer, the sample volume is obtained by the simple formula for the volume of a cylinder with radius 0.0240 m and height of the sample sleeve (0.05 m), and multiplied by 5 because of five subplots:

Sample volume if slide hammer used = $5 * (\varpi * 0.0240^2 * 0.05) = 0.000362\ m^3$

Calculating soil C mass per hectare:

Using the %OC data obtained from the laboratory, the amount of carbon per unit area is given by:

Equation for soil carbon per hectare:

Soil C ($Mg\ ha^{-1}$) = bulk density ($g\ m^{-3}$) * soil depth interval (m) * %OC * 0.01 Soil depth interval = 0.3 for 0-30 cm depth interval, and 0.7 for 30-100 cm interval %OC is expressed as a decimal fraction (e.g., 5% is expressed as 0.05) 0.01 = a conversion factor to convert units to $Mg\ ha^{-1}$

Perform the above calculation for the 0-30 cm depth interval, repeat for the 30-100 cm depth interval. Add the values together to obtain total soil C ($Mg\ ha^{-1}$) for the top meter of soil.

Total Carbon Density and Total Carbon Stock

Total Carbon Density and Carbon Stock

The total carbon density at time t (i.e., resulting from a census in a given year) is estimated by adding all of the component pools.

- First, calculate the mean carbon density ($Mg\ ha^{-1}$) for each component pool (e.g., trees, soil, etc.). For this survey, this requires summing the C mass ($Mg\ ha^{-1}$) across all inventory plots and dividing the sum by the number of plots.

- Total carbon density is estimated by summing the mean carbon density for all component pools across the study area in $Mg\ ha^{-1}$:

Equation for total carbon density:

Total C density ($Mg\ ha^{-1}$) = $C_{treeAG} + C_{treeBG} + C_{deadtree} + C_{sap/seed} + C_{sap/seedBG} + C_{deadsap/seed} + C_{nontreeveg} + C_{woodydebris} + C_{soil}$

Note: Check that total carbon densities are within a reasonable range; most forests have C density on the order of tens to hundreds of Mg C per hectare including above- and belowground pools (commonly between ~50-500 Mg C ha^{-1}). Values far outside of this range should be given extra scrutiny.

- Total carbon stock of SRF is then estimated by multiplying this mean carbon density by the forested area of the reserve (i.e., the project area):

Equation for total carbon stock of a given project area:

$$\text{Total carbon stock of SRF (Gg)} = \text{Total C density (Mg ha}^{-1}\text{)} * \text{Area}_{SRF}\text{ (ha)} * 0.001$$

The factor of 0.001 is used to convert Mg to Gg (10^9 grams), which is a common reporting unit for total carbon stocks, per IPCC guidelines. Other units are acceptable too, but take care to track which units are used.

Combining with Activity Data:

One approach is to use remote sensing activity data to quantify the amount of land area in general classes (e.g., intact forest, non-intact forest, other land use), then multiply these land area values by the C density in each of the classes to obtain C stock by class. The C density by class would be obtained by performing the above calculations within each of the land classes. The resulting C stocks in each class would then be added together to obtain total C stock for the project area.

Converting to CO_2 equivalents

Greenhouse gas inventories (and emissions) are often measured in CO_2 (carbon dioxide) equivalents, as this is the most common greenhouse gas form of carbon. Deforestation and forest degradation result in greenhouse gas emissions dominated by CO_2, with other trace gases such as CH_4 also being released.

If desired or required for reporting purposes, the total carbon density and total carbon stock can be converted to CO_2 equivalents by multiplying C density or stock by 3.67. This is the ratio of molecular weights between carbon dioxide [44] and carbon [12]. The example of total C stock is shown below:

Equation for converting total carbon stock to CO_2 equivalents:

$$\text{Total C stock (Gg } CO_2 \text{ equivalents)} = 3.67 * [\text{total C stock (Gg C)}]$$

If a substantial portion of land-based greenhouse emissions are in the form of methane (CH_4) or nitrous oxide (N_2O), then different conversions are required to obtain CO_2 equivalents. This is because these trace gases have much stronger greenhouse effects than CO_2, typically by orders of magnitude. Therefore, higher conversion factors would be required. For ecosystems such as Sundarbans, relatively little information is available on the ratios of different forms of C emissions, so a default conversion of 3.67 can be used (GOFC-GOLD 2009). See GOFC-GOLD (2009) sourcebook for more information.

Quantifying & Reporting Change in C Pools Over Time

Carbon assessments aim to quantify changes in C pools over time. Two equally valid approaches are used to estimate these changes: stock-change and gain-loss. The stock-change approach estimates the difference in carbon stocks at two points in time, while the gain-loss approach estimates the net balance of additions to and removals from a carbon stock. The stock-change approach is used when carbon stocks in relevant pools have been measured and estimated over time, such as in forest inventories. The gain-loss approach is used when annual data such as biomass growth rates and reliable data on wood harvests are available. In practice, a mix of the two approaches may be used.

This protocol focuses on forest inventory approaches in support of high-tier C assessments. The stock-change approach is emphasized here. Stock-change is an acceptable method for estimating emissions caused by both deforestation and forest degradation in all C pools (GOFC-GOLD 2009). The C stock of a pool at time 1 will represent the initial condition (e.g., intact forest), and the C stock of that pool at time 2 will be the value for the pool under 1) no change—intact forest, 2) the new land use—deforestation, or 3) the non-intact forest (degradation).

To calculate the change in C stocks over a given time period, the C density of each pool at the beginning of the time period is subtracted from the C density at the end of the time period, then divided by the time period length:

Equation for pool-specific change in carbon over a given time period:

$$\Delta C = C_{t2} - C_{t1}$$

ΔC = Change in carbon density of pool (Mg C ha^{-1})
C_{t2} = Carbon density of pool at time 2 (Mg C ha^{-1})
C_{t1} = Carbon density of pool at time 1 (Mg C ha^{-1})

Note that the equation is applied separately for each C pool; e.g., trees, soil, etc. These changes are then summed across all pools to obtain an estimate of change in total C density:

Equation for total change in carbon density over a given time period

$$\Delta C_{total} = \Delta C_{c1} + \Delta C_{c2} + \Delta C_{c3} + \ldots\ldots \Delta C_{cn}$$

ΔC_{total} = Change in total carbon density (Mg C ha^{-1})
ΔC_{c1} = Change in carbon density of pool 1 (Mg C ha^{-1})
ΔC_{c2} = Change in carbon density of pool 2 (Mg C ha^{-1})
etc.

To obtain the change in total C stock, the change in total C density is then multiplied by the project area:

Equation for total change in carbon stock over a given time period:

$$\Delta C_{stock} \text{ (Mg C)} = \Delta C_{total} \text{ (Mg C ha}^{-1}) * \text{Project Area (ha)}$$

To obtain the annual C emission rate over the time period, the change in total carbon stock is then divided by the length of the time period in years:

Equation for annual carbon emission rate over given time period:

$$\text{Annual C emission rate (Mg ha}^{-1}) = \Delta C_{stock} / (t_2 - t_1)$$

ΔC_{stock} = Change in total carbon stock [emission rate] (Mg C yr^{-1})
t_1 = beginning of time period (year)
t_2 = end of time period (year)

Finally, if required, convert values to CO_2 equivalents by multiplying by 3.67.

Note that soils may be tracked somewhat differently using a combination of stock-change and gain-loss approaches, based on several necessary assumptions for soil C when forest land is degraded or converted to other use. See p. 2-77 and 2-78 of GOFC-GOLD (2009) for assumptions and equations for integrating gain-loss for soils. Methods for monitoring mangrove soil carbon with land-use change are not well established.

Combining with activity data:

The sample plots may capture changes in C pools with land use, if plots are in areas where deforestation and/or degradation are occurring. The field data from these plots would then provide information on the fate of C pools upon deforestation or degradation (emission factors). This information could then be combined with remote-sensing activity data on land use changes occurring such as forest land converted to other use (deforestation) or forest land converted from intact to non-intact (degradation). In this manner, activity data and emission factors can be used to assess changes in total C stock over the changed area. The equation for this is:

Equation for change in carbon stock in land converted to new land-use:

$$\Delta C_{CONV} = \sum [(C_{AFTER} - C_{BEFORE}) * \Delta A]$$

ΔC_{CONV} = change in C stock on land converted to different use (e.g., intact forest to other use)
C_{AFTER} = C density on converted land immediately after conversion
C_{BEFORE} = C density on converted land immediately before conversion
ΔA = area of converted land

This calculation can be carried out and summed for all combinations of land-use change (e.g., intact to non-intact forest, intact forest to other land-use, non-intact forest to other land-use; see Figure 1).

Example: Remote sensing indicates that, between time 1 and time 2, 3000 hectares of intact forest within the project area were converted to other land-use such as agriculture. For example purposes, assume that C density of intact forest is 300 Mg ha^{-1} and agricultural land is 100 Mg ha^{-1}. Solving for the above equation yields an estimate of change in C stock due to deforestation of [(100-300) * 3000] = -600,000 Mg C. In other words, a loss of 600,000 Mg C, or 2 202,000 Mg CO_2 equivalent.

Quantifying Uncertainty in Carbon Pools

For carbon assessments it is essential that not just the mean, but also the uncertainty is estimated and reported. Uncertainty reflects the degree of precision in the dataset (i.e., how much variation there is around the mean value). For carbon assessments it is typically reported as a 95% confidence interval (CI), expressed as a percentage of the mean. For example, if the value is 100 Mg ha^{-1} and the 95% CI is 90-110 Mg ha^{-1}, the uncertainty in the estimate is ±10%.

Key definitions relevant to uncertainty should be reviewed on pages 2-92 through 2-93 of GOFC-GOLD (2009).

Uncertainty should be quantified and reported for each component pool as well as total carbon density and total carbon stock.

Uncertainty in Component Pools

The first step is to compute a 95% confidence interval (CI) for each component pool (trees, soil, etc.). For practical purposes, the 95% CI is the mean plus or minus 2 x the standard error of the mean. To get the standard error, first compute the standard deviation (*s*) as:

Equation for standard deviation of a mean:

$$\text{Standard deviation of the mean } (s) = \sqrt{\sum_{i=1}^{n} (Y_i - \overline{Y})^2 / (n-1)}$$

Y_i = value of the *i*th plot,
$\overline{Y}$ = mean value of all plots,
n = the number of plots.

Most statistical or spreadsheet programs easily compute the standard deviation. Next, compute standard error as:

Equation for standard error of a mean:

$$\text{Standard error of the mean (SE)} = \frac{s}{\sqrt{n}}$$

s = standard deviation of mean,
n = number of plots

The 'half-width' of the 95% CI is then computed by:

95% CI half-width = 2 * SE

The 95% CI half-width is then added to and subtracted from the mean. For example if the mean is 200 Mg ha^{-1} and the 95% CI half-width is 10, the 95% CI is 190-210 Mg ha^{-1}.

The 95% CI half-width is also used to express the uncertainty as a percentage of the mean.

Uncertainty (%) = 100* (95% CI half-width) / mean.

In the above example, uncertainty = 100*(10)/200 = 5%.

Uncertainty in Total Carbon Density

Total carbon density is the sum of several pools, each of which has its own uncertainty.

Therefore, calculating uncertainty in total carbon density requires accounting for the uncertainty in each of the component pools.

There are two methods for calculating the total uncertainty for carbon projects (Pearson et al. 2005, Pearson et al. 2007, GOFC-GOLD 2009). The first method uses simple error propagation through the square root of the sum of the squares of the component errors. The second method uses Monte Carlo simulations to propagate errors. The advantage of the first method is that it is simple to use and requires no additional computer software. However, the second method is used when substantial correlations exist between datasets (for example, between two carbon pools), when uncertainties are very large (e.g., greater than 100%), or when data distributions are strongly non-normal. In theory, it is always better to use Monte Carlo simulations because it is robust to most any data structure; thus, if data analysts knowledgeable of this method are available, this is the preferred approach. Nevertheless, in practice the difference in results attained through the two methods is typically small unless correlations and/or uncertainties are very high (Pearson et al. 2007). For practical purposes, the simple error propagation method is often used. The error propagation method is detailed here for its ease of use.

For total carbon density, the formula for the 95% CI half-width is:

Equation for uncertainty in total carbon density:

$$\text{95\% CI half-width for total C density} = \sqrt{([95\%CI_{c1}]^2 + [95\%CI_{c2}]^2 + \ldots\ldots\ldots [95\%CI_{cn}]^2)}$$

Where [95%CI$_{c1}$] is the 95% CI half-width for pool 1, e.g., tree C mass, pool 2, and so on for all pools measured in the plots.

Where [95%CI$_{c1}$] is the 95% CI half-width for pool 1, e.g., tree C mass, pool 2, and so on for all pools measured in the plots.

The total uncertainty in C density can either be expressed as the actual confidence interval (e.g., mean = 300, 95% CI = 270-330), or as a percentage of the mean (e.g., 300 ± 10%).

<u>Uncertainty in Total Carbon Stock</u>

The error propagation technique for total C stock is the same general concept as for total C density. However, the formula for error propagation is slightly different because the estimate of interest requires multiplication rather than addition of inputs (see equation for total C stock above).

The remote sensing analysis of land cover types (e.g., forest, grassland, etc.) should have an uncertainty estimate associated with it. For example, the forested area of SRF may be estimated at 400,000 ha ± 30,000 ha.

Combine this uncertainty with the uncertainty in total C density by the equation:

Equation for uncertainty in total carbon stock:

$$\text{95\% CI half-width for total C stock} = \text{area} * \text{TCD} * \sqrt{([95\%CI_{area}/\text{area}]^2 + [95\%CI_{TCD}/\text{TCD}]^2)}$$

Area = estimated land area in a given category (e.g. forest),
TCD = mean total carbon density within that category,
$95\%CI_x$ = the uncertainty of each parameter (expressed as 95%CI half-width).

For example, if the forested area is estimated at 400,000 ± 30,000 ha, and the TCD is 300 ± 30 Mg ha^{-1}, the total C stock would be reported as 400,000 ha * 300 Mg ha (= 120,000,000 Mg, or 120,000 Gg). The uncertainty around this value is computed as follows:

$$\text{95\% CI half-width for total C stock (Mg)} = 400\,000 * 300 * \sqrt{([30\,000 / 400\,000]^2 + [30 / 300]^2)}$$

$$= 15{,}000{,}000 \text{ Mg} \quad \text{or} \quad 15{,}000 \text{ Gg}$$

Like total carbon density, the uncertainty in total carbon stock can be expressed as the actual interval, or as a percentage of the mean estimate.

Thus, the total C stock would be reported as 120,000 ± 15,000 Gg. Or, 120,000 Gg ± 12.5%.

<u>Uncertainty in Carbon Stock Change</u>

Changes in carbon stocks over time should also have a quantified uncertainty. For the stock-change approach, this can be accomplished in a series of error-propagation steps:

- Compute the change in C density for each pool by subtracting the C density at time 1 from the C density at time 2 (see stock-change equation above).
- Compute the uncertainty in change of each C pool by the equation:

Equation for uncertainty in carbon pool change

$$\text{95\% CI half-width for change in C pool} = \sqrt{([95\%CI_{t1}]^2 + [95\%CI_{t2}]^2}$$

$95\%CI_{t1}$ = 95% CI of the pool at time 1,

$95\%CI_{t2}$ = 95% CI of the pool at time 2.

- Add the changes for all C pools together to estimate change in total C density (as described in previous section).
- Compute the uncertainty for change in total C density by the equation:

Equation for uncertainty in total carbon density change:

$$\text{95\% CI half-width for change in total C density} = \sqrt{([95\%CI_{\Delta c1}]^2 + [95\%CI_{\Delta c2}]^2 + \ldots\ldots\ldots [95\%CI_{\Delta cn}]^2)}$$

$95\%CI_{\Delta c1}$ = 95% CI of the change in pool 1,

$95\%CI_{\Delta c2}$ = 95% CI of the change in pool 2, etc.

- Compute the uncertainty for change in total C stock over the project area by combining uncertainty in total C density with uncertainty in project area:

Equation for uncertainty in change in total carbon stock over the project area:

$$\text{95\% CI half-width for change in total C stock} = \text{area} * \Delta TCD * \sqrt{([95\%CI_{area}/ \text{area}]^2 + [95\%CI_{\Delta TCD}/ \Delta TCD]^2)}$$

Area = estimated land area in a given category (e.g. forest),
ΔTCD = mean total carbon density within that category,
$95\%CI_x$ = the uncertainty of each parameter (expressed as 95%CI half-width).

Note on Stratification

Note that if the landscape of interest was stratified (e.g., into different forest or land cover types), then the above computations of individual C components, total C density, total C stock, and C stock change must be conducted for each stratum separately. These separate computations are then added together to get total C estimates. Uncertainty is also calculated for each stratum, then propagated to get total uncertainty using the additive equation outlined above.

Notes on Establishing a Baseline

The baseline is the historic rate of change in carbon stocks, or the carbon emissions, from a given project area. Forest carbon projects must compare actual future carbon emissions with modeled future emissions based on this baseline rate, which is often referred to as a 'business as usual' scenario. Changes in C stocks/emissions due to the carbon project (e.g. marketable carbon benefits) are quantified as departures from the baseline business as usual scenario.

In general, the two main data types—activity data and emission factors—need to be assessed for an approximately 10-20 year period prior to project initiation.

Methods for establishing the baseline vary and no single method is the absolute standard; these are still under discussion and development at the international level. A typical time period for the baseline is 10-20 years prior to project initiation (e.g., 1995 – 2005 or 1995 – 2010). Some flexibility may be employed in order to utilize past datasets, for example previous forest inventories.

For SRF, forest inventories were conducted in 1985 and 1995. Some of these data can be used to compute C stocks at those times. Depending on the scope of data collected, changes in C stocks for the period 1995 - 2010 could be assessed based on comparison of the most recent and current inventory. This assessment would hopefully identify any past trends in forest C stocks over the project area due to, for example, forest degradation. This information would support quantification of emission factors due to degradation and possibly deforestation (if deforested areas were part of the sample).

The methods outlined in this document for computing carbon stocks from forest inventories could be used for these assessments:

- Obtain previous datasets, which were likely focused on trees, the dominant aboveground C pool.
- Apply biomass and C equations as outlined here for the current inventory. Alternatively, apply BCEFs based on timber volume data (see box above and GOFC-GOLD 2009, pages 2-55 to 2-59).
- Combine these with activity data on land use / land cover to estimate total C stocks at each time point.
- Compare C stocks between inventory years using the stock-change approach. This provides the estimate of baseline C emissions.
- *NOTE*: To the extent possible, use consistent methodologies for computing C stocks at

each time point, including the current inventory. Decisions on approach will need to take into account which pools were measured in a given census (i.e., non-tree pools and soil were likely not measured in the past, so these may need to be excluded from the baseline, or their rates of change estimated based on trends in trees or other scientific sources on these pools). Similarly, selection of allometric approaches (allometrics based on dbh-density only, or dbh-density-height, or BCEFs) should be made as consistent as possible. Conservativeness and transparency in methodology and assumptions are essential.

Remote sensing data and other land cover information must be used to obtain activity data. The specifics of these methods are beyond the scope of this document, but the basic concept is that changes in forest cover, land use, and forest degradation (see Figure 1) are quantified over the time period of interest by comparing time 2 to time 1 (e.g., 1995-2010). These data are combined with C density data in each cover type to estimate changes in total C stocks during the baseline period.

Ideally, uncertainty is also quantified around the mean baseline estimate using the same general approaches as for current C stocks (above). The difference from the baseline (carbon benefit) has a 95% CI associated with it that can be computed by propagating the uncertainty of the baseline projection and the actual C stock at a given time point. Applying the principle of conservativeness (risk of overestimating reduction in emissions should be minimized), the lower confidence bound of this uncertainty interval may be the chosen estimate of emission reduction. See page 4-182 of GOFC-GOLD (2009).

Quality Assurance / Quality Control and Verification

A rigorous quality control / quality assurance (QA/QC) and verification program ensures that all possible measures have been taken to guarantee that high quality data have been collected and can be reproduced. This will be especially important when participating in an international carbon credit market. Qualities of transparency, consistency, comparability, completeness and accuracy are vital.

QC is largely an internal activity performed as part of routine data collection and analysis. These measures should be taken and documented every day that data collection and analysis occurs. Most QC activities are easy to implement, such as reviewing data sheets at the end of a day in the field for completeness, legibility and accuracy, and fixing any mistakes right away. Timely and consistent review of the data also allows any broader problems in data collection and/or entry to be corrected.

QA refers to review procedures performed by persons not directly involved in the data collection and analysis, after the inventory and QC procedures have been completed. Ideally an independent third party completes the QA. QA is designed to verify that the QC activities were effective and that the data collected are of the best possible quality.

Verification activities are designed to ensure reliability of both the methodology and data collected. These procedures are external to the inventory, and use an independent data set.

The specific verification procedures required by a carbon market will likely depend on the market; this protocol will focus on QA/QC measures that will be important regardless of end use for the data. Additional measures may be necessary depending on the carbon market.

A QA/QC plan should be developed and documented for the project. Elements of the plan include data quality objectives, QA/QC activities (includes data collection, recording, entry into database, data analysis, database management, laboratory procedures, etc.), roles and responsibilities, timelines, what to do if errors are found, documentation procedures, data management/archival etc. The plan and documentation of QA/QC activities should be kept in a project QA/QC notebook. Some examples of plan elements are provided below:

- Data quality objectives. Examples may include:
    - Timeliness
    - Completeness
    - Consistency (internal and time series)
    - Accuracy
    - Transparency
- List of QC activities, each includes:
    - Roles and responsibilities
    - Timeline
    - Course of action if errors are found
    - Documentation

Example QC activity: Check for completeness, accuracy, and legibility on datasheets. To be completed by the datasheet recorder or another crew member every day before leaving field plot. Small errors to be corrected by recorder; recorder to ask surveyor if more information is needed, re-measurements may be necessary. Issues in data collection (i.e., incorrect data measurements) should be brought to the attention of surveyors and/or the field supervisor; corrective action should be taken (i.e., reviewing field protocol and re-training of crew members) if needed. QC activities should be documented on the datasheet including name of person completing the QC, the date, and notes on errors found and corrective actions taken.

- List of QA review procedures, each includes:
    - Roles and responsibilities

- Timeline
- Course of action if errors are found
- Documentation

Example QA procedure: Review 10% of datasheets for completeness, accuracy, and legibility. To be completed by (name entity) half-way through data collection and at the end of data collection (more often if significant problems are noted). All issues should be brought to the attention of the field supervisor and corrected on both the datasheet and the electronic database. Issues that require broader action should be dealt with as soon as possible (i.e., incorrect field measurements may require re-training and/or re-measurement). QA procedure, including name of reviewer, date of review, issues/errors found, and corrective actions taken, should be documented on the (name) form and filed in the project QA/QC notebook.

- Data management/archival, each includes:
    - Roles and responsibilities
    - Timeline
    - Data security
    - Documentation

Example: Data management/archival activity: Managing electronic database(s). Once data is entered into an electronic database and reviewed by person entering the data, a read-only copy will be made with the date of the update in the filename. New data will be entered into the original non-read-only copy. The final read-only copy will have the date and “final” in the filename. Analysis should take place on a separate copy of the database that is not read-only. Documentation including filenames, name of database manager, date file created/altered, and notes should be on the form and filed in the project QA/QC notebook. Finally, all original hard-copy datasheets should be kept on file for future reference. A xeroxed hard-copy set of the datasheets should also be kept in an alternate locale.

Sample QA/QC forms are provided in the datasheet file. These should be adapted to meet the specifics of the QA/QC plan developed for the project.

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Appendix 1. Table of species codes for trees.

Common Name	Scientific Name	Species Code
Amur	*Amoora cucullata*	AMCU
Babul	*Acacia nilotica*	ACNI
Baen	*Avicennia officinalis*	AVOF
Ban Jam	*Eugenia fruticosa*	EUFR
Batla/Batul	*Excoecaria indica*	EXIN
Bhaela/Baral	*Intsia hijuga*	INHI
Bhola	*Hibiscus tiliaceus*	HITI
Bon Lichu	*Lepisanthes rubiginosa*	LERU
Bon Notoy	*Mallotus repandus*	MARE
Choyla/Ora/Soyla	*Sonneratia caseolaris*	SOCA
Dhundul	*Xylocarpus granatum*	XYGR
Doyal	*Mucuna gigantea*	MUGI
Gab	*Diospyros peregrina*	DIPE
Garjan/Jhanna	*Rhizophora mucronata*	RHMU
Gewa	*Excoecaria agallocha*	EXAG
Goran	*Ceriops decandra*	CEDE
Jhao	*Tamarix indica*	TAIN
Jir	*Ficus sp*	FISP
Kankra	*Bruguiera gymnorhiza*	BRGY
Karanj/Karanja	*Pongamia pinnata*	POPI
Keora	*Sonneratia apetala*	SOAP
Khalisha/Khalshi/Khulsha	*Aegiceras corniculatum*	AECO
Kirpa/Kripa	*Lumnitzera racemosa*	LURA
Passur	*Xylocarpus mekongensis*	XYME
Sadda Baen/White Baen	*Avicennia alba*	AVAL
Shingra	*Cynometra ramiflora*	CYRA
Sitka/Sitki	*Clerodendrum inerme*	CLIN
Sundri	*Heritiera fomes*	HEFO
Sundri lota	*Brownlowia tersa*	BRTE
Unknown species		UNSP

Appendix 2. Table of allometric equations for computing biomass.

Species group	Equation	Source	Data origin	Max input
Mangrove Tree (dbh-density-ht)	B = 0.0509*□*$(dbh)^2$ *ht	Chave et al. (2005)	Asia, Americas, Australia	50 cm dbh
Mangrove Tree (dbh-density)	B = □ * exp[-1.349 + 1.980*ln(dbh) + 0.207*$(\ln(dbh))^2$ – 0.0281*$(\ln(dbh))^3$]	Chave et al. (2005)	Asia, Americas, Australia	50 cm dbh
Mangrove Tree (dbh-density)	B = 0.168*□*$(dbh)^{2.46}$	Komiyama et al. (2008)	Asia, Australia	49 cm dbh
Palms (*asai* and *pataju*)	B = 6.666 + 12.826*$ht^{0.5}$ *ln(ht)	Pearson et al. (2005)	Central America	33 m ht
Palms (*motacu*)	B = 23.487 + 41.851*$(\ln(ht))^2$	Pearson et al. (2005)	Central America	11 m ht
Lianas	B = $dbh^{2.657}$ * $e^{-0.968}$	Schnitzer et al. (2006)	Asia, Americas	23 cm dbh
Belowground Tree Biomass	BBD = exp(-1.0587 + 0.8836*ln(ABD))	Cairns et al. (1997)	Asia, Americas, Europe	982 Mg ha^{-1}

B = biomass (kg), ht = height (m), dbh = diameter at breast height (cm), □ = wood density (g cm^{-3}), BBD = belowground biomass density (Mg ha^{-1}), ABD = aboveground biomass density (Mg ha^{-1}).

ANNEXURE 1 : Data Forms for Carbon Assessment/Forest Inventory : **Plot Description**

Plot Number:		**Date**:	**Crew Members Present**
Range:	**Compartment**:	**Block**:	
GPS			
Precision +/-: m	Lat: N	Long: E	
Plot Location Notes:			

Site category (Circle): Forest Scrub (<5m height) Grass/Bare Ground Other (describe)

Forest condition (Circle): Intact Degraded Deforested

Topography (Circle): Flat Depression Levee Slope (%)

General Soil (Circle best choices)

Salt crust on soil surface: Not Observed Low Medium High

Soil description: Loose Sand Hard Clay Soft Mud Fluid Mud

Disturbance Evidence (Circle best choices)

Cyclone damage: Not Evident Light Moderate Severe

Heritiera fomes top-dying: Not Evident 0-30% (trees affected) 30-70% 70-100%

Timber harvest: Not Evident Low (< 30% basal area) Medium (30-70%) High (> 70%)

Describe harvest activities

Other disease/disturbance: Not Evident Light Moderate Severe

Describe other

Photo archive: **File Names** **Storage Location**

North South East West

Camera

Digital

Remarks:

Data Review (name, date, notes) **Data Entry** (name, date, notes) **Entry Review** (name, date, notes)

ANEXURE 2 : Data Forms for Carbon Assessment/Forest Inventory : Understory & Canopy Cover (Seedling, herbaceous vegetation and large shrubs)

Plot: **Date**:

Recorder
Surveyors

Seedlings (2-m radius circle)

Subplot	Number of Live Seedlings	Number of Dead Seedlings	Dominant Species
1			
2			
3			
4			
5			

Herbaceous vegetation (Record percent cover in 2-m radius circle)

Subplot 1		**Subplot 2**		**Subplot 3**		**Subplot 4**		**Subplot 5**		Remarks
Grasses	Forbs	Grasses	Forbs	Grasses	Forbs	Grasses	Forbs	Grasses	Forbs	

Canopy cover (Record number of dots not occupied by canopy from subplot center)

Subplot 1		**Subplot 2**		**Subplot 3**		**Subplot 4**		**Subplot 5**		Remarks
N	E	N	E	N	E	N	E	N	E	
S	W	S	W	S	W	S	W	S	W	

Small Shrubs (< 30 cm height, record number of individuals), **Golpatta** (record stem number) (4-m radius circle)

	Subplot 1	**Subplot 2**	**Subplot 3**	**Subplot 4**	**Subplot 5**
Small Shrubs					
Golpatta					
Other (specify)					

Large Shrubs (>30 cm height, 4-m radius circle)

Subplot	Crown Diameter		Max. Height	Remarks
	North-to-South	East-to-West		

Data Review (name, date, notes) **Data Entry** (name, date, notes) **Entry Review** (name, date, notes)

ANNEXURE 3: Data Forms for Carbon Assessment/Forest Inventory : Understory & Canopy Cover (Sapling)

Plot: **Date**: **Recorder**: **Surveyors**:

Saplings (2-m radius circle)

Subplot	Species	DBH	Dead (y)	Subplot	Species	DBH	Dead (y)	Subplot	Species	DBH	Dead (y)

Data Review (name, date, notes) **Data Entry** (name, date, notes) **Entry Review** (name, date, notes)

ANNEXURE 4: Data Forms for Carbon Assessment/Forest Inventory **: Trees**

Plot: **Date**: **Recorder**: **Surveyors**:

Trees (10-m radius circle)

Subplot	Species	DBH	Dead (Y)	Decay Status	Base Diam. status 2	Height (decay status 2 & 3 co-dom)	Heritiera fomes Top-Dying (% crown affected)		Timber Defect (% bole affected)		Remarks
							< 50%	> 50%	< 50%	> 50%	

Data Review (name, date, Notes) **Data Entry** (name, date, notes) **Entry Review** (name, date, notes)

ANNEXURE 5: Data Forms for Carbon Assessment/Forest Inventory : Woody Debris

Plot:

Date:

Transcript A: 45°
Transect B: 135°
Transect C: 225°
Transect D: 315°

Size Class	Size	Transect Sub-Section
Small	0 - 0.6 cm	8 - 10 m
Medium	0.7 - 2.5 cm	5 - 10 m
Large	2.6 - 7.6 cm	0 - 10 m
Extra-Large	> 7.6 cm	0 - 10 m

Recorder:

Surveyors:

Subplot 1

Transect	Record Tally			Record piece diameters	
	Small	Medium	Large	Extra large Sound	Extra Large Rotten
A					
B					
C					
D					

Subplot 2

Transect	Record Tally			Record piece diameters	
	Small	Medium	Large	Extra large Sound	Extra Large Rotten
A					
B					
C					
D					

Subplot 3

Transect	Record Tally			Record piece diameters	
	Small	Medium	Large	Extra large Sound	Extra Large Rotten
A					
B					
C					
D					

ANNEXURE 5 (Contd) : Data Forms for Carbon Assessment/Forest Inventory **: Woody Debris**

Transect A : 45° Transect B : 135° Transect C : 225° Transect D : 315°	
Size Class	Transect SectionSize
Small	8 – 10 m0 – 0.6 cm
Medium	5 – 10 m0.7 – 2.5 cm
Large	0 – 10 m2.6 – 7.6 cm
Extra Large	0 – 10 m>7.6 cm

Subplot 4

Transect	Record Tally			Record piece diameters	
	Small	Medium	Large	Extra large Sound	Extra Large Rotten
A					
B					
C					
D					

Subplot 5

Transect	Record Tally			Record piece diameters	
	Small	Medium	Large	Extra large Sound	Extra Large Rotten
A					
B					
C					
D					

Data Review (Name, date, notes) **Data Entry** (Name, date, notes) **Entry Review** (Name, date, notes)

ANNEXURE 6: Data Forms for Carbon Assessment/Forest Inventory : Soil

Recorder
Surveyors
Pre-lab processors

Date :

Soil Core Equipment (check appropriate box)

Open-Faced Auger	
Slide Hammer	

Bulk Density Samples

Subplot	Depth	Can #	Dry Mass 1	Dry Mass 2	Dry Mass 3	Dry Mass 4	Dry Mass 5	Dry Mass 6	Can Mass
1									
1									
2									
2									
3									
3									
4									
4									
5									
5									

Subplot	Depth	Can #	Dry Mass 1	Dry Mass 2	Dry Mass 3	Dry Mass 4	Dry Mass 5	Dry Mass 6
1								
1								
2								
2								
3								
3								
4								
4								
5								
5								

Remarks :

Data Review (name, date, notes) **Data Entry** (name, date, notes) **Entry Review** (name, date, notes)

ANNEXURE 7: Data Forms for Carbon Assessment/Forest Inventory **(Destructive Harvest): Bamboo**

Date : **Recorder :** **Surveyor :**

Bamboo

Culm	Basal Diameter	Height	Stem Wet Mass	Foliage Wet Mass	Sub-Sample							
					Stem Mass				Foliage Mass			
					Wet Mass	Dry Mass 1	Dry Mass 2	Dry Mass 3	Wet Mass	Dry Mass 1	Dry Mass 2	Dry Mass 3

Remarks :

Data Review (name, date, notes) **Data Entry** (name, date, notes) **Entry Review** (name, date, notes)

ANNEXURE 8: Data Forms for Carbon Assessment/Forest Inventory **(Destructive Harvest): Non Woody Palms**

Date : **Recorder :** **Surveyor :**

Non Woody Palms

Frond	Wet Mass	Sub-Sample			
		Wet Mass	Dry Mass 1	Dry Mass 2	Dry Mass 3
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
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21					
22					
23					
24					
25					
26					
27					
28					
29					
30					
31					
32					
33					

Remarks :

Data Review (name, date, notes) **Data Entry** (name, date, notes) **Entry Review** (name, date, notes)

ANNEXURE 9: Data Forms for Carbon Assessment/Forest Inventory **(Destructive Harvest): Large Shrubs(Crown diameter, height and mass)**

Date : **Recorder :** **Surveyors :**

Large Shrubs (>30 cm)

Shrub	Crown Diameter		Height	Wood Mass	Foliage Mass
	North – to - South	East – to - West			

Remarks :

Data Review (name, date, notes) **Data Entry** (name, date, notes) **Entry Review** (name, date, notes)

ANNEXURE 10: Data Forms for Carbon Assessment/Forest Inventory (Destructive Harvest): Large Shrubs (Wet and dry mass of wood and foliage)

Recorder : **Surveyor :**

Large Shrubs (>30 cm)

Shrub	Sub-Sample							
	Wood Mass				Foliage Mass			
	Wet Mass	Dry Mass 1	Dry Mass 2	Dry Mass 3	Wet Mass	Dry Mass 1	Dry Mass 2	Dry Mass 3
1								
2								
3								
4								
5								
6								
7								
8								
9								
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12								
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29								
30								

Remarks :

Data Review (name, date, notes) **Data Entry** (name, date, notes) **Entry Review** (name, date, notes)

ANNEXURE 11: Data Forms for Carbon Assessment/Forest Inventory **(Destructive Harvest): Small Shrubs**

Date : **Recorder :** **Surveyor :**

Small Shrubs (<30 cm)

Shrub	Wood Mass	Foliage Mass	Sub - Sample							
			Wood Mass				Foliage Mass			
			Wet Mass	Dry Mass 1	Dry Mass 2	Dry Mass 3	Wet Mass	Dry Mass 1	Dry Mass 2	Dry Mass 3
1										
2										
3										
4										
5										
6										
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29										
30										

Remarks :

Data Review (name, date, notes) **Data Entry** (name, date, notes) **Entry Review** (name, date, notes)

ANNEXURE 12: Data Forms for Carbon Assessment/Forest Inventory **(Destructive Harvest): Seedlings**

Date : **Recorder :** **Surveyor :**

Seedlings

Shrub	Wood Mass	Foliage Mass	Sub - Sample							
			Wood Mass				Foliage Mass			
			Wet Mass	Dry Mass 1	Dry Mass 2	Dry Mass 3	Wet Mass	Dry Mass 1	Dry Mass 2	Dry Mass 3
1										
2										
3										
4										
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26										
27										
28										
29										
30										

Remarks :

Data Review (name, date, notes) **Data Entry** (name, date, notes) **Entry Review** (name, date, notes)

Participants carrying out field work

Destructive Sampling