Forest Carbon Accounting Training for Indigenous Peoples and other Forest Dwellers:

MANUAL FOR FACILITATORS

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Acronyms

AGB	Aboveground Biomass
AD	Activity Data
BGB	Belowground Biomass
CB	Community Based
CBP	Capacity Building Program
CSOs	Civil Society Organizations
DBH	Diameter at Breast Height
DGM	Dedicated Grant Mechanism
EF	Emission Factor
FAO	Food and Agriculture Organization
FCPF	Forest Carbon Partnership Facility
FREL/FRL	Forest Reference (Emission) Level
GIS	Geographic Information System
GHG	Greenhouse Gas
GPS	Global Positioning System
IIPFCC	International Indigenous Peoples Forum on Climate Change
IPs	Indigenous Peoples
IPCC	Intergovernmental Panel on Climate Change
MRV	Measurement, Reporting and Verification
NCB	Non-Carbon Benefits
NFI	National Forest Inventory
NFMS	National Forest Monitoring System
PC	Participants Committee
PCM	Participatory Carbon Monitoring
QA/QC	Quality Assurance / Quality Control
REDD+	Reducing Emissions from Deforestation and Forest Degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries
SIS	Safeguard Information System
UNDRIP	United Nations Declaration on the Rights of Indigenous Peoples
UNFCCC	United Nations Framework Convention on Climate Change
WB	World Bank

INTRODUCTION

Indigenous peoples (IPs) and other forest dependent communities have been the inherent rights holders and custodians of the forests and all the natural resources therein. They have managed, protected and used the forest and natural resources sustainably for generations using their traditional knowledge systems and practices and customary governance long before the UNFCCC considered REDD+ as a climate change mitigation measure.

The forest and its natural resources are the subject of REDD+. IPs have and continue to depend on the forests for social and economic livelihoods, and cultural and spiritual well-being. With no recognition of their contributions to sustainable use and management of forest and its natural resources on their customary lands and territories for decades, they asserted their right to participate fully and effectively in REDD+. They intimated governments, donors and other stakeholders that REDD+ will fail without the full and effective engagement of IPs and other forest communities.

The Conference of Parties (COP) of the UNFCCC adopted decisions that respect and recognize IP rights and the contributions of IPs and forest dependent communities in enhancing traditional knowledge systems and sustainable forest management and to support their full and effective participation in REDD+.

TRAINING OBJECTIVES

This manual aims to improve the knowledge of IPs and forest communities on REDD+, introduce them to forest carbon measurement and monitoring and guide them to transfer the knowledge primarily to IPs and forest communities.

It is intended for community facilitators who are indigenous peoples and/or forest dwellers who have basic knowledge and understanding on climate change including REDD+. The participation of women and youth and gender balance among participants is highly recommended. This training manual can also serve as reference for IPs and forest dwellers who:

- are currently conducting Community-based Monitoring and Information Systems (CBMIS) and want to include forest carbon monitoring;
- are working in the area of forestry and climate change who want to understand forest carbon accounting in the context of REDD+;
- want to contribute ground data to their national government for their National Forest Monitoring System (NFMS) or verify data of their NFMS;
- and others who might find this manual useful.

At the end of the course, participants should have enhanced understanding and are enabled to deliver trainings on the following:

- Indigenous Peoples and REDD+;
- Role of participatory carbon monitoring (PCM) in REDD+;
- Basis of forest carbon accounting;

- Setting up field plots to collect information from the forest;
- Forest measurements required for estimating all carbon pools;
- Calculations used to estimate forest carbon stocks and uncertainty from the field measurements; and
- Quality assurance and quality control.

TRAINING COURSE

The manual has 7 modules divided into small sessions (sub-modules). Each module includes a summary to guide facilitators, presentations, exercises, reference/s, and training materials and equipment needed. The modules are arranged as follows in the guide: discussion guide, powerpoint presentation, exercise/s and reference/s. Some exercises are administered prior to or after the inputs as shown in the presentations, however the facilitator may decide to conduct these at some point he/she deems most effective. A suggested agenda of the course accompanies this guide. A soft copy is available in the compilation of educational materials produced under the capacity building project.

Module 1: The role of indigenous peoples in REDD+ as envisaged within the international climate change decisions. This module includes why IPs and other forest dependent communities should be actively engaged in the design and implementation of REDD+ programmes. It introduces participants to participatory carbon monitoring and its role in national forest monitoring systems (NFMS).

Module 1.1: Context of IPs/forest dependent communities in relation to forests and natural resources within their customary lands/territories

Module 1.2: IPs' rights and safeguards related to REDD+

Exercise: What does REDD+ mean to you?

Module 1.3: Participatory carbon monitoring and its role in REDD+ measurement, reporting and verification

Exercise: Value of participation

Module 1.4: Incorporating forestry and non-carbon indicators in REDD+

Exercise: Linking local participation to national objectives

Module 2: Participatory carbon monitoring (PCM) – its contributions to national REDD+ programmes. This builds on the national context established in the previous module and demonstrates a potential model for PCM in the context of REDD+. It clarifies the typical roles and responsibilities of national, sub-national, and non-government agencies including IPs especially those relating to carbon monitoring that IPs and forest dependent communities should understand.

Module 2.1: Structure and function of participatory carbon monitoring for REDD+

Exercise: Roles of the different stakeholders in Participatory Carbon Monitoring (PCM)

Module 2.2: Participatory monitoring considerations

Module 3: National forest monitoring system – data collection standards and protocols, information management and reporting focuses on the National Forest Monitoring System (NFMS) and its primary function. It presents information predominantly generated from the best available internationally recognized Data Collection Protocols and provides standard field measurement approaches to assist in quantifying the amount of carbon stored in various carbon organic pools found within a landscape.

Module 3.1: Data requirements for NFMS
Module 3.2: Forest carbon indicators
Exercise: Familiarization with field equipment

Module 4: Project level field measurements related to REDD+ measurement, reporting and verification discusses in significant details how to conduct field measurements to estimate indicators of carbon stock changes in the forests. It prepares the participants for the actual field data collection the following day. This is done through a combination of explanations and demonstrations. It includes a detailed description of the types of data to be collected, the methods and equipment used to collect the data. Participants will have the chance to try each equipment.

Module 4.1: Field data collection protocol
Module 4.2: Measuring changes in forest area and status
Module 4.3: Measuring forest carbon pools in sample plots
Exercises: Establishing a plot; and Measuring carbon pools

Module 5: Recording field data and conducting quality assurance and quality control procedures revolves on practical techniques and skills required to achieve data quality. The emphasis is the need for data quality, quality assurance and quality control methods and techniques applied at all levels of the inventory process specific to the role of PCM in NFMS for REDD+ Measurement, Reporting and Verification (MRV). The collected field data is entered into the provided spreadsheet.

Module 5.1: Context of quality assurance and quality control (QA/QC)
Module 5.2: QA/QC – collecting field data
Field work: In field QA/QC (Actual field data collection)
Module 5.3: QA/QC – processing field data
Exercises: Data entry, QA/QC checks, and field data processing

Module 6: Analyzing field data and estimating forest carbon stocks familiarizes participants with techniques to assess the quality of collected field data and to understand how the collected data contributes to calculation of carbon in a NFMS. The data entered in the previous module is automatically generated.

Module 6.1: Estimating carbon stocks in measured forest pools
Module 6.2: Estimating emissions and removals
Exercise: Calculating carbon stocks in above ground biomass

Module 7: Preparation for verification. The review is conducted to identify what is working well and could identify areas for improvement. It is part of the REDD+ process and done by

an external independent team. The module explores possible roles of IPs and forest dependent communities in the process.

Module 7.1: What is verification?
Module 7.2: Verification role play
Exercise: Role play - Verification

METHODOLOGY

The course will be delivered through literature reviews, lectures/presentations, group discussions/works, and fieldwork. It is highly suggested that the training team provides reading materials at least one (1) week in advance and for participants to read these.

The suggested agenda below can be modified depending on the time available and level of knowledge of participants. Rather than delivering the training over 5 consecutive days, the training could be broken up into 2 or even three separate sessions, for example:

- Days 1 and 2 on their own or not covered at all if participants have good knowledge of REDD+.

- Days 3, 4 and 5 together as a focused Field Measurement Course. Adding an additional field work day to enable 2 plots to be completed if the focus of the training is to become familiar with field data collection equipment and methods.

- Alternatively, the data analysis day (Day 5) could be extended to two days to explore the spreadsheet and increase understanding of the calculations by extending the allowable time for the hands-on exercises.

Timeframe for training should consider also the distance from the classroom discussion to the fieldwork venue.

TRAINING PREPARATIONS

Training Needs Analysis (TNA): The conduct of a training needs analysis is the discretion of the lead facilitator considering his/her familiarity with the training participants in relation to their level of knowledge on the focus of the course and their needs. A draft TNA Questionnaire is found in Annex 1 which can be modified and translated into local languages.

Facilitators: A training team of at least two (2) is required starting from Module 3 which introduces participants to the field equipment and uses. More so in Module 4 (fieldwork dry run) and the actual field work where participants are divided into work groups. Guidance to the groups cannot be done by a single facilitator if there are more than two (2) groups and/or the groups are dispersed far apart in the forest. Module 5 requires a degree of computer literacy in the use of spreadsheets which at least one (1) member of the work group should possess.

Reading Materials: The presentations and main references should be provided to participants at least one (1) week before the actual training.

Venue: It is advisable to hold the classroom discussions in a location where, as much as possible, has some open space in its surroundings. It would be very conducive for the dry run of the field work if there are at least some small trees.

Arranging the fieldwork would be challenging to organizers. There are several considerations: host, accessibility, transportation, food, field preparations, weather and language among others. It would be very advantageous to select an area/forest where there is a willing support group. The host/community can take on some of the fieldwork preparations. The training budget should be cognizant of these training related expenses. An actual visit to the site is a must for organizers. During this visit, it is advised to gather dos and don'ts in the community and include these in the advisory to confirmed participants. The organizers should monitor the weather forecast and communicate this to participants for their field work preparation.

Timing/Scheduling the Training: Considering the nature of the training, it is best to schedule the conduct of the training on good weather months. It would be too risky going to the forest under the rain!

Training Materials
Coloured post it notes / meta cards
Kraft paper / Flip chart / White Board
Pens and Markers (White board or permanent)
Note: check and prepare materials specific to each Module

Field Equipment and materials (per fieldwork team):

Jungle knife/machete	1 measurement calliper
Hand held GPS	Can of spray paint / chalk / markers (for marking the trees)
Suunto Clinometer	
Compass	Small hammer
1 DBH tape	Small nails
1 50m measurement tape	Plates (for tree numbering which could be small squares cut from aluminum cans or card boards)
1m x 1m Quadrat	
Rope and coloured ribbons	
Weighing scale	1 tarp/large bag
Camera	Sample bags
Stakes	Field data collection protocol documents (Walker et al, and Huy et al, 2013)
Field data sheets	Ball pen

Field Data processing

- Completed data sheets
- Training excel spreadsheet tool
- Field data spreadsheet manual and electronic file
- 1 Lap top / desk top at least per fieldwork group with Microsoft excel (2010 or above) software

First Aid Kit: A kit consisting of first aid medicines for sore throats, fever, headache, toothache, cold, flu, diarrhea, joint pain, monthly period pain and motion sickness among others, is usually brought along during trainings. Considering the nature of this training which includes a field work, the kit should include adhesive bandage/medical plaster (ex: band aid and other brands), rubbing alcohol, cotton, insect repellent, wound cleaner and antibiotic ointment for cuts/wounds, bandage/gauze, pair of scissors and others which organizers consider necessary.

EVALUATION/REVIEW OF PARTICIPANTS' EXPECTATIONS

The training team should decide how they can gather participants' feedback on the entire training on how far the training objectives and participants' expectations were fulfilled. A draft which could be modified is found in Annex 2.

Annex 1: Draft Training Needs Analysis Form

I. Organization Profile		**II. Participant Profile**	
Name (in passport)		Name	
		Gender	
Address		Age	
		Ethnicity	
		Years of service	
		Email address	
Focus of work		Mobile phone	
Years of operation		Highest level of formal education	
Involvement in climate change & REDD+		Position in the organization	
Global			
Regional		Roles/ Responsibilities	
National			
Sub-national			
Community			

III.	**Trainings attended related to climate change and REDD+** (kindly arrange starting from the latest training attended)	
	Title of Training	**Inclusive Dates**
a.		
b.		
c.		
d.		
e.		
f.		
g.		

IV.	**Level of Knowledge on Climate Change, REDD+ and measuring forest carbon stock**		
Instruction: Please rate the level of your knowledge on the following items based on the scale below and respond to the questions on the next two columns.			
Rate	**Description**	**Rate**	**Description**
5	Excellent	2	Below average
4	Above average	1	Very low
3	Average		

Topic	**Level of your knowledge**	**What do you know about the topic?**	**What would you need to know more about the topic?**
Climate change			
Deforestation			
Forest degradation			
Conservation			
Sustainable forest management			
Emissions			
Removals			
Carbon stock			
indigenous peoples (IPs) and natural resources in their customary lands and territories			
UN Framework Convention on Climate Change (UNFCCC)			
UNFCCC decisions that relate to IPs/ forest dependent communities			
Role of IPs in REDD+			
Participatory carbon monitoring (PCM)			
REDD+ elements			
Structure and function of PCM for REDD+			
National forest monitoring systems (NFMS)			
Data requirements for NFMS			
Forest carbon indicators			

Field data collection protocol			
Measuring changes in forest area and status			
Measuring forest carbon pools in sample plots			
Field data quality assurance and quality control (QA/QC)			
Field data processing			
Estimating carbon stocks in measured forest pools			
Estimating emissions and removals			
Preparing for verification			

V. Others
Aside from the topics above, what other subjects do you wanted to learn from this training?
What training methodology/ies would help you maximize your learning from this training?
Do you have other training concerns that the training team should know?
What are your expectations for this training?

Annex 2: Draft PARTICIPANT'S FEEDBACK/EVALUATION FORM

Feedback/Evaluation criteria

Before the Training	Rating	After the Training
Does not know and did not hear anything about the topics	**0**	Cannot remember anything about what was discussed
Heard a little but did not understand anything	**1**	Can remember a few while reviewing the references but cannot discuss or share
Knows the topics partly but cannot discuss or share to others	**2**	Can discuss the main points using references

Knows the topics clearly, can discuss the main points and provide a little explanation with the help of references	**3**	Can discuss main points and provide a little explanation using reference materials
Knows the topics clearly, can discuss the main points and provide good explanations using references	**4**	Can discuss the topics well and provide good explanations using reference materials
Knows the topics very clearly, can discuss and explain confidently	**5**	Can discuss the topics confidently

FEEDBACK/EVALUATION FORM – Part 1

This form should be filled up by all participants and collected **BEFORE** the start of the training. Participants should rate their knowledge on the topics below, using a range of 0-5 with 5 as the highest. The facilitator/s should make sure that all participants understand very well what they should do. All the topics should be given a rating and there should be just one (1) rating marked in each row. Evaluation forms not properly accomplished will be invalidated.

Name (optional)	
Gender (required)	

Topics	Ratings					
	0	**1**	**2**	**3**	**4**	**5**
Climate change						
Deforestation						
Forest degradation						
Conservation						
Sustainable forest management						
Emissions						
Removals						
Carbon stock						
indigenous peoples (IPs) and natural resources in their customary lands and territories						
UN Framework Convention on Climate Change (UNFCCC)						
UNFCCC decisions that relate to IPs/ forest dependent communities						
Role of IPs in REDD+						
Participatory carbon monitoring (PCM)						
REDD+ elements						
Structure and function of PCM for REDD+						
National forest monitoring systems (NFMS)						
Data requirements for NFMS						
Forest carbon indicators						
Field data collection protocol						
Measuring changes in forest area and status						
Measuring forest carbon pools in sample plots						
Field data quality assurance and quality control (QA/QC)						
Field data processing						
Estimating carbon stocks in measured forest pools						
Estimating emissions and removals						
Preparing for verification						

FEEDBACK/EVALUATION FORM – Part 2					
This form should be filled up by all participants and collected **AFTER** the training. Participants should rate their knowledge after the training on the topics below, using a range of 1-5 with 5 as the highest. The facilitator/s should make sure that all participants understand very well what they should do and avoid marking a rating lower than what they marked 'BEFORE' the training. Giving a lower rating after the trainings means their knowledge decreased after participating in the training.					
Name (optional)					
Gender (required)					
Topics	**Ratings**				
	1	**2**	**3**	**4**	**5**
Climate change					
Deforestation					
Forest degradation					
Conservation					
Sustainable forest management					
Emissions					
Removals					
Carbon stock					
indigenous peoples (IPs) and natural resources in their customary lands and territories					
UN Framework Convention on Climate Change (UNFCCC)					
UNFCCC decisions that relate to IPs/ forest dependent communities					
Role of IPs in REDD+					
Participatory carbon monitoring (PCM)					
REDD+ elements					
Structure and function of PCM for REDD+					
National forest monitoring systems (NFMS)					
Data requirements for NFMS					
Forest carbon indicators					
Field data collection protocol					
Measuring changes in forest area and status					
Measuring forest carbon pools in sample plots					
Field data quality assurance and quality control (QA/QC)					
Field data processing					
Estimating carbon stocks in measured forest pools					
Estimating emissions and removals					
Preparing for verification					
Write something about the training:					
Write something about the facilitators/trainers:					

SUGGESTED AGENDA

Day 1	
09:00 – 10:00	Informal welcome and introductions / Structure and Objectives of workshop
10:00 – 10:30	Discuss and document what each participant expects to learn from the training.
10:30 – 11:00	**Break**
11:00 – 11:30	Module 1.1 – Context of indigenous peoples/forest dependent communities in relation to forests and natural resources within their customary lands / territories
11:30 – 12:00	Module 1.2 - Indigenous peoples' rights and safeguards related to REDD+
12:00 – 12:30	Exercise 1.a – What does REDD+ mean to you?
12:30 – 13:00	Report back to the larger group on results from Hands on Exercise
13:00 – 14:00	**Lunch**
14:00 – 14:20	Module 1.3 - Participatory Carbon Monitoring and its role in REDD+ MRV
14:20 – 14:40	Exercise 1.b – Value of participation
14:40 – 15:00	Report back to larger group on results from Hands on Exercise
15:00 – 15:30	Module 1.4 - Incorporating forestry and non-carbon indicators in REDD+
15:30 – 16:00	**Break**
16:00 – 16:30	Exercise 1.c – Linking participation to national objectives
16:30 – 17:00	Report back to larger group on results from Hands on Exercise
Day 2	
09:00 – 10:30	Participants present their National/Project level situation
10:30 – 11:00	**Break**
11:00 – 11:30	Groups session to further explore key successes and challenges identified in presentations
11:30 – 12:00	Module 2.1 – Structure and function of Participatory Carbon Monitoring for REDD+
12:00 – 12:20	Module 2.2 - Participatory Monitoring Considerations
12:20 – 13:00	Exercise 2 – Roles of the different stakeholders in PCM
13:00 – 14:00	**Lunch**
14:00 – 15:30	Module 3.1 - Data Requirements for National Forest Monitoring Systems
15:30 – 16:00	**Break**
16:00 – 16:15	3.2 – Forest Carbon Indicators
16:15 – 17:00	Exercise 3 – Familiarization with field equipment
Day 3	
09:00 – 10:00	4.1 - Field Data Collection Protocol
10:00 – 10:30	4.2 - Measuring Changes in Forest Area and Status
10:30 – 11:00	**Break**
11:00 – 12:00	4.3 - Measuring Forest Carbon Pools in Sample Plots
12:00 – 13:00	Exercise 4.a – Establishing a Field Plot
13:00 – 14:00	**Lunch**
14:00 – 15:30	Exercise 4.b – Measuring Carbon Pools
15:30 – 16:00	**Break**

16:00 – 16:15	5.1 – Context of Quality Assurance/Quality Control (QA/QC)
16:15 – 16:45	5.2 - QA/QC: Collecting field data
16:45 – 17:30	Discussion of Field Trip Logistics and Expectations
Day 4 – (Option to extend this to two days to get more practice with equipment)	
2 hours	Locate and mark a plot in the field using equipment supplied.
2 hours	Record all data within the plot related to aboveground biomass, litter, course woody debris
2 hours	Conduct Quality Assurance and Quality Control (QA/QC) procedures
Homework	Exercise 5.a: Input all data collected into the excel spreadsheet supplied
Day 5	
09:00 – 09:30	5.3 - QA/QC: Processing field data
09:30 – 10:30	Exercise 5.b – Field data processing
10:30 – 11:00	**Break**
11:00 – 11:45	Module 6.1 - Estimating carbon stocks in measured forest pools
11:45 – 13:00	Exercise 6.a – Carbon stocks calculations
13:00 – 14:00	**Lunch**
14:00 – 14:45	6.2 – Estimating emissions and removals
14:45 – 15:30	Exercise 6.b – calculations
15:30 – 16:00	**Break**
16:00 – 16:30	7.1 – What is Verification
16:30 – 17:00	Exercise 7 – Role Plays on external validation/verification
17:00 – 17:30	Review of participants' expectations and wrap up

Forest Carbon Accounting Training for Indigenous Peoples and other Forest Dwellers

1

Course Outcomes

Participants should achieve an enhanced understanding of:

- Indigenous Peoples and REDD+
- The role of participatory carbon monitoring (PCM) in REDD+
- Basis of forest carbon accounting
- Setting up field plots to collect information from the forest
- Forest measurements required for estimating all carbon pools
- Calculations used to estimate forest carbon stocks and uncertainty from the field measurements
- Quality assurance and quality control activities

2

Course Outline

- Module 1: The role of indigenous peoples in REDD+ as envisaged within the international climate change decisions
- Module 2: Participatory carbon monitoring - its contribution to national REDD+ programmes.
- Module 3: National Forest Monitoring System - data collection standards and protocols, information management and reporting
- Module 4: Project level field measurements related to REDD+ measurement, reporting and verification.
- Module 5: Recording field data and conducting quality assurance and quality control procedures
- Module 6:Analysing field data and estimating carbon stocks
- Module 7: Preparation for verification

3

Course Materials

- PowerPoint presentations
- Tutorials / Hands On Exercises Instructions
- Field data collection sheets
- Excel spreadsheet calculations tool
- Ropes and ribbons, paint/chalk/markers, small nails, plates, large and small bags, stakes

4

Training Equipment (per fieldwork team)

- Calliper, camera, clinometer, compass
- DBH tape, measurement tape
- Global Positioning System (GPS)
- Knife/machete
- Quadrat
- Small hammer
- Weighing scale
- Desk top/lap top with Microsoft excel (2010 or above)

5

Course Structure

- Lectures
- Discussion
- Groupwork
- Fieldwork
- Data Analysis

6

Module 1 – The role of indigenous peoples in REDD+ as envisaged within the international climate change decisions

This Module is designed to open the workshop with some broad context of the role of Indigenous Peoples (IPs) and forest dependent communities in REDD+. The intension is to highlight that IPs and forest dependent communities can take an active role in a number of key REDD+ Elements that are the responsibility of the National Government. Active participation of IPs and forest dependent communities can add real value to REDD+ through the:

- design and implementation of interventions (i.e. REDD+ Action Plan / Strategy); and
- monitoring and reporting of GHG and livelihoods outcomes (i.e. National Forest Monitoring System and the Safeguards Information System)

Notes on the core learning outcomes associated with each sub-module are discussed below:

Module 1.1: Context of IPs/Forest Dependent Communities in relation to forests and natural resources within their customary lands / territories

Core Learning Outcome
Deeper appreciation of the context of indigenous peoples/forest dependent communities in relation to forests and natural resources within their customary lands/territories

Core Message
IPs and forest dependent communities have:

- A long history of land/forest custodianship
- As such they have significant knowledge and experience in sustainable land and forest management
- However, IPs are often not effectively engaged in public decision-making processes, hence, the advocacy and assertion to be part of the REDD+ processes
- IPs and their advocates have successfully lobbied the UNFCCC for:
    - Respect and recognition of IP rights and traditional knowledge
    - Full and effective participation
    - Direct access to funds

Module 1.2: Indigenous peoples' rights and safeguards related to REDD+

Core Learning Outcome
Increased understanding of the UNFCC decisions and how they relate to indigenous peoples/forest dependent communities

Core Message

- Decisions of the UNFCCC related to REDD+ call for
    - Broad and inclusive participation of Indigenous People and forest dependent communities
    - Sharing of responsibilities and benefits
    - Strengthening ownership of implementation and monitoring of REDD+ actions
- IPs and forest dependent communities can support the identification and successful implementation of interventions to reduce deforestation and forest degradation
- REDD+ is more than carbon, it should contribute to broader sustainable development, building transparent and effective forest governance structures, making progress on securing land tenure and enhancing or maintaining biodiversity and/or other ecosystem services
- Indigenous peoples and forest dependent communities can contribute to sustainable monitoring of lands through participatory monitoring

Module 1.3: Participatory Carbon Monitoring and its role in REDD+ Measurement, Reporting and Verification

Core Learning Outcome

- Enabled to explore what broad participation, sharing of responsibilities and benefits and strengthened ownership of implementation and monitoring means to indigenous peoples and forest dependent communities; and
- Define the role of participatory monitoring in the REDD+ context

Core Message

- Participatory carbon monitoring is an established concept that is a tangible and pragmatic way for indigenous peoples and forest dependent communities to engage with REDD+
- Monitoring of forest related indictors is important, however only focusing on this is a missed opportunity
- Empowering the indigenous peoples and forest dependent communities to contribute their traditional knowledge in identifying important indicators to monitor the success of REDD+ is important
- Such indicators cover carbon (GHG accounting), broader environmental conditions such as biodiversity, livelihoods such as income or health, and cultural significance

Module 1.4: Incorporating forestry and non-carbon indicators in REDD+

Core Learning Outcome

Understand better the role that participatory monitoring can play in National Forest Monitoring Systems (NFMS)

Core Message

- The core REDD+ elements are:
    - National strategy or Action Plan
    - National Forest Monitoring System
    - Forest Reference Emission Level
    - Safeguard Information System

- Indigenous peoples and forest dependent communities can identify and collect meaningful indicators to achieve MRV requirements across core REDD+ elements

Note: The Forest Reference Emission Level is an accounting framework that is designed and reported once. The other core elements are ongoing operational documents / systems that require ongoing and continuous operation and improvement.

Module 1

The role of indigenous peoples in REDD+ as envisaged within the international climate change decisions

Module Outcomes

Understanding of:

- Context of Indigenous Peoples/Forest dependent communities in relation to forests and natural resources within their customary lands/territories
- UNFCC decisions and how they relate to Indigenous Peoples/Forest dependent communities
- Broad participation, sharing of responsibilities and benefits and strengthening ownership of implementation and monitoring
- The role that participatory monitoring can play in National Forest Monitoring Systems.

Module Outline

1. Context of Indigenous Peoples/forest dependent communities in relation to forests and natural resources within their lands / territories
2. Indigenous peoples' rights & safeguards related to REDD+
3. Participatory Carbon Monitoring role in REDD+ Measurement, Reporting and Verification
4. Incorporating forestry and non-carbon indicators in REDD+





Context of IPs/Forest Dependent Communities in relation to forests and natural resources within their customary lands / territories

Module 1.1





Context of IPs on forests/natural resource base within their customary lands and territories

- Indigenous Peoples and forest dependent communities, may not be legally recognized, but for generations have been the **inherent rights holders, users, managers and protectors** of the forests and natural resources with their rich **traditional knowledge systems and practices, and customary governance**

- As peoples of the land and forests, IPs depend on forests for **social and economic livelihoods**, as well as, for **cultural and spiritual well-being**

Context of IPs on forests/natural resource base within their customary lands and territories

- With this historical and cultural connection to forests, land and resources, IPs **contribute significantly to sustainable use, management and protection** of forests and natural resources, especially through traditional knowledge systems and customary governance

- Even before REDD+ was established as a UNFCCC mitigation mechanism, IPs and forest dependent communities had practiced for generations more sustainable traditional management, use, conservation, protection of forests/natural resources within their customary lands and territories

Context of IPs on forests/natural resources within their customary lands and territories

- With REDD+, IPs and forest dependent communities asserted that there will be no successful REDD+ if the governments and the WB and other fund mechanisms will not **respect and recognize IPs and forest dependent community rights, traditional knowledge systems** on the management of forests and natural resources

- Why? In the context of REDD+, IPs/forest dependent communities are the most vulnerable, more than any other stakeholders; and on the one hand, IPs are often not effectively engaged in public decision-making processes, hence, the advocacy and assertion to be part of the REDD+ processes

Context of IPs on forests/natural resources within their customary lands and territories

IIPFCC **key messages** at the UNFCCC and REDD+ mechanisms are:

- **Respect and recognition of IPs Rights and traditional knowledge**, with reference to the UNDRIP and other international human rights and environmental agreements

- **Full and effective participation** of IPs at the UNFCCC and REDD+ processes

- **Direct access to funds** and appropriate technologies to support capacity building and enhance traditional/knowledge, livelihoods, innovations and other community initiatives

Indigenous peoples' rights and safeguards related to REDD+

Module 1.2

Definition of REDD+

"Reducing emissions from deforestation and forest degradation, forest carbon stock conservation, the sustainable management of forests, and the enhancement of forest carbon stocks in developing countries"

- Mitigation measure that seeks to reduce GHG emissions by preventing or reducing forest loss and degradation

- UNFCCC COP13, December 2007 - first substantial decision on REDD+ was adopted:
  - Decision 2/CP.13: "Reducing emissions from deforestation in developing countries: approaches to stimulate action," calling for demonstration activities to be reported upon two years later and assessment of drivers of deforestation.
  - Also referenced in decision 1/CP.13, the "Bali Action Plan", with reference to all five eligible activities for REDD+ (with sustainable management of forests, conservation of forest carbon stocks and enhancement of forest carbon stocks constituting the "+" in REDD+)

IPs' rights and safeguards related to REDD+

- The UN Framework Convention on Climate Change (UNFCCC) Cancun Decision 1/CP.16 includes several safeguards that "should be respected, addressed, promoted and supported".
- Two of these safeguards provide for:
  1. the respect for the **knowledge and rights** of indigenous peoples and members of local communities, by taking into account relevant international obligations, national circumstances and laws, and noting that the United Nations General Assembly has adopted the **United Nations Declaration on the Rights of Indigenous Peoples**
  2. the **full and effective participation** of relevant stakeholders, in particular, indigenous peoples and local communities.

Additional UNFCCC decisions on IPs' rights and traditional /indigenous peoples' knowledge

- Decision 1/CP 21 (PA 2015), Paragraph 135 which "Recognizes the need to **strengthen knowledge, technologies, practices and efforts** of local communities and indigenous peoples related to addressing and responding to climate change, and **establishes a platform** for the exchange of experiences and sharing of best practices on mitigation and adaptation in a holistic and integrated manner."

- Decision 2/CP 24 (2018) on Local Communities and Indigenous Peoples Platform "Emphasizing that the purpose and functions of the **Local Communities and Indigenous Peoples Platform** and its Facilitative Working Group will be carried out consistent with international law," and also "Emphasizing, in its entirety, the **United Nations Declaration on the Rights of Indigenous Peoples** in the context of the implementation of the functions of the Local Communities and Indigenous Peoples Platform involving indigenous peoples."

Respect for IPs' rights and knowledge related to REDD+

- Respect and recognition of IP rights and the contributions of IPs/forest dependent communities, including women, in enhancing traditional knowledge systems and sustainable resource management

- Support to **policy development** for the recognition of customary land and forest tenure rights to be legally recognized and demarcated on the ground, as essential for equitable benefit sharing, rights to carbon and stopping deforestation and forest degradation.

- Support to **institutional and capacity building** to enhance governance mechanisms and in strengthening collaboration and partnerships with government institutions

- On ERP Meth Framework: The range of **land and resource tenure rights** (including **legal and customary rights of use, access, management, ownership, exclusion**, etc.) and categories of rights-holders present in the Accounting Area (including Indigenous Peoples and other relevant communities)

Full and effective participation of IPs/local communities in REDD+ processes

- Indigenous peoples and local communities, women, youth and other key stakeholders need to be effectively included in the processes of implementing safeguards for REDD+ programs, including those funded by the FCPF Carbon Fund, and in developing and validating national reports to the UNFCCC from safeguard information systems

- Full and effective participation of IPs in the development and implementation of the national REDD+ Strategy and all stages of REDD+
    - Thorough, transparent and inclusive conduct of information dissemination and consultations and the conduct of Free Prior and Informed Consent
    - Representation in relevant bodies and mechanisms relating to REDD+ at local, sub-national, national, regional and global levels
    - Determination of terms for benefit sharing and entitlements of indigenous peoples including on the multiple values of forest
    - Development of programmes for diverse livelihood support and appropriate innovations and social services for poverty alleviation and sustainable development





Direct access to funds for capacity building and support to traditional knowledge, livelihoods, innovations and other community initiatives

- **FCPF-Capacity Building Program (CBP)** for IPs, Forest Dependent Communities and Southern CSOs – resulting from regional and global dialogues between IPs and FCPF-WB. - Approved in 2012 but took 2 -3 years for the selection of regional recipients/intermediaries and approval of operational manuals and fiduciary requirements of the WB. A learning process between the WB teams and the regional recipients and the sub-grantees of the FCPF fund
- **Approval of the FCPF PC for additional fund extension of the CBP to 2020**, including the conduct of regional to global dialogues/consultations on the assessment/knowledge sharing on the past 10 years of REDD+, the CBP and on effective engagement and social inclusion of IPs/CSOs in the REDD+ processes





Direct access to funds for capacity building and support to traditional knowledge, livelihoods, innovations and other community initiatives

- **Dedicated Grant Mechanism (DGM)** for IPLCs under the Forest Investment Program of the CIF-WB is another example of direct access to funds
- Governments, national and international funding agencies should prioritize the development of **direct access mechanisms** by indigenous peoples and local community organizations on a wide range of needs and themes, including dedicated funding through existing projects and programs.





IPs' rights and safeguards related to REDD+

The United Nations Framework Convention on Climate Change(UNFCCC) decisions on REDD+ calls for…

"the full and effective participation of relevant stakeholders, in particular, indigenous peoples and local communities".

- broad and inclusive participation
- shared responsibility and benefits
- strengthening ownership of implementing and monitoring REDD+ actions

Resulting in indigenous peoples and forest dependent communities becoming empowered participants in the process rather than merely bystanders





IPs' rights and safeguards related to REDD+

A **broad and inclusive participation** of stakeholders in national REDD+ programmes can help to ensure the **sharing of responsibilities and benefits**, in addition to **strengthening ownership of implementing and monitoring** REDD+ actions.

Benefit-sharing mechanisms should **respect customary rights to lands and territories and reflect broad community support**, so that REDD+ incentives are applied in an effective and equitable manner.



IPs' rights and safeguards related to REDD+

Broad and inclusive participation

- Identifying and understanding the drivers of deforestation and forest degradation e.g. on IP traditional farming systems vv shifting cultivation
- Identifying opportunities to reduce the impact of drivers

Sharing of responsibilities and benefits

- Responsibilities to directly or indirectly make change
- Being beneficiaries of the change

Strengthening ownership of implementation and monitoring

- Engagement in implementing change and monitoring that change

What role do IPs have in REDD+

REDD+ is increasingly not only about emissions reductions, it also includes:

- social and environmental safeguards
- livelihood benefits and other non carbon benefits: should be culturally appropriate and gender and inter-generationally inclusive*
- biological conservation
- sustainable landscape development

Note: NCB should contribute to broader sustainable development.-,improving local livelihoods, building transparent and effective forest governance structures, making progress on securing land tenure and enhancing or maintaining biodiversity and/or other ecosystem services.*

As an essential component of REDD+, all these aspects should be monitored

**FCPF Carbon Fund Methodological Framework*



Image source: Thomson and Schoonmaker Freudenberger 1997

What role do IPs have in REDD+

One of the ethical underpinnings of REDD+ is **'to avoid doing harm'** to indigenous communities and forest dependent communities.

These principles also apply to participatory monitoring, reporting and verification.

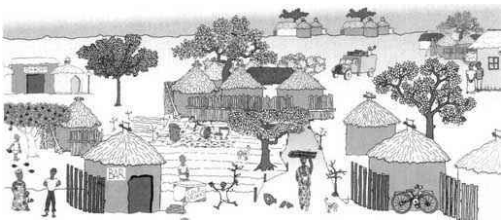


Image source: Thomson and Schoonmaker Freudenberger 1997

What does REDD+ mean to you?

- The participation of indigenous peoples and forest dependent communities in climate change mitigation is considered key to ensuring that their priorities are taken into account.
- Effective participation should help to design effective social safeguards and to improve equity in benefit sharing.
- The participation of indigenous peoples and forest dependent communities has been explored in carbon emission Measurement, Reporting and Verification (MRV) for REDD+.

What does REDD+ mean to you?

The feasibility and sustainability of participatory MRV (PMRV) depends on:

- its relevance to indigenous peoples and forest dependent communities (including incentives to participate),
- their technical capacity
- the existence of appropriate structures for MRV.

What does REDD+ mean to you?

Exercise:

Draw or write what REDD+ means to you.
Consider the following broad themes:

- broad and inclusive participation
- shared responsibility and benefits
- strengthening ownership of implementing and monitoring REDD+ actions

Participatory Carbon Monitoring and its role in REDD+ Measurement, Reporting and Verification

Module 1.3

What is Participatory Monitoring?

A tangible and pragmatic opportunity to promote and support the safeguard on *"the full and effective participation of relevant stakeholders, in particular, indigenous peoples and forest dependent communities"*

Potentially cost-effective contributions to a number of essential carbon and non-carbon elements of REDD+

- Carbon
- Safeguards
- Low emission development planning
- Benefit sharing mechanisms
- Policies and measures to address drivers



Image Source: Said et al 2010.

What is Participatory Monitoring?

A participatory monitoring approach allows REDD+ countries to:

- build broad skills across a number of forest carbon stock monitoring and measuring tasks;
- assist in the creation of carbon accounting system(s) that are transparent and accountable to a broad range of stakeholders.
- actively participate in developing, implementing and monitoring national REDD+ strategies and programmes

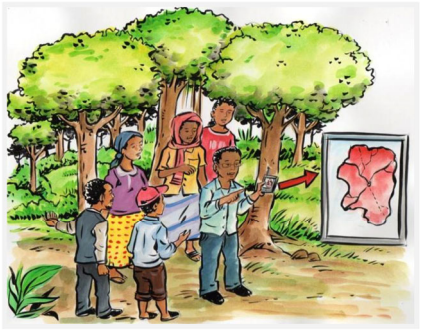


Image Source: Said et al 2010.

Adopting a Participatory Approach

The **benefits of a participatory approach** include:

- **reliable identification of underlying drivers and agents** of deforestation and degradation;
- **potentially reduced costs** of implementation and monitoring of REDD+ activities;
- **increased awareness, ownership and motivation** for implementing and monitoring REDD+ activities;
- monitoring of **environmental, social and GHG accounting indicators**

Adopting a Participatory Approach

The **participatory monitoring approach considerations** include:

- **external validation/verification**
- **data quality**
- **initial capacity investments**
- **incentives for participation**

Value of local participation

Most REDD+ related discussion on PCM are focused on forest dwelling community-based field data collection from forest carbon plots…..

BUT there is a greater opportunity to add value….

Value of local participation

Countries are encouraged to:

- include social and environmental safeguards
- clarify benefit sharing among the different stakeholders involved in REDD+
- propose alternative livelihoods to prevent further deforestation and forest degradation



Image Source: Said et al 2010.

Value of local participation

Exercise:

Draw or write what could be monitored within your communities/forests.

Consider indicators under the following board themes:

- GHG accounting
- environmental
- livelihoods

Incorporating forestry and non-carbon indicators in REDD+

Module 1.4

REDD+ Elements

For a national REDD+ programme to be eligible for results-based financing, the UNFCCC has requested Parties to:

- Identify *drivers of deforestation and forest degradation* and develop **national strategies and actions plans** to address them;
- Use the most recent *Intergovernmental Panel on Climate Change (IPCC) guidance and guidelines* to estimate GHG emissions and removals from forests including in the estimation of the **national forest reference emission level (REL) or forest reference levels (RL)**;
- Establish **a national forest monitoring system (NFMS) that combines remote sensing and ground-based techniques** capable of *measuring, reporting and verifying (MRV)* estimated GHG emissions reduction and removals from forests and land use change in a *transparent, consistent, accurate and suitable for review by the Conference of Parties;*
- Develop a **system for providing information on and ensuring REDD+ safeguards** are addressed and respected.

1.4 35

Four Elements of REDD+

National Strategy / Action Plan
- Plan/Strategy for addressing the drivers of deforestation. Usually consists of a number of interventions

National Forest Monitoring System (NFMS)
- Source of the data (remote sensing and ground data) to support Measurement, Reporting and Verification (MRV) of the climate change mitigation impact of REDD+ interventions

Forest Reference Level
- Benchmark (e.g. based on historical emissions) from which results are measured

Safeguard Information System (SIS)
- Provides information to demonstrate no adverse effects to communities and biodiversity from REDD+ activities



1.4 36

Four Elements of REDD+

National Strategy / Action Plan

- Plan/Strategy for addressing the drivers of deforestation. Usually consists of a number of interventions

National Forest Monitoring System (NFMS)

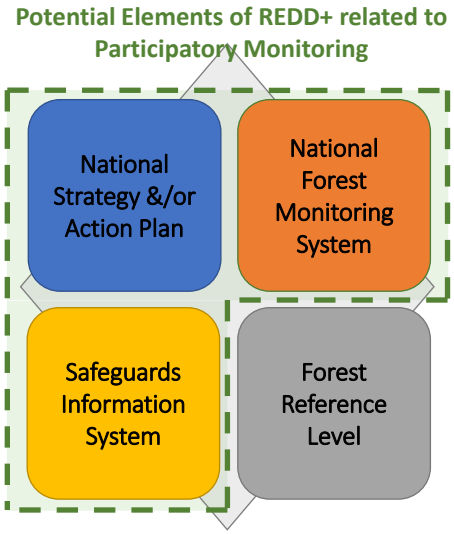
- Source of the data (remote sensing and ground data) to support Measurement, Reporting and Verification (MRV) of the climate change mitigation impact of REDD+ interventions

Forest Reference Level

- Benchmark (e.g. based on historical emissions) from which results are measured

Safeguard Information System (SIS)

- Provides information to demonstrate no adverse effects to communities and biodiversity from REDD+ activities



Linking Local Participation to National Objectives

Exercise:

Reorganize the identified GHG accounting, environmental, cultural and livelihood indicators from the previous exercise into the three elements of the National Forest Monitoring System related to Participatory Monitoring:

- National Strategy / Action Plan
- National Forest Monitoring System
- Safeguards Information System

Module 1 Exercises

There are three exercises in Module 1. The exercises are conducted in groups. The same groups should work together on all three exercises as the exercises build on information collected and documented in the previous activity. The time allocated to each exercise should be strictly adhered to.

Materials	Coloured Post-it notes / Meta cards Kraft Paper / Flip Chart / White Board Pens and Markers (White board or permanent)

Exercise a: What does REDD+ mean to you?	
Guide	The intension of this exercise is to generate discussion of both positive and negative aspect to REDD+. Participants should start to think about their roles in REDD+ both as contributor and benefactor of activities related to REDD+. This exercise is primarily aimed at getting participants to relax and to start thinking about their relationship to REDD+. Team members are asked to draw or write what REDD+ means to them. They can work individually or as a group. Encourage the team members to write words or short descriptions on the post-it notes or meta cards and stick them on the board/paper. There is no order or structure, all ideas should be written down. To stimulate the discussion, the facilitator could walk around to each table to ask questions and encourage team members. He/she can suggest to team members to think about the three broad themes of REDD+ discussed in the presentation, whilst trying not to suggest answers. Some stimulating questions based on each of the themes are listed below, noting this is advisory only and they should feel free to write down anything and everything that comes to mind: **Broad and inclusive participation** • what sort of activities can you do/get involved in? **Shared responsibility and benefits** • what are your responsibilities? • what sort of benefits might be relevant to you? **Strengthening ownership of implementing and monitoring REDD+ actions** • what does REDD+ implementation and monitoring mean to you? At the end of the time allocated, each team should report back on some of the most common findings of the team. They do not have to read all the post-it notes out. The board/paper and post-it notes/meta cards should remain on the table/visible. Team members are encouraged to write additional things as the presentation continues if something comes to mind.
Expected Duration	1 hour including hands on exercise and reporting back to the group

Exercise b: Value of Participation	
Guide	This exercise focuses on monitoring. Teams are asked to think about some things that they can monitor in their forests/landscapes/communities that could support REDD+. In the same teams, start with a new clean sheet of paper/board. As before, teams are asked to write down on the post-it notes/meta cards indicators that they could monitor related to REDD+. The team members should try to write down indicators under the following broad themes: • GHG accounting • Environmental • Livelihoods In this exercise the team members are encouraged to group the indicators into the three categories. To stimulate discussion on possible indicators, the facilitator could give some examples under each theme such as: • GHG accounting – above ground biomass, area of forest, area of agriculture • Environmental - cultural sites of significance, species of significance • Livelihoods – income, access to healthcare/education, community structure, distance to markets The facilitator should write/summarize the responses on a white board (or equivalent) at the front of the room arranged under the three headings. There are no real right or wrong answers, however, as this workshop is primarily about carbon accounting, the facilitator should encourage teams to at least identify the following under the GHG accounting theme: • Above ground biomass (i.e. trees) • Below ground biomass (i.e. roots) • Litter • Deadwood • Soil Organic Carbon Some additional indicators may be: • Area of deforestation or forest degradation • Illegal logging • Fire, Flood, Landslide • Timber harvesting • Firewood Collection If these things are not brought up by the participants, the Facilitator could discuss these during the team reporting back session and add them to the summary on the white board/paper at the front. At the end of the exercise, each team should report back on some of the most common findings of the team. They do not have to read all the post-it notes out/meta cards, but should read at least one per theme. The paper/board and post-it notes/meta cards should remain on the table/visible. Team members are encouraged to write additional things as the presentation continues if something comes to mind.
Expected Duration	40 minutes including hands on exercise and reporting back

Exercise c: Linking Local Participation to National Objectives	
Guide	The objective of this exercise is to demonstrate that indigenous peoples/forest dependent communities can contribute to all REDD+ Elements in some way. At this point, it may also be useful for the Facilitator to mention that the primary **focus of this workshop** is on Carbon Monitoring which relates mostly to the National Forest Monitoring System Element. This exercise will use the indicators identified in the previous exercise and reorder them into the three main National level REDD+ elements as defined by the UNFCCC. The purpose is to try and focus the group to think about the monitoring of indicators related to Carbon which is the primary focus of this workshop, BUT still recognize that there are a number of areas in which Participatory Monitoring can contribute to National level REDD+ goals. The facilitator should ask the teams to start with a clean paper sheet and reorganize the post-it notes/meta cards identified as GHG accounting, environmental and livelihood indicators into the three elements of the National Forest Monitoring System related to Participatory Monitoring: • National Strategy / Action Plan • National Forest Monitoring System • Safeguards Information System If the teams wish, they can mark on the post-it notes/meta cards if it is a GHG accounting, environmental or livelihoods indicator before allocating it to a REDD+ Element.
Expected Duration	1 hour including hands on exercise and reporting back

Module 2 – Participatory carbon monitoring - its contribution to national REDD+ programmes

This module builds on the national context established in Module 1 and focuses the participants' attention to the role of Participatory Carbon Monitoring (PCM). The focus of this session is to demonstrate a potential model for PCM in the context of REDD+. The roles and responsibilities of key National, Sub-national, and Non-Government Agencies are explored in detail across the three core elements of REDD+:

- National Strategy / Action Plan
- National Forest Monitoring System
- Safeguards Information System

By the end of this session typical roles and responsibilities of the various stakeholders should be clear. In particular, for carbon monitoring indigenous peoples and forest dependent communities should understand:

- their role in identifying important indicators to be monitored, especially relating to safeguards, drivers of deforestation/degradation
- their role in identifying interventions to reduce deforestation/degradation without negatively affecting livelihoods
- the standards and protocols for monitoring will be set by the National Government
- that monitoring activities will be checked by an independent person and they will be expected to maintain high standards

Module 2.1: Structure and Function of Participatory Carbon Monitoring for REDD+

Core Learning Outcome

How to organize stakeholders and operationalize carbon accounting within a Participatory Monitoring approach for national REDD+ programmes.

Core Message

- Participatory carbon monitoring involves stakeholders from national government, sub-national governments, IPs and forest dependent communities, non-government institutions and the private sector.
- Generally speaking:
    - **National government institutions** develop data standards and protocols, together with sampling strategy design and information management and reporting (as part of a NFMS).
    - **Sub-national government institutions** are responsible for subnational resource planning and allocation to PCM activities; to on-the ground local stakeholder capacity development; and data management, aggregation and submission of data and information to the NFMS.
    - **Local stakeholders,** be they indigenous peoples, forest owners, managers or users of forest resources, can contribute by applying national protocols in collecting and managing field data, together with subsequent basic analysis

and application of information for adaptive management at the site-based level.
    - **Non-governmental institutions or private sector** may play a critical role in providing technical assistance to any of these stakeholder groups in performing their functional tasks for PCM.
- The PCM structure established must support the collection of data for the four (4) core REDD+ elements
- Activity data and emissions factors are the core data sets required to report REDD+ estimates
- IPs/forest dependent communities have limited direct monitoring opportunities of ACTIVITY DATA which is predominately generated from satellite data at the national level
- Generation of EMISSIONS FACTORS is more reliant on ground data collected from the forest which provides more opportunity for engagement of IPs/forest dependent communities.
- Indigenous peoples and forest dependent communities can play a role in identifying potential land use change activities (interventions) to address local drivers for inclusion in the National Strategy or Action Plan and
- Can provide direct inputs to the safeguard information system

Module 2.2: Participatory Monitoring Considerations

Core Learning Outcome

Participants clearly understand that REDD+ elements require quality data inputs and are subject to external review processes

Core Message

Some concepts that might be explored in the discussion following the presentation are:

<u>Potential Benefits of Participatory Carbon Monitoring (PCM)</u>

Sustainability – The cost-effectiveness of PCM, coupled with broad stakeholder buy-in is likely to lead to a more sustainable monitoring effort, one that promotes ownership and continuity of the monitoring functions, both within and outside of the government institutions.

Social and human capital – The use of PCM builds social and human capital, through training, network development and information exchange, and empowers institutional and individual stakeholders. This can lead to more effective forest management and governance structures.

Connecting indigenous peoples' and forest dependent community's knowledge – PCM approaches provide opportunities to integrate valuable traditional knowledge into managerial considerations and decision-making processes on the sustainable use of forest resources.

Potential Limitations of Participatory Carbon Monitoring

Data quality control – The quality of data is dependent on the existing technical capacity and resources. Without a system to ensuring quality at all levels, data collected through a PCM approach may not be of sufficient quality to support carbon accounting for a national REDD+ programme.

Initial capacity investments – The initial capital outlay for introducing PCM approaches may be high depending on existing capacity to collect data, as well as soft and hardware available to manage those data at the local level. There may also be additional upfront costs in establishing or improving data quality assurance and quality control systems.

Incentives for participation – Incentivising and sustaining participation in PCM approaches could be a challenge for reasons of opportunity cost at the local level (time spent collecting data for REDD+ might compete with on-farm livelihood mainstay activities). IPs and forest dependent communities need to be compensated in some form (financial and/or in-kind contributions) for adopting responsibilities. In addition to direct participation payments, indirect incentives that could attract sustained commitment to a PCM approach include: creating a dialogue on resource use between local stakeholders and government; increased stake and legitimacy in management decision-making processes with regard to resources important to livelihoods; improved natural resource management through informed decision making utilizing monitoring data, yielding more sustained forest product harvests; and attracting external financing for the management of an area.

Module 2

Participatory carbon monitoring - its contribution to national REDD+ programmes.

Module Outcomes

Deeper understanding of:

- how can indigenous peoples and forest dependent communities effectively contribute to national level monitoring systems through participatory carbon monitoring and measurement, reporting and verification
- the benefits of participatory monitoring beyond monitoring GHG emissions
- considerations relating to participatory carbon monitoring

Module Outline

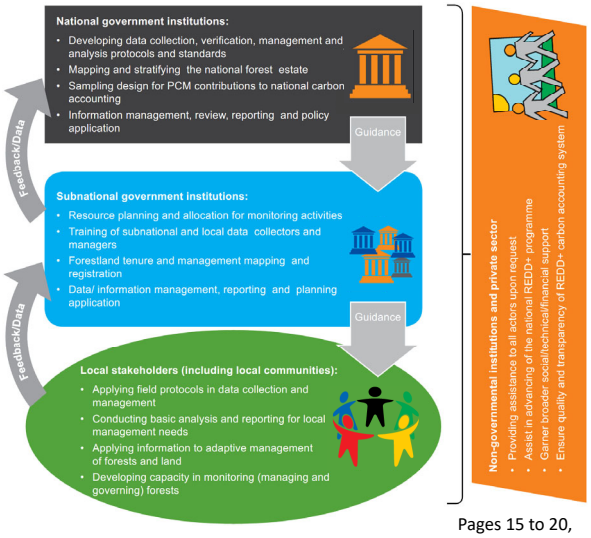
1. Structure and Function of Participatory Carbon Monitoring for REDD+

2. Participatory Carbon Monitoring Operational Requirements for REDD+

Structure and Function of Participatory Carbon Monitoring for REDD+

Module 2.1

Stakeholder Participatory Carbon Monitoring Functions



Pages 15 to 20,
Casarim et al., 2013

Role Play: Roles of the different stakeholders in PCM

Exercise:

Read the material from the previous slide “Stakeholder Participatory Carbon Monitoring Functions”.

In groups present the point of view from another stakeholder:

- Who are they representing in your country
- Consider who they interact with and why
- What is their role and responsibilities

Role Play: Roles of the different stakeholders in PCM

Expected Outcome:

Understanding and appreciation for other stakeholders in the Carbon Monitoring system.

Materials required:

- Pages 15 to 20, Participatory Carbon Monitoring: Operational Guidance for National REDD+ Carbon Accounting [Casarim et al., 2013]

Functional tasks of IP Stakeholders in PCM

Local stakeholders (including communities)	Application of protocols in data collection and management	Identifying the key agents or drivers of forest cover change, forest degradation, and carbon stock enhancement across the landscape/ jurisdiction Collecting field data according to protocols (for verifying or validating remote sensing products and ground-truthing maps of forest cover and tenure) Building capacities contributing to successful REDD+ programme implementation
	Conduct basic analysis and reporting for local management needs	Conducting basic analysis of PCM data and/or accessing information from the NFMS to inform refinement of management interventions (REDD+ activities) Assisting in accuracy assessments of activity data generated for REDD+ Assessing effectiveness of REDD+ activities at the local level

Casarim et al., 2013

Benefits of Participatory Carbon Monitoring

Indigenous peoples and forest dependent communities involvement:

- allows the establishment of 'ownership' in forest management
- strengthens their stake in the REDD+ reward system
- greatly increase transparency in the sub-national/ national governance of REDD finances

Four Elements of REDD+

National Strategy / Action Plan

- Plan/Strategy for addressing the drivers of deforestation. Usually consists of a number of interventions

National Forest Monitoring System (NFMS)

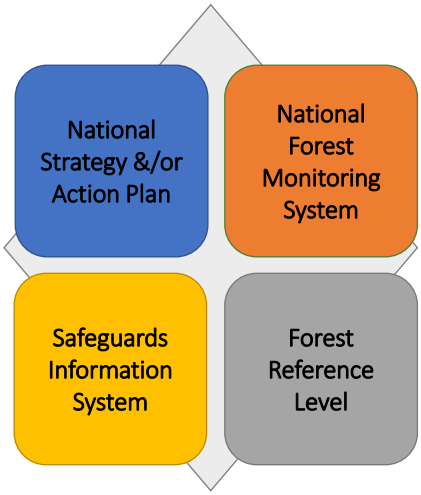
- Source of the data (remote sensing and ground data) to support Measurement, Reporting and Verification (MRV) of the climate change mitigation impact of REDD+ interventions

Forest Reference Level

- Benchmark (e.g. based on historical emissions) from which results are measured

Safeguard Information System (SIS)

- Provides information to demonstrate no adverse effects to communities and biodiversity from REDD+ activities



Participatory Carbon Monitoring in support of National Forest Monitoring Systems

National Forest Monitoring System

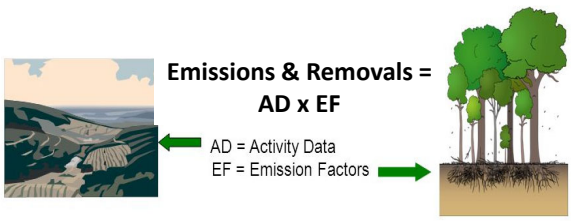
Participatory Carbon Monitoring can contribute to:

- the development of emissions and removals estimates from activity data and emissions factors
- broader monitoring function of a NFMS for assessing the
  - outcomes of polices and measures
  - adaptive management by local communities under a national REDD+ programme

National Strategy &/or Action Plan

Activity Data and Emissions Factors

National Forest Monitoring System



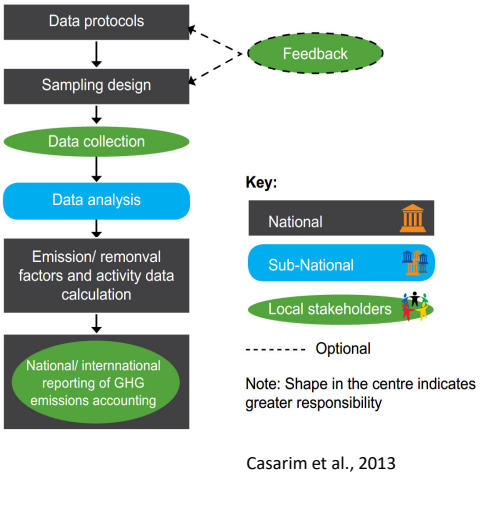
Activity Data (AD) = area affected by change (ha)

Emission Factors (EF) = carbon stock changes OR carbon gains and losses (tCO_2e / ha)

Emissions & Removals = emissions from forest loss or removals from forest growth (tCO_2e)

Generic PCM operational framework for national REDD+ Emissions and Removals

National Forest Monitoring System

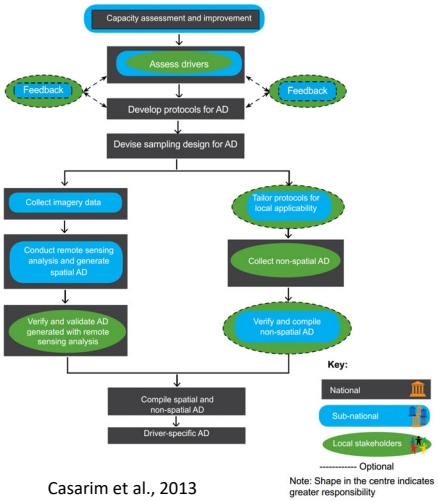


Casarim et al., 2013

- Can contribute to national GHG accounting for land use/land cover change practices.
- QA/QC procedures should be conducted in every step of the national GHG accounting, for improving accuracy and ensuring best practices and strengthening confidence in the estimates produced, whether employing a PCM approach or not.
- The non-governmental institutions and private sector may assist technically, financially, politically and socially, for all of the participating stakeholders involved in national accounting of GHG emissions from the land use sector.

Process of ACTIVITY DATA generation through a PCM approach

National Forest Monitoring System

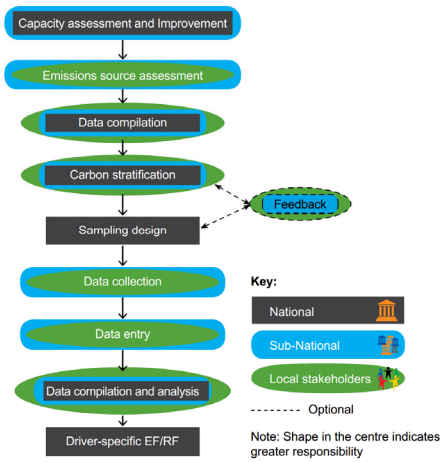


Casarim et al., 2013

- IPs/forest dependent communities have limited direct monitoring opportunities of ACTIVITY DATA
- ACTIVITY DATA is generally generated by national governments or the private sector on their behalf
- Role of PCM predominately related to providing feedback on OR validation of ACTIVITY DATA
- Most of the monitoring utilizes remote sensing data which will be managed at a National level

Process of EMISSION FACTOR generation through a PCM approach

National Forest Monitoring System



Casarim et al., 2013

Increased potential involvement in:

- Emission source assessment
- ground data compilation
- data collection
- data entry

Generation of EMISSIONS FACTORS more reliant on ground data collected from the forest

2.1 15

Participatory Carbon Monitoring in support of National Strategy / Action Plan

National Strategy &/or Action Plan

Indigenous peoples and forest dependent communities can play a role in identifying potential land use change activities (interventions) to address local drivers

Continue to monitor various non-carbon outcomes/safeguards related to the interventions such as the impact on local livelihoods and environment



Image Source: Said et al 2010.

2.1 16

Participatory Carbon Monitoring in support of Safeguards Information System

Safeguards Information System

- REDD+ creates financial incentives for countries and communities that conserve and sustainably manage their forests, in so doing it affect land use patterns.

- REDD+ could therefore have potentially significant impacts (good and bad) on the livelihoods of those who depend on forests and other lands for their subsistence, cultural, and income needs

Participatory Carbon Monitoring in support of Safeguards Information System

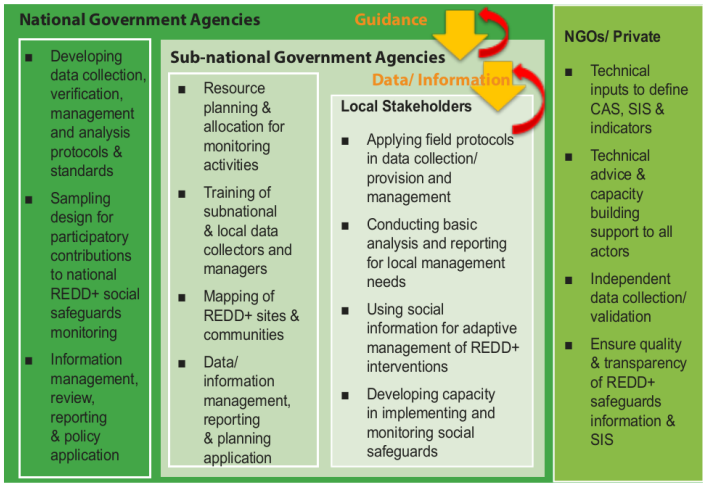
Safeguards Information System

The SIS is intended to provide information on how safeguards are being addressed and respected. Such information could include:

- **Inputs which ensure that safeguards are operationalized.**
  - whether relevant institutions are in place for the receipt of grievances
  - the allocation of budgets for consultation activities
- **Safeguard activities, processes and procedures**
  - monitoring whether the relevant consultation and participation procedures are implemented in practice
- **Actual impacts of REDD+ actions on indigenous peoples and forest dependent communities**
  - land/forest tenure rights (including rights over ownership, management, access and use of lands and forests)
  - livelihoods and security/vulnerability

Participatory Carbon Monitoring in support of Safeguards Information System

Safeguards Information System



Source: Rastall, R. and Nguyen V.D. 2016

Participatory Monitoring Considerations

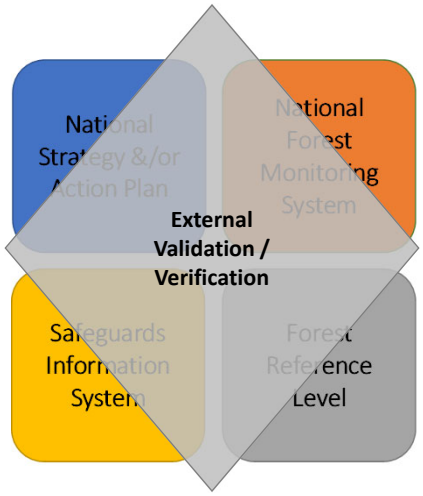
Module 2.2

Potential Participatory Monitoring Considerations

- **external validation/verification**
- **data quality**
- **initial capacity investments**
- **incentives for participation**

External validation/verification

- Monitoring systems for REDD+ are subject to external review (validation/verification)
- Typically external reviewers are experts in a particular field
- Will have also conducted training in the particular program or standard to which the monitoring system is being used to develop reports for

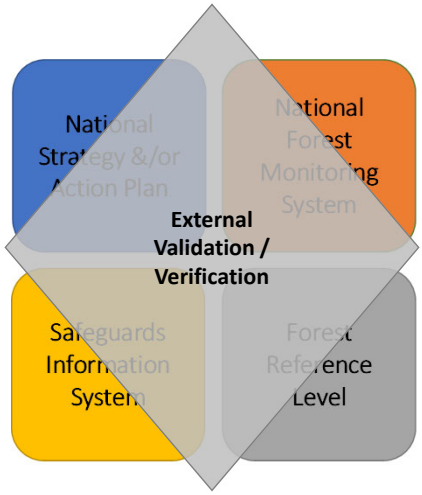


Data Quality

Data collection standards/protocols need to be established and followed

Training and ongoing internal quality control checks can address data quality concerns

Roles, responsibilities and expectations are clear



Initial Capacity Investments

Achieving effective active involvement

Costs:

- investment of time
- capacity building expenses

Benefits:

- Long term value in engagement through
  - broad and inclusive participation
  - shared responsibility
  - strengthening ownership of implementing and monitoring REDD+ actions



Incentives for participation

We all ask "Why should I do the work?" when asked to do something.

"Does this effort improve my livelihood? Does it protect my land/culture/environment?"

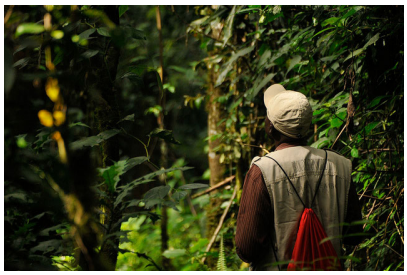


Image Source: Global Forest Watch

Why would I participate?

Possible options are:

- Passive participation - "What do I **get** for my effort?"
  - money, cook stove, boat, equipment
- Active participation – "What do I **want** for my effort?"
  - To be involved (responsibility), opportunities, information, skills
  - Aligned with other community objectives, outcomes, and values



Image Source: Said et al 2010.

Module 2 Exercise

This exercise is designed to increase the participants' understanding and appreciation of the different roles in PCM. It also provides an opportunity, early in the workshop, for the participants to become familiar and comfortable with each other and become accustomed to working in groups.

Material: Copy of Casarim2013_pcm-operational_guidance pages 15-20 in the reference

Role Play: Roles of the different stakeholders in Participatory Carbon Monitoring (PCM)

Guide	The facilitator breaks the room up into 4 groups. Each group is allocated a stakeholder role in PCM: • National government institution • Sub-national government institution • Indigenous People / Forest Dependent Communities (Local stakeholders) • Non-government institution / private sector The participants are asked to read the short descriptions from Casarim 2013 pages 15-20 which describe the potential role of each stakeholder in PCM. Encourage the groups to present in the point of view from another stakeholder by considering: • Who are they representing in their country? • Consider who they interact with and why • What are their roles and responsibilities? They are then asked to conduct a brief presentation which describes their role in PCM. Encourage the teams to think outside the box on ways they can communicate the various roles and report back in creative and interesting ways. Some may choose to act out an interview with a television company, or an office/field discussion of their day to day operations.
Expected Duration	40 minutes including reading the material and presenting the role play

Participatory Carbon Monitoring: Operational Guidance for National REDD+ Carbon Accounting

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Abbreviations

AD	activity data
AFOLU	agriculture, forestry and other land use
CO_2	carbon dioxide
COP	Conference of Parties
EF/RF	emission/removal factor
GHG	greenhouse gas
GIS	geographic information system
IPCC	Intergovernmental Panel on Climate Change
LEDP	low emissions development planning
MRV	measurement, reporting, and verification
NFI	national forest inventory
NFMS	national forest monitoring system
PCM	participatory carbon monitoring
PFM	participatory forest monitoring
PLR	policies, laws and regulations
QA/QC	quality assurance and quality control
REDD+	reducing emissions from deforestation and forest degradation, and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks, in developing countries
RL/REL	reference levels/reference emissions levels
UNFCCC	United Nations Framework Convention on Climate Change

Icons


National government institutions


Subnational government institutions


Local stakeholders (including local and communities)


Non-governmental institutions and private sector

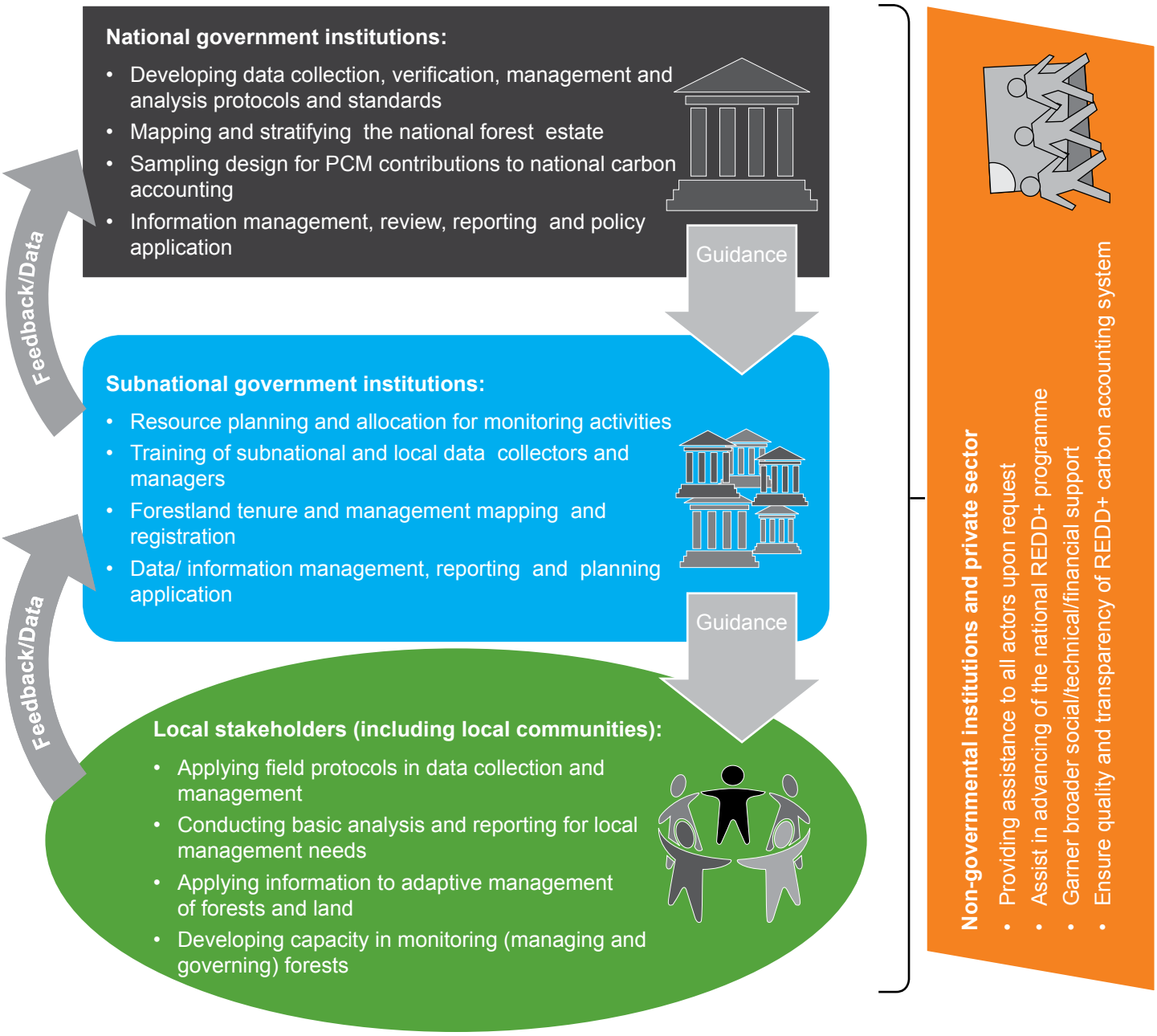
Executive summary

The United Nations Framework Convention on Climate Change calls for a phased approach to REDD+ at the national level, with subnational elements, and the participation of all relevant stakeholders in the development and implementation of national strategies and action plans. A broad and inclusive participation of stakeholders in national REDD+ programmes can help to ensure the sharing of responsibilities and benefits, in addition to strengthening ownership of implementing and monitoring REDD+ actions.

The various stakeholders can each contribute to the development of reference levels (RL/REL) and a robust and transparent national forest monitoring system (NFMS) to support measurement, reporting and verification (MRV) of greenhouse gas emission reductions and enhanced removals from forests and land use change. The national and subnational government institutions as well as local stakeholders, including local communities, each have particular roles to play in these carbon accounting requirements of national REDD+ programmes.

Participatory carbon monitoring (PCM) is presented here as an approach to improve the vertical and horizontal institutional integration of different stakeholders for carbon accounting within a country's national REDD+ programme. This document aims to guide national stakeholders involved in the REDD+ readiness process in understanding: a) what a PCM approach is, and what are potential and limitations involved (Section 1); and b) how to organise stakeholders and operationalize carbon accounting within a PCM approach for national REDD+ programmes (Section 2). PCM applications for REDD+ other than carbon accounting – safeguard compliance; low-emissions development planning; benefit sharing; and monitoring REDD+ policies and measures - are also introduced but not elaborated on in this document.

The document describes roles and key functional tasks for a PCM approach to four distinct stakeholder groups: national government institutions, subnational government institutions, local stakeholders (including local communities), and non-government institutions and private sector. Development of data standards and protocols, together with sampling strategy design and information management and reporting (as part of a NFMS) is the purview of national government institutions. Subnational government institutions are responsible for subnational resource planning and allocation to PCM activities to on-the-ground, local stakeholder capacity development, and data management, and aggregation and submission of data and information to the NFMS. Local stakeholders, be they local community, forest owners, managers or users of forest resources, can contribute by applying national protocols in collecting and managing field data, together with subsequent basic analysis and application of information for adaptive management at the site-based level. Non-governmental institutions or private sector may play a critical role in providing technical assistance to any of these stakeholder groups in performing their functional tasks for PCM.



Key stakeholder categories and their primary participatory carbon monitoring functions

Integration of a PCM approach into NFMS is outlined with simple flow diagrams and accompanying text including step-by-step procedures for participatory generation of the activity data, emission/removal factors necessary to establish reference levels and a subsequent MRV system of the national REDD+ programme's performance. Complementary technical resources for a PCM approach are listed in an annex.

The audience of this operational guidance document is primarily those government agencies responsible for coordinating REDD+ readiness and implementation activities (e.g. REDD+ taskforce and the like), as well those agencies with historical responsibilities for forest inventory and monitoring. Although this document focuses on national REDD+ programmes, the guidance is equally applicable to other, subnational scales of programmatic REDD+.

It is hoped that REDD+ countries and their development partners take both technical and operational PCM guidance to the field and test the methods and systems in 'real world' application. From these practical experiences second generation guidance, together with more interactive decision support tools, can be developed to foster more cost-effective monitoring, not just for REDD+ but multiple management interventions and policy approaches for tropical forests that need good data to ensure and assure impact.

Introduction 1

When forests are cleared or degraded, the carbon stored in the trees, non-tree vegetation, roots, deadwood, litter and soil is released into the atmosphere as carbon dioxide (CO_2), a major greenhouse gas (GHG). In addition, the forest's capacity for additional carbon sequestration is lost or reduced. GHG emissions from deforestation and forest degradation are significant, and have been estimated to account for between 7% and 17% of the total of global anthropogenic CO_2 emissions (Barker et al. 2007, Harris et al. 2012b). A clear need to conserve forests, their ability to sequester CO_2, and enhance or maintain their stored carbon has been identified by the global community as an important element of climate change mitigation.

Under the United Nations Framework Convention on Climate Change (UNFCCC) a climate change mitigation mechanism has been proposed to address GHG fluxes from forestry and other land use sectors - REDD+ (reducing emissions from deforestation and forest degradation, and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks, in developing countries). The UNFCCC Cancun Agreement[1] identifies five mitigation actions comprising REDD+:

a) Reducing emission from deforestation;

b) Reducing emissions from forest degradation;

c) Conservation of forest carbon stocks;

d) Sustainable management of forests; and

e) Enhancement of forest carbon stocks.

The UNFCCC supports and provides guidance on developing REDD+, which calls for a phased approach at the national level, with possible supporting sub-national elements, and the development of national strategies and action plans. For a national REDD+ programme to be eligible for results-based financing, the UNFCCC has requested Parties to[2]:

- Identify of drivers of deforestation and forest degradation and means to address them;
- Identify of national REDD+ activities and development of national strategies and actions plans;
- Use the most recent Intergovernmental Panel on Climate Change (IPCC) guidance and guidelines as basis for estimating GHG emissions and removals from forests;
- Establish a national forest monitoring system (NFMS) that combines remote sensing and ground-based techniques for providing estimates that are transparent, consistent, accurate and suitable for review by the Conference of Parties;







1 UNFCCC Decision 1/CP.16

2 UNFCCC Decision 1/CP.16, UNFCCC Decision 1/CP.13, UNFCCC Decision 4/CP.15

- Estimate the national forest reference emission level (REL) or forest reference levels (RL);
- Measure, report and verify (MRV) estimated GHG emissions reduction and removals from forests and land use change; and
- Develop a system for providing information on and ensuring REDD+ safeguards are addressed and respected.

The Cancun Agreement (2010) requests Parties to the UNFCCC to promote and support a number of safeguards when undertaking REDD+ activities, including inter alia, *'the full and effective participation of relevant stakeholders, in particular, indigenous peoples and local communities'*. The benefits of a participatory approach to developing, implementing and monitoring national REDD+ strategies and programmes have been identified to encompass:

- reliable identification of underlying drivers and agents of deforestation and degradation;
- potentially reduced costs of implementation and monitoring of REDD+ activities;
- increased awareness, ownership and motivation for implementing and monitoring REDD+ activities;
- transparent and independent monitoring and enforcement of regulations; and
- monitoring of environmental, social and GHG accounting safeguards.
  (Foti et al., 2008; Daviet, 2011; Mukama et al., 2012)

Participatory carbon monitoring (PCM) presents a tangible and pragmatic opportunity to promote and support the safeguard of *"full and effective participation of relevant stakeholders"* and make potentially cost-effective contributions to a number of essential elements of REDD+ (Box 3), not least of which is GHG accounting.

National and subnational institutions, together with local stakeholders, each have particular roles to play in the development and implementation of national REDD+ programmes[3]; from the development of forestry and related land use mitigation strategies, to implementing and monitoring REDD+ activities. A PCM approach allows REDD+ countries to meet their obligations under the UNFCCC, build a broad and skilled constituency across a number of forest carbon stock monitoring and measuring tasks, and assist in the creation of carbon accounting system(s) that are transparent and accountable to a broad range of stakeholders.

3 This guidance document focuses on national REDD+ programmes, but is equally applicable to other, subnational scales of programmatic REDD+

1.1 Defining participatory carbon monitoring

PCM is defined here as an approach to improve the vertical and horizontal institutional integration of different stakeholders for GHG accounting within a country's national REDD+ programme. A PCM approach can be regarded as one component of participatory forest monitoring (PFM) – a broad approach for multi-stakeholder engagement in monitoring forest resources and services, together with the environmental and social impacts of different management interventions, including REDD+ (Swan, 2012) (see Box 1). Historically, PFM approaches have demonstrated the potential for engaging local stakeholders under a variety of participatory forest management modalities - such as joint forest management, community forest management, collaborative forest management, co-management - and for a variety of purposes and forest management objectives (Evans and Guariguata 2008, Martin-Garcia and Diez 2012).

Box 1: Characteristics of participatory forest monitoring (PFM)

- Engages different stakeholders, performing different functions based on complementary mandates and skills, from national government to the grassroots level.
- Applies local knowledge and capitalises on the different capacities and competencies of local stakeholders, particularly forest managers and local government officers.
- Is not restricted to any particular forest tenure arrangement or management and governance system; PFM application can range from public or private owned management boards contracting local people to perform certain monitoring functions through to community forest management.
- Employs a variety of data collection, management and analysis protocols, including forest carbon stocks, other ecosystem service indicators, and biodiversity and social impacts of REDD+ implementation.

(Source: adapted from Swan 2012)

Most of the discussion on PCM in the current REDD+ literature is focused on the utilization of communities for *monitoring* REDD+ activities, and is often limited to community-based field data collection (UN-REDD 2011, Danielsen et al. 2011, Scheyvens et al., 2013). While field monitoring of forest carbon by communities is indeed an important part of PCM, this document purposefully focuses on the participatory and collaborative aspect of a broad range of stakeholders that should be involved in carbon accounting for a national REDD+ programme, not just community level field data collection.

1.2 Potential benefits and limitations

Given the UNFCCC requirement for *"full and effective participation of relevant stakeholders"*[4], those designing carbon accounting systems within a NFMS will benefit from an understanding of both the benefits and limitations of broad and inclusive participation of a range of stakeholders in measuring and monitoring forest carbon (Box 2).

4 UNFCCC Decision 1/CP.16

Box 2: Potential benefits and limitations of a participatory carbon monitoring approach for national REDD+ programmes

Potential benefits

- **Cost-effectiveness** – The use of PCM approaches has the potential to be more cost-effective than carbon monitoring conducted solely by government agencies or external technical experts (Skutsch et al. 2010; Danielsen et al. 2011; UN-REDD 2011; I-REDD+ 2012).

- **Sustainability** – The cost-effectiveness of the participatory approach, coupled with broad stakeholder buy-in is likely to lead to a more sustainable monitoring effort, one that promotes ownership and continuity of the monitoring functions, both within and outside of the government institutions.

- **Social and human capital** – The use of PCM builds social and human capital, empowering institutional and individual stakeholders. The building of social and human capital through training, network development and information exchange can engender more pluralistic and effective forest management and governance structures.

- **Connecting local knowledge** – PCM approaches provide opportunities to integrate valuable local knowledge into managerial considerations and decision making processes on the sustainable use of forest resources.

Potential limitations

- **Data quality control** – The quality of data is dependent on the existing technical capacity and resources available to participating stakeholders. Without a system of ensuring quality at all levels, data collected through a PCM approach may not be of sufficient quality to support carbon accounting for a national REDD+ programme. There is also a risk of information loss or erroneous reporting of data during aggregation from local to higher administrative levels. If benefits are linked to results, this could provide an incentive to report false positive trends, so that higher rewards can be obtained.

- **Initial capacity investments** – Although PCM approaches could be more cost-effective than expert based monitoring in terms of operational running costs, the initial capital outlay for introducing PCM approaches may be high depending on existing capacity to collect data, as well as soft and hardware available to manage those data at the local level. There may also be additional upfront costs in establishing or improving data quality assurance and quality control systems.

Box 2 (cont.)

- **Incentives for participation** – Incentivising and sustaining participation in PCM approaches could be a challenge for reasons of political economy at national and subnational levels (vested interests in maintaining expert-based monitoring systems), and for reasons of opportunity cost at the local level (time spent collecting data for REDD+ might compete with on-farm livelihood mainstay activities). When a PCM approach is implemented, local participants need to be compensated in some form (financial and/or in-kind contributions) for adopting responsibilities. In addition to direct participation payments, indirect incentives that could attract sustained commitment to a PCM approach include: creating a dialogue on resource use between local stakeholders and government; increased stake and legitimacy in management decision-making processes with regard to resources important to livelihoods; improved natural resource management through informed decision making utilising monitoring data, yielding more sustained forest product harvests; and attracting external financing for the management of an area.

1.3 Aims, scope and audience

This operational guidance document on PCM approaches describes functional roles of stakeholders at different levels: national, subnational, and local; and how these roles can complement each other and combine to contribute to GHG accounting under a national REDD+ programme. This document aims to guide national stakeholders involved in the REDD+ readiness process in understanding: a) what a PCM approach is, and what potential and limitations (Section 1); and b) how to organise stakeholders and operationalize a PCM approach for national REDD+ programmes carbon accounting (Section 2). A list of publicly available resources that may be used or adopted by stakeholders in implementing such a PCM approach is also included (Annex I). It should be clearly noted that this document is not a technical methodology or protocol for implementing a PCM approach, detailing how to collect, manage, verify and analyse data forest carbon data. The technical aspects of 'how to do create a PCM system' is covered by other literature (see Annex I). This document complements these technical methods and protocols, with operational guidance on PCM systems.

This guidance document considers only the application of PCM approaches to forest carbon accounting for national REDD+ programmes, but there are other applications that could be considered during design of national programmes and strategies (outlined in Box 3), but not elaborated further in this document.

Box 3: Non-carbon accounting applications of participatory carbon monitoring for national REDD+ programmes

- **Safeguards** – PCM, as part of broader participatory forest monitoring approaches, can contribute to the goals laid out in the UNFCCC REDD+ safeguards. Inherent in its name, PCM contributes to safeguard (d) – stakeholder participation - by enhancing the participation of stakeholders at different levels. PCM could also prove effective as a measure to monitor domestic leakage, helping contribute to safeguard (g) – displacement of emissions -, as well as provide data on changes in extent of biomass carbon, as an indicator of natural forest quality, thus addressing safeguard (e) –

Box 3 (cont.)

natural forests and biodiversity. The system of collaborating stakeholders collecting and aggregating (and potentially verifying) data, that would be necessary for effectively implementing PCM for national carbon accounting, could form and integral part of the system required under the UNFCCC to provide information on how the safeguards are being addressed and respected throughout the implementation of REDD+ activities.

- **Low-Emission Development Planning** – (LEDP) is a multi-stakeholder process to meet pro-poor economic development with sustainable land and forest use planning while lowering carbon emissions within a chosen jurisdiction (Stephen 2013). LEDP presents a framework and a participatory process to operationalize national REDD+ programmes at the subnational level. PCM has an important technical role in contributing to carbon accounting and monitoring within the LEDP framework, but also an equally important social role in building and supporting an inclusive and informed decision making process. PCM is a process that can ensure that local stakeholders have the knowledge and capacity to evaluate different low carbon development scenarios and are equipped to make informed decisions regarding trade-offs between economic, environmental and social development objectives under a low emission land use plan and any benefit sharing mechanism linked to this plan.

- **Benefit Sharing Mechanisms** – PCM approaches may assist in the transparent and equitable allocation and distribution of benefits (in cash or in kind, individual or collective) across the range of stakeholders implementing REDD+ activities. A PCM approach could provide local actors with an important source of information relating to their performance, and serve as a 'self-check' against the benefits that is awarded to them under a national REDD+ programme. Interactions and feedback across different actors can assist in creating a more equitable incentive allocation to both participation and performance. If benefit sharing mechanisms are used as a participation-based incentive, stakeholders would receive compensation for the data collected and provided to relevant institutions. Stakeholders distributed across a landscape have the potential to collect data at a high sampling intensity, allowing for benefit distribution to the sub-national level to be more closely tied with localised performance in achieving emissions reductions and removals.

- **Policies & measures** – The development of effective policies and measures comprising a national REDD+ strategy or programme that result in the desired reduced GHG emissions or enhanced removals requires a comprehensive understanding of what drives land use and land use change, in addition to feedback on the range of interventions to address these drivers of deforestation and forest degradation. To design and refine effective REDD+ interventions, the NFMS should be used to inform the national policies and local measures adopted to achieve emissions reductions and enhanced removals in the country or jurisdiction. Involvement of local stakeholders, through a PCM approach, can provide a vital link for monitoring the efficacy of REDD+ policies and measures. Local stakeholders are also likely to provide data inputs on emission/removal activities at a higher frequency than a nationally implemented monitoring programme, thus providing information for refining and adjusting policies and measures more quickly and frequently, as well as informing adaptive management at the local level of activity implementation.

The audience of this guidance document is primarily those government agencies responsible for coordinating REDD+ readiness and demonstration activities (e.g. national REDD+ committees, offices, taskforces and the like). This document also targets those agencies with historical responsibilities for forest inventory and monitoring that would be central in operating NFMSs for REDD+, as well as those who provide technical assistance to these national and sub-national institutions.

2.1 Participating stakeholder groups

The various actors involved in the implementation of a PCM approach will have different functional roles. Four key stakeholder groups are identified as necessary to cover the main functional tasks that would comprise PCM for national carbon accounting purposes. These main stakeholder groups, and the relationships between them are presented in Figure 1.The roles of each main stakeholder category are outlined below and summarised in Box 4.

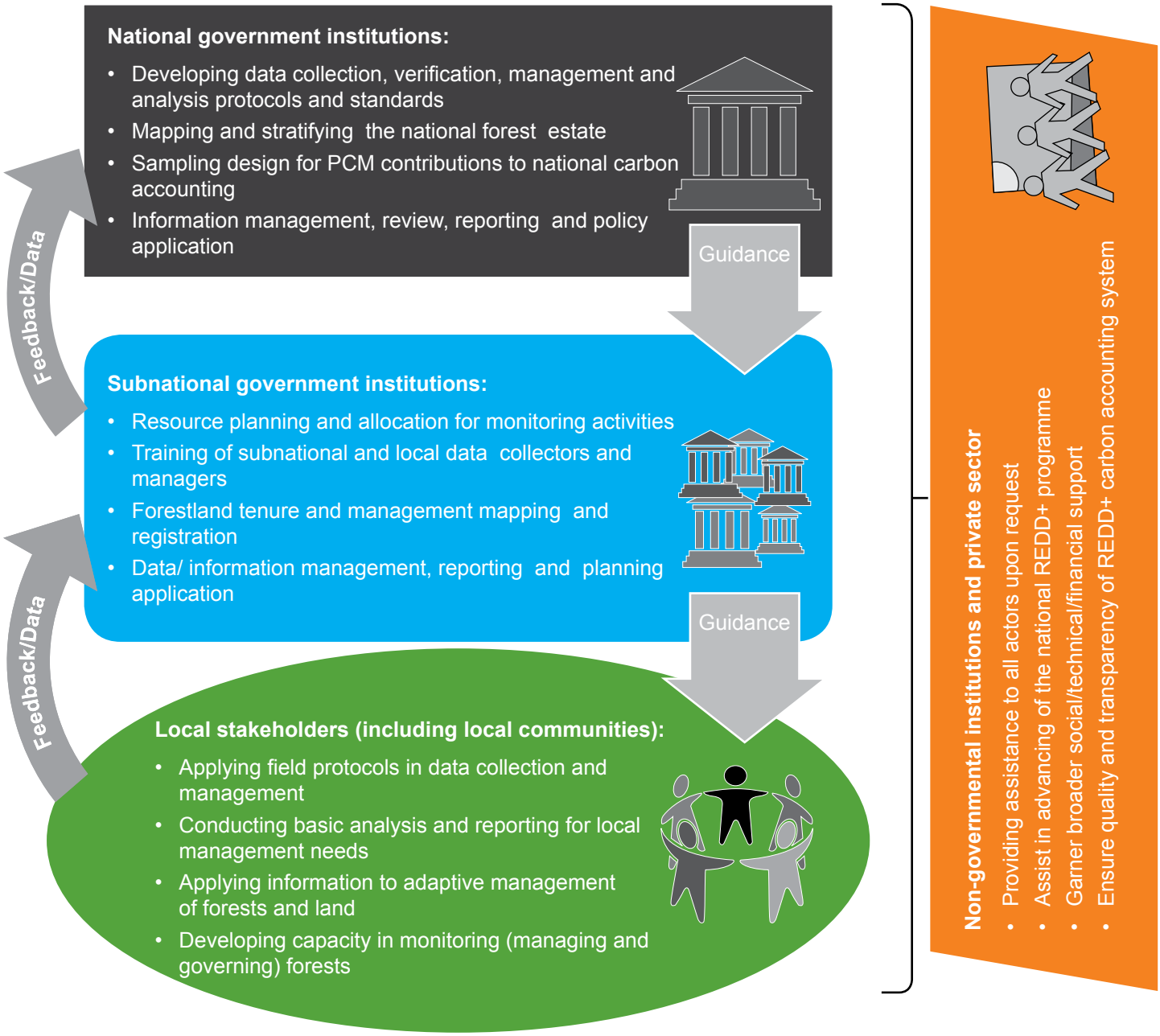


Figure 1: Key stakeholder categories and their primary participatory carbon monitoring functions

National government institutions

REDD+ has intrinsically complex developmental and implementation requirements in regards to policy measures, financial mechanisms, social arrangements and technical components. Given national REDD+ programmes will be implemented over large geographic areas incorporating a diverse array or stakeholders, the agency/agencies coordinating the national REDD+ programme (i.e. REDD+ Secretariat, REDD+ cell, REDD+ office, REDD+ taskforce, etc.) should have a thorough understanding of resource availability, diversity of social groups/ethnicities, potential stakeholder roles and responsibilities, and existing land use/ land cover practices and policies. National government institutions with existing forest inventory and monitoring responsibilities have three basic PCM functions: 1) quality assurance/quality control (QA/QC) through development of national data protocols and standards; 2) sampling strategy through stratification of forests, setting precision targets and determining sampling effort and frequency; and 3) reviewing, reporting (nationally and internationally) and applying carbon accounting information to REDD+ policy approaches.

Subnational government institutions

Subnational government institutions act as the connection between the national government agencies, through hierarchical tiers, and the local stakeholders. These institutions should strive to bridge the gap in communication by promoting transference of knowledge between national government and local stakeholders. Subnational institutions will likely play a crucial role in operationalizing national REDD+ programmes due to their administrative functions governing the areas where REDD+ activities will be implemented. The principal functions of subnational government in PCM are: 1) financial and human resource planning and allocation; 2) forestland tenure and management mapping; and 3) information management and reporting (to the NFMS) and applying PCM data to subnational planning (i.e. through LEDP, see Box 3).

Local stakeholders (including local communities)

Local stakeholders – owners, managers and users of forests and forest frontier lands - are critical for the execution of PCM as they are the actors implementing REDD+ activities and present a large, locally knowledgeable (low-cost) labour force. These actors, which include, but not necessarily limited to local people, and may include individuals and civil society sector entities, should be engaged in the development of REDD+ activities through a participatory consultation processes, in which local actors may inform national and subnational agencies about local land use practices, historic trends in land use and land cover, their interaction with forests, and overall cultural beliefs (Scheyvens et al., 2013). Such information allows further understanding of local land use practices that may lead to GHG







emission reductions or removals, and thus assisting national and subnational agencies in the development of effective REDD+ programmes and plans respectively. In PCM, local stakeholders have the roles of: 1) applying the national data collection and management protocols to generate data to be aggregated into the NFMS; 2) conducting basic analysis and reporting for adaptive management at the site level of REDD+ activity implementation; and 3) developing capacities to improved governing, managing and monitoring forests.

Non-governmental institutions and private sector 

Non-governmental institutions and the private sector correspond to groups and institutions that do not have a direct and immediate stake in the outcome of benefits from the REDD+ programme. They generally have specialized niches of interest and expertise, ranging from policy development to social engagement, to technical assistance. These stakeholders are important actors in furthering and applying REDD+ - locally, nationally and/or globally – as agents of change, and for generating analysis, experience exchange, methodology development, and knowledge development. As such, non-government institutions and private sector may provide targeted assistance to national and subnational institutions as well as local stakeholders in executing any of their core PCM functions as identified in figure above.

Box 4: Main functional tasks of key stakeholder groups under a participatory carbon monitoring approach to national carbon accounting for REDD+

Stakeholder group	Main functional tasks	Description
 National government institutions	Create an enabling policy, legal and regulatory (PLR) environment for PCM	Securing political will and commitment to using a PCM approach and enshrine this in national REDD+ strategies/programmes, and broader PLR reform Instructing subnational agencies in operational and technical aspects of PCM and application of data protocols and standards Deciding on REDD+ benefit sharing and compensation measures for PCM systems Identifying and allocating national resources needed for PCM activities through regular forestry planning cycles
	Development of standards and protocols for data collection and management	Developing standard operating procedures for measuring, monitoring and reporting Defining precision targets, reporting requirements, and others guidelines (e.g. format, content, etc.) Devising and implementing data storage, management and sharing protocols Ensuring consistency and comparability of data, and replicability of standards/ protocols
	Sampling design for PCM contributions to national carbon accounting	Devising sampling strategies and frequency, and designate role of various stakeholders Mapping land use, land cover and stratifying the national forest estate; updating maps and refining stratification through application of data collected using a PCM approach Providing guidance on required frequency of monitoring activities for each of the REDD+ activities that conforms with the requirements of the existing or planned MRV.
	Data (statistical) analysis and information management, review, reporting	Developing and maintain the NFMS to generate rigorous EF/RFs and activity data for RL estimation and MRV events Providing feedback to subnational agencies submitting substandard data quality, together with guidance on corrective actions Ensuring quality and consistency of spatial and temporal analyses internally and externally, wherever analysis is outsourced to non-government organisations or private sector Ensuring appropriate and variable access to nationally managed data and information (e.g. web-based portal) Refining carbon accounting parameters – forest stratification, stratum-specific allometric equation development

Stakeholder group	Main functional tasks	Description
 Subnational government institutions	Subnational resource planning and allocation	Identifying and allocating subnational resources needed for PCM activities through regular forestry planning cycles Providing and maintaining supply of equipment and materials necessary for data collection and management using a PCM approach Adjusting national standards, protocols and guidelines to local technical, financial and literacy capacities
	Capacity development of local data collectors and managers	Training local levels of government through a training of trainers approach, and subsequently private and community forest owners, managers and users in PCM data collection, management and basic analysis Monitoring the participation of local stakeholders and adjust PCM activities accordingly
	Data / information collection, management, reporting and planning application	Executing sampling strategies for the administrative unit(s) based on national forest stratification and sampling strategy protocols Administering field data collection ensuring QA/QC of protocols and provide (or source) technical assistance as needed Electing to collect data directly when/where necessary, e.g. adverse conditions, where special precautions or equipment are necessary Compiling and submitting data and information to NFMS
 Local stakeholders (including communities)	Application of protocols in data collection and management	Identifying the key agents or drivers of forest cover change, forest degradation, and carbon stock enhancement across the landscape/ jurisdiction Collecting field data according to protocols (for verifying or validating remote sensing products and ground-truthing maps of forest cover and tenure) Building capacities contributing to successful REDD+ programme implementation
	Conduct basic analysis and reporting for local management needs	Conducting basic analysis of PCM data and/or accessing information from the NFMS to inform refinement of management interventions (REDD+ activities) Assisting in accuracy assessments of activity data generated for REDD+ Assessing effectiveness of REDD+ activities at the local level

Stakeholder group	Main functional tasks	Description
 Non-governmental institutions and private sector	Technical, financial, political and outreach assistance to stakeholders	Assisting stakeholders in execution of functional tasks by transferring knowledge and building capacity Assisting stakeholders in the development of training materials and training courses for their application Developing and introducing innovative (e.g. Information Communications Technology) methods that assist stakeholders in the implementation of PCM
	Strengthen 'communities of best practice'	Developing knowledge products on international best practice and national context specific solutions for PCM operationally and technically Sharing knowledge and experiences on operational and technical aspects of PCM Securing public and private sector financing for PCM innovation and application in novel contexts Contribute to on-going dialogue on the development of PCM and facilitate the introduction of advances in a process of inclusive and adaptive management
	Third party review/ verification of procedures and data/ information quality	Conducting independent verification and quality assurance/quality control checks Monitoring effectiveness, and guide improvement, of PCM activities throughout REDD+ programme implementation

2.2 Integrating Participatory Carbon Monitoring into the National Forest Monitoring Systems

Countries aiming to undertake REDD+ activities under the auspices of the UNFCCC are requested to develop, *inter alia*, a robust and transparent national forest monitoring system (NFMS) for the monitoring and reporting of these REDD+ activities (with, if appropriate, subnational monitoring and reporting as an interim measure)[5]. The NFMS is a domestic tool to allow countries to assess the results of REDD+ activities, as implemented by different stakeholders and institutions. Importantly, in the context of forest carbon accounting, the NFMS should provides international GHG measurement and reporting functions of the MRV requirement (UN-REDD 2013). A NFMS can encompass multiple objectives beyond monitoring and MRV for REDD+, such as monitoring of changes in timber stocks, non-timber forest products, biodiversity, and other ecosystem services besides carbon sequestration. The carbon accounting aspects of NFMS comprise the estimation of a reference level and the MRV of emissions reductions and enhanced removals that can be attributed to a national REDD+ programme against that reference level.

A PCM approach could contribute to the development of activity data (AD) and emissions/removal factors (EF/RF) – the two fundamental components in carbon accounting partially generated by the NFMS that feed into reference level estimation and the MRV system. PCM approach could also be applied to the broader monitoring function of a NFMS for assessing the outcomes of polices and measures, at the national level, and adaptive management of local activity implementation under a national REDD+ programme (see Box 3). The following guidance concerns only application of PCM to carbon accounting functions of establishing reference levels and subsequent MRV.

Figure 2 below, depicts the general overview of the roles and process for the various stakeholders involved in a PCM approach to carbon accounting for a national REDD+ programme. Although this document provides guidance to engaging the key generic stakeholder groups, the specific division of roles and functions is a sovereign decision. Thus, the guidance presented in here should be tailored to each country's specific needs and reflect national circumstances and legal frameworks for the inclusion of stakeholders in any national REDD+ programme.

5 UNFCCC Decision 1/CP.16

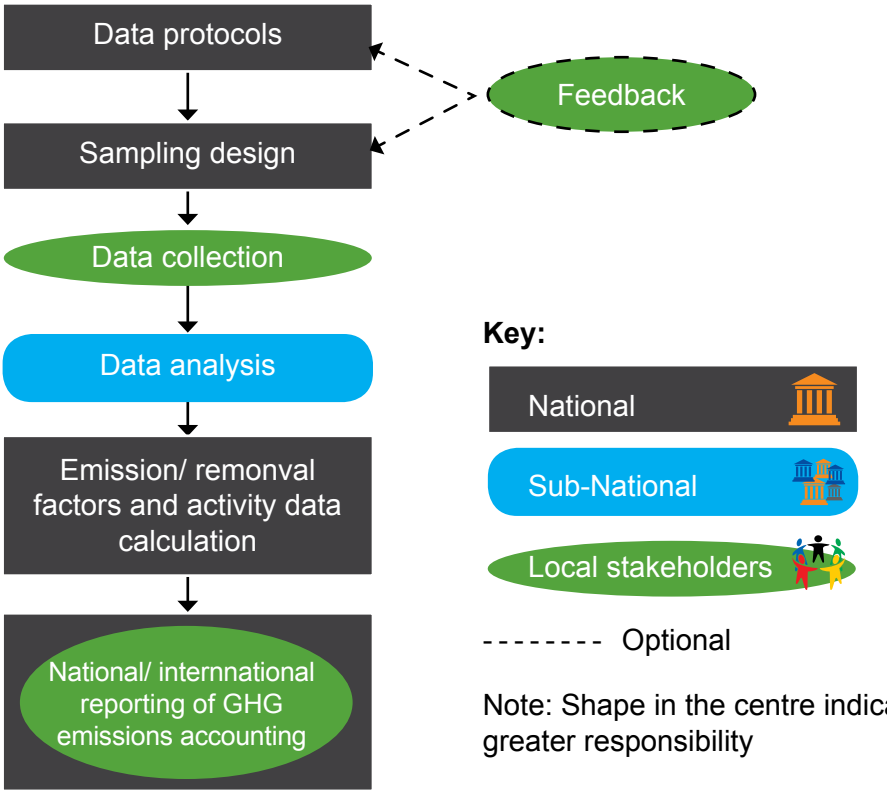


Figure 2: Generic participatory carbon monitoring operational framework for national REDD+ programme carbon accounting

As illustrated in Figure 2, a PCM approach contributes to national GHG accounting for land use/land cover change practices. It is also important to emphasize that QA/QC procedures should be conducted in every step of the national GHG accounting, for improving accuracy and ensuring best practices (IPCC, 2006; GOFC-GOLD, 2013), whether employing a PCM approach or not. Consequently, protocols for QA/QC within a forest carbon accounting system, produced by national and applied by subnational government, are absolutely necessary to reduce errors of data reported, and therefore strengthen the confidence of estimates produced. The non-governmental institutions and private sector may assist technically, financially, politically and socially, for all of the participating stakeholders involved in national accounting of GHG emissions from the land use sector.

2.2.1 Activity data

Activity data (AD) is defined by the IPCC (2006) as the data on the extent of anthropogenic activity over a given period of time that results in emissions. Activity data portrays the magnitude of human intervention on the land use/land cover change leading to GHG emissions and/or removals; therefore activity data is driver-specific. Activity data is often reported in terms of area of change (e.g. hectares deforested), but it is not limited to spatial extent of changes. Activity data can also be reported as non-spatial metrics, such as volume of timber harvested, kilograms of fuelwood collected, amount of fertilizer applied, or even quantity of animals on grazing land. The measurement of such activity data may be monitored with remote sensing technologies detecting changes in land use, or by sampling, as for localised fuel wood collection. The activity data may also be based on developed and proven

relationships between a given activity that results in emissions/removals and easily measured parameters or parameters that are already monitored for other purposes (such as population, timber production, crop production, etc. All stakeholder groups can contribute to the various steps in activity data generation (see Figure 3). A summary of main stakeholder functions and the process of activity data generation through a PCM approach is presented below.

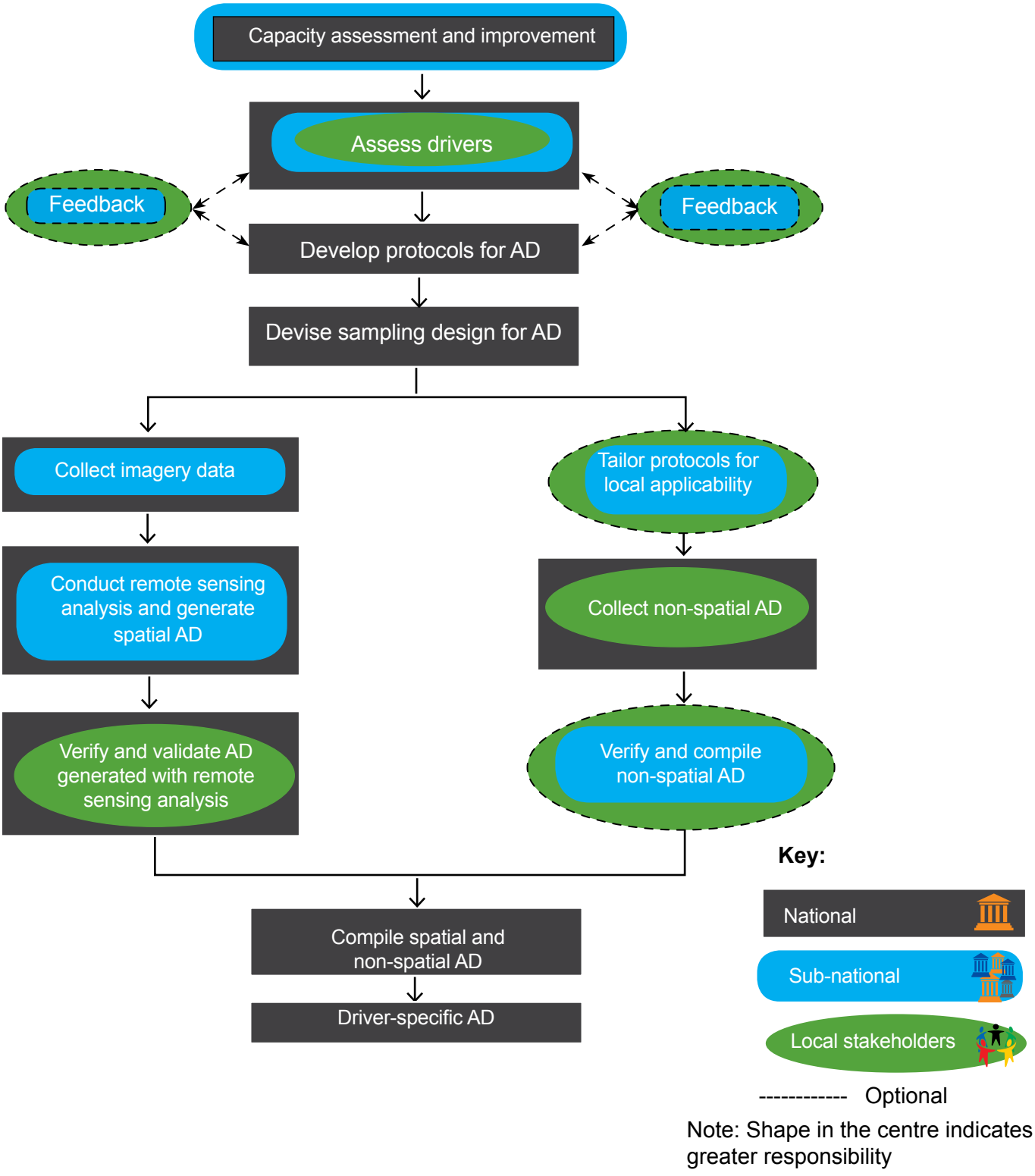


Figure 3: Activity data generation through a participatory carbon monitoring approach

1. Capacity assessment and improvement  : A realistic understanding of the existing capacity and existing infrastructure is key for activity data generation. Needs assessments should be developed by national institutions to identify the required capacity and infrastructure for activity data generation. The subnational institutions should fine-tune these needs assessments towards local applicability and ensure the assessments are given to relevant authorities who responded accurately and in due time. The outcome of these needs assessments shall inform the strategies to develop and improve capacity and infrastructure at all stakeholder levels for activity data generation.

2. Assessment of drivers of GHG emissions/removals  : The assessment of the cause of emissions and removals can be a collaborative and consultative effort involving national, subnational and local stakeholders. Using a PCM approach, local knowledge about common land use practices that lead to GHG emissions/removals can be collected, transferred to subnational institutions and communicated to the national institutions for devising a detailed plan for generating activity data. This driver assessment should include an analysis of the significance of a particular emission/ removal source.

3. Develop protocols  : Protocols shall be developed to ensure standardization of methods for generating activity data at all locations across the nation. Protocols should standardize the imagery collected, software used, sampling methods, sampling intensity/ imagery coverage, algorithms and methods employed in analysis, precision levels, and output format. Prior to the development of protocols, studies may be required to determine the most appropriate, accurate, precise, and cost-effective methods and parameters to monitor a certain activity. For activities that dominate emissions, it is recommended that protocols be developed that result in a high degree of accuracy while activities resulting in smaller emissions may be allowed to be monitored at lower accuracy levels. Protocol development should build upon the prevalent forest measurement conventions as far as practicable. National government institutions should be responsible for developing these protocols applicable to all activity data generation to ensure procedures employed will be nationally consistent and fit within available resources for national REDD+ programme implementation. Protocols will need to be tailored to suit the needs and capacity of those implementing the methods, and therefore a system of providing feedback and protocol alteration should be instituted.

4. Sampling design  : A formal sampling design is necessary to ensure standardized and statistically robust methods are employed in data collection. It is recommended that a national institution be appointed responsible for this task and assume responsibility for the sampling design across forest lands, as this task requires advanced technical background in geospatial modelling and statistics. A transparent, consistent and standard approach to be used across all sampling areas. Direct feedback from subnational institutions and local stakeholders is strongly encouraged, especially because the sampling design should have considerations to applicability of methods to the variety of conditions on the ground.

5. Collection and compilation of data sources  : As previously mentioned, there are spatial and non-spatial activity data. Both types of activity data shall be ultimately compiled by national institutions regardless of which actors collects the information.

a. Spatially explicit activity data  : will entail complex remote sensing interpretation and analysis using geographic information systems (GIS). As such, satellite imagery or other remote sensing and/or GIS products must be collected as stipulated on the protocols developed (See task 3 above). Collection of these datasets may require purchasing appropriate data sources, software and equipment, and formal educational training for technicians in the remote sensing and GIS fields. Depending on the data sources used and the capacity at different institutions, this task may be performed either at a national or subnational levels.

b. Non-spatially explicit activity data  : will entail communication with on-the-ground stakeholders for the collection of non-spatial data such as volumes of timber harvested, kilograms of fuelwood collected, amount of fertilizer applied, number of animals grazing, etc. The collection of this information may be more efficiently done by local stakeholders, with the oversight of subnational institutions. The various non-spatial activity data could be compiled at the subnational institution prior to transferring to the national institution.

6. Accuracy assessment  : Remote sensing based outputs or products have inherent uncertainty, as land-cover classification is done based only on the reflective properties of the earth's surface (e.g. spectral reflectance). Therefore, verification and validation of remote-sensing derived products is necessary. Collection of ground data for verification and validation of these products may be conducted by the local stakeholders, assuming they are dispersed over the landscape and can easily verify the products with ground observations. Training of these stakeholders on field verification techniques will be required, and oversight and quality assurance should be carried out by the subnational institution or non-government institutions. Compilation of field verification data should be conducted by local and subnational institutions and then provided to national institutions for validation of the products.

7. Data analysis  : After collection of appropriate datasets and verification of remote sensing products, analysis of the data by driver is required. This entails using the various remote sensing products in a GIS environment to characterize the activity data per driver and calculate associated statistics, such as uncertainty. Depending on capacity at different institutions and on the protocols established, this step may be performed both at a national and/or the subnational level.

8. Activity data generation  : The magnitude of the activity data is dictated by the different drivers, which are related to local social and economic behaviours and the fluxes/ demand for a particular natural resource. It is recommended for information generated at national and subnational levels to be compiled by national institutions.

It is important to remember that, given their specialized niche of work, non-governmental institutions and private sector may assist the recommended responsible actors in any of the steps towards activity data generation for example, in developing capacity, introducing advanced technologies, providing technical assistance in generating and verifying activity data, etc.

2.2.2 Emission/removal factors

Emission factor/removal factors (EF/RF) are defined by the IPCC (2006) as the emission or removal rate of GHG per unit of the activity. EF/RF are directly linked to the activity that results in GHG emissions and along with the activity data, form the basis for GHG emissions/removals accounting. EF/RF are derived from ground sampling of carbon dynamics and flows in the landscape. Forest carbon assessment is a key process for estimating EF from deforestation and forest degradation, although post-deforestation carbon assessment is an important but often overlooked in the estimation of EFs from deforestation.

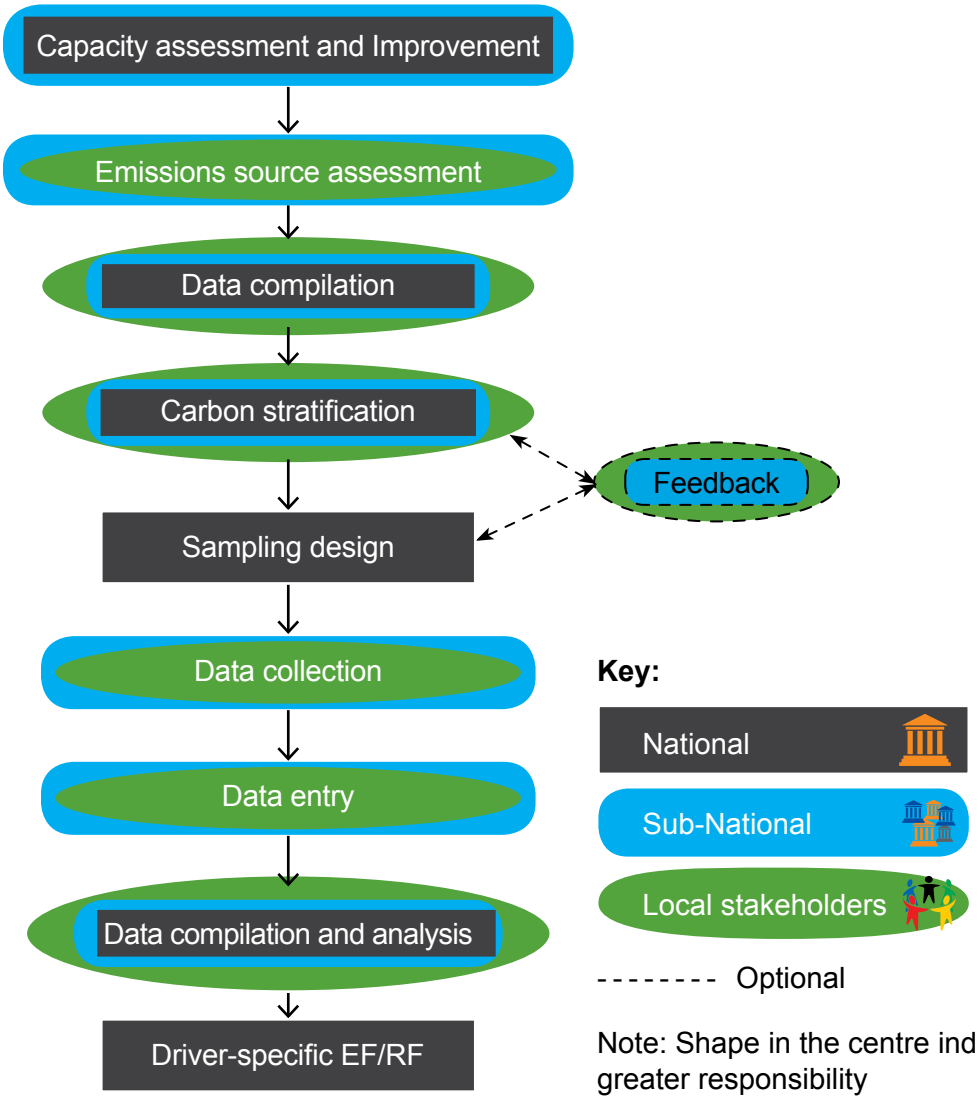


Figure 4: Emission factor/removal factor generation through a participatory carbon monitoring approach

All stakeholder groups can contribute to the different steps that are needed for developing robust emission factor/removal factors (EF/RF) that meet IPCC standards as shown in Figure 4. The general steps to develop EF/RF, indicating key stakeholder groups responsible, are:

1. Capacity evaluation and improvement  : Realistic understanding of the existing capacity and existing infrastructure is critical for EF/RF development. Need assessments should be developed by national institutions to identify the required capacity and infrastructure for development of emission/removal factors. The subnational institutions must fine-tune these need assessments towards local applicability and ensure the assessments are given to relevant authorities who respond accurately and in due time. The outcome of these needs assessments shall inform the strategies to develop and improve capacity and infrastructure for EF/RF generation.

2. Assessment of emission sources  : The assessment of the cause of emissions and removals should be conducted by local stakeholders with oversight from subnational institutions. Using a PCM approach, local knowledge about common land use practices that lead to GHG emissions/removals can be collected and conveyed to the national institutions to inform on the types of EF/RFs that need to be generated.

3. Compilation of existing data  : Existing data on carbon stocks and fluxes from forest and non-forest land cover (i.e. carbon stocks from post-deforestation land use) can be gathered by local stakeholders with the assistance from subnational institution. Ultimately however, the responsibility of assessing the appropriateness of data characterizing the carbon stocks and fluxes in the landscape is recommended to be assigned to national government institutions.

4. Carbon Stratification  : Carbon stratification refers to the division of the landscape into distinct categories (i.e. strata) based on the carbon content of vegetation (GOFC-GOLD, 2013). Stratification can be done multiple ways, but all require spatial information on forest cover (GOFC-GOLD, 2013). Subnational institutions, local stakeholders and communities may contribute to the stratification process by providing ground thruthed data and verifying the products generated from remote sensing and geospatial analysis. However, finalizing carbon strata will most likely need to be conducted by national institutions as carbon stock distribution across the forest estate will cross sub-national administrative boundaries, but needs to be consistent nationally.

5. Develop protocols  : Protocols shall be developed to ensure standardization of methods for generating EF/RF at all locations across the nation. Protocols should standardize the sample design, the field data collection procedures, precision requirements, QA/QC protocols, data calculation methods, and data storage and management systems. National government institutions should be responsible for developing these protocols applicable to all EF/RF generation to ensure procedures employed will be nationally consistent and fit within available resources for REDD+ carbon accounting. The protocols will likely need to be adjusted based on subnational field testing and responding to the needs and capacity of those implementing the methods, and therefore a system of providing feedback and protocol alteration should be instituted. As stated previously, studies may be required to determine the most appropriate EF/RF estimation method. In addition, for activities that dominate emissions, it is recommended that protocols be developed that result in EF/RF with high precision while for activities resulting in smaller emissions emission factors with low precision may be most cost effective.

6. Sampling design  : A sampling design entails determining the procedures for field data collection, the location and frequency of data sampling points, and precision targets. There are multiple ways of designing a sampling strategy for forest carbon across a landscape, but it must ensure that data quality meets the requirement of IPCC guidance and employs the principles of conservativeness and consistency so data collection can be compared across the country. Given the complexity of this task, which requires strong technical background on statistics and geospatial analysis, sampling design is recommend to be carried out by national institutions.

7. Data collection  : Field data collection is necessary when existing data is insufficient or inappropriate. Field data collection must follow the devised sampling design and protocols, and can be conducted by local stakeholders with oversight from national and subnational institutions. With proper training, the methods used for field data collection can be learned by most individuals, regardless of formal education, and thus local communities can effectively conduct such data collection (UN-REDD, 2011; Scheyvens et al., 2013). In order to facilitate data collection, survey instruments and standard operational procedure manuals must be designed in local language(s) with user-friendly illustrations and checklists to reinforce the step-by step protocols. Annex I shows existing resources that can be used. Quality control measures (i.e. QA/QC protocols) should be employed by sub-national institutions to ensure the quality of field data collection and allow for uncertainty estimation from data collection.

8. Data entry  : As far as practicable, data entry should be conducted by the same personnel who led the field data collection (i.e. field crew leader). Thus local stakeholders, assuming quality control checks are conducted by the subnational institution, can be assigned responsibility for this task. Using the same participants for data entry as collection may reduce errors associated with transcribing field data. Proper training on the use of computers, specific software, and any other devices required for entering data should be carried out prior to data entry. Quality control measures (i.e. QA/QC protocols) should be employed by sub-national institutions to ensure the accuracy of data entered. It is important to note that as technologies evolve, systems that automate data entry are being developed in which field data is directly collected in electronic format for later analysis.

9. Data compilation and analysis  : Data analyses require strong organizational skills, attention to detail, and formal education in statistics. Therefore, data compilation, and especially data analysis, should be the responsibility of national institutions. Subnational institutions may also compile and analyse the data, assuming proper training has been conducted. Ultimately, responsibility for data control and quality of analysis should rest with national institutions., so results/estimates are robust, accurately portray the reality on the ground and comparable across the country.

10. Generation of EF/RF  : The transformation of carbon stock data into EF/RF generation is the outcome of all the work conducted in the previous steps. Directing the creation of EF/RF generation should remain with national institutions to ensure a consistent approach.

Once again it is worth emphasizing that non-governmental institution and private sector may effectively assist the relevant stakeholders in any of the steps towards EF/RF generation.

2.2.3 Reference level and measurement, reporting and verification

A reference level is the quantity of GHG emissions and removals that are projected to take place in the absence of a national or subnational REDD+ programme (Harris et al, 2012a). Methodological guidance of the UNFCCC for activities relating to REDD+ recognises that the projection of such emissions/removals for a 'business as usual' scenario (no REDD+ mitigation activities implemented) can be conducted by: i) first establishing historical emissions, and then ii) projecting emissions based on consideration of national circumstances[6]. The MRV function for REDD+ refers to the estimation and international reporting of national-scale forest GHG emissions and removals, which would likely be subject to verification by accredited auditors. Although the three different steps of a MRV process are lumped into a single abbreviation, they are very distinct processes towards ensuring true emissions reductions and removals from the forestry and land use change sector. The measurement component is essentially based on the three components i.e., satellite monitoring of land use change, the national forest inventory (NFI) and the national GHG inventory. At the time of publication of this operational guidance, there has been no detailed methodological guidance or modalities decided by the UNFCCC for developing a reference level or MRV which countries can adopt or apply in their REDD+ programmes. Until such a decision is made, countries may propose and use their own modalities for reference level and MRV development[7]. Recommended guidance for reference level development may be found in Walker et al. (2013).

Through PCM, the local stakeholders who provide the information on spatially explicit drivers of deforestation and forest degradation may be able to contribute information on locally effective mitigation activities that may help national and subnational institutions derive an adjustment to reference level. The non-governmental institutions and private sector may play a role of third party verification of, or adjustment to, such reference level.

Upon the initiation of the national REDD+ programme, the continuous assessment of activity data and EF/RF informs the actual emissions and removals that take place over time through a monitoring system under the NFMS, which will then be used to compare against the projected reference levels to measure the performance of the REDD+ interventions. This process is referred to as 'measurement' and represents the "M" in MRV. The measurement is the component of the MRV that can benefit the most from PCM schemes engaging different stakeholder in the various processes cited above to ultimately measure the emissions and compare it to the estimated reference level

In terms of reporting emissions (reductions or not) – the "R" in MRV – currently no guidance has been made with respect to reporting on REDD+ related activities. Given the complexity and level of formality required for reporting, this is recommended to be conducted at the national government level. Non-governmental institutions and private sector may assist and provide guidance to national governments in preparing and submitting the reports.

The verification process, namely the "V" in MRV, is also recommended to be handled at the national government level, although verifiers might likely want to check information and consistency in implementation of protocols, standards and requirements across all levels of stakeholder engagement. Non-governmental institutions and private sector may assist and provide guidance to any of the stakeholders involved in preparing for the verification process.

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6 UNFCCC CoP15 Decision 4/CP.15

7 It is expected that draft decision on guidance forest reference emissions levels and /or forest reference levels as well as for MRV will be reached at thirty-ninth sessions of SBSTA followed by recommendation for a draft decisions for consideration and adoption by COP 19. (UNFCC/SBSTA/2013/L.12).

Conclusion 3







Participation in national REDD+ programmes is a safeguard requirement under the proposed mechanism of the UNFCCC. But safeguard compliance is not the only or main incentive for adopting a participatory carbon monitoring approach to REDD+. Engaging stakeholders at different levels – national, subnational and local – will engender ownership of the programme's activities and in doing so, mitigating the risk of ineffective REDD+ actions.

Using a PCM approach offers a pragmatic opportunity for different stakeholder, from national government to local forest-dependent villagers, to engage in a national REDD+ programme for mutual benefit. A participatory approach to monitoring forest carbon stocks and fluxes, and forest cover changes, and forest conservation status can contribute to carbon accounting requirements essential to a national REDD+ programme. As such, a PCM approach complements more knowledge-intensive and technical monitoring approaches based on remote sensing products and GIS manipulation as well as highly centralised forest inventory practices.

As indicated in the introductory section defining PCM, the approach has broader REDD+ application than just carbon accounting. Similar operational and technical guidance should be elaborated to expand the scope of PCM applications in subnational low emissions development planning; sharing of benefits (and responsibilities) in the results-based action phase of REDD+; and informing national policy reform and adaptive management of REDD+ activity implementation on the ground.

This guidance document introduces and defines PCM (distinguishing it from 'community-based' carbon monitoring) and presents general steps for its application within a national REDD+ programme, including the generation and verification of activity data and EF/RF necessary for the establishment of forest reference levels and subsequent MRV. To this end, it is hoped that this operational guidance document complements the carbon accounting methodologies already available and collated in Annex I. It is also hoped that REDD+ countries and their development partners take these technical and operational guidance, including this PCM operational guidance document, to the field to test the methods and systems through 'real world' applications. From these practical experiences second generation guidance, together with more interactive decision support tools[8], can be developed to foster more cost-effective forest monitoring practices, not just for REDD+ but for multiple management interventions and policy approaches.

Ultimately, as with all things REDD+, a no regrets approach should be taken wherever possible. Implementing a participatory approach to monitoring carbon, might seem redundant in the absence of REDD+ and the need to account for emissions reductions and enhanced removals. But the underlying principles and operational systems of PCM would still benefit national forest inventory and monitoring programmes, through strengthened capacities of all stakeholders to collect, manage and apply better data for better management and governance of tropical forested landscapes.

8 *cf.* Harris et al. (2012a) for developing reference levels for REDD+; and Broadhead et al. (2013) for integrated REDD+ accounting frameworks and nested national approaches.

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Module 3 - National Forest Monitoring System data, collection standards and protocols and information management and reporting

This Module focuses on the National Forest Monitoring System NFMS). The primary function of this system is to collect, collate, analyse and report on data related to the greenhouse gas dynamics (emissions and removals) from forests. It covers the:

- important design and data elements of the NFMS
- data collected from forests to estimate carbon stock changes

The information presented is predominately generated from the best available internationally recognised Data Collection Protocols (Walker et, al., 2018). It provides standard field measurement approaches to assist in quantifying the amount of carbon stored in the various organic pools found within a landscape.

The methods presented in each Standard Operating Procedure (SOP) have been developed over time by foresters and ecologists to accurately and efficiently estimate carbon stocks. The SOPs are grouped by purpose. The first set of SOPs are general and can be used for many field measurement goals.

The SOPs present a generic approach that will be appropriate for most land cover types, ecosystems, and locations. However, all the field measurement methods presented in this document may require adaptation for the specific ecosystem, land cover, and vegetation type in the location where sampling will take place.

The SOP manual is also not specific to any regulatory or voluntary market standard such as the Clean Development Mechanism (CDM), Climate Action Reserve (CAR), American Carbon Registry (ACR), Verified Carbon Standard (VCS), CarbonFix, or PlanVivo. Therefore, it is imperative that methods presented here are adapted into a specific SOP manual, developed for a specific field measurement campaign. The particular adaptations required should be conducted by a forester or ecologist with detailed knowledge in field carbon stock measurement and in the particular carbon market regulatory requirements.

This manual does not specify guidance on stratification, sampling design, sampling intensity, spatial distribution of sampling points, pool measurement selection, or the methods needed to transform field measurement data into carbon stock estimates. Additional guidance on sampling can be accessed from provided references Sharma, 2017; GFOI, 2016 and McRoberts et al., 2015.

Module 3.1: Data Requirements for National Forest Monitoring Systems

Core Learning Outcome
Understand the core data sets and plot design requirements in collecting quality data for the National Forest Monitoring System (NFMS)

Core Message

- Remote sensing data (to generate Activity Data) and ground data (to generate Emissions Factors) are combined to generate estimates of carbon changes in forests
- Details on remote sensing data sources is for information but is generally managed by national governments or the private sector due to the size of the data and complexity in its analysis
- Ground data is collected to measure various carbon pools. There are 5 specific pools that are measured and reported. Generally, the above- and belowground pools are prioritized.
- The ground data is of most relevance to indigenous peoples and forest dependent communities in the context of PCM
- Many data collection protocols are available and the scope and complexity depends on forest conditions and budgets.
- Collection of data using statistical methods is very important for data quality and confidence in estimates
- Systematic sampling is common for national level inventories; stratified random sampling is more common for projects and sub-national estimates
- The number of plots is based on statistical information such as natural variation in forest structure (which can be estimated by taking a smaller set of plots, say 3) to inform the larger number of plots required.
- An online calculator is available to do this and a link is provided for more information *(NOTE: This tool is not covered in any more detail here. The tool itself is very well commented describing how to use it.)*
- Plot designs are visually presented and described. These designs are taken from internationally recognized Field Protocols (Walker et al 2018). These plot descriptions are consistent with those to be established and used in the workshop fieldwork later in the training

Some additional concepts that might be explored in the discussion following the presentation are:
Develop protocols – National Governments are responsible for establishing protocols to ensure standardization of methods for data collection. Protocols should standardize the sample design, the field data collection procedures, precision requirements, quality assurance/quality control (QA/QC) protocols, data calculation methods, and data storage and management systems. The protocols will likely need to be adjusted based on sub-national field testing and responding to the needs and capacity of those implementing the methods, and therefore a system of providing feedback and protocol alteration should be instituted.

Sampling design - A sampling design entails determining the procedures for field data collection, the location and frequency of data sampling points, and precision targets. Given the complexity of this task, which requires strong technical background on statistics and geospatial analysis, sampling design is recommended to be carried out by national institutions.

Data collection - Field data collection must follow the devised sampling design and protocols, and under PCM can be conducted by indigenous peoples and forest dependent communities with oversight from national and sub-national institutions. With proper training, the methods used for field data collection can be learned by most individuals, regardless of formal education, and thus indigenous peoples and forest dependent communities can effectively conduct such data collection. In order to facilitate data collection, survey instruments and standard operational procedure manuals must be designed in local language(s) with user-friendly illustrations and checklists to reinforce the step-by step protocols. Quality control measures (i.e. QA/QC protocols) should be employed by sub-national institutions to ensure the quality of field data collection and allow for uncertainty estimation from data collection.

Module 3.2: Forest Carbon Indicators

Core Learning Outcome
Understand the types of data/information to be collected from the forests to estimate carbon stock changes

Core Message

- Data collected from the forest is a combination of qualitative and quantitative information that describes the conditions at the plot
    - Qualitative information includes: Location (GPS points); eco-region (from national classification system); Land cover/land use (what is happening at the plot); species
    - Quantitative information includes: tree diameter; height; deadwood litter and soil carbon measurements

Module 3

National Forest Monitoring System
Data, collection standards and protocols, information management and reporting



1



Module Outcomes

Understanding of:

- important design and data elements of the NFMS
- data collected from forests to estimate carbon stock changes



2



Module Outline

1. Data requirements for National Forest Monitoring Systems
2. Forest carbon indicators and estimating emissions and removals





Data Requirements for National Forest Monitoring Systems

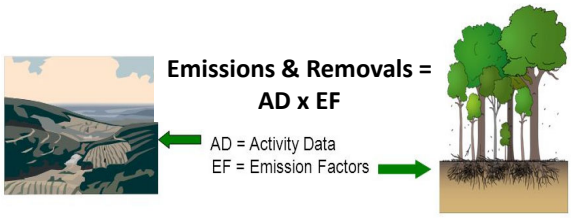
Module 3.1





Data Requirements for National Forest Monitoring Systems

National Forest Monitoring System



Typically requires a combination of:

remote sensing data (to generate Activity Data) and

ground data (to generate Emissions Factors)

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Data Requirements for National Forest Monitoring Systems

Remote Sensing Data

- Typically 30m Landsat satellite imagery is used to see changes in land cover through time.
- Landsat is free and has a long historic archive of images.
- Higher resolution imagery is generally used in a sample based approach to estimate the accuracy of the classification of Landsat imagery
- Higher resolution imagery has a cost and a more limited historical archive

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Data Requirements for National Forest Monitoring Systems

Remote Sensing Data

- Land cover/ land use change statistics (i.e. activity data) are generated from remote sensing
- Maps of land cover/land use and change in land cover/land use are also generated
- The maps can be useful in the stratification of lands when designing a ground sampling frame (as described in the next slides)





Data Requirements for National Forest Monitoring Systems

Ground Data

- Generally, forest inventory is carried out on the national level to collect ground-based measurements (such as tree height, DBH and tree species) on plots selected through a sampling design.
- Project or sub-national level sampling can also be conducted on a smaller scale where data from a national forest inventory is not available





Data Requirements for National Forest Monitoring Systems

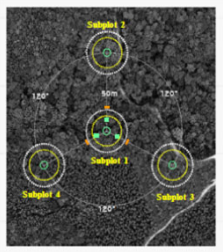
Ground Data

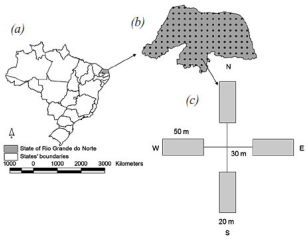
- Data collected from a forest inventory can be used to generate carbon stocks (and emissions factors) for the carbon pools:
  - Aboveground biomass
  - Belowground biomass
  - Deadwood
  - Litter
  - Soil organic carbon

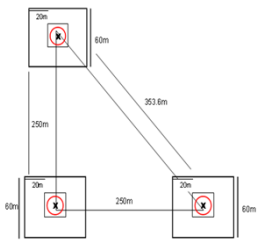
9

Data Collection Protocols

- Diverse approaches around the world based on National circumstances
- Can be influenced by landscape, forest types, budget…….







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Data Collection Protocols

Most important that the design:

- enables the collection of **multipurpose information** for **domestic** information needs for improving and monitoring forest-related policies, strategies, and management as well as **international reporting objectives**
- can support **repeated consistent measurement and estimation** on a statistical basis





Remote Sensing Data

- Satellite images can be analyzed using manual, semi-automated or fully automated processes.
- This analysis is then combined with other auxiliary information such as GIS layers and ground data to generate land use maps and change statistics if data is available for more than 1 time period.
- This analysis can assist in determining the number of hectares deforested, reforested and, in some cases the number of hectares that have transitions from closed to open forest (e.g. possible degradation)
- When this data is presented as maps or GIS layers, this can be used to support the design of a ground sampling frame





Remote Sensing Data

- Data generated from remote sensing is generally assessed for accuracy using a sampling approach.
- The samples can either be of higher resolution data OR from ground plots (known as ground truthing).
- The sampling framework can be established using the same principles as those for designing a forest inventory (as discussed in the next slides)

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Ground Data

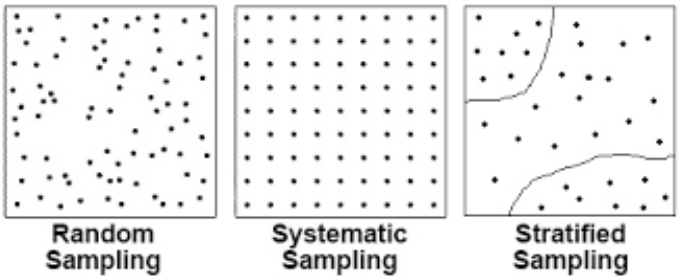
Sample frame considerations:

- **Sample design**
  - Forest inventories commonly use **simple random, systematic, or stratified random sampling designs**.
- **Number of plots**
  - The number of plots required/measured depends on variability of the population, the precision required and available budget for fieldwork.
- **Size of plot**
  - Typically NFIs consist of an array of plots (or clusters of sub-plots) that represent an area of between 0.1 – 1 ha. Larger plots are recommended for tropical forest areas, smaller plots for plantations.

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Ground Data

Sample Design



15

Ground Data

Sample Design

- Simple random
  - **advantage** is the sample should represent the target population and eliminate sampling bias
  - **disadvantage** is that it is very difficult to achieve (i.e. time, effort and money).
- Systematic
  - **advantage** is that it is simpler and more straightforward than random sampling and can also be more conducive to covering a wide study area.
  - **disadvantage** is that introduces certain arbitrary parameters in the data which can cause over- or under-representation of particular patterns.
  - Popular due to simplicity
- Stratified random
  - **advantage** is that for a fixed cost you minimize the standard error. You can choose different sampling rates for different strata. This is an advantage if some strata are more variable than others or have a much greater average
  - **disadvantage** is that you need a variable you can use to set up your strata.

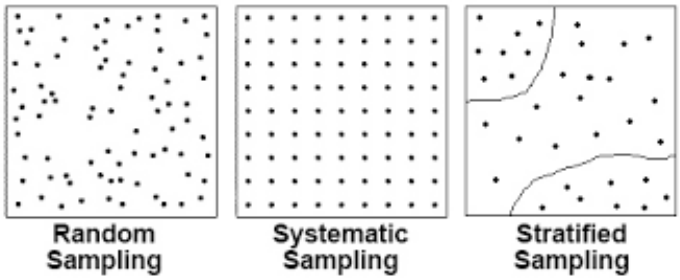
16

Ground Data

Sample Design

More common in National Forest Inventories

Typically selected for Projects and sub-national monitoring

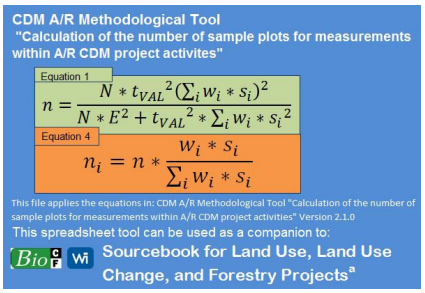


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Ground Data

Number of Plots

- With some knowledge of the variability in the forest carbon stock, statistical estimators (equations) can be used to estimate how many plot are required.
- Can use the Winrock Sample size calculator
  - https://www.winrock.org/document/winrock-sample-plot-calculator-spreadsheet-tool/
  - see instructions in the spreadsheet for how to apply it



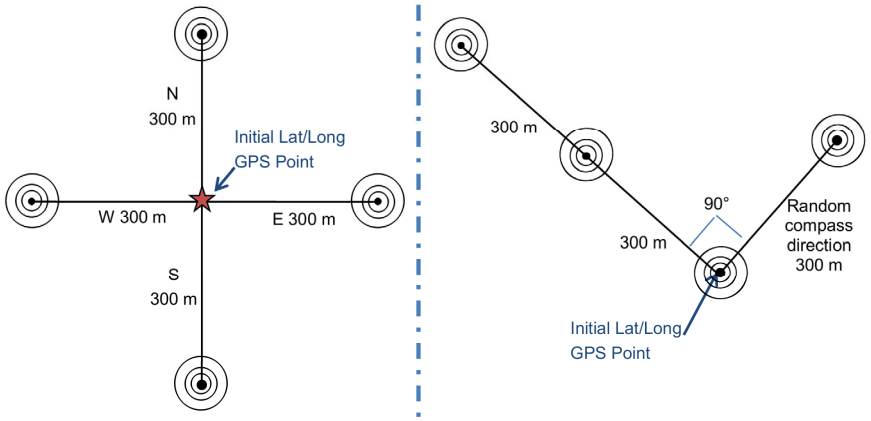
18

Ground Data

- **Single or clustered plots?**
  - **single plots** are often used for measurements in areas where afforestation/reforestation is taking place.
  - **clustering of plots** at each sampling unit is often recommended for natural forest areas and areas that have been selectively logged.
  - clustering of plots within one area can often allow field crews to sample a large area while reducing travel time between plots.

19

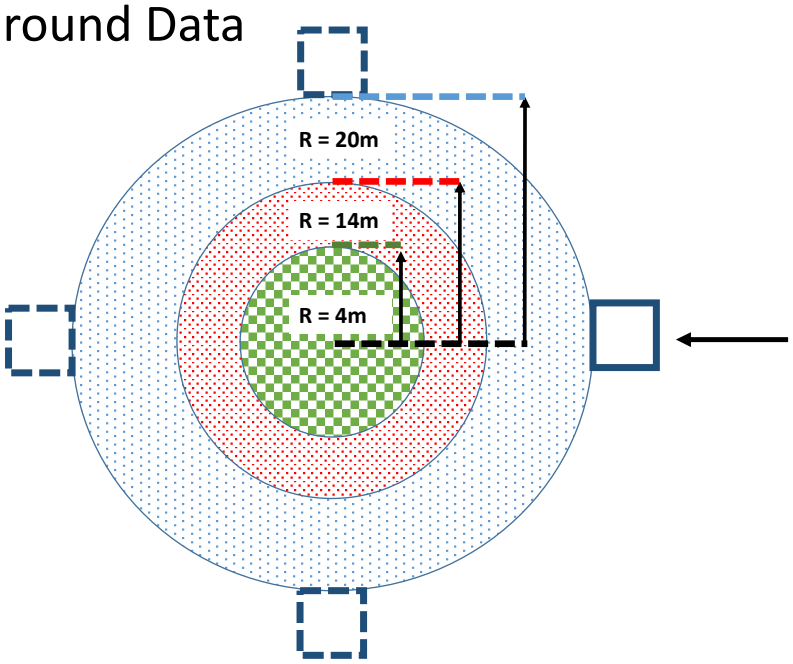
Ground Data



Common cluster plot designs
Source: Walker et al, 2018

20

Ground Data

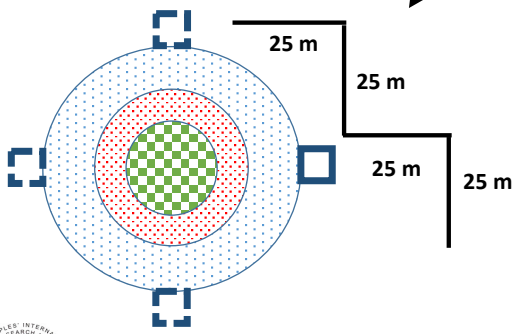


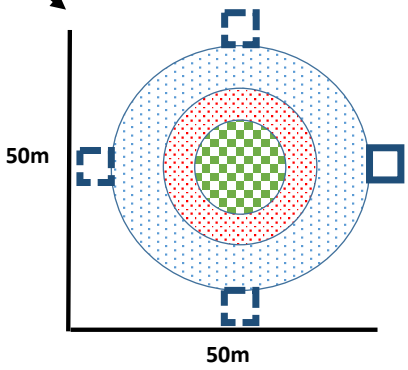
Quadrat for Litter measurements immediately outside the plot boundary

21

Ground Data

Two options for deadwood transects





Not to scale

Source: Walker et al, 2018

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Ground Data

Size of Plots

- The size and shape of the sample plots is a trade-off between accuracy, precision, time, and cost for measurement.

- Experience has shown that for mature natural forests the plot sizes below represent a reasonable balance of effort and precision.

Stem diameter	Circular plot radius	Square plot side lengths	Square plot diagonal length
†Saplings	2 m	3 m x 3 m	4.2 m
5 – 20 cm dbh	4 m	7 m x 7 m	9.9 m
20 – 50 cm dbh	14 m	25 m x 25 m	35.3 m
> 50 cm dbh	20 m	35 m x 35 m	49.5 m

† Saplings are defined as: stems <5 cm dbh, height >1.3 m

Source: Walker et al, 2018

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Ground Data

Size of Plots

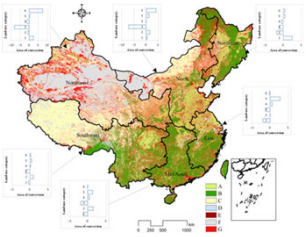
- If a single plot size is used then the plot size should be large enough that at least 8-10 trees per plot will be measured within the plot boundaries at the end of the project activity.

- Therefore, where afforestation is taking place substantially more than 8-10 trees will be measured per plot at the start of the project activity.

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Uses of Ground Data from Participatory Monitoring

Confirm the classification of remote sensing data (accuracy assessment of activity data)



Source: Lai, et. al., 2016

Collect tree measurements to estimate carbon stock changes



Source: GFOI, 2016

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Forest Carbon Indicators

Module 3.2

26

Types of Data Collected

- Location
- Eco-region
- Land Cover/Land Use description
- Species
- Diameter
- Height
- Deadwood diameter/length
- Deadwood decay status
- Litter weight

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Familiarization with Field Equipment

Exercise:

Get to know the equipment.

Handle the equipment and give it a try.

Discussion on how it is used in the field and what information is collected from its use.

28

Equipment List

Field data collection sheet

Global Positioning System (GPS)

Compass

Camera

Botanical Guide OR Species Expert

Diameter at breast height (DBH) tape

Clinometer

Calliper

20m/50m tape

1m x 1m quadrat

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Tools & Materials

- **GPS –** used to find/record the latitude and longitude of the plot centre
- **Camera –** visual records of forest/land condition at the plot
- **Compass –** assist with navigation AND orientation of quadrats and deadwood transects
- **DBH tape –** measure diameter at breast heigl of the tree
- Clinometer – used to measure plot slope (%) and tree heights (m)
- **Caliper –** used to measure the diameter of lying deadwood



Source: Huy et al, 2013

30

Types of Data Collected

- **Location**
- **Eco-region**
- Land Cover/Land Use description
- Species
- Diameter
- Height
- Deadwood diameter/length
- Deadwood decay status
- Litter weight



A GPS device can be used to give location coordinates

A compass is also very useful

31

Types of Data Collected

- Location
- Eco-region
- **Land Cover/Land Use description**
- Species
- Diameter
- Height
- Wood density
- Deadwood diameter/length
- Deadwood decay status
- Litter weight



Description is noted by the field crews and supported by photographic evidence at the 4 cardinal points using a compass

32

Types of Data Collected

- Location
- Eco-region
- Land Cover/Land Use description
- **Species**
- Diameter
- Height
- Deadwood diameter/length
- Deadwood decay status
- Litter weight



Species identification using a botanical guide OR Species Expert

33

Types of Data Collected

- Location
- Eco-region
- Land Cover/Land Use description
- Species
- **Diameter**
- Height
- Deadwood diameter/length
- Deadwood decay status
- Litter weight



Measurement using DBH tape

34

Types of Data Collected

- Location
- Eco-region
- Land Cover/Land Use description
- Species
- Diameter
- **Height**
- Deadwood diameter/length
- Deadwood decay status
- Litter weight



Measurement using a clinometer

35

Types of Data Collected

- Location
- Eco-region
- Land Cover/Land Use description
- Species
- Diameter
- Height
- **Deadwood diameter/length**
- **Deadwood decay status**
- Litter weight



Diameter and length measurement using a caliper and tape

36

Types of Data Collected

- Location
- Eco-region
- Land Cover/Land Use description
- Species
- Diameter
- Height
- Deadwood diameter/length
- Deadwood decay status
- **Litter weight**



Litter collected from inside the quadrat

Module 3 Exercise

Familiarization with Field Equipment

Materials: Global Positioning System (GPS), Compass, Diameter at Breast Height (DBS) Tape, Clinometer, Caliper, 20m/50m Tape, 1m x 1m Quadrat, Field Data Collection Protocol documents and field data sheets

Guide	All participants should be familiar with the field equipment and their uses and are encouraged to handle and use the equipment prior to the field demonstration and field trip. Work systematically through all the equipment explaining its use and how to use it. It is recommended to start with navigation items, moving onto equipment used in establishing the plot and then finishing with the equipment used in data collection. The equipment familiarization can be done inside the room while delivering the PowerPoint presentation OR alternatively the PowerPoint presentation can be delivered and then the familiarization is done outside when establishing the demonstration plot (see next exercise). If there is time, familiarization both during the presentation and again when establishing the demonstration plot could be conducted. It is a good time during this exercise to establish the field data collection teams in preparation for the field data collection demonstration (see Exercise on Measuring Carbon Pools) which will be conducted in teams. This way the teams can work together to learn about the equipment and to understand the different members' strengths and start thinking about the different roles and responsibilities required to collect data. Each team should consist of a minimum of four (4) people and should not be more than seven (7). Everyone should be allocated to a team prior to leaving for the field demonstration and field trip and a Team Leader is identified. The facilitator should communicate that it is good practice to have each member of the team taking responsibility for a particular piece of equipment / task during the actual field data collection. This helps with consistency in data collection. At the end of the Field Equipment Familiarization Exercise, they should check that their team has all the equipment they need for the field trip and that it is all working and confirm that they are clear on how to use it. The teams should also be reminded to bring the Field Data Collection Protocol documents and field data sheets on the field trip.
Expected Duration	45 minutes

Standard Operating Procedures for Terrestrial Carbon Measurement

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Distribution:
The methods in this manual remain the intellectual property of Winrock International. This manual may be freely distributed and adapted, however, the source of the methods is requested to be included in all documentation.

INTRODUCTION AND HOW TO USE THIS DOCUMENT

The active and important role vegetation and soil play in the global carbon cycle and global climate change is now internationally recognized. Vegetation and soil can act as both a net source and a net sink of greenhouse gas (GHG), depending on how the land is managed. Alterations in land use management techniques that result in changes to net GHG emissions are now a significant component to the regulatory and voluntary actions taking place globally to combat climate change.

The purpose of this document is to provide standard field measurement approaches to assist in quantifying the amount of carbon stored within the various organic pools found within a landscape. The methods presented in each Standard Operating Procedure (SOP) have been developed over time by foresters and ecologists to accurately and efficiently estimate carbon stocks.

The SOPs are grouped by purpose. The first set of SOPs are general and can be used for many field measurement goals. A set of SOPs are also presented on the measurement of all the carbon pools. These can be used to estimate the standing stock of a carbon pool within a stratum. Another set of SOPs are presented to estimate the emissions resulting from selective logging. Various SOPs are also presented on estimating canopy cover. These SOPs should only be used when the purpose of data collection is known.

This manual *does not* specify guidance on stratification, sampling design, sampling intensity, the spatial distribution of sampling points, pool measurement selection, or the methods needed to transform field measurement data into carbon stock estimates. Therefore, additional guidance is required prior to any field data collection.

The SOPs present a *generic* approach that will be appropriate for most land cover types, ecosystems, and locations. However, all the field measurement methods presented in this document may require adaptation for the specific ecosystem, land cover, and vegetation type in the location where sampling will take place.

The SOP manual is also *not specific* to any regulatory or voluntary market standard such as the Clean Development Mechanism (CDM), Climate Action Reserve (CAR), American Carbon Registry (ACR), Verified Carbon Standard (VCS), CarbonFix, or PlanVivo.

Therefore, it is imperative that methods presented here are adapted into a specific SOP manual, developed for a specific field measurement campaign. The particular adaptations required should be conducted by a forester or ecologist with detailed knowledge in field carbon stock measurement and in the particular carbon market regulatory requirements.

In addition, the SOPs should not be conducted without receiving extensive field training in the measurement methods performed by a qualified forester or ecologist.

It is expected that this manual will be updated overtime as the carbon market changes and as terrestrial carbon science evolves. Therefore, it is recommended that prior to use, users visit Winrock International's website to determine if a more recent version is available at www.winrock.org/ecosystems.

GENERAL SOPS:

The following Standard Operating Procedures are used for a variety of purposes and studies. They provide general guidance or provide guidance on the use of a specific measurement tool.

SOP Field Safety
SOP Quality Assurance/Quality Control
SOP Data Storage and Archiving
SOP Labeling of Plots
SOP Calibration of Haglöf DME 201 Cruiser
SOP Use of a Clinometer
SOP Measurement of Height

SOP Field safety

No matter what activities are engaged in or where they are carried out, *safety is the first priority* and all precautions must be well thought out in advance and then strictly adhered to. Planned field activities must remain flexible and allow for adjustments in response to on-the-ground assessments of hazards and safety conditions. Accordingly, field personnel must be vigilant and always avoid unnecessary risks.

Field crew members in particular must be well prepared. It is recommended that personnel engaging in field activities hold general first aid training and if possible training in CPR.

The following guidelines will apply to all field-based activities:

- Mandatory buddy system. Field crews will include no less than two people who must be directly accompanying each other for the entire duration of field work. Ideally field crews should include a minimum of three people; in case of an accident resulting in injury one person may leave to seek help while another person stays with the injured crew member.
- For each day in the field, specific location and scheduling information must be logged in advance with a point person who can be reached at any time during the anticipated duration of field work. While in the field, crews should check in with their designated point person once per day.
- Each independent crew must carry a radio, satellite phone or cell phone provided by the institution. Crews should make sure to check batteries each time before entering the field.
- Trip planning will include identification of the nearest medical facility and specific directions to reach that facility. When in areas with poisonous snakes, advance communication should be made to verify that appropriate antivenins are available. Where applicable, hunting regulations should be checked with local state agencies prior to field work.
- Personnel will carry personal and institutional insurance cards with them at all times. As well, personnel will carry identification and, if possible, institutional business cards at all times.
- Field crews will carry a first aid kit with them at all times. First aid kits should contain Epinephrin/Adrenalin or an antihistamine for allergic reactions (e.g. bee/wasp stings). Sun block and insect repellent should be carried in the field.
- Where poisonous snakes are common, snake chaps are recommended. In the event of snake bite, the victim should be taken immediately to a medical facility. Conventional “snake bite kits” (e.g. suction cups, razors) have been proven ineffective or even harmful and should not be used.
- Basic field clothing should be appropriate for the range of field conditions likely to be encountered. This will include: sturdy boots with good ankle support or rubber boots, long sleeves and pants, rain gear, and gloves. Blaze orange (vest or hat) is recommended when and where hunting may be taking place. Where necessary, to avoid extended contact with plant oils, ticks, and/or chiggers, a change of clothes should be made at the end of each day in the field and field clothes should not be reworn without first laundering.
- Ensure personnel stay sufficiently hydrated and carry enough clean water for the intended activity. Carry iodine tablets or other water purification tablets in case there is a need to use water from an unpurified source.
- Heightened caution should be given while operating any motor vehicle, particularly on backcountry roads where conditions are unreliable and rights-of-way are often not designated or adhered to. ATVs should always be operated at low speeds (<15 mph).
- Some plots may be too hazardous to sample. Situations include: plot center on a slope too steep to safely collect data (i.e., >100% slope or on a cliff); presence of bees; volcanic activity; illegal activities; etc. When hazardous situations arise, a discussion should be conducted among the team members to assess the situation.

SOP Labeling Plots

The following provides recommendations on how plots should be labeled. However, this SOP must be altered and provide explicit instructions on how each plot will be labeled for a given field measurement campaign.

Proper plot labeling is important because it provides a unique signature to sampled plots as well as information about the sampling conducted. Experience has shown that plots should be named with multiple characters defining the type of sampling conducted, the area, the number of the plot and any other relevant information.

All plots must be numbered with a unique name and number. The labeling system must be finalized prior to data collection. The character denoting the number of the plot should include at least as many digits as total numbers of plots expected to be sampled. In other words, if the number of plots is expected to be greater than 100 but less than 1000, the number characters must be at least three integers eg 001 to 999.

The following is an example of a recommended plot labeling format: number/letter/number/three numbers.

- The first number indicates the parcel or location number.
- The letter is one letter that describes the strata. It is recommended that all strata be given a unique letter before the field phase starts, and that the letter best describes the strata. For example, use Y for young secondary, V for very young secondary, M for mid-secondary, P for pasture, R for regenerating, T for tall evergreen etc.
- The next number is a unique number to correspond to the same stratum– 1, 2, 3, 4 etc.
- The last three numbers identify the specific plot within the strata and project area.

All plots must be numbered uniquely after the first number for the stratum. For example, if all plots in stratum 1 are numbered 1001 through 1020, then plots in stratum 2 are numbered 2021 onwards; if all plots in stratum 2 are numbered through 2104, then plots in stratum 3 are numbered starting with 3105, etc. The reason for this is that if after the field phase a plot is found to be in the wrong stratum, the letter and stratum number can be changed but the plot will still have a unique number based on the last three digits.

An example of plot numbers are:

7-Y1-001 (location 7, Young secondary, strata number 1, plot 001)

7-D4-125 (location 7, Degraded mature, strata number 4, plot 125).

SOP Quality Assurance/Quality Control

Those responsible for aspects of data collection and analysis should be fully trained in all aspects of the field data collection and data analyses. Standard operating procedures should be followed rigidly to ensure accurate measurement and remeasurement. It is highly recommended that a verification document be produced and filed with the field measurement and calculation documents that show that QA/QC steps have been followed.

Quality Assurance

Data collection in field:

During all data collection in the field, the crew member responsible for recording must repeat all measurements called by the crew member conducting the measurement. This is to ensure the measurement call was acknowledged and that proper number is recorded on the data sheet. In addition, all data sheets should include a 'Data recorded by' field with the name of the crew member responsible for recording data. If any confusion exists, the transcribers will know which crew member to contact.

After data is collected at each plot and before the crew leaves the plot, the crew leader shall double check to make sure that all data are correctly and completely filled. The crew leader must ensure the data recorded matches with field conditions, for instance, by verifying the number of trees recorded.

Data sheet checks:

At the end of each day all data sheets must be checked by team leaders to ensure that all the relevant information was collected. If for some reason there is some information that seems odd or is missing, mistakes can be corrected the following day. Once this is verified and potential mistakes checked, corrected data sheets shall be handed over to the person responsible for their safe keeping while the crew is still in the field. Data sheets shall be stored in a dry and safe place while in the field. After data sheets have been validated by crew leaders, the data entry process can commence.

Field data collection Hot Checks:

After the training of field crews has been completed, observations of each field crew and each crew member should be made. A lead coordinator shall observe each field crew member during data collection of a field plot to verify measurement processes and correct any errors in techniques. It is recommended that the crew chiefs switch to a different crew to ensure data collection procedures are consistent across all field crews. Any errors or misunderstandings should be explained and corrected. These types of checks should be repeated throughout the field measurement campaign to make sure incorrect measurement techniques have not started to take place.

Data Entry checks:

To ensure that data is entered correctly, the person entering data (whether during fieldwork or after a return to the office) will recheck all of the data entered and compare it with the original hard copy data sheet before entering another sheet. It is advised that field crew leaders either enter the data, or participate in the data entry process. Crew leaders have a good understanding of the field sites visited, and can provide insightful assistance regarding potential unusual situations identified in data sheets. Communication between all personnel involved in measuring and analyzing data should be used to resolve any apparent anomalies before final analysis of the monitoring data can be completed. If there are any problems with the plot data (that cannot be resolved), the plot should not be used in the analysis.

Quality Control

Field measurement error estimation

A second type of field check is used to quantify the amount of error due to field measurement techniques. To implement this type of check, a complete remeasurement of a number of plots by people other than the original field crews is performed. This auditing crew should be experienced in forest measurement and highly attentive to detail. A total of 10% of plots (or clusters if clustered plots are used) should be randomly or systematically chosen to be remeasured. Where clustered plots are used, all plots within a selected cluster shall be

measured. All trees shall be remeasured in each plot. Field crews taking measurements should not be aware of which plots will be remeasured whenever possible.

After remeasurement, data analysis is conducted and biomass estimates are compared with estimates from the original data. Any errors discovered could be expressed as a percentage of all plots that have been rechecked to provide an estimate of the measurement error.

For all the verified plots:

$$\text{Measurement Error (\%)} = \left| \frac{(\text{t C/ha of measured plot} - \text{t C/ha of remeasured plot})}{\text{t C/ha of remeasured plot}} \text{ x } 100 \right|$$

This error level will be included in the carbon stock reporting.

Data Entry quality control check:

After all data has been entered into computer file(s), a random check shall be conducted. Sheets shall be selected randomly for re-checks and compared with data entered. Ten percent of all data sheets shall be checked for consistency and accuracy in data entry. Other techniques such as data sorting and verification of resulting estimates shall be employed to ensure data entered properly corresponds to field sites visited. Personnel experienced in data entry and analysis will be able to identify errors especially oddly large or small numbers. Errors can be reduced if the entered data is reviewed using expert judgment and, if necessary, through comparison with independent data.

QA/QC of Laboratory Measurements

Standard operating procedures (SOPs) should be created and rigorously followed for each part of all laboratory analyses. All instruments should be calibrated.

For example, all combustion instruments for measuring total C or C forms should be calibrated using commercially-available certified C standards. SOPs should include steps to calibrate and check analyses. Blanks can be analyzed, or analytical runs can include a check sample of known C concentration. One standard per batch/run should be included in the samples sent to a remote lab as an additional check of the quality of the instruments and lab procedures.

All balances for measuring dry weights should be calibrated against known weights. Where possible, 10-20 % of samples could be reanalyzed/reweighed to produce an error estimate.

SOP Data Storage and Archiving

Field equipment
Field log book/electronic field log book
Laptop computer
Desktop computer
External data storage (harddrive, cloud, usb)
Connection to network server
Scanner

This SOP describes the methods for storing and archiving data in a simple yet safe and retractable way, so data can be accessed whenever necessary. Data storage and archiving is a very important and final component of the data collection process. The basic framework involving data storage and archiving follows.



Data storage in the field

In the field one person is responsible for storing and keeping the field data sheets; this person can also be the person who also validates the data on the sheets and is one of the team leaders.

If the data entry process is being done or started in the field, these sheets will be used after which they must be returned to the person responsible for their safe keeping. These sheets are stored in a dry and safe place where they cannot be tampered with until they are transported to the office.

Data storage in the Office

In the office, all original field data sheets shall be scanned and compiled into a document to be stored electronically. This avoids any changes to be made to the original sheets.

Hard copy

The original data sheets are photocopied and are kept in separate location. The data sheets are placed in a special jacket folder in the filing cabinet with the location name and date written on the label. Inside of these jackets there are folders with the different types of data collected (Biomass, Logging, Skid trails,Roads and

Decks, Regrowth, Wood Density etc.). After all data has been entered into a digital format and SOP QA/QC completed, the two sets of data sheets are then stored in secure fireproof filing cabinets in two separate locations.

Soft Copy

The scanned data sheets are stored on a computer in the office, along with all tools with the entered data, including data entered in the field laptop. These data files are backed up on a server. Folders containing data and folders containing tools should be properly named and adequately organized. All digital data collected and compiled (photos, proposal and report for exercise) are also stored in the archive file on both the desktop in the office and on the server. On the server there are a few folders in which all data are placed as follows:

1. '*Field Data'*, in which sub folders are created and are named the same way (Location) as the hard copy folder so as to have a uniform filing system. In each sub folder there are two folders; pictures and scanned data sheets in which the respective information are placed;
2. '*Data Analysis*' in which all completed tools are placed after the data entry has been completed;
3. '*Template*' in which all tool templates and field data sheets used in the data analysis are placed;
4. '*Documents*' in which all documents related to the project are placed; and
5. '*Field Proposal & Report'* in which all field exercise proposals and report are placed.

Procedure for Data File Backup

Any file(s) that is updated during the data analysis will be backed up to a network server. This back up will be done daily on the office computer(s), and at the end of every week they **must** be saved on an external hard drive and the folder on the server which is specifically designated for this data storage.

Procedure for Compiling and Managing Field Log Book or Electronic Log Book

This log book will be both of an electronic form and of the traditional book keeping format (a book). Both log forms will be updated simultaneously and twice for each field venture, before and after each trip. Log books will be used for recording the logistics of the field exercise, and providing explanation about field campaigns (e.g. date of departure to the field and date of returning, number of plots, location, field crew, challenges etc.). Each field campaign will be given a unique reference number and each report will also be given a reference number related to that of the campaign. This is to facilitate cross referencing processes.

Upon returning to the office after field records are entered, the log books will be stored in a secure filing cabinet or placed on the network server via desktop computers respectively, after being updated. Upon the completion of field reports of which each report will be given a unique reference number, the log books will be revisited and the report number will be inserted for future references.

It is important to restrict access to log books and information only to users, as they alone are responsible for making changes.

SOP Calibration of Haglöf DME 201 Cruiser

This equipment may be used to establish the boundaries of permanent or temporary circular plots. Please see the SOP Plot Design for more information. The Haglöf Distance Measuring Equipment (DME) 201 Cruiser[1] contains two components: the measuring unit and the transponder. The DME uses ultrasound waves to calculate distance between the measuring unit and the transponder. However, the speed that sound waves travel through air is slightly influenced by humidity and temperature. If the DME is being used in a desert the sound waves will travel slightly faster than in a tropical humid environment. Therefore it is important to calibrate the device prior to data collection in each plot.

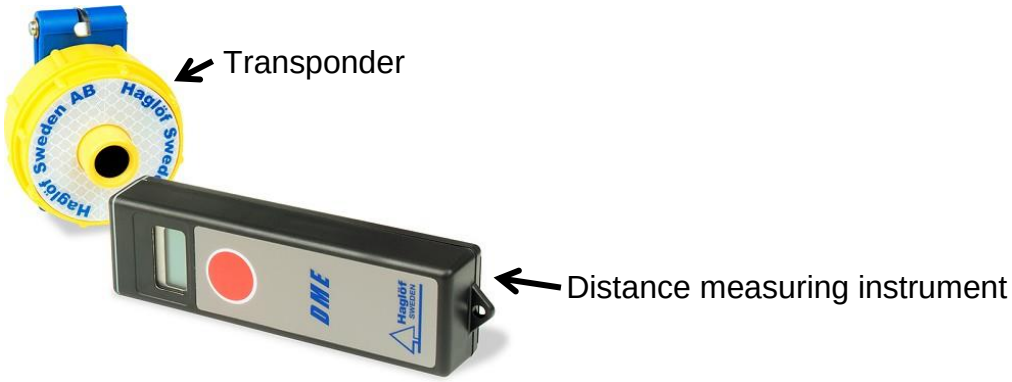


Figure: Haglöf DME 201 Cruiser

(photo source: http://www.forestry-suppliers.com/product_pages/View_Catalog_Page.asp?mi=1378&title=Hagl%F6f+DME+201+Cruiser)

1) Before the crew arrives in the field, the crew chief should have already taken the measuring instrument (grey rectangular box) out of the box. This instrument needs a minimum of 10 minutes to adjust to local temperature conditions. Therefore it should not be in its box or in someone's pocket immediately prior to use. It needs to be in contact with the open air for at least 10 minutes before it is used, if not, it can cause inaccurate readings. It is allowable for this instrument to be carried using a neck strap.
2) After the DME has had a chance to adjust to local temperature and humidity conditions, it is ready to be calibrated. One person should hold the transponder in their hand while the crew chief takes the measuring instrument and a measuring tape and proceeds to a clear point 10 m away. The measuring tape should be pulled tight and should not be draped on the ground. The measuring tape and the transponder and measuring instrument must be parallel to each other.
3) The crew chief should hold the measuring instrument in one hand and the end of the measuring tape in the other. The second person at the other end of the tape should do the same with the transponder. The crew chief should then point the measuring unit at the transponder and press the red button nine times. Hold the measuring unit very still until 10 m is displayed on the screen. If it does not, repeat.
4) The DME can display in metric or English units, i.e. feet or meters, make sure for field work that the DME is set to measure in meters. To change the DME to display in meters or feet click the red button on the measuring unit five times. Meters display with two decimal places but only one decimal place when it is set for feet.
5) Place the transponder on the tripod so that it is placed directly over the plot center.

[1] For example: www.forestry-suppliers.com

SOP Use of a clinometer:

A clinometer is a piece of equipment used to measure angles. This equipment is widely used in the field for multiple reasons, among them: measuring slope of the terrain, and measuring tree height. Usually a clinometer has two sets of units for measuring angles:

Right side: percent (%)

Left side: degrees

The Clinometer will indicate the units. For example, if using a Suunto® Clinometer, look into the clinometer and tilt your head back to look all the way up. The right side will say %.

To measure an angle using a clinometer:

1. Holding the clinometer string, bring it up to your dominant eye (the string on the clinometer should be below the eye piece, stretching downward)
2. Keep both eyes open and simultaneously aim at the object you want to measure in the distance and look at the numbers through the clinometer
3. Record the % or degrees at the point that crosses what you are measuring.

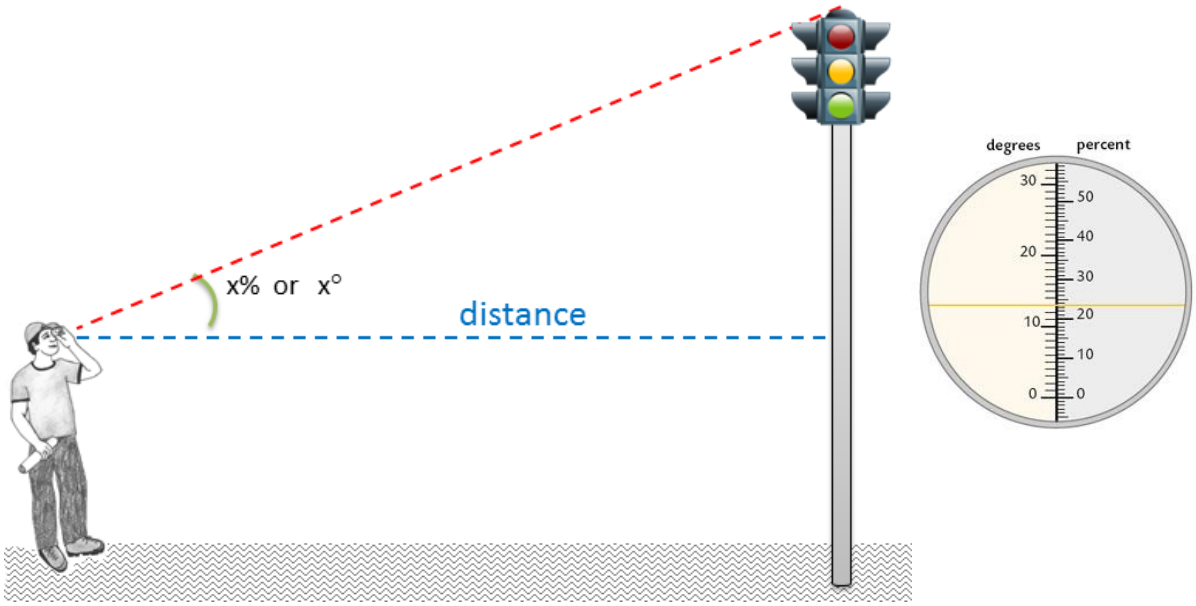


Figure: Measuring angle degrees or % using clinometer

SOP Measurement of Height

Field equipment:

Clinometer
Laser Range Finder or >50m measuring tape
Relascope (optional)

The height of trees, palms, and other things is usually done by creating two right triangles. The distance from the object and the person measuring is measured and two angles are measured. The actual height is then calculated using trigonometry during data analysis.

1. Walk around the tree and find the best location to view the top of the tree.
2. Stand far enough away from the tree so that the top of the tree is less than 90 degrees above the line of sight.
3. Measure total tree height (see Figure below):
    a. Always stand up-slope of the tree. Standing down-slope of the tree should only take place when no other option exists.
    b. Using clinometer, measure the angle in % to top of the canopy of the tree (a%)
    c. Using clinometer, measure the angle in % to base of the tree (b%)
    d. Using Laser Range Finder or measuring tape, measure distance from eye of person measuring tree to the tree (dis_{tree}) in meters. Be certain that the distance measured is horizontal and not along the slope. Record the horizontal distance to the nearest 0.01 meter
4. Repeat measurements in another location, thus measuring tree height in two locations.
5. If you are not able to stand far enough from the tree so that the top of the tree is less than 90% above you, then take the measurements (a) and (b) in degrees (units on left side of clinometer). CAREFULLY NOTE ON THE DATA SHEET THE CHANGE IN UNITS! Tree height must be calculated differently if degrees are used!

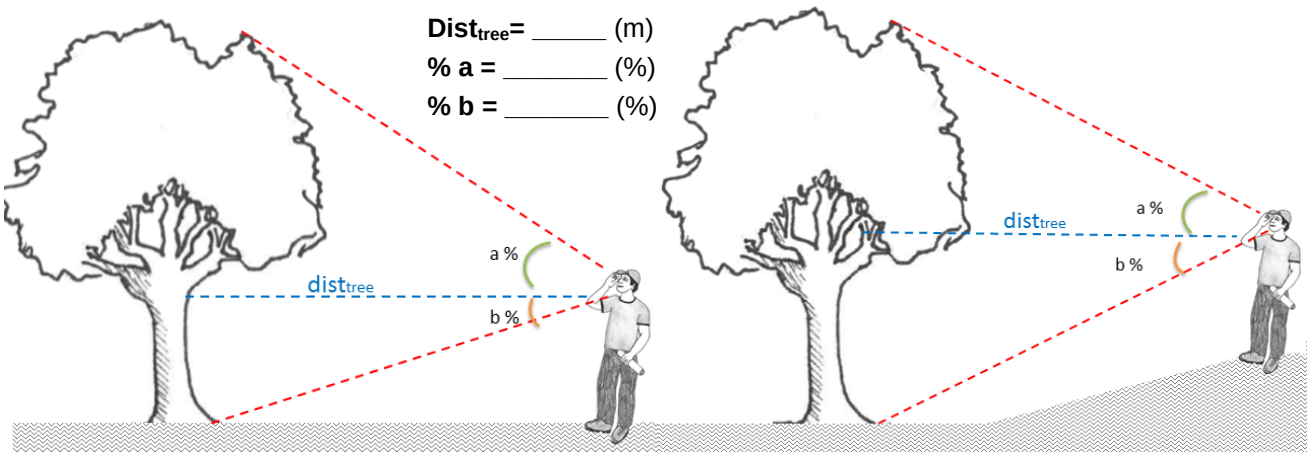


Figure Tree height field measurements

STOCKS OF CARBON POOLS SOPS:

The following set of SOPs can be used to establish plots to estimate the standing carbon stock of the various carbon pools. These SOPs will need to be altered based on the specific methods used by the field campaign.

SOP Stratification, Sampling Design and Layout
SOP Establishment of Plots
SOP Measurement of Trees
SOP Measurement of Palms, Lianas, and Bamboo
SOP Measurement of Non-tree Woody Vegetation
SOP Measurement of Non-woody Vegetation (herbaceous)
SOP Measurement of Litter Layer
SOP Sampling Soil Carbon
SOP Measurement of Standing Dead Wood
SOP Measurement of Lying Dead Wood

SOP Measurement and Estimation of Dead Wood Density Classes
SOP Destructive Sampling of trees, saplings, palms, bamboo, and Non-tree woody vegetation

SOP STRATIFICATION, SAMPLING DESIGN AND LAYOUT

This SOP describes the methods to determine the locations where sampling will take place along with the sampling layout and shape of sampling plots for all vegetation types and carbon pools. This SOP must be implemented prior to field data collection and requires operations in a GIS environment.

The sampling design must address where sampling will be conducted, how it will be carried out, and what elements will be sampled. These items are addressed below, with initial recommendations for how best to address each item.

Stratification

Due to the spatial variability of land-use change drivers as well as the spatial variability of forest carbon stocks, **a stratified sampling design** is often useful in a forest carbon sampling design. Stratification of forest land can reduce sampling effort while maintaining accuracy and precision in estimates of carbon stocks.

The goal of stratification is to reduce within stratum variance and improve the precision of each stratum, thereby minimizing the number of samples required to achieve an overall level of certainty. A stratified sampling design also allows flexibility in designing a sampling protocol within each stratum that is tailored to the desired level of precision (targeted at a 90% confidence interval with a half width equivalent to ±10% of the mean) as well as the time and resources available to collect the data. For instance, if there are certain areas that are unlikely to experience change in the next ten years, it may be appropriate to reduce sampling in those areas relative to sampling conducted in areas more likely to experience change.

Potential criteria to be used in determining strata include:

- Forest type/species composition
- Land use and past management practices
- Age of vegetation
- Slope
- Precipitation and drainage
- Elevation
- Proximity to urbanization

Existing data can be used to identify and divide sampling units into relatively homogenous strata with regard to the factor of interest. Land within each stratum should be similar with respect to carbon stocks, with different strata having different carbon stocking. Each stratum may be comprised of one large block of land or several small blocks of land, provided that all of the blocks are similar with respect to carbon stocks.

Prior to implementing this approach, the strata must have been chosen and a separate GIS shapefile created for each stratum. In addition, the minimum mapping unit must also have been determined and all locations within all forest land cover layers must meet the definition of a forest (e.g. all forest polygons must meet the definition of a forest).

This SOP must be repeated for *each* stratum separately.

Determine Sampling Locations using stratified two-stage sampling.

For the estimation of carbon stocks in the tree, non-tree woody, non-woody vegetation, and deadwood pools, sampling should take place across a stratum in an unbiased way. Sampling layout and the design for determining sampling locations can differ for each stratum, however, the below approach is recommended for most forest stratum. The following method should be implemented for one stratum at a time.

This sampling design consists of selecting **primary sampling units (PSUs)** at the first stage and then selecting **secondary sampling units** (**SSUs)** at the second stage of sampling. The approach described ensures that any location has an equal probability of being sampled. The initial sampling units are chosen by using a systematic sampling with a random start approach. A ‘grid’ is placed across the area to be sampled in a randomly selected orientation. The grid cells will then serve as the ‘primary sampling unit’ (PSUs). Once the PSUs are chosen, a particular location within the PSU is randomly chosen to initiate field sampling. This is referred here to as the SSU1.

Thus, the definition of these terms is:

- **PSU-grid** cell: an individual grid cell of a known and defined size (e.g. 5 x 5 km square) within the grid that has been superimposed across the area to be sampled. PSU-grid cell is given a unique ID. This ID number will then be used within the identification of a PSU.

- **PSU$_i$** – this is the spatial extent of the stratum *i* within a given PSU-grid cell. The label of the PSU shall correspond to the PSU-grid ID and include stratum notation (here denoted as *i*).
- **SSU1$_i$** – this is a point, representing the starting point of the sampling at this location. The SSU1$_i$ is located within selected PSU$_i$.

Methods and Procedures

The following steps 2 to 4 to implement two-stage list sampling design shall be repeated for each stratum separately. The entire gridded area shall be used to determine selected PSUs for each stratum and thus each PSU-grid cell shall have an equal probability to be selected during the list sampling selection for all stratum. (If one PSU-grid happens to be selected for both strata A and B, this is allowable. There will then a PSU$_A$ for stratum A and a PSU$_B$ for stratum B, and thus two SSU points located within the boundary of this PSU, one for stratum A and one for stratum B.)

First, the size of the grids needs to be defined (Figure 1). The size of the grid cells takes into consideration other field surveys that may occur in the population of interest. The PSU-grid cell size shall be small enough so that a sufficient quantity of PSU-grid cells will be available for sampling yet large enough to ensure both that the field cluster plot design can fit within a PSU selected and that sample plots are well distributed across the landscape.

Step 0: Create inaccessible area

To create inaccessible area as a mask for hiding features by using following conditions.

• Areas with slope >65%

• Scrub / Forest areas under 2 ha completely surrounded by the land class ‘barren land and rock’

STEP 1: Create PSU-grid (3 x 3 km)

To create a PSU-grid across the area to be sampled, a 3km x 3km grid polygon shape file needs to be created in ArcGIS through function of “Create Fishnet”. Each square of the grid should be considered a “PSU” The shape file has a unique identification number (ID) for each PSU-grid (PSU_ ID).

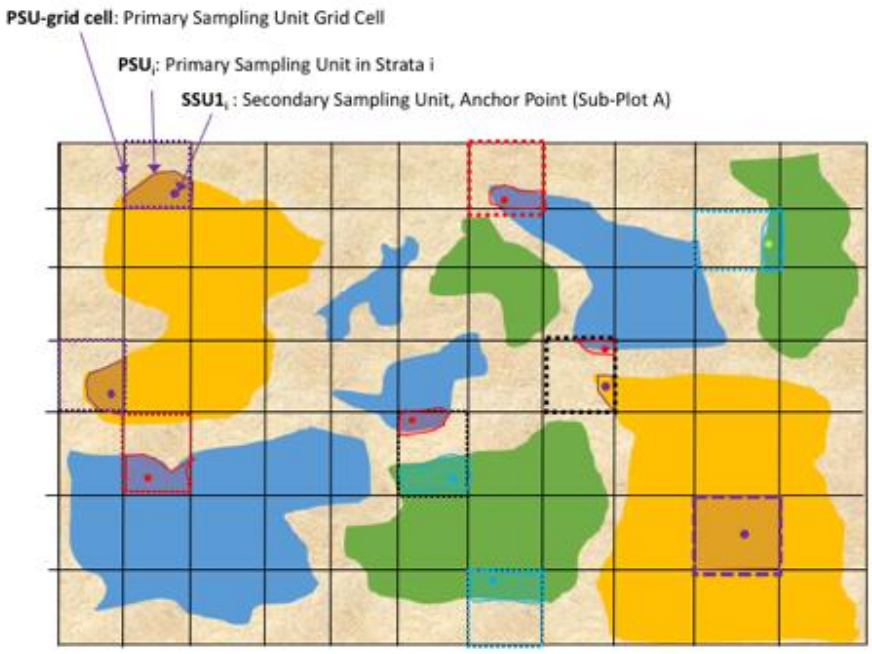


Figure 1: Example of selected PSU-grids in dashed lines and selected PSUs (polygons) with SSUs (dots) assigned within. Note, some PSU-grids may randomly be selected for two different stratum.

STEP 2: Create a list of PSUs for the stratum of interest

To create PSU$_i$s for each stratum, use Intersect function in ArcGIS to combine the PSU-grid shapefile with the stratum shapefile. Next calculate the area of each PSU$_i$ for each stratum in ArcGIS. If the area of the PSU$_i$ is less than the minimum area of the forest definition, exclude that PSU$_i$ in the two stage list sampling procedure

(The reason for this is that we are respecting the minimum threshold area for defining forest, thus only PSUs with area greater than such threshold should be included in the PSUs grid list.). A list of all PSUs should be created and the attribute table exported as DBF table, maintaining record of PSU_i_ID and area in hectares.

STEP 3: Select PSUs with probability proportional to size

To ensure all locations within a stratum have an equal probability of being measured, the probability that a given PSU_i will be selected must be made proportional to its area. To select PSU_is with probability proportional to their size, use the list of PSUs from Step 2 and calculate the cumulative area of each stratum associated with each PSU. Cumulative area is defined as sum of all PSUs in the list up to and including the PSU itself. Once the cumulative areas are calculated, a random number between the smallest and the largest cumulative area should be generated. To select a PSU for forest sampling, the random number should be less than PSU's cumulative area and larger than the cumulative area for the previous PSU in the list.

All of the operations conducted in Excel are explained below:

1. After opening the DBF file in Excel, calculate the cumulative area for each PSU in a new column.
2. In the next column, create a list of random numbers between the minimum and maximum cumulative area of the PSUs grid list shall be generated created using following formula:
   =RAND ()*(B - A) + A

Where:

B is the maximum cumulative area, and

A is the minimum cumulative area for the list of PSUs

Once the random numbers have been created, convert the formula in each cell into a number to prevent new random numbers from being generated.

To select a PSU_i for sampling, the random number should be compared to the cumulative PSU area. The PSU_i shall be selected when the random number is smaller than the PSU cumulative area and greater than the previous PSU in the list cumulative area.

For example, if the random number is 26,446.42 and the cumulative area for PSU_i with ID=1151 is 32,689.23 ha and the cumulative area for the previous PSU is equal to 22,758.71 ha, the PSU ID=1151 will be selected, because 26,446.42 (random number) < 32,689.23 (PSU_i cumulative area) and 26,446.42>22758.71 (cumulative area of the previous PSU in the list)

A table of selected PSU_is following the order of random number generated shall be created containing information on PSU ID, PSU_i area, PSU_i cumulative area, the order of the generated random number and random number itself.

STEP 4: Assign secondary sampling unit ($SSU_{n,i}$)

The table of selected PSUs in Excel shall be imported to ArcGIS and joined to the stratum PSUs shapefile to identify the selected PSUs. Generate a random point which will serve as the $SSU_{n,i}$.

STEP 5: Create two potential sampling location points

In the remaining area, use GIS software to generate 1 point in association with the $SSU_{n,i}$. One additional point shall be randomly placed within 1000 m of the $SSU_{n,i}$ and must be within the same stratum. They shall be allocated as 'primary' and 'backup' options for field sampling locations. Field crews will first navigate to the 'primary' option. If this point is not suitable for sampling because it does not fulfill the criteria described in SOP Establishment of Sampling Plots, then the 'backup' option will be used as the sampling location. For the point chosen for sampling, this will serve as the 'Anchor Point' for that sampling point.

Sampling Layout

Sampling Point Layout

Once the location of each sampling unit is chosen, the layout of sampling for each of the pools will need to be determined. Sampling can take place within one area per sampling point or sampling can take place at within multiple areas associated with each other per sampling point. This is often referred to as clustered sampling. The clustering multiple subplots together at one sampling unit allows field crews to sample a larger area per

sampling point. Clustering of subplots at each sampling unit is recommended for natural forest areas and especially areas that have been selectively logged. Single-plots will be sufficient for stratum where the distribution of trees and the size classes of trees is expected to be relatively uniform and the whole area of interest is relatively accessible. For example, single plots are often used for measurements in areas where afforestation/reforestation is taking place.

Please note: this standard operating guidance is designed to be applicable to sampling approaches using both single plots and a cluster of subplots, therefore, in the following text, the term 'plot' is often used. However, where sampling is conducted using a clustered design, the sampling unit is the 'cluster-plot' and therefore each of the smaller areas sampled are actually subplots.

Single Plot Distribution

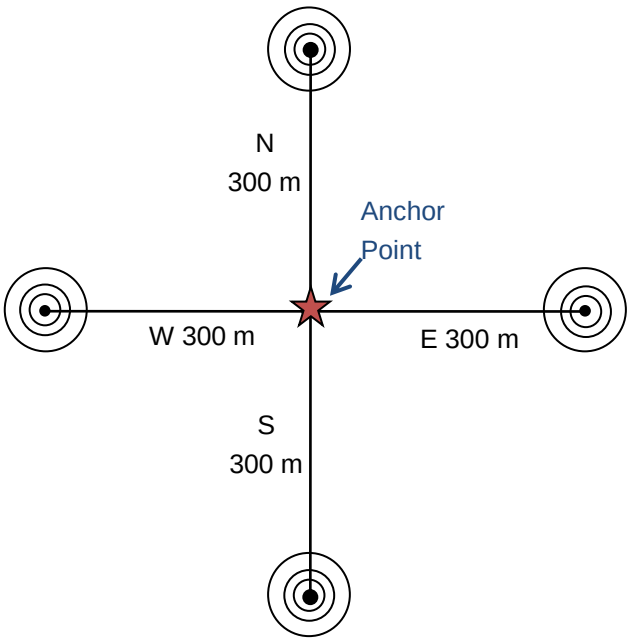
At each latitude/longitude sampling location determined prior to field data collection, one tree plot may be established. Once at the initial coordinates, to establish the plot center, walk an additional 10 steps in the direction of travel. This point shall be the plot center. These additional steps reduce bias in choosing the plot center.

Cluster-plot Distribution

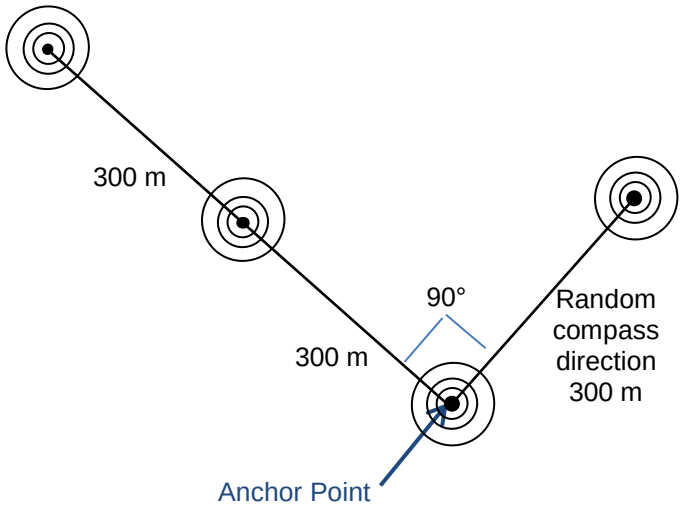
If a cluster of subplots will be sampled for each sampling location, then all subplots within a cluster-plot must be within the same land cover stratum. Subplot labels must include cluster number and subplot number. Carbon stock calculation methods specific for clustered plots must be used.

To establish the Cluster center – referred to here as the Anchor Point, navigate to the initial latitude/longitude coordinates determined prior to field data collection, then walk an additional 10 steps in the direction of travel. This point will be the Anchor Point.. These additional steps reduce bias in choosing the Anchor Point.

Different cluster designs may be used. Two static options for tree biomass are presented in the Figure below. These are recommended for areas with large contiguous forest areas where it is very likely that all subplots will fall within the same stratum. Recommendations on the sampling layout for other vegetation types and carbon pools (bamboo, lianas, palms, non-tree woody, herbaceous, deadwood, litter, soil) are presented within the SOP for that vegetation/soil type.



Layout a. For each Cluster, four subplots are established at each of the cardinal points. The plot center is established 300 m away from the Cluster center



Layout b. For each Cluster, four subplots are established. At anchor point, one subplot is established. A random compass point is chosen to determine the direction of the plot on the short arm of the L. The other plots are located on the long arm of the L set at 90° to the short arm.

Figure: Examples of layouts of one Cluster-lot of four tree subplots

For extremely fragmented stratum, a 'floating cluster nested tree plot design' is recommended. This is described below. For each stratum, all sampling will take place in association with the Anchor Point. For live trees, dead trees, and bamboo, sampling will use a 'floating' clustered design with four nested tree-plots. Where sampling for non-tree pools will be included, lying dead wood and clip-plot measurements (square boxes) shall be conducted for each plot. Sampling locations for these pools is described below. In the 'floating' cluster nested tree-plot design, all sampling at each sampling point takes place only in locations under the same stratum. The location of the 'anchor point' and of each nested tree-plots is determined prior to field sampling and in a GIS environment. Due to the highly fragmented landscape and the terrain causing some locations to require significant time to access, a set of four potential subplot locations are chosen in GIS. In GIS, for a given stratum an Anchor Point is placed using the two-staged sampling design described above. The first tree-plot center (tree-plot A) is then placed on this Anchor Point. Three additional points (B, C, D) are then randomly placed within the given stratum within a 300 m radius of the Anchor Point, but no closer than 50 m from each other, the Anchor point, or the edge of the stratum to avoid overlap between tree-plots and tree-plots spanning more than one stratum. These serve as the center of four potential tree-plots.

When crews are in the field and have reached the anchor point, based on the accessibility of the tree-plots, the field teams will select which three additional points will serve as the tree-plots. See SOP establishment of Sampling Plots for more details.

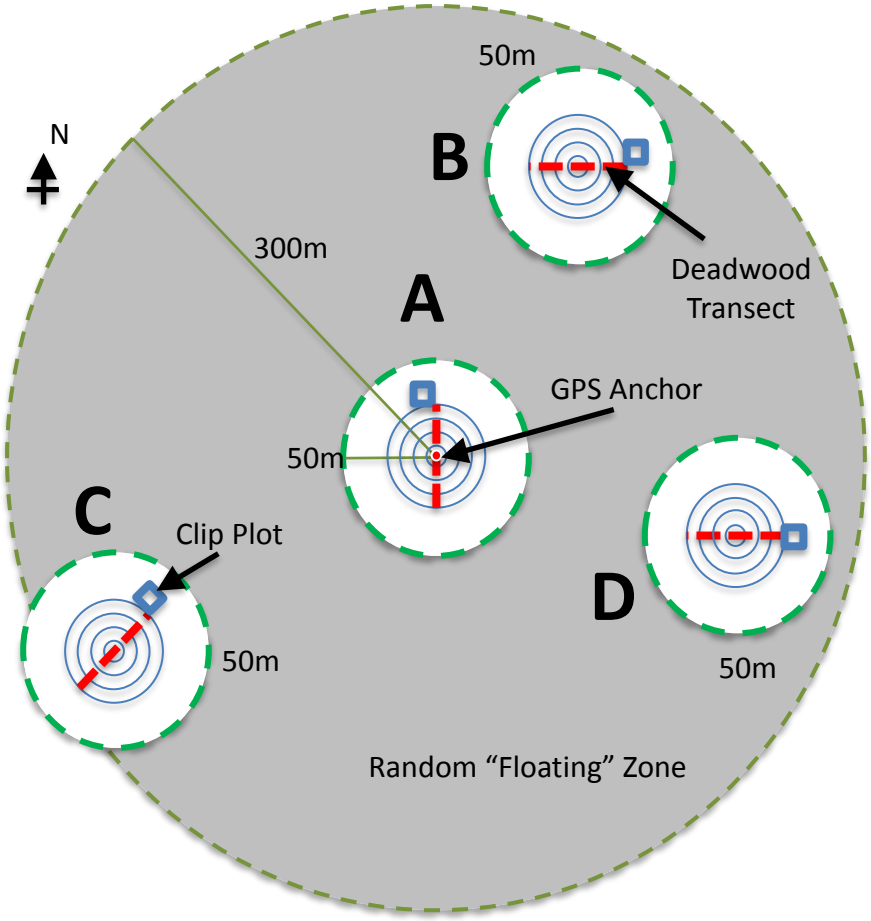


Figure 2: A "floating" cluster plot with a fixed center subplot. Red lines represent 40 m lying deadwood transects while blue boxes represent clip plots

Determining the size and shape of tree plots and subplots

The size and shape of the area to be sampled to estimate tree biomass is a trade-off between accuracy, precision, time, and cost for measurement. The most appropriate size and shape may also be dependent on the vegetation type found in the sampling area.

Tree Plot Shape

Plots can be circles, squares, or rectangles. Experience has shown that circular plots are more efficient because the actual boundary around the plot does not need not to be marked. The use of distance measuring equipment (e.g. the DME, Haglöf, Sweden) is the most recommended method for the establishment of circular plots. Although the initial investment may seem high, experience has shown that this method is time efficient and results in low levels of field measurement errors.

Alternatively, the plot boundaries of a circular plot can also be delineated using rope/cord of length(s) equal to the radius of the plot (this method can only be used where area corrections for slope are performed during data analysis. See SOP Establishment of Tree Plots). Square or rectangular-shaped plots can also be efficiently laid out with tape measures and stakes.

Where rope or other materials are used to measure plot boundaries, extreme care must be taken to ensure the rope length is equal to the measurement required. Such rope should be measured repeatedly as many types of rope will lengthen or contract over time and under various field conditions, such as when wet.

Nested Tree Plots

Experience has shown that sample tree plots containing smaller sub-units varying in size (nested tree plots) are cost efficient and scientifically robust for most vegetation types with trees. Nested plots are composed of several plots (typically 2 to 4, depending upon forest structure) plots and each plot in the nest should be viewed as being a separate plot. The tree plots could take the form of nested circles or nested

squares/rectangles. In systems with low structural variation, such as single species, even-aged plantations, or in areas where trees do not exist, a single plot can be effectively used.

In each tree plot within a nest of plots, trees representing different diameter classes are measured. When trees attain the minimum size for one of the nested plots they are measured and included, and when they exceed the maximum size, measurement of that tree in that nest stops and begins in the next larger plot of the nest. See Table 1 for an example.

Tree Plot and Nest Size

It is possible to calculate the appropriate tree plot size specifically for each project; however, this adds an additional complication and an additional effort to the process. See Pearson, TRH, Brown, S, and Ravindranath, NH. 2005. *Integrating carbon benefit estimates into GEF projects*.

For simplicity, tree plot size rules are presented below that can be applied to forest types that include mature trees and where dbh will be measured (Figures below). Experience has shown that these plot sizes represent a reasonable balance of effort and precision. However, prior to initiation of plot measurement, it is recommended that limited sampling take place to determine the size of the largest trees. In a land cover stratum with few trees greater than 50 cm dbh, the minimum stem diameter measured within the largest nest may need to be adapted. For non-forest, savanna, and woodland strata, nest plot sizes and stem diameter sizes will need to be delineated.

If instead of nested plots, a single plot size is used then the plot size should be large enough that at least 8-10 trees per plot will be measured within the plot boundaries at the end of the project activity. Therefore, where afforestation is taking place substantially more than 8-10 trees will be measured per plot at the start of the project activity.

The actual plot sizes and tree diameter sizes used for each nest must be determined prior to the initiation of field measurements. This SOP must be altered to state the plot sizes and tree sizes that will be measured.

Table:Example tree stem diameter classes and nested plot sizes

Stem diameter	Circular plot radius	Square plot	
		side lengths	diagonal length
†Saplings	2 m	3 m x 3 m	4.2 m
5 – 20 cm dbh	6 m	7 m x 7 m	9.9 m
20 – 50 cm dbh	14 m	25 m x 25 m	35.3 m
> 50 cm dbh	20 m	35 m x 35 m	49.5 m

† Saplings are defined as: stems <5 cm dbh, height >1.3 m

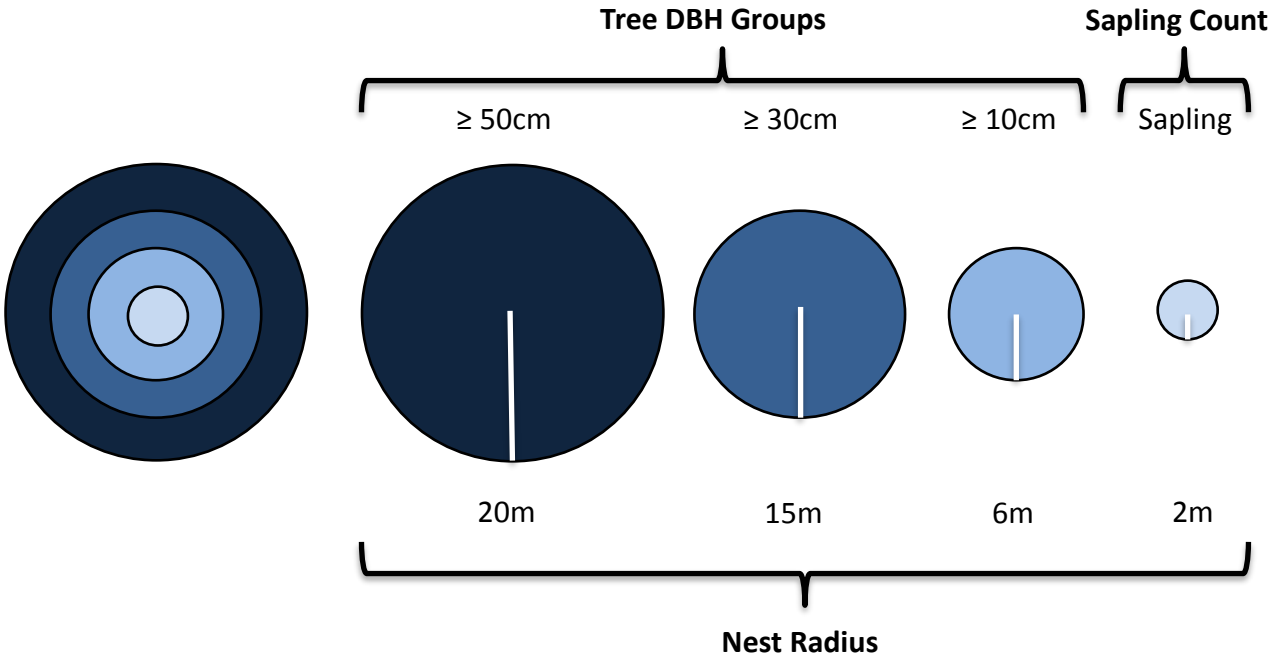


Figure: Schematic diagram of three-nest circular sampling plots (when slope <10% and size classes for each nest. Sapling defined as tree with height >1.3 m and DBH of <10 cm

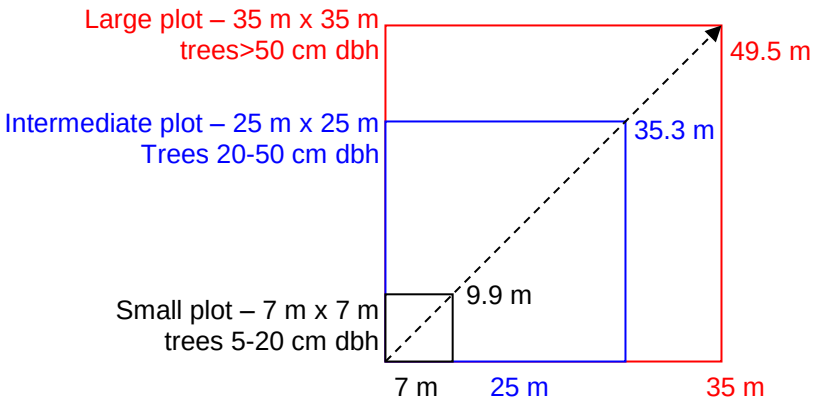


Figure: Schematic diagram of three-nest square sampling plots

Other vegetation and carbon pools

Each team will also measure standing and lying deadwood, non-tree vegetation in clip plots, and in clip plots. The location of sampling should follow the above sampling point layouts. Field measurement procedures should follow the relevant SOP.

SOP ESTABLISHMENT OF TREE PLOTS/SUBPLOTS

Required equipment:

All Tree Plots
GPS
Flagging tape
Rope
Clinometer (to measure slope)
>10 m measuring tape (to calibrate DME)

Circular Plots
Distance Measuring Equipment (DME)

Square/Rectangular Plots
Right Angle
Measuring tape
Rope
Stakes

Additional Items for Permanent Plots
Aluminum tags
Metal (usually iron) bar about 1-2 cm in diameter and 30 cm long
PVC tubing (1 m) and caps
Hammer
Fluorescent paint
Duct tape
Permanent marker

Prior to Field Sampling:

Based on SOP Sampling Layout, the location, size, and shape of the tree plots should be determined. In addition, the lat/long sampling unit locations that each team will navigate to should be uploaded to each team's GPS. Using a combination of spatial data such as land cover, elevation, roads, rivers, slope and local knowledge a plan shall be created on how plots will be located and the order in which plots measurements will take place.

Where a clustered-plot design will be used, each tree plot is actually a subplot within the cluster. However, since this guidance has been written to apply to both single and clustered designs, the term 'tree plot' will be used to refer to either a single tree plot OR a tree subplot within a cluster.

Establishing Anchor Point

When clustered sampling designs are used, the first step is to establish the anchor point. Each of the clusters are then established. If a single plot design is used, this step can be skipped.

Navigate to predetermined latitude and longitude of the primary sampling location using a GPS. Walk an additional 10 steps in the direction of travel. These additional steps reduce bias in choosing the anchor point. At the anchor point, mark a 'waypoint' on GPS and record GPS coordinates, accuracy, elevation, and waypoint number on data sheet or tablet. To record a GPS location, place the GPS at the plot center/corner and let it record for > 5 minutes prior to marking a 'waypoint'. The minimum precision level should be ±5 m. Leaving

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the GPS at one location for several minutes allows the GPS to get a more accurate location by averaging many location acquisitions. The longer the GPS acquires locations the more accurate the final location. The accuracy of the location is estimated and is displayed by the GPS. If there is heavy vegetation cover, it may take a longer time to acquire an accurate location. In some cases, it may be necessary to move slightly or devise a way of getting the GPS higher in the air to acquire satellite signals. For more information, see SOPs on the use of GPS and the manual of the GPS being used[2] .

Label the Anchor Point plot based on SOP Labeling Plots.

Establish Clustered Nested Tree-plots

As stated above, cluster plots can contain various numbers of nested tree-plots. The following assumes each cluster includes 4 circular nested tree-plots are sampled at each Sampling Location.

If an entire tree-plot would fall within the GIS allocated stratum at this location, then establish 'tree-plot A'. At the anchor point, evaluate the stratum at "**tree-plot A**". If an entire tree-plot would fall within the GIS allocated stratum at this location, then establish 'tree-plot A'.

If the GIS determined stratum is not the same as the stratum found on the ground at the Anchor Point, the sampling location shall be moved to 100m east from original Anchor point. If moved point is not still the same with GIS determined stratum, move to 100m south from original Anchor point. If the stratum is still incorrect after moving south, return to the Anchor and shift 100m west. Lastly, if the western point is still not in the correct stratum, make a final sift of 100m north.

If all 4 options (East, South, West and North) fall in an incorrect stratum than determined by the original GIS classification, then no sampling shall take place at "**tree-plot A**". The team leader should make an entry for "**sub-plot A**" on the datasheet or tablet, indicating the reason why the sub-plot was not installed. The team should move on to a different sub-plot sampling location.

For 'tree-plot B', and 'tree-plot C' this same procedure shall be repeated. If tree-plot A, B and C would fall in a different stratum than determined in GIS, then no sampling shall take place at this sampling location and it is not necessary to conduct 'tree-plot D'. At least two sub-plots must be the correct strata in order to justfy keeping the cluster plot for biomass calculation.

In summary, a few simple rules will help field teams understand and make field-based decisions during collection, these include:

1. If any sub plot observed in the field does not match with the correct strata of interest, the sub plot should be shifted 100m from the Anchor point until the correct strata is found.
2. Sub-plot shifting progression should be first East, then South, West and then North.
3. At least 2 sub-plots must be in the correct strata in order to keep the cluster plot. If sub-plots A, B and C are all incorrect strata, then the cluster plot can be abandoned.
4. Data entries must be made for all sub-plots, even if:
    - no data was collected,
    - a team did not go to the location,
    - access was impossible,
    - stratum was incorrect,

In the nested tree-plots, the following vegetation types will be sampled: Trees; Saplings; Standing Dead Trees and Bamboo. The methods for sampling each of these vegetation types in the subplots are described in the respective SOP.

The dimensions and vegetation types sampled in each nest is presented in SOP Sampling Design and Layout. Based on the Sampling Layout determined in SOP Sampling Design and Layout, walk to the subplot center point.

[2] If a Garmin GPS Map60 is being used, the following steps can be used: a) prior to saving new waypoint, press MENU. b) Highlight 'Average Location' and press ENTER. c) Let GPS sit for many minutes until 'Estimated Accuracy' stabilizes. d) press ENTER to save location. (see manuals at www.garmin.com for more information)

At the subplot center point, mark a 'waypoint' on GPS and record GPS coordinates, accuracy, elevation, and waypoint number on data sheet. To record a GPS location, place the GPS at the plot center/corner and let it record for > 5 minutes prior to marking a 'waypoint'. The minimum precision level should be ±5 m. Leaving the GPS at one location for several minutes allows the GPS to get a more accurate location by averaging many location acquisitions. The longer the GPS acquires locations the more accurate the final location. The accuracy of the location is estimated and is displayed by the GPS. If there is heavy vegetation cover, it may take a longer time to acquire an accurate location. In some cases, it may be necessary to move slightly or devise a way of getting the GPS higher in the air to acquire satellite signals. For more information, see SOPs on the use of GPS and the manual of the GPS being used[3] .

1. Label the subplot based on SOP Labeling Plots
2. Measure the slope using a clinometer following the 'SOP Use of a Clinometer and Measurement of Slope'. If the slope is greater than 10% record the exact slope.
3. Correct for the size of the tree-plot area to account for the slope. (see below 'Tree-plot Area correction'), record the sizes of each of the nests for that tree-plot on the data sheet and inform all crew members.
4. Describe land and vegetation conditions of plot and if there is anything unique or unusual in the plot or directly surrounding the plot. This could include things such as small streams, trails, large boulder or termite nest, and proximity to a paved road.
5. Mark center of the plot with wooden stake wrapped with flagging tape. This plot center mark will be used to identify the plot center during any third-party verification or quality checks.

A long lasting material stake shall be placed at the plot center in circular plots This will be used to facilitate verification of plot measurements where required.

When using Distance Measuring Equipment (DME) the only requirement is to place the DME stand in the center point of the plot. In areas with dense vegetation, it is recommended that a piece of bright colored flagging be placed on branches above the DME stand to increase visibility. Because the DME is essential for establishing circular plots, extra batteries should always be carried into the field. Alternatively, a rope/cord and/or a tape measure may be used to identify the boundary of circular plots. If a rope is used, the length of the rope must be measured prior to each plot establishment with a tape measure as many ropes are made out of material that stretches over time or when wet.

Temporary Plots

Where plots are temporary in nature, a long lasting material stake shall be placed at the plot center in circular plots and at each corner in square/rectangular plots. This will be used to facilitate verification of plot measurements where required.

Circular plots

When using Distance Measuring Equipment (DME) the only requirement is to place the DME stand in the center point of the plot. In areas with dense vegetation, it is recommended that a piece of bright colored flagging be placed on branches above the DME stand to increase visibility. Because the DME is essential for establishing circular plots, extra batteries should always be carried into the field. Alternatively, a rope/cord and/or a tape measure may be used to identify the boundary of circular plots. If a rope is used, the length of the rope must be measured prior to each plot establishment with a tape measure as many ropes are made out of material that stretches over time or when wet.

Square/Rectangular plots

a. With a stake, mark the GPS waypoint as the first corner.
b. Determine a random compass direction (Select random number using second hand on watch and multiply this number by six.). Using this compass direction, measure to second corner. Mark the corner for each nest with a stake. Return to first corner, using a right angle and a compass, measure to the opposite corner. Mark the corner for each nest with a stake. Returning to the first corner, use compass to measure out the length of the diagonal. Mark the final corner with a stake. Mark the corner for each

[3] If a Garmin GPS Map60 is being used, the following steps can be used: a) prior to saving new waypoint, press MENU. b) Highlight 'Average Location' and press ENTER. c) Let GPS sit for many minutes until 'Estimated Accuracy' stabilizes. d) press ENTER to save location. (see manuals at www.garmin.com for more information)

nest with a stake. (See figure below as example). If desired, rope marked with nest plot lengths can be repeatedly used for each plot. However, the length of the rope and markings should be checked daily to make sure the rope has not stretched.

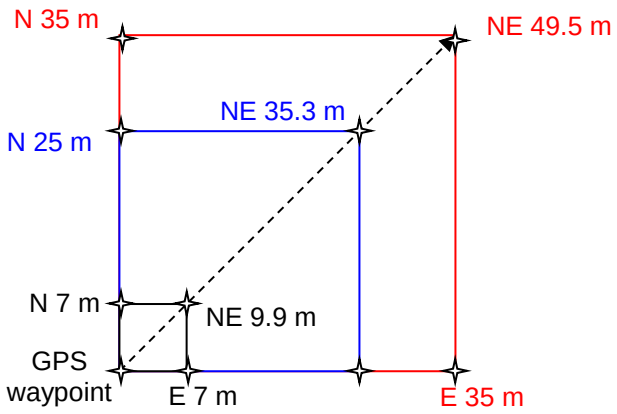


Figure: Schematic diagram of location of stakes in a nested square sampling plot

Permanent Plots

Permanent plots shall be marked using materials that will last longer than the project lifetime.

Circular plots

Recommended steps for marking the center of permanent plots with metal rebar (iron bar) and PVC pipe are described below. These materials are convenient, inexpensive, and readily available in most parts of the world. However, the risk of theft of these materials from permanent plots must be considered. Appropriate alternatives to these materials may need to be identified. The goal is to mark the center / corners in a manner that will allow the plot to be located in the future and therefore other strategies can be used. However: the GPS location alone *cannot* be used to locate the plot center in the future as the error in GPS measurements is too large.

a. At the plot center / corners, hammer a ~30 cm section of metal pipe/bar into the ground. The metal pipe/bar should be hammered until it is completely in the ground. If there are rocks or other obstructions in the soil, move the metal pipe/bar to another spot (within 2 m of the original location).
b. Hammer a 1 m section of PVC pipe over the metal bar. It is important that the PVC pipe is hammered straight into the ground. It should not lean. Use a block of strong wood to cover the top of the PVC pipe when hammering it into the ground, to prevent the PVC from splitting. At least 50 cm of the PVC should go into the ground.
c. Paint the PVC pipe with bright orange or bright blue spray paint (black, yellow and red will not be visible enough in a forest).
d. It is important that the plot be identified permanently for future monitoring. The best way is to place a plot-numbered tag inside the top of the pipe with a piece of wire, and a cap placed on top of the pipe to hold the tag in place. In addition, wrap duct tape around the top of the pipe and use a permanent black marker to write the plot number on the duct taped portion of the pipe.
e. At the plot center, mark tree branches with flagging tape to increase visibility.

Square/rectangular plots

For square or rectangular plots mark *each* of the corners with rebar and PVC tubing (as for circular plots), including the corners for each nest size.

Invisible plots

If there is a concern that the metal pipe and PVC pipe may be removed by someone or if the marking of the plot may lead to preferential treatment of the trees within those plots, then the invisible marking of plots should be considered. For this method a piece of iron (e.g. a piece of rebar) should be sunk below the soil surface at the plot center or at the corners of a square/rectangular plot. A metal detector would subsequently be used at each subsequent sampling to find the plot following initial navigation using the GPS.

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Slope Corrections

Area correction due to slope – Conducted in the field

If the subplot falls on a slope that is greater than 10%, then slope angle should be measured using a clinometer so that an adjustment can be made to the subplot area. If slope is less than 10%, correction is not required.

Slope Measurement

Slope is measured with the person using the clinometer identifying the eye-level of a partner of approximately the same height. One person should stand in the center of the subplot and the partner should go to the edge of the larger nested subplot. The person with clinometer, standing in center of subplot, shall then aim at the eye-level location of the partner and record the angle reading displayed in the clinometer. This angle is the slope angle and should be recorded as percent (in the cases of very steep slopes, it can be recorded as degrees, making sure to note the unit used in the data sheets.

Tree plot area correction

Where tree plots are on sloped ground, tree plot size has to be adjusted to reflect the true horizontal projection. When a tree plot is to be established on sloped terrain, the radius for each of the nests within the tree plot may need to be adjusted. That means the radii for the various nests will be slightly longer in the field to ensure the vertical projection of each of the nested subplots will yield the same area as if the tree plot were established on flat terrain.

To determine the corrected radius, the radius on the slope is first calculated, using the following equation:

$$Sloped\_Radius = \frac{Nest\_Radius}{Cos\theta}$$

Where:

Sloped_Radius = Length of radius (m) on slope that corresponds to horizontal radius

Nest_Radius = Length of radius agreed upon in flat terrain (m)

Cosθ = Cosine of the slope angle

The true horizontal projection of a circular plot on a slope is an ellipse, but because it is not possible to establish an ellipse in the field with accuracy, the plot is adjusted to be a circle having the same area as the ellipse. Therefore, after determining the corrected radius on the slope, the area is calculated as follows:

$$Corrected\_Area = \pi * Nest\_Radius * Sloped\_Radius$$

The corrected radius, to be used in the field, is then calculated as follows:

$$Corrected\_Radius = \sqrt{\frac{Corrected\_Area}{\pi}}$$

The correction of the subplot nests should be conducted in the field by the crew leader, based on the corrected radius for the appropriate slope as shown in the table below. Measured slope gradient should be approximated to the nearest slope gradient. A correction table is presented in the appendix. This should be printed and used by the crew leader.

Area correction due to slope – Conducted during data analysis

Carbon measurements are reported on a horizontal-projection basis, thus, plots established on sloping lands must use a correction factor. This correction factor accounts for the fact that when distances measured along a slope are projected to the horizontal plane, they will be smaller. If the plot falls on a slope that is greater than 10%, then slope angle should be measured using a clinometer so that an adjustment can be made to the plot area at the time of analysis. If the slope is less than 10%, correction is not required. The calculation of area correction is done during data analysis. In the field, only the average slope measurement is taken.

Following data collection, the slope will be used to estimate the projected horizontal area of the plot (see Figure below). It is recommended this be done as part of data analysis within computer spreadsheet.

$$L_{horixaonta} = L_{field} * \cos(slope)$$

Where:

$L_{horizontal}$	True horizontal length; m (for circular plots, this will be the radius. For square/rectangular plots, this will be the side parallel to the slope)
L_{field}	Length measured in the field, parallel with the slope; m (for circular plots, this will be the radius. For square/rectangular plots, this will be the side parallel to the slope)
Slope	Slope, measured in degrees
Cos	the cosine of the angle

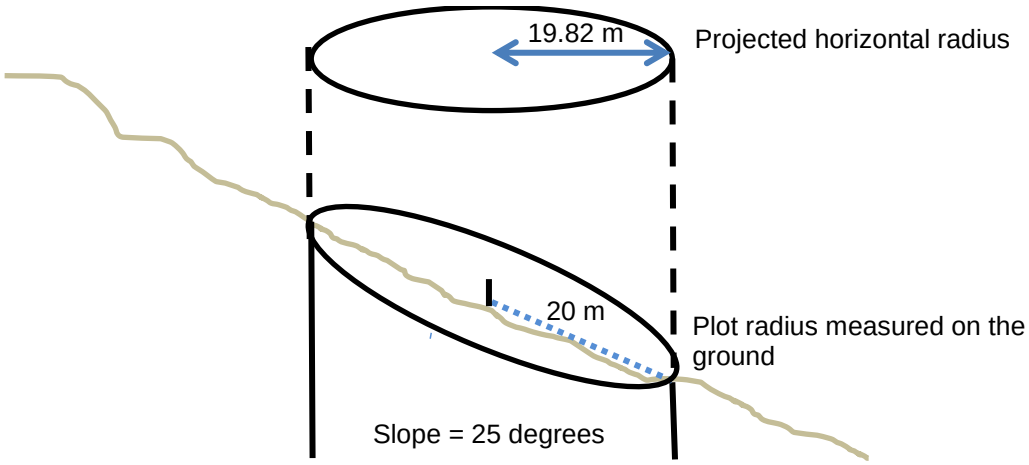


Figure Plot measurement on ground and projected horizontal size of plot. In this example, with a slope of 25 degrees, although the plot radius on the ground is measured as 20 m radius, the projected horizontal size of the plot has a radius of 19.82 m (20 m * cos(25 degrees) = 19.82 m).

Extrapolation to Hectare – Conducted during data analysis

Following field data collection, during data analyses, any measurements taken at the plot level are extrapolated to the area of a full hectare to produce carbon stock estimates on a 'per hectare' basis. Extrapolation is done by the use of scaling factors that are calculated as the proportion of a hectare (10,000 m^2) that is occupied by a given nested plot or clip plot:

$$Scaling\_factor = \frac{10{,}000\,m^2}{Horizontal\_Area\_of\_nest\_(m^2)}$$

SOP MEASUREMENT OF TREES

Field equipment:

Tree name list

For measuring DBH:

Diameter tapes

Flagging tape

Tree poles: Small-diameter PVC piping cut the exact length of diameter measurements (eg 1.3 m if DBH will be measured)

Chalk sticks

Portable retractable ladder (3 m)

Portable retractable poles (at least 5 m)

For measuring height (see SOP Measurement of Height):

Clinometer

Laser Range Finder or >20m measuring tape

For permanently marking trees:

Aluminum nails and/or fishing line or aluminum wire (determine most appropriate material given local conditions eg. aluminum nails are not recommended for young trees <5cm)

Tree tags with unique sequential numbers

Hammers and/or wire cutters

Prior to Field Sampling

Allometric Equation(s) Selection

The biomass of live trees is usually estimated using an allometric equation that relates tree biomass with one or more specific tree variables such as tree species, diameter at breast height (DBH) diameter at stump height (DSH), total tree height, and/or wood density. The tree variable(s) measured in the field are then used to calculate biomass during data analysis.

Prior to field data collection, the allometric equation(s) that will be applied to trees must be determined. There are many existing allometric regression equations that have been previously developed and published. Documentation on the equation should list the minimum size tree applicable to the equation (e.g. Trees with a DBH ≥5 cm). It is recommended to use an existing equation where possible, however, prior to using a chosen equation, the applicability of the equation to the forest type / species must be assessed. Alternatively, an equation can be developed for the forest type and/or species of interest. See 'SOP Destructive sampling of trees, saplings, palms, and bamboo' for more information on how such equations are created and/or the applicability of existing equations verified.

Prior to field data collection, a standard list of tree names shall be developed. Depending on the biomass regression equation(s) used, the tree names may relate to actual tree species, tree genus, or tree family. A standard tree name list and tree name abbreviation list shall be created and brought to the field for reference and for filling out data sheets.

The minimum sized tree to be measured as a "tree" must be defined, usually this is based on the allometric equation applicability criteria (e.g. trees with a DBH of ≥5 cm and a height of ≥1.3 m). All trees of appropriate size will be measured in plots. Where nested plots are used, measurement will only occur for trees that meet

the size class requirements for a given nest. For permanent plots, only trees measured shall be tagged with an aluminum numbered tag and nail.

Seedlings and Saplings

The biomass of trees smaller than the minimum size tree applicable to the allometric equation can be estimated using alternative approaches. One recommended approach is to divide small trees into two groups: seedlings and Saplings. Seedling biomass is included in non-tree biomass measurements (see SOP Measurement of Non-woody Vegetation). The size range of Saplings must be defined in this SOP (a common definition is trees ≤5 cm DBH and ≥1.3 m tall) and can be estimated by counting the number of saplings within a certain area and multiplying that by the average weight of a sapling. To estimate the average weight of a sapling, the sapling portion of 'SOP Destructive sampling of trees, saplings, palms, and bamboo' must be implemented prior to field data collection. In the field, saplings should be counted in a 2-m radius plot but should not be tagged. Another recommended approach is to measure the biomass of all trees below a minimum size in the non-tree biomass measurements (see SOP Measurement of Non-woody Vegetation). Where non-woody vegetation biomass will not be measured in the field, it is recommended saplings be accounted for using the Sapling Count method.

This SOP must be altered to describe the approach used for the measurement of trees and saplings. This will aid in field data collection initially and allow future measurements to be completed efficiently and accurately. Because DBH and height are common inputs for allometric equations used to estimate the biomass of trees, this SOP focuses on the measurement of DBH and height. If other parameters are to be measured, this information must be included in the SOP used for field data collection.

Field Measurements

The design and establishment of plots shall be determined following SOP Plot Design and SOP Establishment of Plots. The instructions here assume these SOPs have already been followed. As stipulated by such SOPs, tree measurements can be taken in either temporary or permanent sample plots.

1. Assign one person to record the data and all others should be measuring and marking trees. The recorder should stand in the center of the nested plot being measured. He or she should track those measuring the trees and should try and ensure that no trees are missed.
2. To avoid either missed trees or double recording, measurement should begin to the North and the first tree should be flagged. After a tree is measured, a chalk mark facing the center of the plot should be placed on tree to allow the person recording the data to track measured and unmeasured trees.
3. Count the number of saplings (defined as trees <5 cm DBH and >1.3 m tall) in the smallest plot (e.g. 2 meter radius plot) and record on data sheet. (After field data collection, the number of saplings will be combined with the average sapling weight to estimate total sapling biomass (see 'SOP Destructive sampling of trees, saplings, palms, and bamboo')).
4. For temporary plots, trees should not be tagged. Move to step 6.
5. In **permanent** measurement plots, all trees of appropriate sizes for each nested plot should be tagged with the placement of an *aluminum* numbered tag and nail or alternatively fishing line or wire (see Figure below). The risk of theft of these materials must be considered. Appropriate locally available alternatives may need to be considered. The steps are as follows:
    a. To avoid any errors in the measurements due to the development over time of a bump at the site of the nail, it is recommended that the nail and tag be placed 10 cm below DBH. See detail instructions on where to measure the DBH below.
    b. In future inventories DBH will be measured 10 cm up from the nail.
    c. If the trees in the project area will be subjected to some kind of harvest in the future, the nail and tag may be placed at the base of the tree to avoid any chainsaw or other equipment accidents. Be sure the nail is placed *well below* the height of future cutting, as it is very dangerous for a chainsaw to hit a nail. Chainsaws *can* cut through aluminum, but contact between the nail and chainsaw or other equipment should be avoided to prevent the

possibility of accidents. Alternatively, tags may be attached to trees with fishing line or metal wire as shown below.

d. Each plot should contain a description of what approach was used so that future measurements can be completed efficiently and accurately.

e. Do not insert the nail fully so that there is room for the tree to grow, however, insert it deep enough to hold the tag firmly.

f. *Only* aluminum nails should be used.



Figure. Examples of tagged tree using fishing line (left) and a nail (right).

6. Measure the tree parameters required for the allometric equation to be used (eg diameter at breast height (DBH), diameter at stump height (DSH) and total tree height (H)) for all trees of appropriate sizes for each nested plot. Steps for measuring DBH of all trees of appropriate sizes for each nested plot are described below. If other tree parameters are required for the allometric equation to be used, this SOP should be altered to explicitly describe the procedures to be followed. It is important that the diameter tape is used properly using the following steps to ensure consistency of measurements:

   a. Record the name of the tree, based on tree naming system developed prior to field data collection.

   b. **Tree Pole placement**: For each tree, place the Tree Pole (e.g. 1.3 m plastic pole) against the tree to indicate the location of measurement (eg DBH). Placement of the Tree Pole depends on the slope of the ground, leaning angle of the tree, and shape of the tree bole (see Figure below for correct placement of diameter tape).

      i. **Slope:** Always place tree pole and measure diameter on the *upslope* side of the tree

      ii. **Leaning tree**: Always measure the height of a measurement (e.g. 1.3 m) parallel with the tree, *not* perpendicular to the ground. Therefore, if the tree is leaning, measure underneath the lean, parallel with angle of tree. If a tree is not straight, a tape measure must be used to measure the bole distance from ground to location of measurement (e.g. DBH).

      iii. **Dead tree**: If a tree is in dead class 1 (see SOP Measurement of Standing Dead Wood), mark as dead on data sheet. Trees are considered alive if there are green leaves present. Even if there are only one or two green leaves present the tree is considered alive. However, in deciduous forests during a season when trees drop their leaves (ie dry season) a branch or the stem must be cut to verify that the cambium is alive in order to determine if the tree is alive or dead.

      iv. **Multi-stem tree**: If the tree is multi-stemmed with forking below the point of measurement (eg 1.3 m), measure the diameter on each stem and tag the stems that exceed the minimum diameter for the nest. Record it as if each stem were a different tree on the data sheet, but with a note that the stems make up one tree.

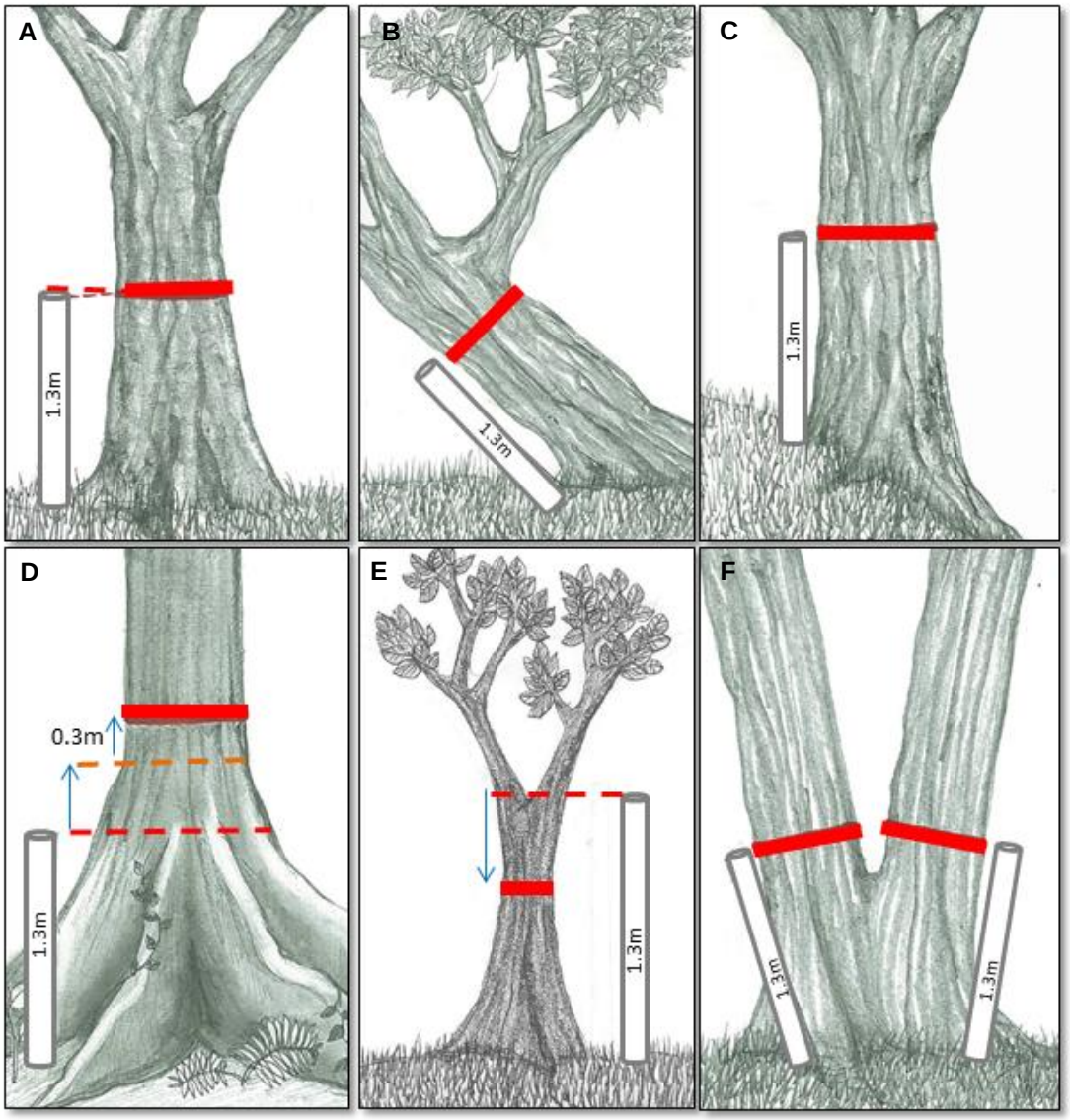


Figure: Proper placement of diameter tape when allometric equation used requires measurement at DBH (1.3 m)

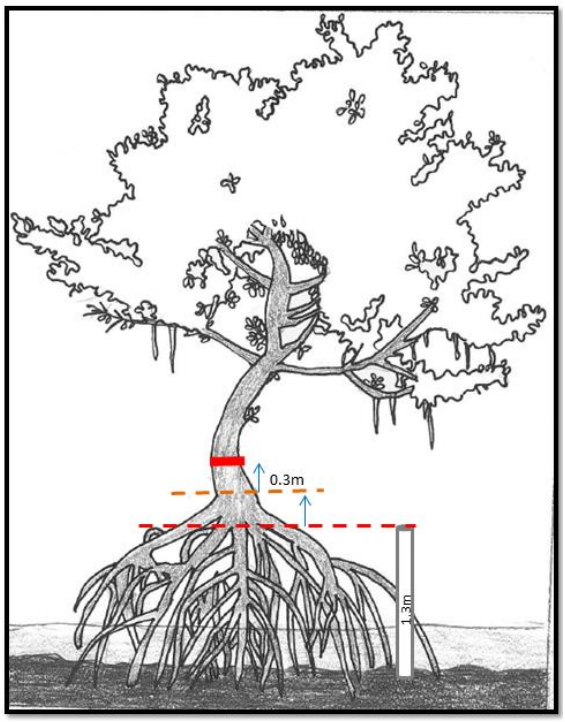


Figure Proper placement of diameter tape for a mangrove tree

v. Buttressed tree or mangroves

1. If the buttress or mangrove roots are shorter than the allometric equation's dictated measurement point (e.g. 1.3 m, measure the diameter at the standard (e.g. 1.3 m) height.
2. If the buttress or mangrove roots are taller than 1.3 m, measure the diameter at 30 cm above top of buttress as shown in example D in the figure above, and above the top of the mangrove roots in the figure below. In cases where the buttress or mangrove roots are too tall and out of reach, the following procedure shall be followed:

   i) Use portable retractable ladder and lean ladder against tree to allow for measurement of DBH 30 cm above from the top of the buttress.

   ii) If ladder is unavailable, and taking into consideration the safety of field crew, climb the tree to take measurement 30 cm above the top of the buttress. In fluted buttress, it is possible to carve steps on the buttress itself to allow climbing to top of buttress. Extreme caution should be employed and climbing should only be performed when conditions are deemed safe by field crew leader.

   iii) If ladder is unavailable, and climbing is considered unsafe, retractable poles should be use. Poles shall be placed against the tree, at the edge of its circumference, projecting the diameter at exactly 30 cm above top of buttress down to the ground. An observer is required to ensure poles are properly placed at the very edge of tree's circumference in a way that linear distance between poles represents the diameter of tree at 30 cm above end of buttress. The **linear distance** between the two poles shall be measured. At least two measurements shall be taken on opposite sides of tree using this method, and then averaged to estimate tree DBH.

   Note: The distance between poles shall be measured linearly, and thus proper measuring tape shall be used. Poles can be made from tall saplings found outside the sampling plot in the forest or by linking Tree Poles together (e.g. with pvc connectors).

c. **Diameter measurement:** Tree diameter should be measured to the nearest 0.1 cm (eg diameter of 10.2 cm *not* 10 cm).

i. If the diameter tape has a hook, push the hook into the bark of the tree slightly to secure it and pull the tape to the right. The diameter tape should always start left and be pulled right around the tree, even if the person taking the measurement is left-handed. As the diameter tape wraps around the tree and returns to the hook the tape should be above the hook. The tape should not come around the tree below the hook. The tape should not be upside down; the numbers must be right side up. (see Figure below)

ii. If a liana or vine is growing on a tree that is going to be measured, do not cut the liana to clear a spot to measure the tree's diameter. If possible, pull the liana away from the trunk and run the diameter tape underneath. If the liana is too big to pull away from the trunk, estimate the diameter of the liana and subtract from total tree diameter. Cutting a liana from a tree should only be done if there are no other options. The same standard should be followed for any other type of natural organisms (mushrooms, epiphytes, fungal growths, termite nests, etc.) that are found on the tree.

iii. Place chalk mark on the tree to indicate to crew members that the tree has been measured.



Figure: Measurement of diameter using a diameter tape and tree pole

d. **Other tree parameters:** Measure all other tree parameters included in the biomass regression equation to be used. If the allometric equation to be used requires height as an input for each tree/palm measured, two measurements of height should be taken to improve the precision of measurements, especially if it is difficult to identify the top of the tree/palm measured. See SOP Measurement of Height on how to measure tree height.

e. **Boundary trees:** Occasionally trees will be close to the border of the plots. The plots are relatively small and will be expanded to estimate biomass carbon on a per hectare basis. It is therefore important to carefully decide if a tree is in or out of a plot. To definitively determine whether the tree is in or out of the plot, use a tape measure to measure out from the plot center (or plot corner) to the base of the boundary tree. If the plot is on sloped ground, make sure the measurement follows the slope. If more than 50% of the base of the trunk is within the boundary of the nest, the tree is in. If more than 50% of the base of the trunk is outside of the boundary, it is out and should not be measured. If it is exactly on the border of the plot, flip a coin to determine if it is in or out.

7. When all of the trees in the plot have been measured, there should be a double-check to see that all of the trees have been measured.

SOP MEASUREMENT OF PALMS, LIANAS, AND BAMBOO

Field equipment:

Tree name list

For measuring DBH:

Diameter tapes

Flagging tape

Tree poles: Small-diameter PVC piping cut the exact length of diameter measurements (eg 1.3 m if DBH will be measured)

Chalk sticks

For measuring height (see SOP Measurement of Height):

Clinometer

Laser Range Finder or >20m measuring tape

For permanently marking trees:

Aluminum nails and/or fishing line or aluminum wire (determine most appropriate material given local conditions)

Tree tags with unique sequential numbers

Hammers

Prior to Field Sampling

The biomass of palms, lianas, and bamboo varies significantly between land cover types. Prior to data collection initial field research should be undertaken to determine the distribution and dominance of these vegetation types within a land cover type. If such a vegetation type is common and dominant, field measurements methods are described below. If the vegetation type (palm, liana, bamboo) is not common and it is conservative to underestimate forest biomass, it is recommended that the vegetation type not be measured. This SOP must be altered to describe the approach that must be used for the measurement of palms, lianas, and bamboo.

The biomass of palms, lianas, and some types of bamboo is usually estimated using a previously created regression equation that relates biomass with one or more specific vegetation parameters such as species, diameter, height, and/or number of stems. Prior to plot establishments and measuring, the regression equations to be used to estimate the palm, liana, and bamboo biomass must be selected from existing equations and field verified for applicability or newly developed for the land use type of interest. See 'SOP Destructive sampling of trees, saplings, palms, and bamboo' for more information on how such equations are created and/or verified.

Prior to field data collection, a standard list of palm, liana, and bamboo names shall be developed. Depending on the biomass regression equations used, the names may relate to actual tree species, tree genus, or tree family. A standard name list and name abbreviation list shall be created and brought to the field for reference and for filling out data sheets.

The size classes to be measured in each nest will need to be determined prior to initiation of fieldwork. Measurement will only occur for individuals that meet the size class requirements for a given nest. For permanent plots, only individuals measured shall be tagged with an aluminum numbered tag and nail.

The biomass of individuals below a certain size threshold can be estimated by counting the number of individuals within a certain area and multiplying that by the average weight of an individual sapling. This

'sapling count' method is often used for trees (see SOP Measurement of Trees). To estimate the average weight of an individual, the sapling portion of 'SOP Destructive sampling of trees, saplings, palms, and bamboo' must be implemented prior to field data collection. In the field, such individuals should be counted in a 2-m radius plot but should not be tagged. Alternatively, the biomass of individuals below a size threshold can be included in the non-tree biomass measurements ('SOP Measuring non-tree vegetation'). However, only one approach can be taken for each stratum.

This SOP must be altered to describe the approach used for the measurement of palms, lianas, and bamboo. This will aid in field data collection initially allow future measurements to be completed efficiently and accurately.

Field Measurements

The design and establishment of plots shall be determined following SOP Plot Design and SOP Establishment of Plots. The instructions here assume these SOPs have already been followed.

The following are the steps to be used in collecting measurements in the field. Often, these field measurements are taken at the same time as the measurement of trees.

Measuring Palms

The specific field measurements taken will be dependent on the allometric equation used, therefore, the below description offers only general guidance. A size threshold of 1.3 m height is usually used. All smaller palms should be measured either using the 'sapling count' method or with non-woody vegetation. Only one method can be used.

In tree plots, only palms with a stem taller than 1.3 m should be measured. Smaller palms will be measured either as non-tree woody vegetation or herbaceous vegetation.

a. Measure palms at the same time as trees.
b. Measure all palms taller than 1.3 m within the medium nested plot.
c. Measure the required palm variable (often this is Height of the palm from the base to the top of the stem).
d. For permanent sample plots, tag the palm in the same location as for trees.

Measuring Lianas

a. Lianas can be measured at the same time as trees. It is recommended that lianas be measured within the smallest nest.
b. The only lianas that should be measured are those originating from the nest (e.g. liana emerges from ground within nested plot where measurements taking place). Measure the liana variables (eg DBH) required by the allometric equation that will be applied.
c. Take care that the same liana is not measured more than one time.
d. If using permanent plots lianas should also be tagged in the same location as for other trees.

Measuring Bamboo

Allometric equations can be used to estimate the biomass of a bamboo patch. Usually the equations relate basal diameter and height to biomass. If no appropriate allometric equations exist, one must be created. See 'SOP Destructive sampling of trees, saplings, palms, and bamboo'. The specific field measurements taken will be dependent on the allometric equation used, therefore, the below description offers only general guidance.

a. The nest size within which bamboo will be measured will be dependent on the prevalence of bamboo. If highly prevalent, then the smaller nest size can be used. Otherwise, all bamboo patches should be measured in the medium nested plot.

b. Measure the bamboo parameters required in the biomass regression equation developed. This would include things such as height (using a clinometer), the basal diameter (using DBH tape), and the number of culms in a patch. Note: the exact measurements made will be dependent on the factors included in the allometric equation used.

SOP MEASUREMENT OF NON-TREE WOODY VEGETATION

Field Equipment:

Clip plot frame (see below for explanation) (for clip plot method only)

Measuring tape

Clippers and hand saw to remove vegetation (for clip plot method only)

5 kg hanging scale (for destructive sampling, appropriate size dependent on size of non-tree woody vegetation)

300 g hanging scale (for subsample)

Hanging scale

Durable plastic sheeting

Durable plastic tarp

Cloth or paper sample bags (for clip plot method only)

Compass

Calibration weights (see below) (for clip plot method only)

Laboratory Equipment:

Drying oven

Laboratory scale

Prior to Field Sampling

Prior to field sampling, it will need to be decided how non-tree woody vegetation, such as non-tree woody vegetation, will be measured in a given land cover class/stratum. Different methods of measurement may be used for different land cover classes. This SOP must be altered to describe the approach that must be used for the measurement of non-tree woody vegetation. This must include a detailed description of what types of vegetation are included within this vegetation type.

1. **Determine Sampling Method:** The two main methods that can be used to estimate non-tree woody vegetation biomass will be destructive sampling within a small area (referred to here as a 'clip plot') or through the use of an allometric equation. The development and use of allometric equations are best used where non-tree woody vegetation are large and are a dominant vegetation type. In land cover types where non-tree woody vegetation are small or very uncommon 'clip plots' can be used. 'Clip plots' can also be used to estimate non-tree woody vegetation biomass in areas where non-tree woody vegetation are common but where it is not possible to identify individual 'non-tree woody vegetation' or 'non-tree woody vegetation clumps'.

2. **Determine Vegetation types sampled:** Where 'clip plots' will be used to measure non-tree woody vegetation, it must be decided whether non-tree woody vegetation will be measured separately from non-woody vegetation and tree seedlings (trees smaller than a sapling) or if these will be measured together. Please note that certain regulatory and voluntary Standards (e.g. CDM, VCS, ACR) and Methodologies may provide explicit rules on how non-tree woody vegetation and non-woody vegetation may be measured. If non-tree woody, non-woody vegetation, and tree seedling vegetation will be measured separately, very clear rules will need to be created delineating what will be defined as a 'non-tree woody vegetation' and what will be defined as 'non-woody vegetation'. All field members must understand these definitions.

3. **Create Clip plot frames**: Clip plot frames can be made out of various materials and can be circular or rectangular. A square clip plot frame made of PVC pipe 50 cm x 50 cm is usually sufficient for sampling (see Figure below). The clip plot frame should ***not*** be one continuous piece of material. The pieces of PVC piping should ***not*** be glued together into a permanent square. Instead it must remain in pieces so that it can be constructed around existing vegetation. The 'elbows' used to connect two pieces of piping together may be glued to one piece of piping. This step is only required where the 'clip plot' method is to be used.

4. **Create 'calibration weights' to calibrate hanging scales:** Prior to going into the field, the scales that will be used to weigh samples must be calibrated. The ideal approach is to calibrate the hanging scales that will be used in the field with the laboratory scale that will be used to measure the dry weight of subsamples. Only required if 'clip plot' method will be used.
    a. Ensure the laboratory scales are calibrated
    b. Medium hanging scale (5 kg):
        ii. Find an item that weighs about 3 kg and does not change weight when wet (metal tool of some sort). Weigh this item using the laboratory scale 5 times. Record weights and take average weight.
        iii. Calibrate hanging field scale using this item and the average recorded weight. This can take place at a base camp and therefore does not have to take place at the site of the destructive sampling. Do this every day prior to weighing items in field.
    c. Small hanging scale (~300 g):
        iv. Find an item that weighs 100-250 g and does not change weight when wet (metal tool of some sort, stack of coins taped together). Weigh this item using the laboratory scale 5 times. Record weights and take average weight.
        v. Calibrate hanging field scale using this item and the average recorded weight. This can take place at a base camp and therefore does not have to take place at the site of the destructive sampling. Do this every day prior to weighing items in field.

Field Measurements - Clip Plot Method

1. Determine clip plot locations
    a. The design and establishment of clip plots shall be determined following SOP Plot Design and SOP Establishment of Plots.
    b. Where non-tree woody vegetation sampling is taking place in association with tree plots, sampling for non-tree woody vegetation can occur at a total of 4 clip plot locations as follows:
        i. If using the single tree plot design, sample 4 clip plot locations at each tree plot
        ii. If using the cluster tree plot design, sample one clip plot at each of the 4 tree plots within the cluster.
    c. Where sampling is taking place in a land cover class without tree plots, the initial point of sampling shall be determined prior to entering the field.
    d. Starting at the tree plot center or the sampling point, determine a random compass bearing. This can be done using various methods such as using a random number table. Another method is to use a watch that has a second hand. At a random moment one individual can look at his/her watch and then the direction that the second hand is facing will be used as the compass bearing.
    e. Using the compass bearing walk 30 paces from the tree plot center (e.g. outside the largest tree nest and thus tree plot boundary). If temporary tree plots are being used, it is allowable for the number of paces to be reduced, however, if permanent tree plots are being used clip-plots must be located outside the boundaries of the tree plot.
    f. Walk 5 more steps (These additional steps reduce bias in choosing the sampling location).
2. Place clip plot frame at this location (see Figure below). Clip plot frame may need to be placed around existing vegetation and then constructed. For example, a tree may be located within the clip plot location.
3. Identify which non-tree woody individuals have stems originating from inside the area of the clip plot. This non-tree woody vegetation shall be cut at ground level. Any non-tree woody vegetation which have branches hanging into the plot but whose stem base is located outside the area of the clip plot shall ***not*** be clipped and measured.
4. Weigh clipped vegetation. If other types of non-tree vegetation (eg non-woody, bamboo, palms) are being sampled separately from the non-tree woody vegetation, do not include these other types of vegetation when weighing the non-tree woody vegetation. Record the total fresh weight of non-tree woody vegetation within the clip plot.
5. If there is no non-tree woody vegetation within the clip plot area, the clip plots should *not* be moved. Instead the non-tree woody vegetation biomass shall be recorded on the data sheet as 'zero'.
6. Take a sub-sample of vegetation. This should be representative of the total sample and shall be made up of a mix of species and vegetation found within the total sample. Place vegetation temporarily in a sample bag.

7. Repeat steps 1-6 for the remaining three clip plot locations.
8. Combine the four sub-samples into one sub-sample bag. If a single tree plot design is used, these four subsamples will come from the 4 clip plots associated with the tree plot. Where clustered tree plot design is used, these four subsamples will come from the clip plot associated with each of the 4 tree plots.
    a. Weigh the subsample bag empty. Record weight.
    b. Combine the subsamples from all 4 clip plots into one subsample bag.
    c. Weigh the subsample bag with the subsample inside. The weight should be between 100-300 g. Record the actual weight.
    d. Label the subsample bag with the plot identification number, subsample identification number, and weight of subsample.
    e. Take the subsample bag and the subsample from field. Bring them to the laboratory and dry the subsample. Reweigh subsample. This subsample will be used to create a wet-to-dry ratio. This ratio will then be used to estimate the total dry weight of non-tree woody vegetation found within the clip plot.
9. It is allowable for there to be a delay between field data collection and laboratory analysis. However, cloth sample bags must be placed in a location that allows air drying to occur.



Figure: Clip plot on forest floor

Field Measurements - Allometric Equation Method

For non-tree woody vegetation species where the allometric equation method will be used, non-tree woody vegetation will be measured within plots of a known area.

1. Determine plot location
    a. The design and establishment of plots shall be determined following SOP Plot Design and SOP Establishment of Plots.
    b. Where non-tree woody vegetation sampling is taking place in association with tree plots, sampling for non-tree woody vegetation should occur within the tree plots. Non-tree woody vegetation shall be measured in either the 'medium' or 'large' nest size. This must be decided prior to field work taking place and non-tree woody vegetation measured in a consistent area for all tree plots measured. This will be dependent on the prevalence of non-tree woody vegetation.
    c. Where sampling is taking place in a land cover class without tree plots, the initial point of sampling shall be determined prior to entering the field. Plot sizes can vary, dependent on prevalence of non-tree woody vegetation, however, a 20 m radius circular plot or 35 m x 35 m is recommended. See 'SOP Plot Design' and 'SOP Establishment of Plots' for information on how to set up a plot.

2. For each individual non-tree woody plant within the plot, measure the required vegetation parameters. These vegetation parameters will depend on the allometric equation used.

SOP MEASUREMENT OF NON-WOODY VEGETATION (HERBACEOUS)

Field Equipment
Clip plot frame
Measuring tape
Clippers to remove vegetation
2-5 kg hanging scale (appropriate size dependent on density of non-tree vegetation)
300 g hanging scale (for subsample)
Durable plastic sheeting
Durable plastic tarp
Cloth or paper sample bags
Compass
Calibration weights (see below)

Laboratory Equipment:
Drying oven
Laboratory scale

Sampling for non-tree non-woody vegetation (e.g. herbaceous) may occur in a known small area in which all non-tree non-woody vegetation (herbaceous) is cut at the base and weighed. The average weight of non-woody vegetation within the land use area is then extrapolated based on the average biomass found within the areas sampled. This SOP must be altered to describe the approach that must be used for the measurement of non-woody vegetation.

Prior to Field Sampling

1. **Determine vegetation types sampled:** It must be decided what vegetation types will be sampled within the 'non-woody vegetation'. Clear rules will need to be created delineating what will be defined as a 'non-tree woody vegetation' and what will be defined as 'non-woody vegetation'. All field members must understand these definitions. Please note that certain regulatory and voluntary Standards (e.g. CDM, VCS, ACR) and Methodologies may provide explicit rules on how non-tree woody vegetation and non-tree non-woody vegetation may be measured.

2. **Create clip plots frames**: The small areas where vegetation is measured are here referred to as 'clip plots'. Clip plot frames can be made out of various materials and can be circular or rectangular. A square clip plot frame made of PVC pipe 50 cm x 50 cm is usually sufficient for sampling (see Figure below). The clip plot frame should ***not*** be one continuous piece of material. The pieces of PVC piping should ***not*** be glued together into a permanent square. Instead it must remain in pieces so that it can be constructed around existing vegetation. The 'elbows' used to connect two pieces of piping together may be glued to one piece of piping.

3. **Create 'calibration weights' to calibrate hanging scales:** Prior to going into the field, the scales that will be used to weigh samples must be calibrated. The ideal approach is to calibrate the hanging scales that will be used in the field with the laboratory scale that will be used to measure the dry weight of subsamples.
    d. Ensure the laboratory scales are calibrated
    e. Medium hanging scale (2-5 kg):
        vi. Find an item that weighs about half the maximum weight of the scale and does not change weight when wet (metal tool of some sort). Weigh this item using the laboratory scale 5 times. Record weights and take average weight.

vii. Calibrate hanging field scale using this item and the average recorded weight. This can take place at a base camp and therefore does not have to take place at the site of the destructive sampling. Do this every day prior to weighing items in field.

f. Small hanging scale (~300 g):

viii. Find an item that weighs 100-250 g and does not change weight when wet or over time (metal tool of some sort, stack of coins taped together). Weigh this item using the laboratory scale 5 times. Record weights and take average weight.

ix. Calibrate hanging field scale using this item and the average recorded weight. This can take place at a base camp and therefore does not have to take place at the site of the destructive sampling. Do this every day prior to weighing items in field.

Field Measurements

10. Determine clip plot locations
    a. The design and establishment of clip plots shall be determined following SOP Plot Design and SOP Establishment of Plots.
    b. Where non-tree woody vegetation samples have been taken in clip-plots, the same locations shall be used for non-woody vegetation sampling.
    c. Where non-woody vegetation sampling is taking place in association with tree plots, sampling for non-woody vegetation can occur at a total of 4 clip plot locations as follows:
        i. If using the single tree plot design, sample 4 clip plot locations at each tree plot
        ii. If using the cluster tree plot design, sample one clip plot at each of the 4 tree plots within the cluster.
    d. Where sampling is taking place in a land cover class without tree plots, the initial point of sampling shall be determined prior to entering the field.
    e. Starting at the tree plot center or the sampling point, determine a random compass bearing. This can be done using various methods such as using a random number table. Another method is to use a watch that has a second hand. At a random moment one individual can look at his/her watch and then the direction that the second hand is facing will be used as the compass bearing.
    f. Using the compass bearing walk 30 paces from the tree plot center (e.g. outside the largest tree nest and thus tree plot boundary). If temporary tree plots are being used, it is allowable for the number of paces to be reduced, however, if permanent tree plots are being used, clip-plots must be located outside the boundaries of the tree plot.
    g. Walk 5 more steps (These additional steps reduce bias in choosing the sampling location).
11. Place clip plot frame at this location (see Figure below). Clip plot frame may need to be placed around existing vegetation and then constructed. For example, a tree may be located within the clip plot location.
12. Identify which non-tree woody individuals have stems originating from inside the area of the clip plot. This non-woody vegetation shall be cut at ground level. Any non-woody vegetation which have branches hanging into the plot but whose stem base is located outside the area of the clip plot shall ***not*** be clipped and measured.
13. Weigh clipped vegetation. If other types of non-tree vegetation (eg non-woody, bamboo, palms) are being sampled separately from the non-woody vegetation, do not include these other types of vegetation when weighing the non-woody vegetation. Record the total fresh weight of non-woody vegetation within the clip plot.
14. If there is no non-woody vegetation within the clip plot area, the clip plots should *not* be moved. Instead the non-woody vegetation biomass shall be recorded on the data sheet as ‘zero’.
15. Take a sub-sample of vegetation. This should be representative of the total sample and shall be made up of a mix of species and vegetation found within the total sample. Place vegetation temporarily in a sample bag.
16. Repeat steps 1-6 for the remaining three clip plot locations.
17. Combine the four sub-samples into one sub-sample bag. If a single tree plot design is used, these four subsamples will come from the 4 clip plots associated with the tree plot. Where clustered tree plot design is used, these four subsamples will come from the clip plot associated with each of the 4 tree plots.
    a. Weigh the subsample bag empty. Record weight.
    b. Combine the subsamples from all 4 clip plots into one subsample bag.
    c. Weigh the subsample bag with the subsample inside. The weight should be between 100-300 g. Record the actual weight.
    d. Label the subsample bag with the plot identification number, subsample identification number, and weight of subsample.

e. Take the subsample bag and the subsample from field. Bring them to the laboratory and dry the subsample. Reweigh subsample. This subsample will be used to create a wet-to-dry ratio. This ratio will then be used to estimate the total dry weight of non-woody vegetation found within the clip plot.

18. It is allowable for there to be a delay between field data collection and laboratory analysis. However, cloth sample bags must be placed in a location that allows air drying to occur.



Figure: An example of measuring non-woody vegetation biomass within a clip plot in Indonesia and the weighing of a subsample in China

SOP MEASUREMENT OF LITTER LAYER

Field Equipment:
Clip plot
Machete or knife
Clippers to remove vegetation and cut litter along edge of plot
2 kg hanging scale (appropriate size dependent on density of non-tree vegetation)
300 g hanging scale (for subsample)
Durable plastic sheeting
Durable plastic tarp
Cloth or paper sample bags
Permanent marking pen
Compass
Calibration weights (see below)

Laboratory Equipment:
Drying oven
Laboratory scale

The litter layer is defined as all dead organic surface material on top of the mineral soil. Some of this material will still be recognizable (dead leaves, twigs, dead grasses, and small branches) and some will be unidentifiable decomposed fragments of organic material. Note that dead wood with a diameter of less than 10 cm is included in the litter layer.

Clip plots should be used to sample litter and the clip plots can be the same as the ones used for non-woody vegetation material (see SOP for Non-woody Vegetation).

Sampling of litter may occur in a known small area in which all litter within the area is removed and weighed. The average carbon stock of litter within the land use area is then extrapolated based on the average weight found within the areas sampled and the assumed percent carbon of litter. This SOP must be altered to describe the approach that must be used for the measurement of litter.

Sampling can take place at the same location as sampling for non-woody vegetation (see SOP Measurement of Non-woody Vegetation).

Prior to Field Sampling

1. **Create clip plot frames**: The small areas within which litter is measured are called 'clip plots'. Clip plot frames can be made out of various materials and can be circular or rectangular (see Figure below). A square clip plot frame made of PVC pipe 50 cm x 50 cm is usually sufficient for sampling. The clip plot frame should ***not*** be one continuous piece of material. The pieces of PVC piping should ***not*** be glued together into a permanent square. Instead it must remain in pieces so that it can be constructed around existing vegetation (such as trees and saplings). The 'elbows' used to connect two pieces of piping together may be glued to one piece of piping.

2. **Create 'calibration weights' to calibrate hanging scales:** Prior to going into the field, the scales that will be used to weigh samples must be calibrated. The ideal approach is to calibrate the hanging scales that will be used in the field with the laboratory scale that will be used to measure the dry weight of subsamples.
    a. Ensure the laboratory scales are calibrated
    b. Medium hanging scale (2-5 kg):
        i. Find an item that weighs about half the maximum weight of the scale and does not change weight when wet (metal tool of some sort). Weigh this item using the laboratory scale 5 times. Record weights and take average weight.
        ii. Calibrate hanging field scale using this item and the average recorded weight. This can take place at a base camp and therefore does not have to take place at

the site of the destructive sampling. Do this every day prior to weighing items in field.

c. Small hanging scale (~300 g):
    i. Find an item that weighs 100-250 g and does not change weight when wet or over time (metal tool of some sort, stack of coins taped together). Weigh this item using the laboratory scale 5 times. Record weights and take average weight.
    ii. Calibrate hanging field scale using this item and the average recorded weight. This can take place at a base camp and therefore does not have to take place at the site of the destructive sampling. Do this every day prior to weighing items in field.

Field Measurements

1. Determine clip plot locations
    a. The design and establishment of clip plots shall be determined following SOP Plot Design and SOP Establishment of Plots.
    b. Where non-tree woody vegetation and/or non-woody vegetation samples have been taken in clip-plots, the same locations shall be used for soil sampling.
    c. Where non-tree woody vegetation sampling is taking place in association with tree plots, sampling for non-tree woody vegetation can occur at a total of 4 clip plot locations as follows:
        i. If using the single tree plot design, sample 4 clip plot locations at each tree plot
        ii. If using the cluster tree plot design, sample one clip plot at each of the 4 tree plots within the cluster.
    d. Where sampling is taking place in a land cover class without tree plots, the initial point of sampling shall be determined prior to entering the field.
    e. Starting at the tree plot center or the sampling point, determine a random compass bearing. This can be done using various methods such as using a random number table. Another method is to use a watch that has a second hand. At a random moment one individual can look at his/her watch and then the direction that the second hand is facing will be used as the compass bearing.
    f. Using the compass bearing walk 30 paces from the tree plot center (e.g. outside the largest tree nest and thus tree plot boundary). If temporary tree plots are being used, it is allowable for the number of paces to be reduced, however, if permanent tree plots are being used, clip-plots must be located outside the boundaries of the tree plot.
    g. Walk 5 more steps (These additional steps reduce bias in choosing the sampling location).
2. Place clip plot frame at this location (see Figure below). Clip plot frame may need to be placed around existing vegetation and then constructed. For example, a tree may be located within the clip plot location.
3. If needed, remove all vegetation to allow litter to be collected.
4. Collect all litter inside the clip plot frame. A knife can be used to cut pieces that fall on the border of the sampling frame. Place the litter on the plastic sheeting or tarp.
5. Weigh litter. Record the total weight of litter within the clip plot.
6. If there is no litter within the clip plot area, the clip plots should *not* be moved. Instead the litter shall be recorded on the data sheet as ‘zero’.
7. Take a sub-sample of litter. This should be a representative subset of the total sample and shall be made up of a mix of litter types found within the total sample. Place subsample temporarily in a sample bag.
8. Repeat steps 1-6 for the remaining three locations.
9. Combine the four sub-samples into one sub-sample bag. If a single tree plot design is used, these four subsamples will come from the 4 clip plots associated with the tree plot. Where clustered tree plot design is used, these four subsamples will come from the clip plot associated with each of the 4 tree plots.
    a. Weigh the subsample bag empty. Record weight.
    b. Combine the subsamples from all 4 clip plots into one subsample bag.
    c. Weigh the subsample bag with the subsample inside. The weight should be between 100-300 g. Record the actual weight.
    d. Label the subsample bag with the plot identification number, subsample identification number, and weight of subsample.
    e. Take the subsample bag and the subsample from field. Bring them to the laboratory and dry the subsample. Reweigh subsample. This subsample will be used to create a wet-to-dry ratio. This ratio will then be used to estimate the total dry weight of litter found within the clip plot.

10. It is allowable for there to be a delay between field data collection and laboratory analysis. However, cloth sample bags must be placed in a location that allows air drying to occur.



Figure: Example of litter clip plots

SOP SAMPLING SOIL CARBON

Field equipment

Soil corer or probe (for soil corer method only)

Non-breakable rod (for soil corer method only. Used to remove soil from corer/probe)

Soil bulk density rings (for soil pit method only)

Digging instrument (for soil pit method only)

Hammer (for soil pit method only)

Durable wood piece that covers diameter of bulk density rings (for soil pit method only)

Cloth bags (if soil core method is used, cloth bags must be at least ~40 cm length to accommodate total length of soil sample)

Durable plastic tarp

Permanent marking pen

Lab equipment

Drying oven

Laboratory scale

Capacity to analyze soil for C, dry combustion carbon analyzer preferred

Soil carbon is estimated by collecting soil to a certain depth and then analyzing it in a laboratory for carbon content. This information is then combined with a collected bulk density measurement to estimate the average mass of carbon within the soil to a certain depth.

Prior to Field Sampling

Prior to field data collection, the soil laboratory to be used must be identified. An assessment must be made to ensure the soil laboratory applies commonly accepted standard procedures for sample preparation (e.g., mixing and sieving), drying temperatures, and method for carbon analysis. In addition, the soil laboratory may have a minimum soil sample weight requirement for soil processing. For bulk density determination, make sure the lab dries the samples in an oven at 105˚C for a minimum of 48 hours. For soil carbon determination, the material is sieved through a 2-mm sieve and then thoroughly mixed. The dry combustion method using a controlled-temperature furnace (e.g., a LECO CHN-2000 or equivalent) is the recommended method for determining total soil carbon (Nelson and Sommers 1996) but the Walkley-Black method is also commonly used.

Field Measurements

1. Determine sampling location
    a. Where non-tree woody vegetation, non-woody vegetation, and/or litter samples have been taken, the same locations shall be used for soil sampling.
    a. Where soil sampling is taking place without sampling for litter and non-woody vegetation and it is in association with tree plots, sampling for soil can occur at 4 locations as follows:
        i. If using the single plot design, sample 4 locations at a single tree plot
        ii. If using the cluster plot design, sample one location at each of the 4 tree plots within the cluster.
    b. Where sampling is taking place in a land cover class without tree plots, the initial point of sampling shall be determined prior to entering the field. Sampling for soil should also occur at 4 locations around the initial point.
    c. Starting at the tree plot center or the sampling point, determine a random compass bearing. This can be done using various methods such as using a random number table. Another method is to use a watch that has a second hand. At a random moment one individual can

look at his/her watch and then the direction that the second hand is facing will be used as the compass bearing.

d. Using the compass bearing walk 30 paces from the tree plot center (e.g. outside the largest tree nest and thus tree plot boundary). If temporary tree plots are being used, it is allowable for the number of paces to be reduced, however, if permanent tree plots are being used, sampling point must be located outside the boundaries of the tree plot.

e. Walk 5 more steps (These additional steps reduce bias in choosing the sampling location).

2. Remove all vegetation and litter from the sampling location. Because the carbon concentration of organic materials is much higher than that of the mineral soil, including even a small amount of surface material can result in a serious overestimation of soil carbon stocks.

3. There are two options for sampling the soil: using a standard soil corer (option 1) or digging a small pit (option 2). Sampling forest soils with a standard soil corer can often present difficulties as the corer can hit roots frequently, which makes it difficult to extract a full core.

4. Option 1 – Soil corer method

   a. Insert the soil corer/probe steadily to standard depth of 30 cm.

   b. If the soil is compacted, use a rubber mallet to fully insert. If the probe will not penetrate to the full depth, do not force it as it is likely that a stone/root is blocking its route and if forced the probe will be damaged. If blocked withdraw the probe, clean out any collected soil, and insert in a new location.

   c. If depth of soil at sampling point is less than standard depth measured, then the depth of the soil sampled must be recorded.

   d. Carefully extract the probe and put soil into a cloth bag. Assign bag a unique ID number.

   e. To reduce variability, repeat steps a-d at a total of 4 points as per step 1b above.

   f. Mix all four samples thoroughly to a uniform color and consistency. It is important to take special care to remove pieces of litter and charcoal from samples at any sites.

   g. Place one thoroughly mixed subsample into a labeled sample bag. Ensure total weight of soil in bag is greater than the minimum soil weight required by the soil laboratory (if soil is very wet, this should be taken into consideration in determining mass of soil contained in soil sample bag).

   h. At each sampling location, take two additional cores for determination of bulk density. When taking cores for measurements of bulk density, care should be taken to avoid any loss of soil from the cores.

   i. Each sampling plot (e.g. single tree plot or cluster plot) will have three soil samples: 1 bag for soil carbon estimation, and 2 bags containing soil for bulk density determination.

5. Option 2- Soil pit method

   Four small pits, one at each of the four sampling locations, will be dug and aggregated into one sample.

   a. Dig a soil pit 30 cm deep, making sure that one of the walls is perpendicular to the soil surface. A folding entrenching shovel (military type, with a flat shovel) is usually light and versatile for digging the pit, however any digging instrument can be used.

   b. Using the shovel take a slice of soil from one of the walls of the soil pit. The slice should be uniform throughout the 30 cm profile, i.e. an equal amount of soil should be collected from the first 15 cm as the last 15 cm. Soil carbon usually decreases with depth, and if the slice collected contains more soil from the top of the pit versus the bottom the soil carbon estimate will be biased.

   c. Repeat steps a-c at the other 3 sampling locations.

   d. Mix all four samples thoroughly to a uniform color and consistency. It is important to take special care to remove pieces of litter and charcoal from samples at any sites.

   e. Place one thoroughly mixed subsample into a labeled sample bag. Ensure total weight of soil in bag is greater than the minimum soil weight required by the soil laboratory (if soil is very wet, this should be taken into consideration in determining mass or soil contained in soil sample bag).

   f. For each sampling plot, four measures of bulk density shall be taken using a bulk density ring. This should take place at each of the 4 sampling locations.

i. After removing the soil for carbon measurements, place the bulk density ring over the mid-point of the soil pit. This would normally be at 15 cm (see figure).

ii. Cover the ring with a piece of wood and hammer the ring into the side of the soil pit (avoid compacting the soil).

iii. When the ring is flush with the side of the soil pit dig around the ring until the soil ring can be removed along with all the soil inside. If soil falls out of the ring, the process must be repeated.

iv. Carefully place the soil contained in the bulk density ring into a sample bag and label

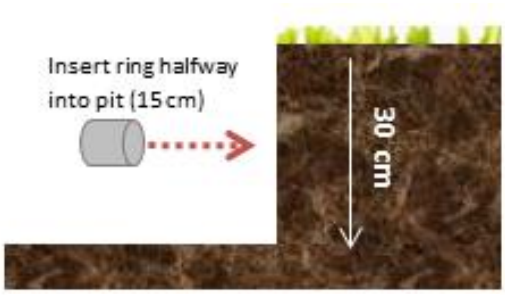


Figure Inserting a bulk density ring

j. Therefore, each sampling plot will have two soil samples: 1 bag for soil carbon estimation and 1 bag containing 4 rings of soil for bulk density estimation.

6. It is allowable for there to be a delay between field data collection and laboratory analysis. However, sample bags must be placed in a location that allows air drying to occur.
7. Promptly send soil samples to a professional lab for analysis.

References:

Nelson, D.W., and L.E. Sommers. 1996. Total carbon, organic carbon, and organic matter. p. 961-1010. In: D.L. Sparks et al. (eds.) Methods of soil analysis. Part 3.Chemical methods.SSSA, Madison, WI.

SOP MEASUREMENT OF STANDING DEAD WOOD

Field Equipment:
DBH tape
Clinometer
Laser range finder (OPTIONAL)
Relascope (OPTIONAL)
Measuring tape

Laboratory Equipment:
None

Other:
'Sound dead wood' density estimate (see SOP 6 Measurement of dead wood density)

Standing dead wood refers to trees that have died but are still upright. Usually the minimum size class of dead trees measured is the same as the minimum live tree measured (for example trees greater than 5 cm DBH and taller than 1.3 m). However, standing dead wood generally also includes dead wood stumps from trees that were greater than 5 cm DBH when alive but have a current height of less than 1.3 m. This SOP must be altered to describe the definition of deadwood that will be used and the exact approach that must be used for the field measurement of standing dead wood.

This SOP must be done in conjunction with the SOP Measurement and Estimation of Dead Wood Density.

Standing dead wood can be measured within the permanent or temporary plots used to measure live trees. Generally, measurements of standing dead wood take place concurrently with live tree measurements. It is recommended that standing dead trees be measured in the medium tree nest size. Each standing dead trees should be classified into two classes (see Figure below):

Class 1: Dead tree with branches and twigs and resembles a live tree except for absence of leaves (make sure tree is dead and not deciduous)

Class 2: Dead trees containing large branches or no branches at all, including stumps.

By classifying trees into these two simplified classes, a conservative estimate of biomass will be taken.

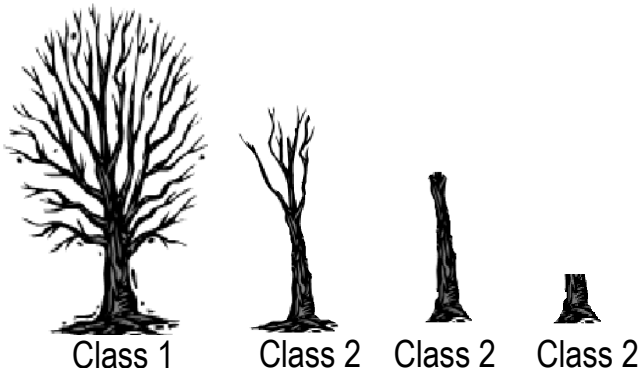


Figure: Example of trees in Class 1 and Class 2

Field Measurements

The design and establishment of plots shall be determined following SOP Plot Design and SOP Establishment of Plots. The instructions here assume these SOPs have already been followed.

Class 1 trees:

1. Follow the same measurement protocols as for the measurement of live trees, including the measurement of tree variables (eg DBH, H) (see SOP Measurement of Trees). If species/genus specific allometric equations require different field measurements, rules must be included in this SOP stating which field measurements will be made for which type of dead tree (for example – for all Class 1 dead trees, the 'other' tree allometric equation will used and DBH of dead trees will be measured.) If nested plots are used, it is recommended that dead trees be measured in the medium nest. Mark tree as 'Dead' on datasheet.

Class 2 trees (see Figure below):

1. The biomass of these trees is based on estimating the volume of the remaining tree and multiplying the volume by the wood density.
2. Measure DBH using methods for live trees. Measure all dead trees in medium nest.
3. Measure the diameter at the base of the tree. ($\mathbf{D}_{base}$)
4. Measure height of stem (H) either using a clinometer and measuring tape or laser range finder (see SOP Measurement of tree height) or through direct measurement using tape measure (eg when dead wood is less than 2 m high)
5. Measure diameter at top of stump ($\mathbf{D}_{top,}$) either through direct measurement (e.g. when diameter at top can be reached directly) or through the use of a relascope. Alternatively, do not take a measurement at the top of the stump and write 'None' or 'NA' on datasheet.

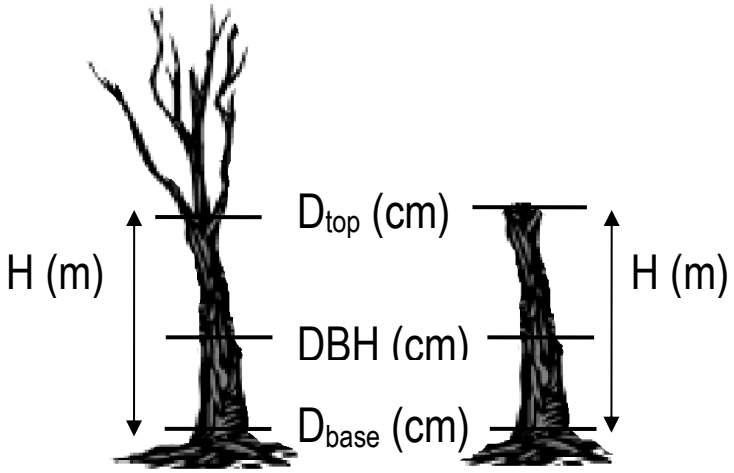


Figure2 Standing dead tree measurement locations

Volume Equations

A full description of the steps required to estimate standing dead wood biomass per hectare are not included here. However, equations are provided to estimate the volume of an individual standing dead tree. Different approaches can be used for different trees, depending on whether it is possible to measure the diameter at the top of a given dead tree.

To estimate the biomass of an individual standing dead tree, the estimated volume is multiplied by the average density calculated for 'sound wood' (see SOP Measurement of Deadwood Density).

1. Option 1: Diameter at top (Dt_{op}) was measured directly:

   Volume estimated assuming tree is a truncated cone:

   $$Volume = \left(\frac{\pi * Height}{12}\right) \cdot \left(D_{base}^2 + (D_{base} \cdot D_{top}) + D_{top}^2\right)$$

2. Option 2: Diameter at top (Dt_{op}) was measured using a Relascope:

   Volume estimated assuming tree is a truncated cone:

$$Volume = \left(\frac{\pi * Height}{12}\right) \cdot \left(D_{base}^2 + (D_{base} \cdot D_{top}) + D_{top}^2\right)$$

3. Option 3: Diameter at top (Dt_{op}) estimated using taper equation:

$$D_{top} = D_{base} - \left[H \cdot \left(\frac{D_{base} - DBH}{130 \cdot 100}\right)\right]$$

Volume estimated assuming tree is a truncated cone:

$$Volume = \left(\frac{\pi * Height}{12}\right) \cdot \left(D_{base}^2 + (D_{base} \cdot D_{top}) + D_{top}^2\right)$$

4. Option 4: Diameter at top (Dt_{op}) is assumed to be zero.
Volume estimated assuming tree is a cone

$$Volume = \frac{1}{3} \cdot \pi \cdot \left(\frac{D_{base}}{2}\right)^2 \cdot H$$

SOP MEASUREMENT OF LYING DEAD WOOD

Field Equipment:
Calipers (preferred) or DBH tape
Measuring tape
Two 50 m long ropes (with 25 m marked) or two 25 m long ropes
Machete

Laboratory Equipment:
None

Other:
Dead wood density estimates (see SOP Measurement of dead wood density)

Lying dead wood is measured using the line-intersect method outlined in Harmon and Sexton (1996)[4]. Lying dead wood is defined as all woody material on the ground with a diameter ≥10 cm. Smaller diameter pieces of wood are sampled as part of the litter pool (see SOP of Litter Layer).

This SOP must be done in conjunction with the SOP Measurement and Estimation of Dead Wood Density.

Prior to Field Sampling

Using the following method, dead wood is grouped into three dead wood classes: sound, intermediate, and rotten. Prior to field measurements, samples of each dead wood class shall be collected for demonstration purposes. So that consistent measurements are made throughout sampling, all field members must be trained on what type of dead wood will be considered in each class.

Field Measurements

The location of plots shall follow SOP Plot Design. It is common to locate lying dead wood transects in association with tree plots, however this is not required. If permanent tree plots are used, it is best practice to locate the line transect outside the permanent tree plot. This prevents damage inflicted on plot area through measurement from impacting lying dead estimates.

1. Starting at the tree plot center (or the sampling point when lying dead wood measurements are not associated with tree plots), determine a random compass bearing. This can be done using various methods such as using a random number table. Another method is to use a watch that has a second hand. At a random moment one individual can look at his/her watch and then the direction the second hand is facing will be used as the compass bearing.
2. Using the compass bearing, walk 100 paces from the plot center. (For permanent tree plots, sampling must take place outside the tree plot boundary. For temporary tree plots, the sampling can take place within the tree plot boundary)
3. Walk 5 more steps (These additional steps reduce bias in choosing the sampling location)
4. Lay out two 50 m lines at right angles outside plot. Determine the direction of the first line using same random compass angle as above and place the other line at right angle to first. If necessary, 4 25 m lines can be laid out. However, the lines should not overlap or cross into tree plot. (see Figure below)

[4]Harmon, M. E. and J. Sexton. 1996. Guidelines for measurements of woody detritus in forest ecosystems. Publication no. 20. U.S. Long-term Ecological Research (LTER) Network Office, University of Washington, Seattle, Washington, USA

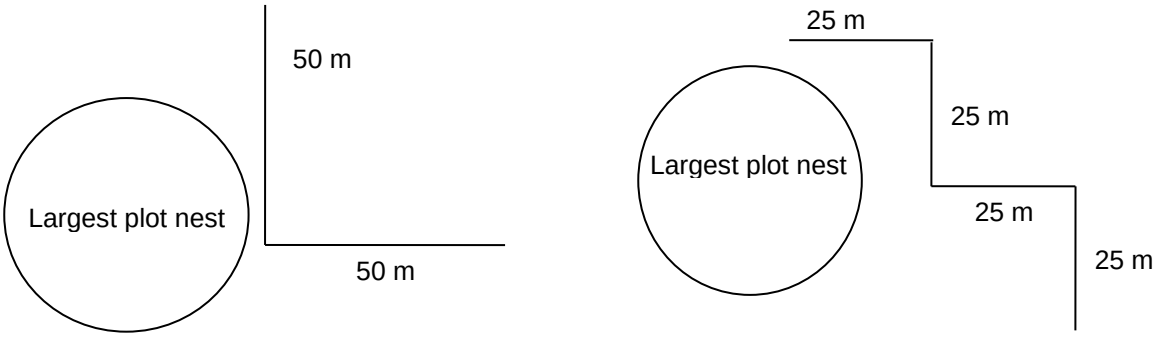


Figure: Two examples of the location of line transects to be used to estimate lying dead wood

5. Along the length of the line, measure the diameter of each intersecting piece of coarse dead wood (≥ 10 cm diameter) (see Figure below). Calipers work best for measuring the diameter. When measuring the diameter of dead wood it is not always possible to place a tape around the log. It can also be dangerous because logs are usually home to snakes, spiders, etc. If you are going to measure the diameter of the piece of dead wood with a diameter tape, make sure the route is clear before placing your hand underneath the log.



Figure: Use of callipers to measure the diameter of lying deadwood along line transect

6. A piece of dead wood should only be measured if: (a) more than 50% of the log is aboveground, and (b) the sampling line crosses through at least 50% of the diameter of the piece—see figures below. Some examples are displayed in the Figure below.

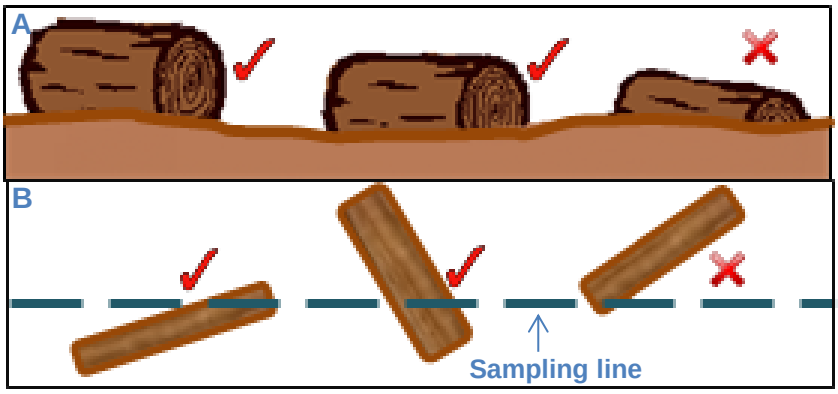


Figure A: Schematic of which dead wood should be measured. The first two logs should be measured because the log is more than 50% above ground, but the third log should not be measured. The horizontal line represents the soil surface.

Figure B: Schematic of which dead wood should be measured. The first two logs should be measured because the sampling line crosses more than 50% of the diameter of the logs. Conversely, the third log should not be measured because the sampling line does not cross more than 50%.

7. If the log is hollow at the intersection point, measure the diameter of the hollow; the hollow portion in the volume estimates is excluded.
8. Assign each piece to one of three density states: sound, intermediate, or rotten. To determine what density class a piece of dead wood fits into, each piece will be struck with a machete. If the machete does not sink into the piece (bounces off), classify it as sound. If the machete sinks partly into the piece, and there has been some wood loss, classify it as intermediate. If the machete sticks into the piece, if there is more extensive wood loss, and the piece is crumbly, classify as rotten. Record on data sheet.
9. The volume of lying dead wood and then carbon stocks will be estimated using the diameters of each piece of wood and the length of the line transect.

SOP MEASUREMENT AND ESTIMATION OF DEAD WOOD DENSITY CLASSES

Field Equipment:
Measuring tape
Chainsaw or handsaw
Cloth bags
Permanent marking pen

Laboratory Equipment:
Drying oven
Laboratory scale
1L Graduated cylinder with milliliter markings and wide mouth
Very fine elongated rod/needle

--TO BE CONDUCTED ONE TIME ON EVERY STRATUM DURING FIELD SAMPLING--

In the field, dead wood is classified into three dead wood density classes. This SOP provides the field measurement, laboratory measurements, and data analysis methods that shall be used to estimate the average density that will be assigned to each dead wood density class.

This field work and analysis needs to take place one time during a field sampling effort. This must take place for each stratum where dead wood will be measured. If only the standing dead wood pool is being measured, then only the density of 'sound wood' needs to be estimated. After the densities are determined, this SOP does not need to be repeated unless a new stratum is identified and measured.

Prior to Field Sampling:

1. Determine which type(s) of dead wood will be measured (standing and/or lying).
2. Determine where samples will be collected. The location where samples are collected should be representative of the stratum, however it is not necessary for samples to be collected in a random distribution throughout the stratum.
3. Randomly collect a small amount of around 30 samples of dead wood at various stages of decomposition from each of the stratum. These pieces will only be used to agree upon density classes and therefore can be collected close to any base camp directly prior to field measurements taking place.
4. All dead wood will be classified into three density classes: sound, intermediate, and rotten. These classes can be determined using the 'machete test'. The 'machete test' consists of raising the machete up to shoulder height and allowing it come down to the dead wood piece with the force of gravity. No additional force should be applied to the motion of the machete.
    a. Sound: : Machete does not sink into the piece (bounces off)—this does not necessarily mean the wood shows no sign of decomposition—lying dead wood can lose all the sapwood and bark but yet the heartwood is still sound—this would be classified as sound
    b. Intermediate: Machete sinks partly into the piece, and there has been some wood loss
    c. Rotten: Machete sticks into the piece, there is more extensive wood loss, and the piece is crumbly—the key here is that the dead wood is decomposed throughout and very soft and crumbly
5. Agreement shall be made on which pieces of wood fit into which dead wood density class. All field team members must be trained on all agree on consistent classes of dead wood.

Field measurements:

Collect wood samples for each density class for density determination (dry weight per green volume). The number of wood samples will depend on the variability between tree species within the forest. A minimum of 10 samples should be collected for each density class of each species group. For example, for a forest containing mixed broadleaf and palm species , a minimum of 10 samples of dead wood from each tree group should be collected per density class—for a total number of 30 samples for broadleaf species and 30 for palms.

1. For sound class of dead wood:
    a. Using a chainsaw or a handsaw, cut a complete disc from the selected piece of dead wood.
    b. Measure the diameter (L1 and L2) and thickness (T1 and T2) of the disc to estimate volume (Figure below). The dimensions of the sample should be recorded on data sheet. The fresh weight of the disc does not have to be recorded.
    c. All samples shall be placed in a labeled cloth bag.
    d. Samples shall be stored in location in manner that allows for air drying to take place prior to laboratory measurements.
    e. This sample will then be taken to the laboratory

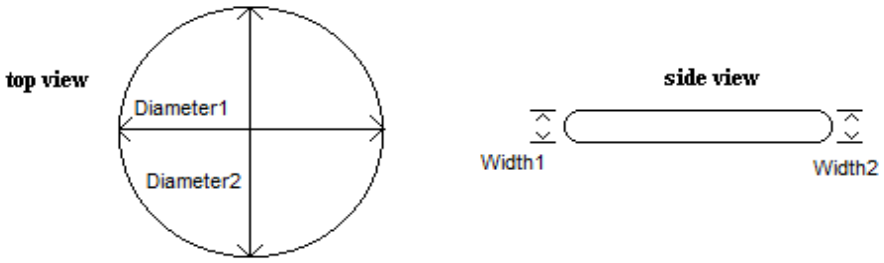


Figure: Measurements to be taken on disc cut from coarse dead wood samples

2. For intermediate and rotten classes:
    a. Collect a contiguous sample of the dead wood that is not too small nor too large (i.e. that fit in the graduated cylinder).
    b. Place sample in a bag, label the bag. Make sure sample doesn't break into smaller pieces when transporting it. If the sample is very crumbly, it can be placed on a piece of clear plastic wrap (e.g. cling wrap as used in food storage), and tightly wrapped around the piece of wood.
    c. This sample will be taken to the laboratory. Carefully transport sample to laboratory where it volume will be measured.
3. Train all field crew members on how different pieces of dead wood are should be classified, based on the sampling that was conducted.

Laboratory Measurements and Data Analysis:

1. Dry Weight: Place samples in drying oven at 70°C until sample reaches constant weight (i.e. all moisture is evaporated). Record the dry weight (g).
2. Volume: If the wood disc sampled from the field is a regular shape (eg circular disk) the 'calculated volume' method below can be used. If the wood disc is an irregular shape, the 'water displacement volume' method shall be used.
    a. Calculated Volume Estimate Method:
        i. Calculate the volume using the measurements taken in the field:

$$Volume = \pi * \left(\frac{\frac{Diameter_1 + Diameter_2}{2}}{2} \right)^2 * \left(\frac{Width_1 + Width_2}{2} \right)$$

Where:

Volume = Volume of sample;cm^3
$Diameter_1$ = First diameter of sample; cm
$Diameter_2$ = Second diameter of sample; cm
$Width_1$ = First width of sample; cm
$Width_2$ = Second width of sample; cm

ii. Calculate density using the following formula:

$$\text{Density} = \frac{Dry\_weight}{Volume}$$

Where:

Density = Density of sample; g/cm^3
Volume = Volume of sample; cm^3
Dry Weight = measured dry weight of sample; g

iii. Calculate the mean the density for that wood density class.

b. Water Displacement Method: The most commonly used technique to measure the volume of irregularly shaped objects.
   i. Create a subsample from the wood sample brought from the field. This subsample must fit inside the graduated cylinder to be used.
   ii. Weigh the subsample created and record weight.
   iii. Fill the graduated cylinder to a known volume (e.g. 1L). Make sure there is enough water to submerge the piece and enough empty room in the graduated cylinder to allow water to rise without spilling over.
   iv. Place dead wood sample inside the graduated cylinder.
   v. Using the very fine elongated needle, push sample under the water until completely submerged. Make sure water doesn't spill over or rise above the last milliliter marking on the graduated cylinder.
   vi. On the data sheet, record the volume of water displaced by submerging the sample. That is the volume of the sample collected.
   vii. Calculate density using the following formula:

$$\text{Density} = \frac{Dry\_weight}{Volume}$$

Where:

Density = Density of sample; g/cm^3
Volume = Volume of sample; cm^3
Dry Weight = measured dry weight of sample; g

c. Calculate the mean the density for that wood density class.

SOP DESTRUCTIVE SAMPLING OF TREES, SAPLINGS, PALMS, BAMBOO, AND NON-TREE WOODY VEGETATION

Field Equipment:
Professional chainsaw operator
Chainsaw
Handsaws
Machetes
DBH tape
Clinometer
Laser Range Finder or measuring tape (to measure height)
Tree corer
50 kg scale
5 kg scale
~300 g scale
Durable, but thin plastic sheeting ~2 m x 2 m
Durable plastic tarp ~2 m x 2 m
Cloth or paper sample bags for subsamples
Flagging tape
'Diameter fork' (see below)
Marker (to label bags and samples)
10 m of rope, 1 – 2 cm thick (to tie up scale and to weigh branches)
'Calibration weights' (see below)

Laboratory Equipment:
Drying oven
Laboratory scale

Biomass regression equations or 'allometric equations' are commonly used to estimate biomass based on one or more vegetation variables, such as diameter of trunk at 1.3 m. Different equations give different estimates for biomass because each one is designed for a specific type of forest and climate type. The existence of allometric equations that may be applicable to the species or vegetation type should be properly investigated. It must be determined if a species specific or vegetation-type specific allometric equation will be used. To either develop a new biomass regression equation or to check the appropriateness of an existing one, it is necessary to destructively sample the vegetation. The following methods describe how to destructively sample the vegetation. However, additional guidance is required to create a biomass equation.

Prior to Field Sampling

1. **Create 'calibration weights' to calibrate hanging scales:** Prior to going into the field, the scales that will be used to weigh samples must be calibrated. The ideal approach is to calibrate the scales that will be used in the field with the laboratory scale that will be used to measure the dry weight of subsamples.
    a. Ensure the laboratory scales are calibrated
    b. Large hanging scale (50 kg):
        i. Find an item that weighs about 10-30 kg and does not change weight when wet (e.g. metal tool of some sort) or over time. Weigh this item using the laboratory scale 5 times. Record weights and take average weight.

ii. Calibrate hanging field scale using this 'calibration weight' item and the average recorded weight. Do this every day prior to weighing items in field. This can take place at a base camp and therefore does not have to take place at the site of the destructive sampling. Ideally the item used to calibrate the scale should be a piece of field or base-camp equipment of an appropriate weight.

c. Medium hanging scale (5 kg):
   i. Find an item that weighs about 3 kg and does not change weight when wet (metal tool of some sort). Weigh this item using the laboratory scale 5 times. Record weights and take average weight.
   ii. Calibrate hanging field scale using this item and the average recorded weight. This can take place at a base camp and therefore does not have to take place at the site of the destructive sampling. Do this every day prior to weighing items in field.

d. Small hanging scale (~300 g):
   i. Find an item that weighs 100-250 g and does not change weight when wet (metal tool of some sort, stack of coins taped together). Weigh this item using the laboratory scale 5 times. Record weights and take average weight.
   ii. Calibrate hanging field scale using this item and the average recorded weight. This can take place at a base camp and therefore does not have to take place at the site of the destructive sampling. Do this every day prior to weighing items in field.

2. **Create Diameter Fork:** Create a diameter fork that has two openings equating to the size classes that will be used during destructive sampling (see Figure below). For example: 20 cm wide and 10 cm wide. Or create different diameter forks – eg one 20 cm opening and another with a 10 cm opening. The 'diameter fork' can be made out of plastic or aluminum, anything that is relatively stiff and will not break apart easily.

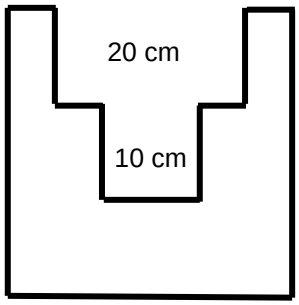


Figure Example of a diameter fork

Destructive Sampling of Trees

To ***verify the applicability*** of an existing selected biomass regression equation, select 5 trees to be destructively sampled. These trees should focus on the upper range of trunk diameters found in the sample population and must contain at least two large trees (if possible at least greater than 60-70 cm DBH). For large trees, the weight of the main bole of the tree will be estimated by measuring the volume and estimating the density of the tree. The branches of the tree are weighed directly by cutting the tree into parts and weighing the branches.

When developing ***new biomass regression equations*** (recommended for trees with unique forms or densities or for forests dominated with only 1-2 species), ***at least*** 30 trees covering the full range of diameter classes need to be harvested (if the 30 trees do not result in a significant equation with high r-squared, then additional trees will need to be harvested). Harvesting sufficient numbers of trees to develop new regression equations is very time intensive and one needs to make sure that none of the existing equations from the literature will suffice. Sampling locations should be selecting using a two-staged stratified sampling approach, as described in SOP Stratification, Sampling Design and Layout.

Prior to cutting down any tree, it is essential to obtain all necessary permits and secure authority to cut down the trees. Where possible, it is highly advisable to implement the destructive sampling of trees in locations where trees are being commercially harvested. It is recommended that a professional undertake the task of cutting the tree down. Felling trees is dangerous work, and everyone participating should observe the highest safety standards. To minimize the risk, it is recommended that information on the condition of the bole be ascertained by the chain saw user (generally common practice by professionals). If for example, the center of a tree is rotten, cutting into it with a chainsaw can cause the tree to collapse suddenly. If possible, have the tree cutter fell the tree in a location that will make measurements easy to obtain but above all in a safe location. People who are not cutting the tree should receive direction from the professional tree cutter and stand very far away from the tree in case it starts to fall in an unexpected direction.

If the diameter of the tree to be measured is less than 20 cm, then the size classes of tree components can be altered to include leaves, twigs, and branches <10 cm in diameter, and branches 10-20 cm in diameter.

Determining trees to destructively sample

Once the sampling point has been randomly identified (through a stratified two-stage sampling approach), assign each sampling location the tree size classes to be sampled. Navigate to the sampling location and find the GPS point. From the GPS point, using a compass, find direct north and start walking north. Destructively sample the first tree of the tree size class within 20 m of the line walking north. If the randomly selected tree of the correct size class cannot be safely felled, select the next closest tree within the same size class.

Prior to Tree felling

Before the tree is cut down, measure all tree parameters used in all potential biomass regression equations that may be applicable (e.g. DBH, total height, height to first branch, species). Care must be taken to measure all tree parameters using the exact same methods that would normally be used in the field.

8. Assign one person to record the data
9. Measure all the tree parameters that will be potentially used in the allometric equation to be developed and those in existing equations (eg DBH, DSH, H) for the tree to be destructively sampled prior to felling. For trees with more than one stem, the parameters for each stem must be measured separately and the weight of each stem must be measured separated. The height of the bole prior to branching must also be measured. It is important that the diameter tape is used properly using the following steps to ensure consistency of measurements:
    f. Record the name of the tree, based on tree naming system developed prior to field data collection.
    g. **Tree Pole placement**: For each tree, place the Tree Pole (1.3 m plastic pole) against the tree to indicate the location of measurement (eg DBH). Placement of the Tree Pole depends on the slope of the ground, leaning angle of the tree, and shape of the tree bole (see Figure below for correct placement of diameter tape).
        vi. **Slope:** Always place tree pole and measure diameter on the *upslope* side of the tree

vii. **Leaning tree**: Always measure the height of a measurement (1.3 m) parallel with the tree, *not* perpendicular to the ground. Therefore, if the tree is leaning, measure underneath the lean, parallel with angle of tree. If a tree is not straight, a tape measure must be used to measure the bole distance from ground to DBH.

viii. **Dead tree**: If a tree is in dead class 1 (see *SOP Measurement of Standing Dead Wood*), mark as dead on data sheet. Trees are considered alive if there are green leaves present. Even if there are only one or two green leaves present the tree is considered alive. However, in deciduous forests during a season when trees drop their leaves (ie dry season) a branch or the stem must be cut to verify that the cambium is alive in order to determine if the tree is alive or dead.

ix. **Multi-stem tree**: If the tree is multi-stemmed with forking below the point of measurement (eg 1.3 m), measure the diameter on each stem and tag the stems that exceed the minimum diameter for the nest. Record it as if each stem were a different tree on the data sheet, but with a note that the stems make up one tree.

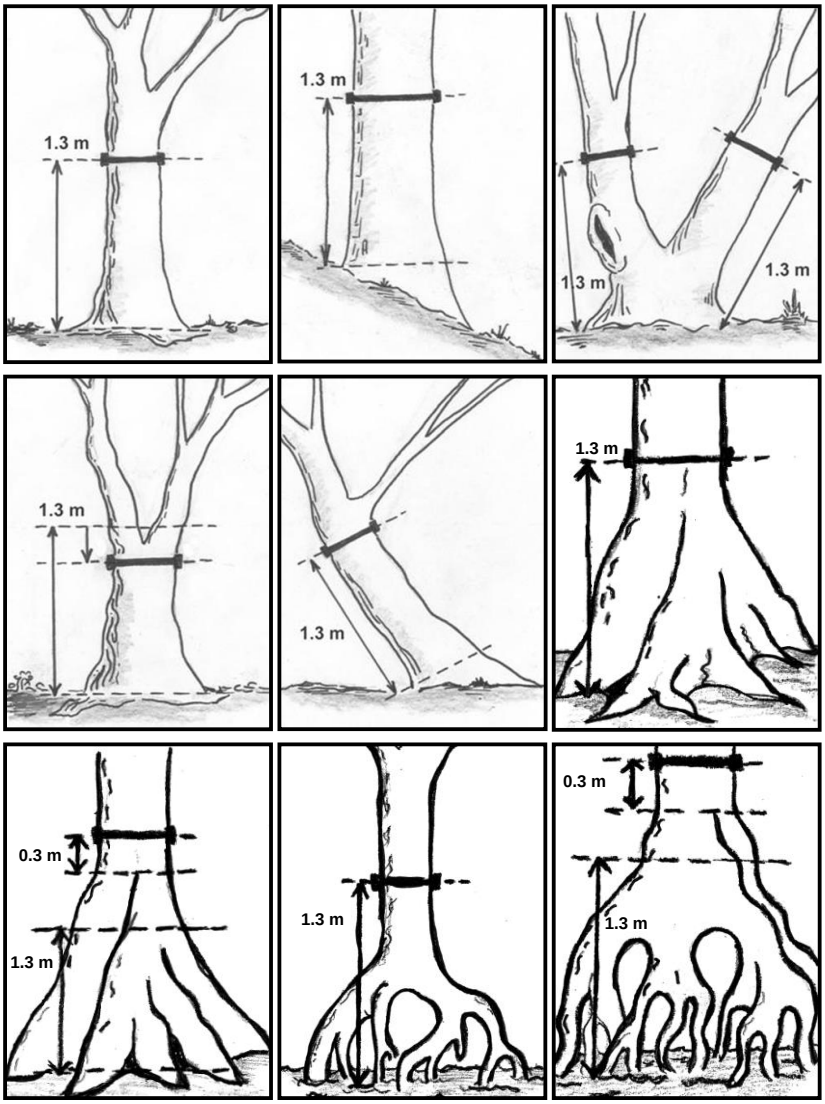


Figure: Proper placement of diameter tape

x. Buttressed tree

1. If the buttress is shorter than 1.3 m, measure the DBH at the standard (1.3 m) height.
2. If the buttress is taller than 1.3 m, measure the diameter at 30 cm above top of buttress as shown in figure below. In cases where buttress is too tall and out of reach, the following procedure shall be followed:

i) Use portable retractable ladder and lean ladder against tree to allow for measurement of DBH 30 cm above from the top of the buttress.

ii) If ladder is unavailable, and taking into consideration the safety of field crew, climb the tree to take measurement 30 cm above the top of the buttress. In fluted buttress, it is possible to carve steps on the buttress itself to allow climbing to top of buttress. Extreme caution should be employed and climbing should only be performed when conditions are deemed safe by field crew leader.

iii) If ladder is unavailable, and climbing is considered unsafe, retractable poles should be use. Poles shall be placed against the tree, at the edge of its circumference, projecting the diameter at exactly 30 cm above top of buttress down to the ground. An observer is required to ensure poles are properly placed at the very edge of tree's circumference in a way that linear distance between poles represents the diameter of tree at 30 cm above end of buttress. The **linear distance** between the two poles shall be measured. At least two measurements shall be taken on opposite sides of tree using this method, and then averaged to estimate tree DBH.

Note: The distance between poles shall be measured linearly, and thus proper measuring tape shall be used. Poles can be made from tall saplings found outside the sampling plot in the forest or by linking Tree Poles together (e.g. with pvc connectors).

h. **Diameter measurement:** Tree diameter should be measured to the nearest 0.1 cm (eg diameter of 10.2 cm *not* 10 cm).

iv. If the diameter tape has a hook, push the hook into the bark of the tree slightly to secure it and pull the tape to the right. The diameter tape should always start left and be pulled right around the tree, even if the person taking the measurement is left-handed. As the diameter tape wraps around the tree and returns to the hook the tape should be above the hook. The tape should not come around the tree below the hook. The tape should not be upside down; the numbers must be right side up. (see Figure below)

v. If a liana or vine is growing on a tree that is going to be measured, do not cut the liana to clear a spot to measure the tree's diameter. If possible, pull the liana away from the trunk and run the diameter tape underneath. If the liana is too big to pull away from the trunk, estimate the diameter of the liana and subtract from total tree diameter. Cutting a liana from a tree should only be done if there are no other options. The same standard should be followed for any other type of natural organisms (mushrooms, epiphytes, fungal growths, termite nests, etc.) that are found on the tree.

vi. Place chalk mark on the tree to indicate to crew members that the tree has been measured.



Figure: Measurement of diameter using a diameter tape and tree pole

i. **Other tree parameters:** Measure all other tree parameters included in the biomass regression equation to be used. If the allometric equation to be used requires height as an input for each tree/palm measured, two measurements of height should be taken to improve the precision of measurements, especially if it is difficult to identify the top of the tree/palm measured. See *SOP Measurement of Height* on how to measure tree height.

Tree Felling

1. Calibrate hanging scales at start of each day with 'calibration weights'.
2. A chainsaw operator must undertake the task of cutting the tree down and cutting the tree into components
3. After the tree is cut down the following measurements need to be made (see Figure below):
    a. Length of tree (from the stump to the top of the crown) (in meters to the nearest 0.01 m)
    b. Length of bole (from the stump to the first main branch) (in meters to the nearest 0.01 m)
    c. Diameter of stump (in cm to the nearest 0.1 cm)
    d. Diameter at breast height (in cm to the nearest 0.1 cm)
    e. Diameter at the center of bole (in cm to the nearest 0.1 cm)
    f. Diameter at top of bole (in cm to the nearest 0.1 cm)
    g. Where possible, after these measurements are made, the chainsaw operator should cut, or mark, the length of the bole that would be extracted for timber.
    h. Length of the commercial log and the diameter at both ends of the log (in meters to the nearest 0.01 m)

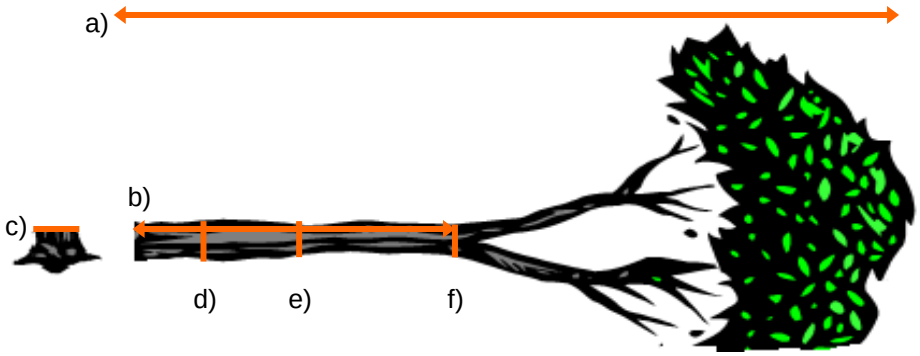


Figure Location of measurements following cutting down of tree

4. Attach a 50-kilogram (kg) scale to either a tripod or a strong branch (if the tree is smaller, a smaller scale can be used)
5. Divide tree into size classes and estimate weights:
    a. **Bole**: The bole is the main trunk of the tree, from the stump to the first major branch. To estimate bole biomass, volume measurements will be taken and a density value applied.
        i. Measurements to estimate volume of bole (see Figure below):
            a) Measure the total length of the bole
            b) Measure the diameter at ~5 m intervals along the bole to the first branch. Record the diameter and the length of each interval. Be sure to measure the diameter at the bottom and the top of the bole.

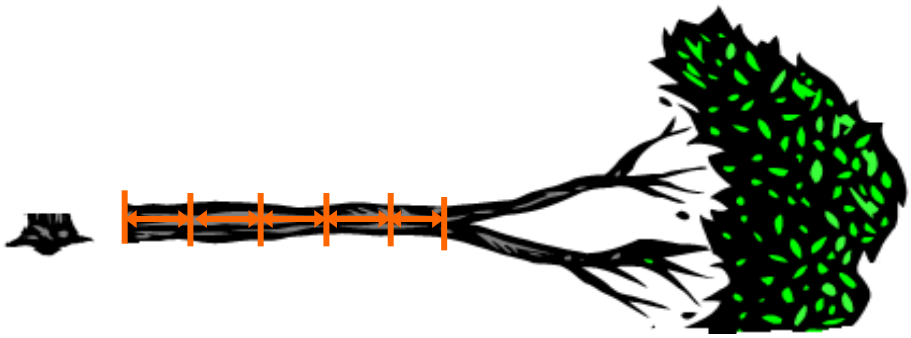


Figure Measurements of diameter and length along the bole of tree

1.

ii. Estimate Wood Density:

a) If verifying applicability of existing equation AND published wood density of species exists, the published wood density estimates will be used. No field measurements of wood density shall be taken. (See *SOP Wood Density* Reyes et al. 1992)

b) If creating new equation OR no published wood density of species exists, samples must be taken to estimate wood density. Disk samples must be taken from the main bole at several locations along its length.

i) Cut 5 disc samples from different sections of bole(if a commercial log will be extracted from tree then it may be difficult to obtain a sample from several places—instead collect a sample from top of the stump and bottom on the crown.)

ii) Record the dimensions of the disc (see Figure below). If the discs are too big to fit into any of the cloth or paper subsample bags, after the dimensions are measured carefully cut the disc into pieces and place the pieces into one bag. Try to minimize the wood fiber loss when cutting the discs. It is better to avoid cutting the disc if possible.

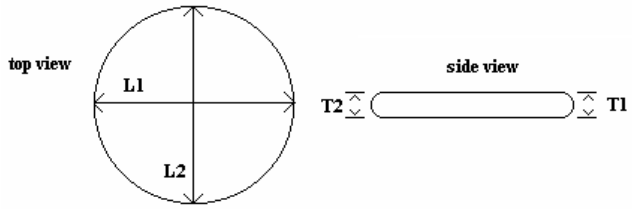


Figure: Wood disc measurement locations

iii) If the discs are too large and heavy to return to the laboratory they can be subsampled: either halved or quartered. Field sheets need to be annotated to this effect. The volume of the subsection will be estimated as either a quarter or half of the total volume estimated from the diameter and thickness measurements.

iv) Until samples are taken to the laboratory, place samples in location that allows air drying to occur.

v) Take discs to laboratory to estimate density. The fresh weights of disc samples do not need to be taken.

vi) Subsamples must be dried until a constant weight and weighed. To estimate density, divide dry subsampled weight by fresh volume of subsample. Alternatively, density may be estimated using the water displacement method. The calculated density will be used to estimate the weight of the entire bole.

b. Buttress:

i. If there is a buttress, the weight will need to be estimated.

ii. Cut the buttress into pieces and weigh on the scale. Record weight of each piece
iii. Take 2 sub-samples:
   a. Cut two 'pie pieces' out of the buttress (be sure both the center and edge of the buttress is included in a 'pie piece')
   b. Weigh each 'pie piece'
   c. Label each subsample and record weight
   d. Take subsample from field. Until samples are taken to the laboratory, place samples in location that allows air drying to occur. Bring to laboratory and dry subsample. Reweigh subsample. This subsample will be used to create a wet-to-dry ratio. This ratio will then be used to estimate the dry weight of the entire buttress.

c. Stump:

i. If stump is relatively small:
   a. After the bole and the other parts of the tree are measured cut the stump as close to the ground as possible.
   b. Cut the stump into pieces and weigh on the scale.
   c. Take 2 sub-samples:
      i. Cut two 'pie pieces' out of the buttress
      ii. Weigh each 'pie piece'
      iii. Label the subsample bag with the tree name, tree identification number, subsample identification number, and weight of subsample
      iv. Take subsample bag and subsample from field. Until samples are taken to the laboratory, place samples in location that allows air drying to occur. Bring to laboratory and dry subsample. Reweigh subsample. This subsample will be used to create a wet-to-dry ratio. This ratio will then be used to estimate the dry weight of the entire stump.
ii. If it is too big to cut up and weigh, estimate the volume of the stump through measurements. Measure the diameter at the base and top of the stump, along with the length of the stump. Tree density obtained from the bole measurements can be used to estimate the density of the stump.

d. Branches from 10-20 cm in diameter.

ii. Use the diameter fork to select branches that have a diameter from 10 to 20 cm.
iii. Use a chainsaw or hand saw to cut the branches and place them in a pile on the large plastic tarp
iv. Weigh the branches.
   a. Take a ~2 m x 2 m piece of plastic and weigh only the plastic. Record this weight
   b. Branches can be then placed on plastic and weighed.
   c. Alternatively, some branches can be weighed directly on scale.
v. Record the weights of all branches on the data sheet, noting if branches weighed on plastic or if were weighed directly.
vi. Take 5 sub-samples:
   d. Each subsample should weigh about 200-500 g. Each subsample should be made up of a mix of the sizes of branches found.
   e. Weigh the subsample bag empty. Record weight.
   f. Weigh the subsample bag with the subsample inside. Record weight.
   g. Label the subsample bag with the tree name, tree identification number, subsample identification number, and total weight of subsample and subsample bag.
   h. Take subsample bag and subsample from field. Until samples are taken to the laboratory, place samples in location that allows air drying to occur. Bring to laboratory and dry subsample. Reweigh subsample. This subsample will be used to create a wet-to-dry ratio. This ratio will then be used to estimate the dry weight of all branches 10-20 cm in diameter.

e. Leaves and branches < 10 cm in diameter:

i. Lay a large plastic tarp on the ground. Collect all the branches with a diameter <10 cm and all leaves. Note: the leaves **do not** need to be removed from the branches. Place vegetation on plastic tarp.
ii. Take a ~2 m x 2 m piece of plastic and weigh only the plastic. Record this weight
iii. Put a pile of the small branches and leaves onto the plastic and weigh. Record weight
iv. Repeat until all small branches and leaves have been weighed
v. Take 5 sub-samples:
    a. Each subsample should weigh about 200-500 g. Each subsample should be made up of a mix of the sizes of branches and leaves.
    b. Weigh the subsample bag empty. Record weight.
    c. Weigh the subsample bag with the subsample inside. Record weight.
    d. Label the subsample bag with the tree name, tree identification number, subsample identification number, and weight of subsample
    e. Take subsample bag and subsample from field. Until samples are taken to the laboratory, place samples in location that allows air drying to occur. Bring to laboratory and dry subsample. Reweigh subsample. This subsample will be used to create a wet-to-dry ratio. This ratio will then be used to estimate the dry weight of all the leaves and branches <10 cm in diameter.

Destructive Sampling of Palms

To *verify the applicability* of an existing selected biomass regression equation, select >5 individuals to be destructively sampled. These individuals should focus on the upper range of sizes found in the sample population. When developing ***new biomass regression equations***, ***at least*** 30 individuals covering the full range of sizes need to be harvested (if the 30 individuals do not result in a significant equation with high r-squared, then additional trees will need to be harvested).

1. Before cutting the palm, measure the palm parameters included in the equation to be verified. If a new equation is being created, measure all parameters that may serve as a good indicator of biomass. This would include: DBH, height of each stem, total height of each stem, number of palm fronds, and number of stems. Care must be taken to measure all parameters using the exact same methods that would normally be used in the field.
2. Calibrate hanging scales at start of each day with 'calibration weights'.
3. Cut it down and remeasure all the parameters possible, such as height of each stem and total height of palm.
4. Divide the palm into stem and palm fronds.
5. **Stem:**
    a. Weigh each stem.
    b. Cut stems into sections where needed.
    c. Record weight of each stem
    d. Take total of 5 sub-samples of stems from palm:
        i. Each subsample should weigh about 200-500 g. Each subsample should be made up of a mix of the sizes of stems.
        ii. Weigh the empty subsample bag. Record weight of just the bag.
        iii. Weigh the subsample bag with the subsample inside. Record weight.
        iv. Label the subsample bag with the palm identification number, subsample number, and weight of subsample
        v. Take subsample bag and subsample from field. Bring to laboratory and dry subsample. Reweigh subsample. This subsample will be used to create a wet-to-dry ratio. This ratio will then be used to estimate the dry weight of the palm.
6. **Fronds:**
    a. Weigh all palm fronds.
    b. Record weight of each frond
    c. Take a total of 5 sub-samples of fronds from palm:

i. Each subsample should weigh about 200-500 g. Each subsample should be made up of a mix of the sizes of fronds.
ii. Weigh the empty subsample bag. Record weight of just the bag.
iii. Weigh the subsample bag with the subsample inside. Record weight.
iv. Label the subsample bag with the palm identification number, subsample number, and weight of subsample
v. Take subsample bag and subsample from field. Bring to laboratory and dry subsample. Reweigh subsample. This subsample will be used to create a wet-to-dry ratio. This ratio will then be used to estimate the dry weight of the palm fronds.

Destructive Sampling of Bamboo

To ***verify the applicability*** of an existing selected biomass regression equation, select >5 samples to be destructively sampled. When developing ***new biomass regression equations***, ***at least*** 30 samples covering the full range of sizes need to be harvested (if the 30 individuals do not result in a significant equation with high r-squared, then additional individuals will need to be harvested).

If a new equation is being developed an assessment shall be made to determine what sampling strategy may be used to estimate bamboo biomass. This will vary depending on the growth structure of a given bamboo species. For some bamboo types, it may be determined that bamboo biomass will be estimated using the 'SOP Measurement of Non-woody Vegetation'. In this case a regression equation is not used and this step should not take place.

1. If an existing equation is being verified all variables included in the equation shall be measured. If a new equation is being created, measure all variables that may serve as a good indicator of biomass. This would include such things as: diameter at 0.30 cm, DBH, total height of each stem, number of stems, and basal area of culm. Care must be taken to measure all parameters using the exact same methods that would normally be used in the field.
2. Calibrate hanging scales at start of each day with 'calibration weights'.
3. Cut down all stems in sample
4. Weigh each stem and re-measure each stem. Record weights and height of each stem.
5. Weigh all stems
6. Take total of 5 sub-samples of stems from sample:
    a. Each subsample should weigh about 200-500 g. Each subsample should be made up of a mix of the sizes of stems.
    b. Weigh the empty subsample bag. Record weight of just the bag.
    c. Weigh the subsample bag with the subsample inside. Record weight.
    d. Label the subsample bag with the bamboo identification number, subsample number, and weight of subsample
    e. Take subsample bag and subsample from field. Bring to laboratory and dry subsample. Reweigh subsample. This subsample will be used to create a wet-to-dry ratio. This ratio will then be used to estimate the dry weight of the bamboo.

Destructive Sampling of Non-tree woody vegetation (shrubs)

See 'SOP Measurement of Non-tree Woody Vegetation' for a discussion on when the creation of an allometric equation for non-tree woody vegetation shall be created.

Prior to the creation of a new non-tree woody vegetation equation, research shall be conducted to determine whether any non-tree woody vegetation equations applicable to the non-tree woody vegetation found within the land use class exist. It must also be determined if a species specific or a general 'non-tree woody vegetation' allometric equation will be created.

To *verify the applicability* of an existing selected biomass regression equation, select >5 individuals to be destructively sampled. These individuals should focus on the upper range of sizes found in the sample population. When developing ***new biomass regression equations***, ***at least*** 30 individuals covering the full range of sizes need to be harvested (if the 30 individuals do not result in a significant equation with high r-squared, then additional individuals will need to be harvested).

1. If an existing equation is being verified all parameters included in the equation shall be measured. If a new equation is being created, measure all parameters that may serve as a good indicator of biomass. Care must be taken to measure all parameters using the exact same methods that would normally be used in the field. This would include such things as:
    a. diameter of each stem at 0.30 cm
    b. DBH of each stem
    c. total height of each stem
    d. number of stems
    e. total height of non-tree woody vegetation
    f. diameter of the crown in North-South direction and East-West direction
    g. diameter at narrowest point and diameter at widest point.
2. Cut down entire individual and weigh
3. Take total of 5 sub-samples from sample:
    a. Each subsample should weigh about 200-500 g. Each subsample should be made up of a mix of the sizes of stems and leaves.
    b. Weigh the empty subsample bag. Record weight of just the bag.
    c. Weigh the subsample bag with the subsample inside. Record weight.
    d. Label the subsample bag with the non-tree woody vegetation identification number, subsample number, and weight of subsample
    e. Take subsample bag and subsample from field. Bring to laboratory and dry subsample. Reweigh subsample. This subsample will be used to create a wet-to-dry ratio. This ratio will then be used to estimate the dry weight of the non-tree woody vegetation.

Destructive Sampling of Regenerating Vegetation / Fallow Cropland

Regenerating vegetation following cropping is often comprised of a variety of vegetation types, and therefore will require destructive sampling of saplings, small diameter trees, as well as non-tree woody vegetation. Prior to the undertaking of field data collection, a comprehensive assessment of shifting cultivation regimes should be conducted on shifting cultivation systems, fallow lengths, and geophysical conditions to determine appropriate strata. This process may elucidate the need to create specific allometric equations for different types of fallow cropland altogether.

At least five sites should be sampled per stratum, and vegetation classes should be delineated into woody herbaceous vegetation, bamboo, saplings, and trees. To ***verify the applicability*** of an existing selected biomass regression equation, select >5 samples of each vegetation class (i.e. woody herbaceous vegetation, bamboo, etc.) to be destructively sampled. When developing ***new biomass regression equations***, ***at least*** 30 samples covering the full range of sizes need to be harvested. If the 30 individuals do not result in a significant equation with high r-squared, then additional individuals will need to be harvested.

Trees

Although trees will likely be present in some fallow cropland areas, it is unlikely that large diameter trees will be growing in fallow cropland. Trees across the range of diameter classes should be targeted for measurement, including the upper range of DBH sizes.

Prior to Tree Felling

1. Assign one person to record the data
2. Measure all the tree parameters that will be potentially used in the allometric equation to be developed and those in existing equations (eg DBH, DSH, H) for the tree to be destructively sampled prior to felling. It is important that the diameter tape is used properly and protocols for tree measurement defined in *SOP Destructive Sampling of Trees* are followed.

Tree Felling

1. Calibrate hanging scales at start of each day with ‘calibration weights’.
2. A chainsaw operator must undertake the task of cutting the tree down and cutting the tree into components
3. After the tree is cut down the following measurements need to be made (see Figure below):
    i. Length of tree (from the stump to the top of the crown) (in meters to the nearest 0.01 m)
    j. Length of bole (from the stump to the first main branch) (in meters to the nearest 0.01 m)
    k. Diameter of stump (in cm to the nearest 0.1 cm)
    l. Diameter at breast height (in cm to the nearest 0.1 cm)
    m. Diameter at the center of bole (in cm to the nearest 0.1 cm)
    n. Diameter at top of bole (in cm to the nearest 0.1 cm)
    o. Where possible, after these measurements are made, the chainsaw operator should cut, or mark, the length of the bole that would be extracted for timber.
    p. Length of the commercial log and the diameter at both ends of the log (in meters to the nearest 0.01 m)

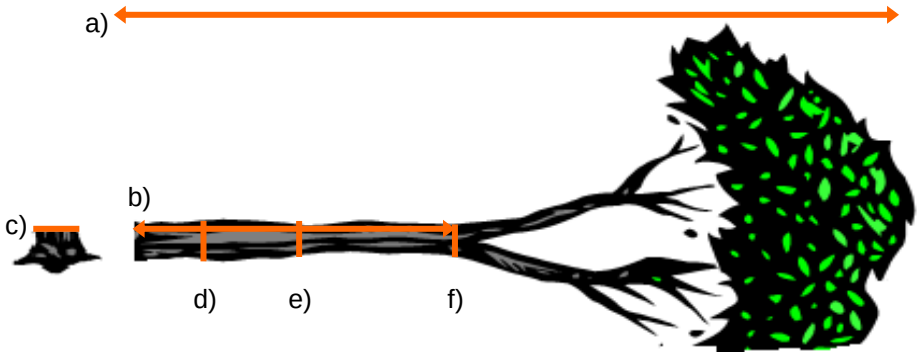


Figure Location of measurements following cutting down of tree

4. Attach a 50-kilogram (kg) scale to either a tripod or a strong branch
5. Divide tree into size classes and estimate weights:

b. **Bole**: The bole is the main trunk of the tree, from the stump to the first major branch. To estimate bole biomass, volume measurements will be taken and a density value applied.

iii. Measurements to estimate volume of bole (see Figure below):

a) Measure the total length of the bole

b) Measure the diameter at ~5 m intervals along the bole to the first branch. Record the diameter and the length of each interval. Be sure to measure the diameter at the bottom and the top of the bole.

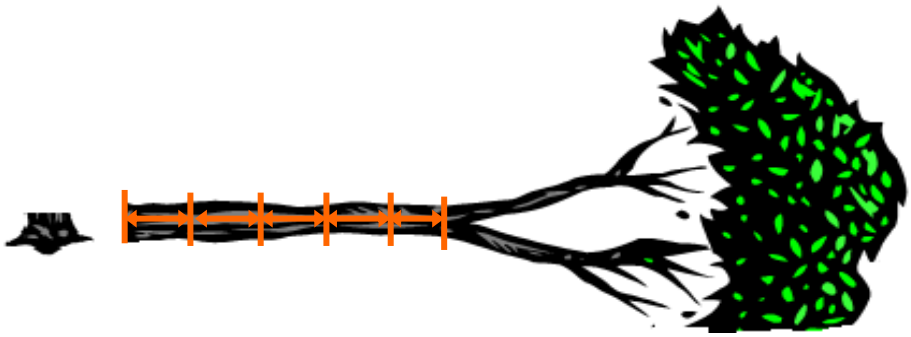


Figure Measurements of diameter and length along the bole of tree

2.

iv. Estimate Wood Density:

c) If verifying applicability of existing equation AND published wood density of species exists, the published wood density estimates will be used. No field measurements of wood density shall be taken. (See *SOP Wood Density* Reyes et al. 1992)

d) If creating new equation OR no published wood density of species exists, samples must be taken to estimate wood density. Disk samples must be taken from the main bole at several locations along its length.

vii) Cut 5 disc samples from different sections of bole(if a commercial log will be extracted from tree then it may be difficult to obtain a sample from several places—instead collect a sample from top of the stump and bottom on the crown.)

viii) Record the dimensions of the disc (see Figure below). If the discs are too big to fit into any of the cloth or paper subsample bags, after the dimensions are measured carefully cut the disc into pieces and place the pieces into one bag. Try to minimize the wood fiber loss when cutting the discs. It is better to avoid cutting the disc if possible.

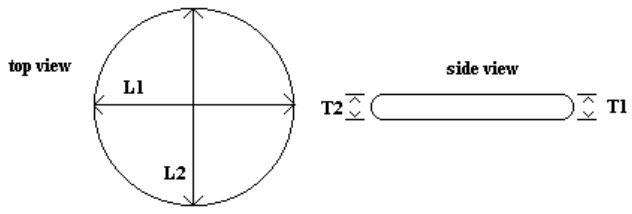


Figure: Wood disc measurement locations

ix) If the discs are too large and heavy to return to the laboratory they can be subsampled: either halved or quartered. Field sheets need to be annotated to this effect. The volume of the subsection will be estimated as either a quarter or half of the total volume estimated from the diameter and thickness measurements.

x) Until samples are taken to the laboratory, place samples in location that allows air drying to occur.

xi) Take discs to laboratory to estimate density. The fresh weights of disc samples do not need to be taken.

xii) Subsamples must be dried until a constant weight and weighed. To estimate density, divide dry subsampled weight by fresh volume of subsample. Alternatively, density may be estimated using the water displacement method. The calculated density will be used to estimate the weight of the entire bole.

f. Buttress:

iv. If there is a buttress, the weight will need to be estimated.

v. Cut the buttress into pieces and weigh on the scale. Record weight of each piece

vi. Take 2 sub-samples:

a. Cut two 'pie pieces' out of the buttress (be sure both the center and edge of the buttress is included in a 'pie piece')

b. Weigh each 'pie piece'

c. Label each subsample and record weight

d. Take subsample from field. Until samples are taken to the laboratory, place samples in location that allows air drying to occur. Bring to laboratory and dry subsample. Reweigh subsample. This subsample will be used to create a wet-to-dry ratio. This ratio will then be used to estimate the dry weight of the entire buttress.

g. Stump:

iii. If stump is relatively small:

d. After the bole and the other parts of the tree are measured cut the stump as close to the ground as possible.

e. Cut the stump into pieces and weigh on the scale.

f. Take 2 sub-samples:

i. Cut two 'pie pieces' out of the buttress

ii. Weigh each 'pie piece'

iii. Label the subsample bag with the tree name, tree identification number, subsample identification number, and weight of subsample

iv. Take subsample bag and subsample from field. Until samples are taken to the laboratory, place samples in location that allows air drying to occur. Bring to laboratory and dry subsample. Reweigh subsample. This subsample will be used to create a wet-to-dry ratio. This ratio will then be used to estimate the dry weight of the entire stump.

iv. If it is too big to cut up and weigh, estimate the volume of the stump through measurements. Measure the diameter at the base and top of the stump, along with the length of the stump. Tree density obtained from the bole measurements can be used to estimate the density of the stump.

h. Branches from 10-20 cm in diameter.

vii. Use the diameter fork to select branches that have a diameter from 10 to 20 cm.

viii. Use a chainsaw or hand saw to cut the branches and place them in a pile on the large plastic tarp
ix. Weigh the branches.
    i. Take a ~2 m x 2 m piece of plastic and weigh only the plastic. Record this weight
    j. Branches can be then placed on plastic and weighed.
    k. Alternatively, some branches can be weighed directly on scale.
x. Record the weights of all branches on the data sheet, noting if branches weighed on plastic or if were weighed directly.
xi. Take 5 sub-samples:
    l. Each subsample should weigh about 200-500 g. Each subsample should be made up of a mix of the sizes of branches found.
    m. Weigh the subsample bag empty. Record weight.
    n. Weigh the subsample bag with the subsample inside. Record weight.
    o. Label the subsample bag with the tree name, tree identification number, subsample identification number, and total weight of subsample and subsample bag.
    p. Take subsample bag and subsample from field. Until samples are taken to the laboratory, place samples in location that allows air drying to occur. Bring to laboratory and dry subsample. Reweigh subsample. This subsample will be used to create a wet-to-dry ratio. This ratio will then be used to estimate the dry weight of all branches 10-20 cm in diameter.

i. Leaves and branches < 10 cm in diameter:

vi. Lay a large plastic tarp on the ground. Collect all the branches with a diameter <10 cm and all leaves. Note: the leaves **do not** need to be removed from the branches. Place vegetation on plastic tarp.
vii. Take a ~2 m x 2 m piece of plastic and weigh only the plastic. Record this weight
viii. Put a pile of the small branches and leaves onto the plastic and weigh. Record weight
ix. Repeat until all small branches and leaves have been weighed
x. Take 5 sub-samples:
    f. Each subsample should weigh about 200-500 g. Each subsample should be made up of a mix of the sizes of branches and leaves.
    g. Weigh the subsample bag empty. Record weight.
    h. Weigh the subsample bag with the subsample inside. Record weight.
    i. Label the subsample bag with the tree name, tree identification number, subsample identification number, and weight of subsample
    j. Take subsample bag and subsample from field. Until samples are taken to the laboratory, place samples in location that allows air drying to occur. Bring to laboratory and dry subsample. Reweigh subsample. This subsample will be used to create a wet-to-dry ratio. This ratio will then be used to estimate the dry weight of all the leaves and branches <10 cm in diameter.

ESTIMATION OF CARBON STOCK DAMAGE FROM SELECTIVE LOGGING SOPS

Selective logging is the harvesting of a portion of the trees in a stand or forest. When specific trees are cut, there will usually be additional damage to the forest area resulting in a change in various carbon pools. This includes damage and/or death of other trees and other vegetation types and the creation of new trails, roads, and logging decks. Following selective logging, the annual biomass accumulation rate in the remaining forest may also be affected.

The calculation of forest carbon stock damage from selective logging involves the use of two SOPs:

- SOP Carbon Stock Damage in Logging Gaps Due to Tree Felling
- SOP Area Damaged due to log extraction

By following this framework, emission factors can be created between the volume of timber extracted and the change in carbon pools. Once created, such emission factors can be used to estimate the change in carbon pools based on the volume of timber extracted and length of infrastructure constructed to allow extraction.

Field methods to estimate the long term impact of selective logging on tree biomass accumulation in the area directly impacted by the logging are included in the SOP:

- SOP Measurement of the Regrowth after Selective Logging

These field methods are designed to estimate carbon stock damage only under logging with specific criteria:

- Selective logging areas remain above the definition of a forest after logging has taken place. If logging is extensive and results in either areas that are heavily degraded or do not meet the country definition of a forest, this method is unlikely to produce reliable estimates.
- The tree top/crown remains in the forested area and is not removed
- The logging practice does not pile and/or burn logging slashes.

Prior to data collection, the sampling design strategy and the area where sampling will take place must be determined. This sampling design must include steps for identifying which roads, skid trails, and tree felling areas will be measured. This SOP must be altered to describe the sampling design approach and rules.

Where selective logging takes place within known and delineated areas (such as logging blocks), sampling can take place within randomly or systematically chosen sub-areas of the selective logging area (population of interest). Within the population of interest, sampled trees maybe selected using a random or systematic with random start approach (for example: ‘every 3rd logging gap will be measured’).

It is highly recommended that data collection take place immediately after felling timber-tree, prior to substantial regrowth of vines and non-woody vegetation that may obscure damaged trees and trails. In many moist-wet tropical areas, such sampling is recommended to occur within three months of tree felling.

It is also recommended to have the field crew include individual(s) that participated in the selective logging operations that took place or who are familiar with the logging and management practices of the selectively logged area. Such an individual may serve either as a guide or as a field crew member.

This method is dependent on being able to accurately estimate the DBH of the tree, and the volume of log removed from each individual timber tree cut. Volume is estimated by measurement of the diameters of the timber tree and the length of the timber removed. Therefore, the measurement of DBH, diameters, and length of the log should be directly measured prior to removal of the log from the site. If necessary, the measurement of DBH and log length and the other measurements can take place at different times.

The sampling design developed must include what procedures to follow in instances when the actual log has been removed or moved prior to field measurements taking place. This will require methods to estimate the volume of the log removed. If the crown of the timber-tree has also been moved by equipment, or it has slid/fallen down a slope, it may be impossible to estimate the length of the log. It is allowable for the sampling design rules to indicate that no measurements shall take place in logging gaps where the log has been removed and/or when the crown of the tree has been moved.

The methods provided can also be used to estimate the volume of potentially merchantable timber that is not currently removed for timber (e.g “avoidable wood waste”). If this estimate is desired, the minimum size diameter accepted by the sawmill must be known prior to field data collection.

SOP CARBON STOCK DAMAGE IN LOGGING GAPS DUE TO TREE FELLING

Field Equipment:

Flagging
Machete or knife
GPS receiver
DBH tapes
Measuring tape
Saw or blade to cut wood discs and branches
50 kg scale
Clippers to remove vegetation
~5 kg Hanging scale (will be dependent on expected weight of vegetation)
300 g Hanging scale (for subsamples)
Durable plastic sheeting
Durable plastic tarp
Paper or cloth sampling bags
Permanent marking pen
Compass
Analog watch (e.g. one with hands)
Calibration weights (see below)

Laboratory Equipment:

Drying oven
Laboratory scale

This SOP describes methods for estimating the biomass of the timber tree(s) felled and the biomass of any other trees that are killed or damaged when the timber tree is felled. The concept underlying these methods is based on the "Gain-Loss" method described by the IPCC (2006). The measurements taken within this SOP can be used to create a relationship between the volume of timber removed and the reduction in live tree biomass from such logging activities. This relationship can then be used to estimate the change in live tree biomass in logging gaps from measurements of timber volume extracted.

The sampling design must include steps for determining which felled tree spots will be measured. Under selective logging, the cutting of one or more trees for timber at a given spot is here referred to as a 'logging gap'. The portion of the timber-tree extracted out of the forest for commercial use and/or processing is referred to as the 'log'. This SOP must be altered to describe the specific rules that will be followed.

Estimating carbon emissions due to selective logging practices consists of an investigative activity, where field technicians must take accurate measurements. Amongst the measurements taken in the field, **DBH** and the **volume of timber removed** are especially **important**. These measurements must be accurate and reflect the real conditions in the field (see figure below).

The measurement of DBH and the field measurements to estimate volume of the timber log should be taken directly prior to the removal of the log(s) from the site. This requires that the log must have been cut and not removed when field measurements occur. Therefore, interactions between the logging activity and field measurements must be well coordinated. When necessary, the measurement of tree DBH and of the log, and the other measurements of damage presented below can take place at different times. When this occurs, the stump of each logged tree measured must be tagged and extreme care must be taken to ensure that the correct log measurements are matched with the respective felled timber-tree damage measurements. If the log has been removed and no measurements of DBH and log length have been taken, alternative measurements are presented below to estimate these attributes. However, this is strongly discouraged as it may increase uncertainties.

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Prior to Field Sampling

1. **Establish sampling design:** Prior to field sampling, the sampling design must be established. This should include the area where sampling will occur and steps for choosing which logging gaps to measure.
2. **Establish arrangements with logging operators:** Since some field measurements must take place prior to the removal of the log itself, all activities must be coordinated between those responsible for the logging and those taking field measurements to ensure safety.
3. **Identify timber volume estimation methods:** In locations where the volume of timber extracted is well inventoried, identify the field methods used to estimate timber volume. These measurement methods shall be repeated in the field. This SOP shall be altered to include these measurement steps.
4. **Create 'calibration weights' to calibrate hanging scales:** Prior to going into the field, the scales that will be used to weigh samples must be calibrated. The ideal approach is to calibrate the scales that will be used in the field with the laboratory scale that will be used to measure the dry weight of subsamples.
    a. Ensure the laboratory scales are calibrated
    b. Large hanging scale (50 kg):
        i. Find an item that weighs about 10-30 kg and does not change weight when wet (e.g. metal of some sort) or over time. Weigh this item using the laboratory scale 5 times. Record weights and take average weight.
        ii. Calibrate hanging field scale using this 'calibration weight' item. Do this every day prior to weighing tree-parts in field. This can take place at a base camp and therefore does not have to take place at the site of sampling. Ideally the item used to calibrate the scale should be a piece of field or base-camp equipment of an appropriate constant weight.
    c. Medium hanging scale (5 kg):
        i. Find an item that weighs about 3 kg and does not change weight when wet (metal of some sort). Weigh this item using the laboratory scale 5 times. Record weights and take average weight.
        ii. Calibrate hanging field scale using this 'calibration weight' item. This can take place at a base camp and therefore does not have to take place at the site of sampling. Do this every day prior to weighing items in field.
    d. Small hanging scale (~300 g):
        i. Find an item that weighs 100-250 g and does not change weight when wet (metal of some sort, stack of coins taped together). Weigh this item using the laboratory scale 5 times. Record weights and take average weight.
        ii. Calibrate hanging field scale using this 'calibration weight' item a. This can take place at a base camp and therefore does not have to take place at the site of sampling. Do this every day prior to weighing items in field.

Establishing Logging Gap to be measured:

1. Once the logging gap has been identified, walk around the area to determine how many felled timber trees are located within the specific logging gap. The felled timber trees and all killed and/or damaged trees caused by tree felling will be measured as one logging gap plot. Measurements must be taken for each felled timber tree.
2. Where the log has been removed prior to data collection (if allowed in sampling design):
    a. Locate the stump and crown of each felled tree. Be sure to verify that the crown is from the selected stump by determining the angle of the tree fall, species and reasonable distance from stump.
    b. Determine if it appears whether one or more of the timber-tree crowns have moved from the point of felling. This would include being moved by a piece of equipment or simply through sliding down a steep slope. Under some conditions is possible to determine the original location of the crown even after it has been moved. For example, a long line of sawdust. If it is suspected one or more crowns have moved, follow the sampling design rules. These rules may indicate that the particular logging gap should not be measured.

   c. Depending on the sampling design rules, if the crown of one felled tree has been moved or cannot be located, the entire logging gap shall not be measured.

3. At one of the timber-tree stumps within the logging gap, mark a 'waypoint' on GPS and record GPS coordinates, accuracy, elevation, and waypoint number on data sheet. To record a GPS location, place the GPS at the location and let it record for > 5 minutes prior to marking a 'waypoint'. The minimum precision level should be ±5 m. Leaving the GPS at one location for several minutes allows the GPS to get a more accurate location by averaging many location acquisitions. The longer the GPS acquires locations the more accurate is the final location of waypoint. The accuracy of the location is estimated and is displayed by the GPS. If there is heavy vegetation cover it may take a longer time to acquire an accurate location. In some cases, it may be necessary to move slightly. For more information, see SOPs on the use of GPS and the manual of the GPS being used[5].
4. Label the plot based on SOP Labeling Plots. All felled timber-trees and incidental damage within one logging gap should be labeled under the same plot.
5. Label each timber-tree within the plot. If measurements of the timber log and other field measurements are taken separately, then the stump of each timber tree must be tagged.
6. Describe land and vegetation conditions of plot and if there is anything unique or unusual in the plot or directly surrounding the plot. This could include things such as small streams, trails, rocky outcroppings, and the existence of steep slope.

Measurements on Felled Tree(s) to Estimate Tree Biomass and Volume of Timber:

1. These measurements must be taken for each felled timber-tree in the logging gap.
2. All measurements should be measured to the nearest 0.1 cm
3. Locate stump and crown of the logged tree. Identify all sections of the log that will be extracted and of the timber tree bole and buttress that are not part of the log to be extracted and will remain in the forest.
4. Record tree species
5. Measure timber-tree DBH (and/or other tree attributes used in tree allometric equation to estimate biomass, e.g. height)
   a. If log is still present and the stump is tall enough, measure DBH directly according to SOP Measurement of Trees (including rules for the measurement of DBH on buttressed trees).
   b. If log is still present and the stump is too short to measure DBH on the stump, follow SOP Measurement of Trees, to attempt to determine the location of DBH prior to the felling of the tree. This may include measuring the height of the stump and section(s) of bole until 1.3 m is reached. For example, if the stump height (H_{stump}) is 0.850 m and the first bole section is 2.3 meters, measure the diameter of the bole section at 0.450 m (0.850 m + 0.450 m = 1.3 m).
   c. If the log has been extracted and DBH would have been located on the log, the data sheet should indicate that no DBH measurement could be taken.
6. If the tree is buttressed, measure the height where the buttress ends ($H_{Buttress}$) and the diameter of the bole directly above the buttress ($d_{buttress}$).
7. Measurements on the stump of the tree:
   a. Measure the height of the remaining stump (H_{Stump}).
   b. Measure the diameter at the top of the stump (d_S).
      i. If the tree is not buttressed at the top of the stump, measure the diameter of the stump as a tree (wrapping the tape around the stump) (see SOP Measurement of Trees).
      ii. If the tree is buttressed at the top of the stump, measure the diameter of buttressed stump using a compass and watch and taking three measurements total: 12 to 6, 2 to 8, 4 to 10, where 12 o'clock always points due north when diameter

[5] If a Garmin GPS Map60 is being used, the following steps can be used: a) prior to saving new waypoint, press MENU. b) Highlight 'Average Location' and press ENTER. c) Let GPS sit for many minutes until 'Estimated Accuracy' stabilizes. d) press ENTER to save location. (see manuals at www.garmin.com for more information)

measurement is horizontal. Record all three measurements on the datasheet. During data analysis, the average of these three measurements will be the diameter of the top of the stump (d_S)

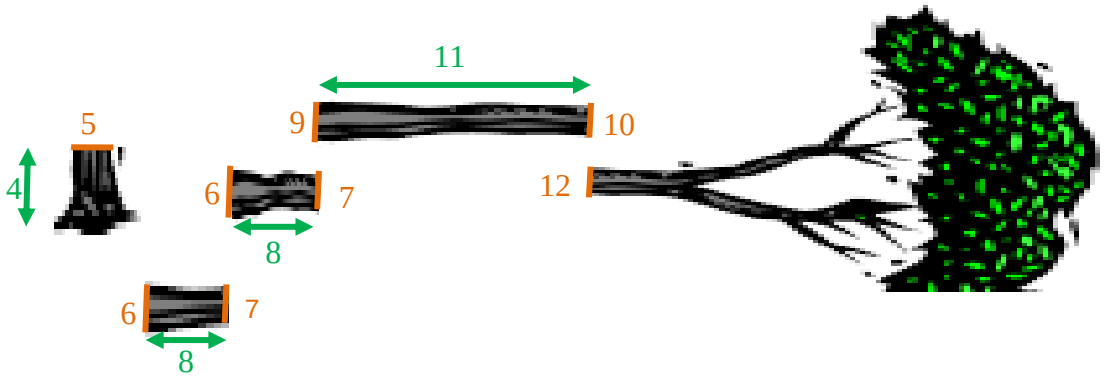
8. Measurements on buttress and bole sections remaining in forest:
    a. For each section of the buttress and/or bole of the tree cut and left in the forest (i.e. will not be removed for timber), take measurements to estimate the volume. Measure the length ($l_{Piece,n}$) and the diameter at the bottom ($d_{Piece\text{-}B,n}$) and top of the piece ($d_{Piece\text{-}T,n}$).
    b. If the piece is buttressed at the top or bottom, measure the buttress diameter using a watch and taking three measurements total: 12-to 6, 2 to 8, 4 to 10, where 12 o'clock always points due north when diameter measurement is horizontal, or upward to the sky when diameter is vertical (i.e. piece lying on the ground).
9. Measurements on log(s) that will be extracted for timber:

    The following measurements shall be taken to estimate the volume of timber that will be removed from the forest. If the bole of timber-tree has been cut into more than one piece, take measurements on each piece so that the volume of each log can be calculated.
    a. Measure the diameter at the base ($d_{log\text{-}B)}$) and top ($d_{log\text{-}T)}$) of log.
    b. Measure the length of log (l_{Log}). The length of the log is the length that will be extracted for timber.
        i. If the log is still present, take measurements on the log itself directly.
        ii. If log has not yet been removed and the bottom and top cuts of the log have not yet been made, the field crew must assess location where bole will be cut at the bottom (if lower portion of bole will not be taken as a log) and at the top (at the base of the crown), and then measure this distance, which represents the length of the log. Expert knowledge will be necessary to accurately ascertain the location these cuts – this should be attained by consulting with the chainsaw operator that will cut the bole into a log, or based on expert judgment of harvesting operations manager if available onsite.
        iii. If the log has already been extracted, the length of the log is the length between the top section of the piece remaining and the bottom of the crown left in the forest. If the entire bole is removed, the length of the log is the distance measured from the stump to the bottom of the crown of timber-tree left in the forest. If sections of the bole remain, rules must be delineated to state how this distance will be estimated. The most accurate procedure will be somewhat dependent on the logging practices. (For example, this distance can be estimated as the distance from the top of the stump to the bottom of the crown, minus the total length of each tree piece and buttress section left in the forest.)
10. Measurements on tree crown:

    Measure the diameter of the bole at the top cut (d_{Top}). Above this point is the remaining bole and crown that are not extracted from the forest.
11. Measurements on 'merchantable waste':

    It is also possible to estimate the volume of merchantable waste left in the forest. To do this, take measurements of each piece of bole and branch that meets the minimum diameter accepted by sawmills. Measure the diameter at the bottom ($d_{AMW\text{-}B,n}$) and top of each piece ($d_{AMW\text{-}T,n}$) along with the length of each piece ($l_{AMW,n}$). (Please note: these measurements are only used to estimate merchantable waste and therefore are not required to estimate the damage from logging.)
12. Logging practice timber volume measurements:

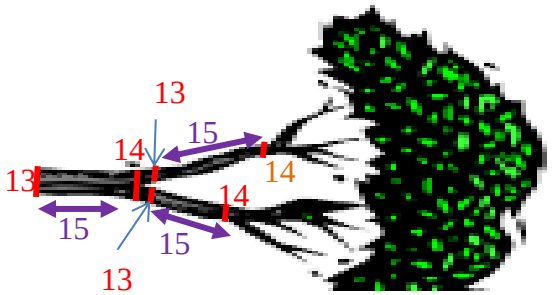
    Take all field measurements that are taken normally by timber crews to estimate the volume of timber extracted. This section of the SOP shall be altered to include information on how to collect this field data.



Where:

1. DBH (cm)
2. Height at top of buttress (cm)
3. Diameter directly above buttress ($d_{buttress}$)
4. Height of the stump (H_{Stump}) (m)
5. Diameter of the top of stump (D_{Stump}) (cm)
6. Diameter of the bottom of piece *n* ($d_{Piece\text{-}B}$) (cm) (only if exists)
7. Diameter of the top of piece *n* ($d_{Piece\text{-}T}$) (cm) (only if exists)
8. Length of piece *n* (l_{Piece}) (cm) (only if exists)
9. Diameter of bottom of timber bole ($d_{Log\text{-}B}$) (cm)
10. Diameter of top of timber bole ($d_{Log\text{-}B}$) (cm)
11. Length of the bole (l_{Log}) (m)
12. Diameter at the top cut (d_{Top}) (cm)

Figure: Measurements required in a logging plot. All heights and lengths should be measured in meters and all diameters in centimeters. All measurements should be measured to the nearest 0.1 cm (e.g. 13.242 m or 34.5 cm)



Where:

13. Diameter at the bottom of the avoidable merchantable waste piece *n* ($d_{AMW\text{-}B,n}$) (cm)
14. Diameter at the top of the avoidable merchantable waste piece *n* ($d_{AMW\text{-}T,n}$) (cm)
15. Length of avoidable merchantable waste piece *n* ($l_{AMW,n}$) (m)

Figure: Measurements required to estimate merchantable waste. All measurements should be measured to the nearest 0.1 cm (e.g. 13.242 m or 34.5 cm)

Incidental damage measurements:

When a timber-tree is felled, it incidentally damages the residual stand in two main ways: 1) by knocking down or breaking other trees and essentially killing them and 2) breaking off large branches of surviving trees. Measurements of incidental damage should be conducted as follow:

1. Walk along the area where the timber tree fell in a clockwise direction starting from the stump and walking around the entire crown, and identify all trees significantly damaged and branches broken off due to felling of the timber-tree.
2. For all trees (with DBH ≥10 cm) that have been either uprooted or the bole snapped off:

a. Classify the tree as either:
    i. Uprooted, lying on ground (G)
    ii. Crown snapped off (S)

    Note: Bent or leaning trees are assumed to not be dead and will survive.

b. Measure the DBH and note the species. If tree was snapped below 1.3m, either attempt to locate 1.3 m of the snapped tree or measure diameter at the highest point on the remaining trunk. Follow good practices outlined in 'SOP Measurements of Trees' for measuring DBH. Do not measure any pre-existing dead trees.

3. Measure the branches (base diameter of branch ≥10 cm) that have been snapped off living trees due to the felling the timber tree. Please note: It is very important that any branches on the forest floor be clearly identified as originating from a surviving tree and not from an already measured damaged tree or the timber tree to prevent double counting. Efforts must also be taken to ensure branches were snapped during tree fall and do not represent down dead wood predating the harvest. Such branches should be sound, and have evidence of being relatively recently fallen (e.g. presence of leaves, twigs, complete bark, etc.).
   Branches are measured using either of the following methods. The first method is preferred.
   a. Estimate weight of entire branch directly with proper scale, and take subsample to estimate dry weight:
      If branches can be weighed directly, measure the weight following the destructive sampling concept outlined in SOP for Destructive Sampling of Trees, Saplings, Palms and Bamboo. A brief description of the destructive sample methods are as follow:
        i. Weigh branch using calibrated hanging scale
        ii. Take a representative subsample and weigh. The subsample should weigh between 100-300 grams.
            1. Weigh the subsample bag empty. Record weight.
            2. Weigh the subsample bag with the subsample inside. Record weight.
            3. Label the subsample bag with the plot identification number, subsample identification number, and weight of subsample
            4. Take subsample bag and subsample from field. Bring to laboratory and dry subsample. Reweigh subsample. This subsample will be used to create a wet-to-dry ratio. This ratio will then be used to estimate the total dry weight of all non-woody vegetation in the clip plot.
   b. Estimate weight using volume and density:
      This method can be used where the branch is too large to weigh directly.
        i. Cut off end smaller branches that are small enough to weigh directly.
            1. Weigh branch using scale
            2. Take a representative subsample and weigh. The subsample should weigh between 100-300 grams.
                a. Weigh the subsample bag empty. Record weight.
                b. Weigh the subsample bag with the subsample inside. Record weight.
                c. Label the subsample bag with the plot identification number, subsample identification number, and weight of subsample
                d. Take subsample bag and subsample from field. Bring to laboratory and dry subsample. Reweigh subsample. This subsample will be used to create a wet-to-dry ratio. This ratio will then be used to estimate the total dry weight of all non-woody vegetation in the clip plot.
        ii. Estimate the volume of the portion of the branch too large to weigh.
            1. Measure the diameter at both ends of the branch
            2. Measure the length of the branch.
            3. These measurements will be used to calculate the volume.

$$Volume = \pi * \left[\frac{(d1 + d2)}{4}\right]^2 * length * \pi$$

            4. The volume of each branch will then be multiplied by a species specific wood density to estimate biomass.

SOP AREA DAMAGED DUE TO LOG EXTRACTION

Field Equipment:
GPS receiver
Laser Range Finder or Measuring tape

This SOP describes the methods used to estimate the area of land where carbon stocks are damaged due to the removal of logs from the forest, such as: skid trails, new haul roads, and logging decks. The methods will be more accurate when done soon after trees are harvested and removed from the forest area. This most often will be done in conjunction with 'SOP Carbon Stock Damage in Logging Gaps Due to Tree Felling'.

Definitions:

Skid trail: a temporary trail traveled by ground skidding equipment or manual clearing while moving logs to road or loading area. The machinery or manual clearing used to create the skid trail often will be able to push over and kill smaller trees but will have a maximum sized tree it is able to knock down. All larger trees will remain standing and the trail path will avoid such trees. The skid trails are not traveled by other vehicles, such as logging trucks.

Logging road: a temporary or more permanent road constructed to allow the transportation of logs to pre-existing roads. The logging road is used by trucks and other vehicles. Generally the path of the road is not altered to avoid trees. Instead, all trees and non-tree vegetation is cleared during the creation of the road.

Logging deck: an area cleared of all trees and non-tree vegetation, or in some cases cleared of brush and smaller trees only. This is the centralized area where logs are gathered, delimbed and cut to length if necessary, and loaded onto log trucks for transport.

Prior to Field Sampling

Prior to field sampling, the sampling design will need to be determined. This will include steps to identify which skid trails, roads, and logging decks will be measured and the distance between such measurements. The area where sampling will take place must also be clearly delineated within GIS and known by field crews. Extreme care must be taken to ensure all skid trails, roads, and logging decks area measured within the delineated sampling area. It is allowable to sample skid trails only within a known and GIS delineated sub-set of the total sampling area.

Determine the logging management practices for the construction of skid trails, roads, and logging decks. Where possible, obtain all maps and GIS data available for the logging area. Clear rules will need to be developed to differentiate between a skid trail and a logging road for the sampling area.

Determine what types of equipment are used in the construction of skid trails and roads. Where different types of techniques and equipment are used to create skid trails, skid trails may need to be grouped into skid trail types/strata. Likewise, if different types of roads are created, roads may also need to be grouped into road types. If a consistent type of machinery is used to create the skid trails, the width of the skidder plow should be measured. In addition, a survey may be conducted to determine what the maximum size each type of skidder equipment is able to knock over. The logging management plan may also indicate the maximum size skidders are allowed to knock over.

This SOP must then be altered to describe the approach that will be used.

Field Measurements

Skid trails:

Option 1: Carbon damage related to area of skid trails created.

To be used in most situations. This method assumes the area of the skid trail is completely cleared of vegetation:

1. Estimate average width of skid trails: Using a random or systematic sampling approach, measure the width of selected skid trails at different points along the selected skid trail.



Figure: Skid trail in Guyana. Skid trail is completely cleared of vegetation so Option 1 should be used for field measurements.

Option 2: Carbon damage estimated through measuring biomass of trees killed during skid trail creation

This method can only be used in areas where skid trails are narrow paths into the forest with live vegetation on the floor of the skid trail.

1. Estimate average biomass of trees killed by skid trail within certain length:
    a. Use a random or systematic sampling approach to select which skid trail to measure and where along the skid trail measurements should be taken.
    b. At first sampling point, using a measuring tape, lay out a 100 m transect following the skid trail.
    c. Measure the DBH and species of all trees clearly damaged (snapped or uprooted) due to skid trails construction along the 100 m of the skid trail.
    d. Repeat at next sampling point.
2. Estimate length of skid trails: Using the tracking feature of the GPS, track entire length of skid trails within the entire sampling area. It is important to ensure all skid trails within a given delineated area have been measured. Often it will assist measurements to indicate that a trail has been measured (e.g. mark skid trail entrance with spray-paint, chalk or flagging tape).
3. The total area of skid trails sampled can then be estimated by multiplying the average skid trail width by the total length of skid trails within the sampling area.
4. The calculation methods and rules will determine how carbon stock damage due to skid trails is estimated.



Figure: Skid trail in Brazil. Skid trail is narrow and contains live vegetation so Option 2 should be used for field measurements.

Logging decks:

Care must be taken to ensure *all* logging decks within the sampled area are measured.

Option 1a or 1b will be used in most situations. This method assumes the area of the logging deck is completely cleared of vegetation:

Option 1a: Direct area measurement

Measure the area of the logging deck by breaking the area down into simple geometric and non-overlapping shapes. Shapes must be either: oval, circle, rectangle or square. They cannot be complex shapes. Draw shapes onto data sheet. Measure and record the length and width of each shape with either the Range Finder or the tape measure. **Remember** – to measure the area of an oval, one must measure diameter of major axis *and* minor axis

Option 1b: Area measurement using GPS

Turn on polygon feature of GPS and walk around the edge of the entire logging deck. Choose close polygon option after returning to starting point and save polygon in GPS accordingly. The area of each logging deck will be measured within GIS.

Option 2: Carbon damage estimated through measuring biomass of trees killed during logging deck creation

This method can only be used in areas where logging decks are cleared areas that still have multiple trees standing within them.

1. Within the deck, measure the DBH and species of all the trees that were clearly damaged during the clearing of the deck (snapped or uprooted).
2. Estimate the biomass of the damaged trees using an appropriate allometric equation and sum the biomass of all the trees to determine the total impact.



Figure: Logging deck in Guyana. The deck is completely cleared of vegetation so either option 1a or 1b should be used for field measurements.



Figure: Logging deck in Colombia. The deck contains many trees and so should use option 2 for field measurements.

Logging Roads

1. Estimate average width of logging roads: Using a predetermined random or systematic sampling approach, measure the width of selected roads at different points along the selected road.
2. Estimate length of all logging roads: Using the tracking feature of the GPS, track entire length of roads within the entire sampling area. It is important to ensure all roads within a given delineated area have been measured. Alternatively, where the resolution is sufficient and cloud-cover is low, remote sensing imagery may be used to delineate length of roads.
3. Collect GPS waypoints at beginning and end of each road



Figure: Logging road in Republic of Congo

Winrock International 2018

SOP MEASUREMENT OF THE REGROWTH AFTER SELECTIVE LOGGING

Field Equipment:
Flagging tape
GPS receiver
Clinometer (to measure slope)
Measuring tape
Machete or knife
Data sheets and pencils
Permanent marking pen

For plot establishment:
Right Angle
Measuring tape
Rope
Stakes
Hammer

For measuring trees (see SOP Tree Measurement)
Tree name list
Diameter tapes
Tree poles: Small-diameter PVC piping cut the exact length of diameter measurements (eg 1.3 m if DBH will be measured)
Chalk sticks
Clinometer

This SOP provides an innovative approach to estimating growth (ingrowth and regrowth) induced as a result of canopy opening due to selective logging. These measurements are conducted in a "Regrowth Plot".

This SOP provides an approach to estimating growth induced as a result of canopy opening due to selective logging. The selective logging of trees can result in "anthropogenic induced" growth in trees affected by the removal of the timber tree. This is because by felling a tree, the competition for resources amongst other trees is reduced. These resources include, but are not limited to light, water, nutrients, etc.

The approach is based on establishing a chronosequence of logging gaps for biomass sampling that are established in the same stratum (based on logging practice and extraction rate) at various points in time in the past. The change in biomass over the several years sampled will indicate the rate of growth (ingrowth and regrowth) of the regenerating forest.

To ensure that a standard approach is used for each regrowth plot, the method is designed to accommodate plots with one felled tree only. It is possible that the logging gaps could be stratified by the number of trees in the gap, and if such occurrence is common then the gaps need to be stratified. However, if the occurrence of such gaps is low (<10% of all gaps), this is not cost effective. Also it is likely that gaps created by two to three felled trees could have faster rates of regrowth as the gaps would be larger, thus by not including these gaps the regrowth rates obtained could be underestimate—this would result in net emission from logging to be higher and thus producing a conservative result.

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This SOP requires documentation on the year(s) logging took place within the sampling area. Logging gaps formed across a sequence of ages will be used to estimate the change in biomass over time. Prior to field sampling, a sampling design will need to be created. This sampling design will include steps to determine what logging areas will be sampled, the dimensions of the 'regrowth plot', the number of logging gaps required, and within each logging area, which logging gaps will be measured. The length and width of the logging plot shall be based on the common total length of the felled trees (determined from results of the field data from the logging gaps; SOP Carbon stock in logging gaps due to tree felling). The SOP Measurement of Trees shall be used to measure trees within sampling plots.

The following methods for plot selection and establishment shall be applied:

Field measurements

1. Identify a logging gap based on sampling design—it is important that the gap be based on a clearly identifiable stump of a felled tree
    a. Make sure the plot does not overlap a road or logging deck
    b. If the plot dimensions overlap a skid trail, this plot shall be excluded
2. Temporary rectangular plots will be established.
   Establish a rectangular biomass plot covering the entire area of the gap opening and a portion of the shaded area immediately adjacent to opening. Based on previous field assessments, rectangular plots 8m wide and the length determined from the field data from logging gaps (SOP Carbon stock in logging gaps due to tree felling) are generally adequate. If plot size is changed for any reason, it is important that plot size be recorded for calculation of the scaling factor to be used in analysis.
    a. Plot shape:
        i. The long sides of rectangle shall be parallel to the direction the tree fell (see Figure below; in this example the common length of felled trees was 40 m)).
        ii. The stump of the felled tree must be 2 meters inside of the plot on the short side of the rectangle. The center of the circumference of the stump shall be 4 meters away from either edge of the plot defining the long side of the rectangle.
        iii. A sapling plot shall also be placed within the regrowth plot. This plot will be placed two meter from the front of the stump, in line perpendicular to the short side of the rectangle. At 2 meters in front of the stump, a rectangular plot of 2m x 2m will be placed. The same definition of sapling as presented in 'SOP Measurement of Trees' shall be used.

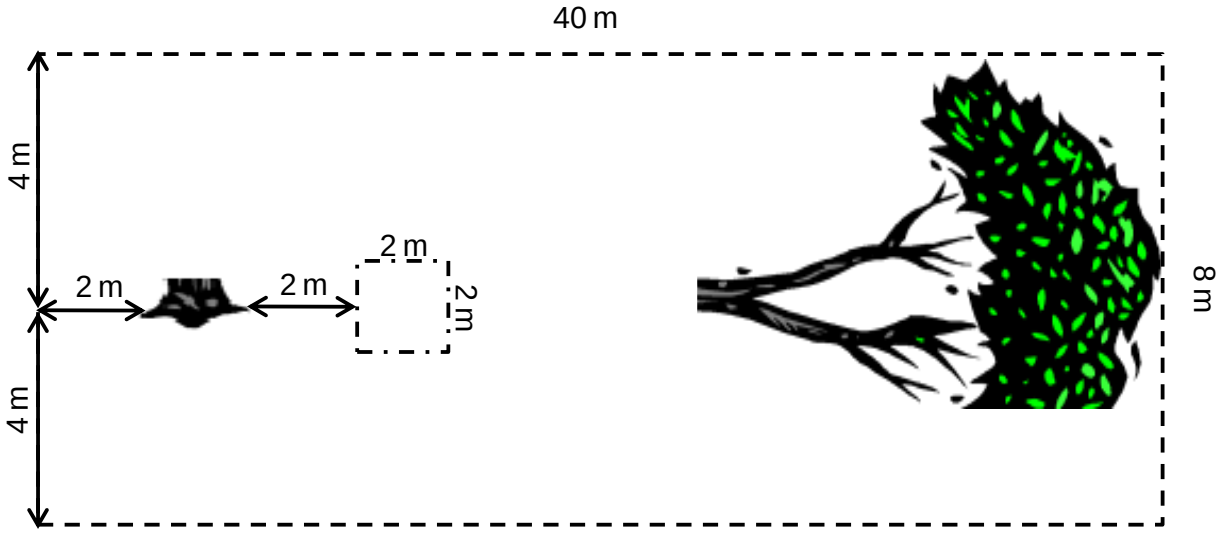


Figure Diagram of regrowth plot establishment

3. At the stump of the felled tree, mark a 'waypoint' on GPS and record GPS coordinates, accuracy, elevation, and waypoint number on data sheet. To record a GPS location, place the GPS at the plot center/corner and let it record for > 5 minutes prior to marking a 'waypoint'. The minimum precision level should be ±5 m. Leaving the GPS at one location for several minutes allows the GPS to get a

more accurate location by averaging many location acquisitions. The longer the GPS acquires locations the more accurate the final location. The accurate of the location is estimated and is displayed by the GPS. If there is heavy vegetation cover it may take a longer time to acquire an accurate location. In some cases, it may be necessary to move slightly or devise a way of getting the GPS higher in the air to acquire satellite signals. For more information, see SOPs on the use of GPS and the manual of the GPS being used[6] .

4. Label the plot based on SOP Labeling Plots
5. If the slope is greater than 10%, measure and record the exact slope using a clinometer. See SOP Use of a clinometer. The person using the clinometer first identifies the eye-level sight in a partner of approximately the same height. This person should stand at one end of the plot and the partner should go to the other end of the plot. The person with the clinometer shall then aim at the eye-level location in the partner and record the angle reading displayed in the clinometer. This angle is the slope angle and could be recorded as degrees (unit should be delineated in field sheets).
6. Describe land and vegetation conditions of plot and if there is anything unique or unusual in the plot or directly surrounding the plot. This could include things such as small streams, trails, large boulder or termite nest, and proximity to a paved road.
7. Measure all trees inside the rectangular plot with DBH>5 cm following the methods outlined in SOP Measurement of Trees. Trees do not need to be tagged.

[6] If a Garmin GPS Map60 is being used, the following steps can be used: a) prior to saving new waypoint, press MENU. b) Highlight 'Average Location' and press ENTER. c) Let GPS sit for many minutes until 'Estimated Accuracy' stabilizes. d) press ENTER to save location. (see manuals at www.garmin.com for more information)

VARIOUS CANOPY COVER STUDY-SPECIFIC SOPS

The following SOPs are only to be used for specific and known purposes. These SOPs have been developed by Winrock for specific studies estimating canopy cover. These SOPs only should be implemented with known purpose and study developed.

SOP Measurement of Canopy Cover

SOP Area of Canopy Opening

SOP Crown Area from the Ground

SOP MEASUREMENT OF CANOPY COVER

Field equipment

Densitometer (e.g. GRS Densitometer, http://grsgis.com/densitometer/index.htm)

Measuring tape

Rope

To measure canopy cover, measurements of presence or absence of canopy cover will be made at different points within a square sampling plot. These sampling plots do not need to be located in association with tree plot measurements. The location of each sampling location must be determined prior to entering the field.

1. Navigate to sampling location using a GPS.
2. Walk an additional 10 steps in the direction of travel. This will be the first sampling point.
3. Starting at this point, determine a random compass bearing. This can be done using various methods such as using a random number table. Another method is to use a watch that has a second hand. At a random moment one individual can look at his/her watch and then the direction the second hand is facing will be used as the compass bearing.
4. Using this compass bearing, lay out a 15 m transect.
5. A measurement of the presence/absence of canopy will be made every 3 m along this transect.
6. Starting at 0 cm, use the Densitometer to determine the presence/absence of vegetation.

   Looking through the densitometer you can see two spirit levels. When both are centered you are looking directly overhead. In the center of the field of vision there is a small circle. If you can see vegetation (leaves, branches, twigs, etc), mark the data sheet to indicate the presence of canopy cover.
7. Move forward 3 m and repeat until reaching 15 m (6 recordings)
8. Move tape measure 3 m to your right and repeat measurements along transect. Move tape measure 4 more times until 6 transects have been completed. A total of 36 presence/absence measurements should be taken at each sampling location.

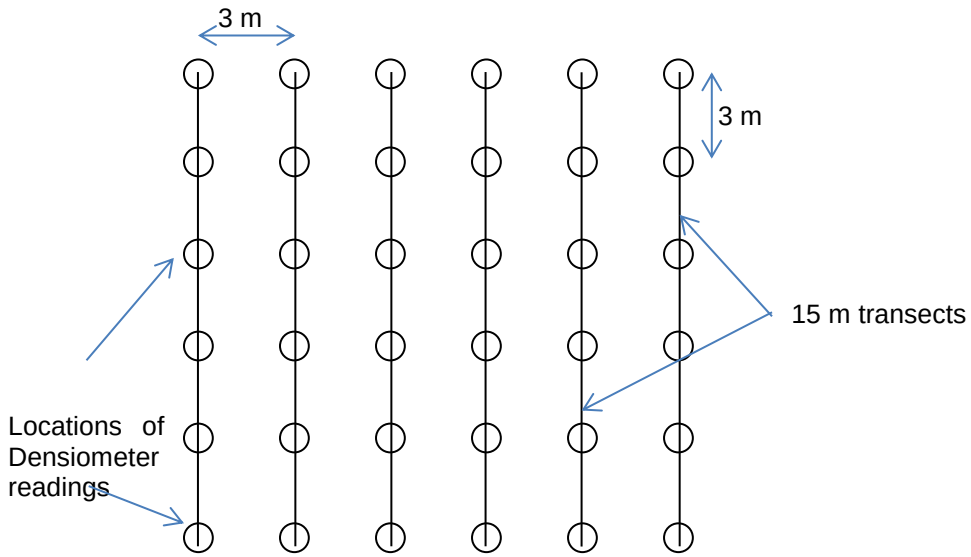


Figure 3 Layout of transects and location of densiometer readings along transects (lines indicate transects and circles represent densitometer reading locations)

SOP AREA OF CANOPY OPENING

Field Equipment:
Laser Range Finder or 50 m tape

This SOP is used to estimate the area of canopy opening created when a logging tree(s) are selectively logged in a forest.

This SOP must be done in conjunction with 'SOP Framework for Estimation of Carbon Stock Damage from Selective Logging' and 'SOP Carbon Stock Damage in Logging Gaps Due to Tree Felling'. See the logging gap SOP for information on locating and establishing the logging gap.

1. Once the logging gap has been identified, walk around the area to determine how many felled timber trees are located within the specific logging gap. The felled timber trees and all killed and/or damaged trees caused by tree felling will be measured as one logging gap plot. Measurements must be taken for each felled timber tree.
2. Locate the stump and crown of each felled tree. Be sure to verify that the crown is from the selected stump by determining the angle of the tree fall, species and distance from stump.
3. Walk around the entire gap, locating every section of canopy gap formed. Mentally divide the gap into different *non-overlapping* ovals or rectangles. Shapes must either be either: oval, circle, rectangle or square. They cannot be complex shapes unless detailed angles are taken). Draw shapes onto data sheet.
4. Measure and record the length and width of each shape with either the Range Finder or the tape measure. **Remember** – to measure the area of an oval one must measure diameter of major axis *and* minor axis.

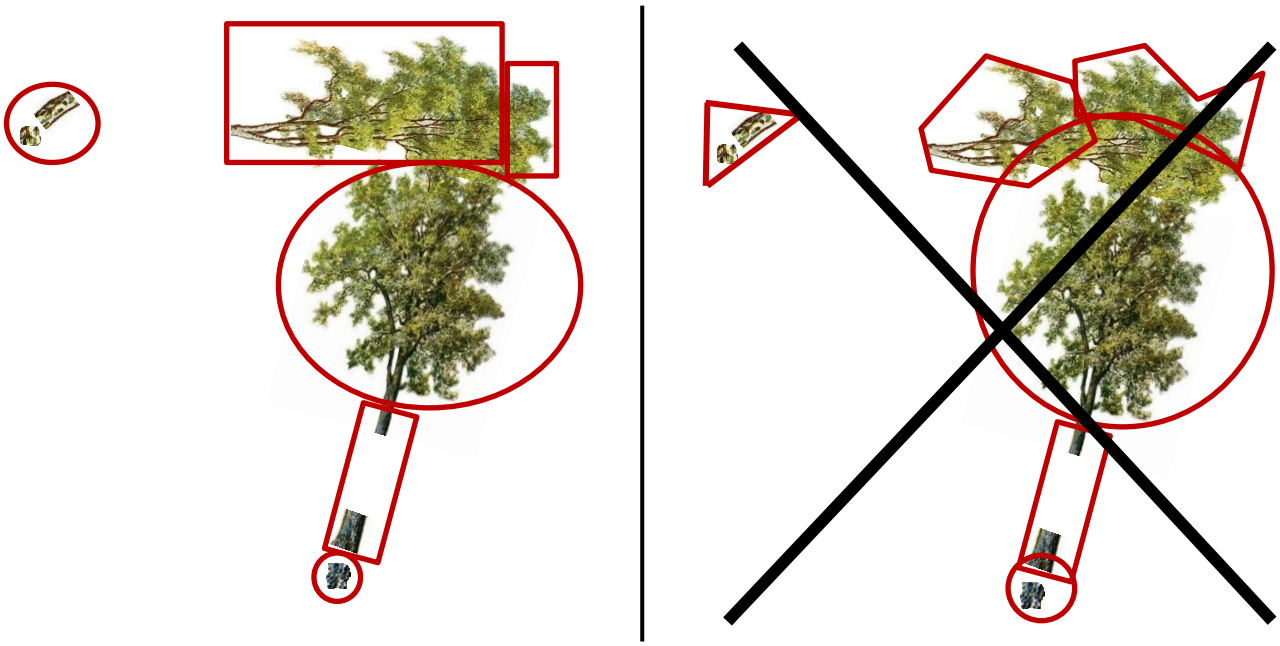


Figure: Division of logging gap canopy opening. Proper measurement on left, incorrect measurement on right

SOP TREE CROWN AREA FROM THE GROUND

Field Equipment:
Clinometer
Laser Range Finder

This SOP is used to estimate the crown area of a tree. These measurements are used for specific purposes including formulating relationships between tree biomass and crown area for use in aerial imagery analysis. The purpose of the field measurements must be clearly delineated and a sampling design created prior to implementation of this SOP. The sampling design must include steps for determining which trees will be measured.

1. For each tree to be measured, measure the DBH and species of tree using the procedures in SOP Measurement of Trees.
2. At each tree to be measured a total of four measurements of the angle and distance to canopy should be taken.
    a. For each cardinal direction stand with your back to the tree trunk. If clearer sight of the first branch with leaves is not aligned with a cardinal direction, be sure the subsequent three sides are perpendicular to each other. Using the clinometer, estimate the angle in degrees to the first branch with leaves ($\angle_1$).
    b. Use the range finder, measure the distance from the eye of the person measuring the trunk to the branch (d_1) in meters. Be certain that the distance measured is horizontal and not along a slope.
3. To calculate the area of the canopy from the measurements:

$$Canopy\ Area = \left(\frac{\left(\left(\cos\left(\frac{\angle_1 * \pi}{180}\right) * d_1\right) + \left(\cos\left(\frac{\angle_3 * \pi}{180}\right) * d_3\right) + \left(\frac{dbh}{100}\right)\right)}{2}\right) * \left(\frac{\left(\left(\cos\left(\frac{\angle_2 * \pi}{180}\right) * d_2\right) + \left(\cos\left(\frac{\angle_4 * \pi}{180}\right) * d_4\right) + \left(\frac{dbh}{100}\right)\right)}{2}\right)$$

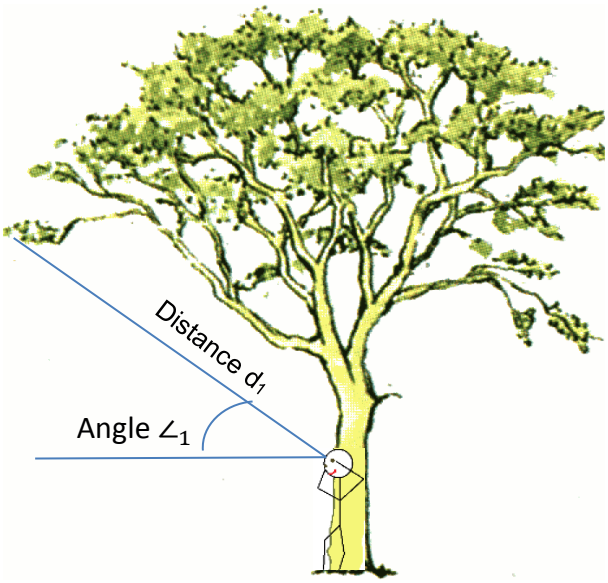


Figure: Example of angle measurement with clinometer and distance measurement with laser range finder

APPENDIX I: GUIDANCE ON ALLOMETRIC EQUATION DEVELOPMENT

APPENDIX II: EXAMPLE DATASHEETS

1. Nested Tree plot Radius Correction Table
2. Carbon stock measurements
   Includes: trees, saplings, standing dead wood, lying dead wood, non-tree vegetation, litter, and soil
3. Dead wood density datasheet
4. Sapling weight datasheet
5. Destructive sampling datasheet
6. Logging plot datasheets
7. Canopy cover datasheet

Nested Tree plot Radius Correction Table – to correct area of plot based on slope

Slope (%)	Corrected Radii (m)																												
0	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
10	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0	14.0	15.0	16.0	17.0	18.0	19.0	20.0	21.1	22.1	23.1	24.1	25.1	26.1	27.1	28.1	29.1	30.1
15	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.1	10.1	11.1	12.1	13.1	14.1	15.1	16.1	17.1	18.1	19.1	20.1	21.1	22.1	23.1	24.1	25.1	26.1	27.2	28.2	29.2	30.2
20	2.0	3.0	4.0	5.0	6.1	7.1	8.1	9.1	10.1	11.1	12.1	13.1	14.1	15.1	16.2	17.2	18.2	19.2	20.2	21.2	22.2	23.2	24.2	25.2	26.3	27.3	28.3	29.3	30.3
25	2.0	3.0	4.1	5.1	6.1	7.1	8.1	9.1	10.2	11.2	12.2	13.2	14.2	15.2	16.2	17.3	18.3	19.3	20.3	21.3	22.3	23.4	24.4	25.4	26.4	27.4	28.4	29.4	30.5
30	2.0	3.1	4.1	5.1	6.1	7.2	8.2	9.2	10.2	11.2	12.3	13.3	14.3	15.3	16.3	17.4	18.4	19.4	20.4	21.5	22.5	23.5	24.5	25.5	26.6	27.6	28.6	29.6	30.7
35	2.1	3.1	4.1	5.1	6.2	7.2	8.2	9.3	10.3	11.3	12.4	13.4	14.4	15.4	16.5	17.5	18.5	19.6	20.6	21.6	22.6	23.7	24.7	25.7	26.8	27.8	28.8	29.9	30.9
40	2.1	3.1	4.2	5.2	6.2	7.3	8.3	9.3	10.4	11.4	12.5	13.5	14.5	15.6	16.6	17.6	18.7	19.7	20.8	21.8	22.8	23.9	24.9	25.9	27.0	28.0	29.1	30.1	31.1
45	2.1	3.1	4.2	5.2	6.3	7.3	8.4	9.4	10.5	11.5	12.6	13.6	14.7	15.7	16.8	17.8	18.8	19.9	20.9	22.0	23.0	24.1	25.1	26.2	27.2	28.3	29.3	30.4	31.4
50	2.1	3.2	4.2	5.3	6.3	7.4	8.5	9.5	10.6	11.6	12.7	13.7	14.8	15.9	16.9	18.0	19.0	20.1	21.1	22.2	23.3	24.3	25.4	26.4	27.5	28.5	29.6	30.7	31.7
55	2.1	3.2	4.3	5.3	6.4	7.5	8.5	9.6	10.7	11.8	12.8	13.9	15.0	16.0	17.1	18.2	19.2	20.3	21.4	22.4	23.5	24.6	25.6	26.7	27.8	28.8	29.9	31.0	32.0
60	2.2	3.2	4.3	5.4	6.5	7.6	8.6	9.7	10.8	11.9	13.0	14.0	15.1	16.2	17.3	18.4	19.4	20.5	21.6	22.7	23.8	24.8	25.9	27.0	28.1	29.2	30.2	31.3	32.4
65	2.2	3.3	4.4	5.5	6.6	7.6	8.7	9.8	10.9	12.0	13.1	14.2	15.3	16.4	17.5	18.6	19.7	20.7	21.8	22.9	24.0	25.1	26.2	27.3	28.4	29.5	30.6	31.7	32.8
70	2.2	3.3	4.4	5.5	6.6	7.7	8.8	9.9	11.0	12.2	13.3	14.4	15.5	16.6	17.7	18.8	19.9	21.0	22.1	23.2	24.3	25.4	26.5	27.6	28.7	29.8	30.9	32.0	33.1
75	2.2	3.4	4.5	5.6	6.7	7.8	8.9	10.1	11.2	12.3	13.4	14.5	15.7	16.8	17.9	19.0	20.1	21.2	22.4	23.5	24.6	25.7	26.8	28.0	29.1	30.2	31.3	32.4	33.5
80	2.3	3.4	4.5	5.7	6.8	7.9	9.1	10.2	11.3	12.4	13.6	14.7	15.8	17.0	18.1	19.2	20.4	21.5	22.6	23.8	24.9	26.0	27.2	28.3	29.4	30.6	31.7	32.8	33.9
85	2.3	3.4	4.6	5.7	6.9	8.0	9.2	10.3	11.5	12.6	13.7	14.9	16.0	17.2	18.3	19.5	20.6	21.8	22.9	24.1	25.2	26.3	27.5	28.6	29.8	30.9	32.1	33.2	34.4
90	2.3	3.5	4.6	5.8	7.0	8.1	9.3	10.4	11.6	12.8	13.9	15.1	16.2	17.4	18.6	19.7	20.9	22.0	23.2	24.4	25.5	26.7	27.8	29.0	30.2	31.3	32.5	33.6	34.8
95	2.3	3.5	4.7	5.9	7.0	8.2	9.4	10.6	11.7	12.9	14.1	15.3	16.4	17.6	18.8	20.0	21.1	22.3	23.5	24.7	25.8	27.0	28.2	29.4	30.5	31.7	32.9	34.1	35.2
100	2.4	3.6	4.8	5.9	7.1	8.3	9.5	10.7	11.9	13.1	14.3	15.5	16.6	17.8	19.0	20.2	21.4	22.6	23.8	25.0	26.2	27.4	28.5	29.7	30.9	32.1	33.3	34.5	35.7
105	2.4	3.6	4.8	6.0	7.2	8.4	9.6	10.8	12.0	13.2	14.4	15.7	16.9	18.1	19.3	20.5	21.7	22.9	24.1	25.3	26.5	27.7	28.9	30.1	31.3	32.5	33.7	34.9	36.1
110	2.4	3.7	4.9	6.1	7.3	8.5	9.8	11.0	12.2	13.4	14.6	15.9	17.1	18.3	19.5	20.7	21.9	23.2	24.4	25.6	26.8	28.0	29.3	30.5	31.7	32.9	34.1	35.4	36.6
115	2.5	3.7	4.9	6.2	7.4	8.6	9.9	11.1	12.3	13.6	14.8	16.0	17.3	18.5	19.8	21.0	22.2	23.5	24.7	25.9	27.2	28.4	29.6	30.9	32.1	33.3	34.6	35.8	37.0
120	2.5	3.7	5.0	6.2	7.5	8.7	10.0	11.2	12.5	13.7	15.0	16.2	17.5	18.7	20.0	21.2	22.5	23.7	25.0	26.2	27.5	28.7	30.0	31.2	32.5	33.7	35.0	36.2	37.5
125	2.5	3.8	5.1	6.3	7.6	8.9	10.1	11.4	12.7	13.9	15.2	16.4	17.7	19.0	20.2	21.5	22.8	24.0	25.3	26.6	27.8	29.1	30.4	31.6	32.9	34.2	35.4	36.7	38.0
130	2.6	3.8	5.1	6.4	7.7	9.0	10.2	11.5	12.8	14.1	15.4	16.6	17.9	19.2	20.5	21.8	23.1	24.3	25.6	26.9	28.2	29.5	30.7	32.0	33.3	34.6	35.9	37.1	38.4
135	2.6	3.9	5.2	6.5	7.8	9.1	10.4	11.7	13.0	14.3	15.6	16.9	18.1	19.4	20.7	22.0	23.3	24.6	25.9	27.2	28.5	29.8	31.1	32.4	33.7	35.0	36.3	37.6	38.9
140	2.6	3.9	5.2	6.6	7.9	9.2	10.5	11.8	13.1	14.4	15.7	17.1	18.4	19.7	21.0	22.3	23.6	24.9	26.2	27.5	28.9	30.2	31.5	32.8	34.1	35.4	36.7	38.0	39.3
145	2.7	4.0	5.3	6.6	8.0	9.3	10.6	11.9	13.3	14.6	15.9	17.3	18.6	19.9	21.2	22.6	23.9	25.2	26.5	27.9	29.2	30.5	31.9	33.2	34.5	35.8	37.2	38.5	39.8
150	2.7	4.0	5.4	6.7	8.1	9.4	10.7	12.1	13.4	14.8	16.1	17.5	18.8	20.1	21.5	22.8	24.2	25.5	26.9	28.2	29.5	30.9	32.2	33.6	34.9	36.3	37.6	38.9	40.3

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LIVE BIOMASS AND SOIL MEASUREMENT AND SAMPLING DATA SHEET

Plot ID #:_____ Location:_____ Land cover type:_____ Crew chief:_____ Data recorded by:_____ # people in crew: _____
Date:_____/_____/_____Start Time:_____ End time:_____ Total Time: _____
GPS Datum: _____GPS Waypoint:_____ Lat:_____ Long:_____ Precision: _____ Elevation: _____
Slope (%): _____ Photo Number(s):_____
Notes:

Saplings:
of Saplings: _____ Sapling Plot dimensions (m): _____
LIVE TREE MEASUREMENTS.

TREES

Nested Plot radius (m): small:_____ medium:_____ large:_____

Nested plot tree diameter sizes (cm): small:_____ medium:_____ large:_____

Tree #	Species	DBH (cm)	Tree #	Species	DBH (cm)	Tree #	Species	DBH (cm)

PALMS, Tree Ferns, Bamboo

Palm Plot Radius (m):_____

Tree Fern Plot Radius (m):_____

Bamboo Plot Radius (m):_____

Tree #	Species	Height (m)	Clinometer angle +	Clinometer angle -	Eye to tree (m)	Equipment Used

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Plot ID #:_____

CLASS 2 STANDING DEAD WOOD MEASUREMENTS:

Diam at base (at 0.1 m) (cm)	DBH (at 1.3 m) (cm)	Diameter at top (cm) (if measured directly)	Height (m) (if measured directly)	Height Measurement 1				Height Measurement 2			
				Clinometer angle (%) +	Clinometer angle (%) -	Distance from eye to tree (m)	Height of eye (m)	Clinometer angle (%) +	Clinometer angle (%) -	Distance from eye to tree (m)	Height of eye (m)

SOIL

Soil C
Sample ID # _____
Sample method: _____
Sample volume (cm^3): _____
Sample depth (cm): _____

Bulk density
Sample ID# _____
Sample method: _____
Sample volume (cm^3): _____
Sample depth (cm): _____

Sample ID# _____
Sample method: _____
Sample volume (cm^3): _____
Sample depth (cm): _____

NON-TREE WOODY VEGETATION (CLIP PLOTS)

Clip-plot dimensions: _____ (if clustered tree plots, only 1 measurement per plot)

Weight of bag or sheet (g)	Weight of bag + material (g)	Clip-plots subsample ID #	Weight of subsample bag (g)	Weight of subsample bag + subsample material (g)

LITTER CLIP PLOTS

Clip-plot dimensions: _____ (if clustered tree plots, only 1 measurement per plot)

Weight of bag or sheet (g)	Weight of bag + material (g)	Clip-plots subsample ID #	Weight of subsample bag (g)	Weight of subsample bag + subsample material (g)

LYING DEADWOOD MEASUREMENTS:

(wood greater than 10 cm diameter) Transect length (m) = _____

Diam (cm)	Density Class (S,I,R) S=Solid, I=Intermediate, R=Rotten	Hollow diam (cm)

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DEAD WOOD DENSITY DATA SHEET

Stratum: _____ Location:_____

Date: _____/_____/_____ Data recorded by:_____

Notes:

A minimum of 10 samples should be collected for each density class at the beginning of the field sampling effort. Diameter and width should be recorded for each sample. Empty bag weight should be recorded.

Photo #	Dead Wood ID	Wood Density Class: S, I, R*	Diameter2 (cm)	Diameter2 (cm)	Width1 (cm)	Width2 (cm)	Volume (cm^3)	Bag weight (g)

* S = sound, I = intermediate, R = rotten

DATA SHEET FOR SAPLINGS

Stratum:___________ Location:______________________

Date:___________ Data recorded by:_________________

Notes:

At least 30 saplings must be cut and weighed.

Plot ID	Sapling ID	Total Wet Weight (g)	Weight of empty subsample bag (g)	Subsample Wet Weight + Bag (g)

DESTRUCTIVE SAMPLING DATA SHEET

Plot ID:_____Location:_____GPS Lat:_____ Long:_____
Date:_____ Team Leader:_____Timestart:_____Time end:_____
Tree ID: _____Stratum:_____ Photo ID: _____

(ADD ADDITIONAL NOTES TO BACK OF LAST PAGE OF DATA SHEET)

MEASUREMENTS BEFORE TREE CUT

Species: _____
DBH: _____ cm
Tree Height:

Height Measurement 1				Height Measurement 2			
Clinometer angle (%) +	Clinometer angle (%) -	Distance from eye to tree (m)	Height of eye (m)	Clinometer angle (%) +	Clinometer angle (%) -	Distance from eye to tree (m)	Height of eye (m)

*Enter in degrees (º) when percentage is greater than 90%.

MEASUREMENTS AFTER TREE CUT

Bole measurements

Diameter at bottom of bole: _____cm
Diameter at top of bole: _____cm
DBH of bole: _____cm
Length of bole: _____cm
Length of tree: _____m

Starting at the bottom of the bole, divide the bole into 2-m sections and list the dimensions of each section below:

Section #	**Lower diameter (cm)**	**Upper diameter (cm)**	**Length of section (cm)**	**Section #**	**Lower diameter (cm)**	**Upper diameter (cm)**	**Length of section (cm)**

For density determination:

Subsample disc 1		Subsample disc 2		Subsample disc 3	
Label: _____		Label: _____		Label: _____	
L1:	_____ cm	L1:	_____ cm	L1:	_____ cm
L2:	_____ cm	L2:	_____ cm	L2:	_____ cm
T1:	_____ cm	T1:	_____ cm	T1:	_____ cm
T2:	_____ cm	T2:	_____ cm	T2:	_____ cm

Stump measurements

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- If entire stump is weighed:
  Total fresh weight: _____kg Partial weights (kg): (write total at left)

Subsamples for determination of dry:wet ratio:

Subsample 1:		**Subsample 2:**
Bag Label:	_____	Bag Label: _____
Fresh weight:	_____ kg	Fresh weight: _____ kg

- If stump is cut and part of it is estimated by volume rather than weighing the whole stump:
  Draw shape of cut stump to the right, note its dimensions and weigh the remaining pieces and report as fresh weight above.)

Dimensions of stump: Length 1: _____cm Width 1: _____cm
Length 2: _____cm Width 2: _____cm

Dimensions of cross section sample for determining density:
L1: _____ cm W1: _____ cm
L2: _____ cm W1: _____ cm

Buttress Measurements:

Total fresh weight: _____ kg Partial weights: (write total at left)

Subsamples for determination of dry:wet ratio:

Subsample 1:		**Subsample 2:**
Bag Label:	_____	Bag Label: _____
Fresh weight:	_____ kg	Fresh weight: _____ kg

Tree Crown Measurements:

Leaves and branches <10 cm:

Total fresh weight: _____ kg Partial weights: (write total at left)

Subsamples for determination of dry:wet ratio:

Subsample #	**Bag Label**	**Fresh Weight (kg)**
1		
2		
3		
4		
5		

Branches 10-20 cm:

Total fresh weight: _____ kg Partial weights: (write total at left)

Subsamples or determination of dry:wet ratio:

Subsample #	**Bag Label**	**Weight (kg)**
1		
2		

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3
4
5

Branches >20 cm:

- If entire branch is weighed in pieces:

  Total fresh weight: _____ kg Partial weights: (write total at left)

  Subsamples for determination of dry:wet ratio:

Subsample #	Bag Label	Weight (kg)
1		
2		
3		
4		
5		

- If volume is estimated instead of weight for branches >20 cm, then mentally divide the branch into sections and list the dimensions of each section below:

Branch #	Section #	Bottom diameter (cm)	Top diameter (cm)	Length of section (cm)

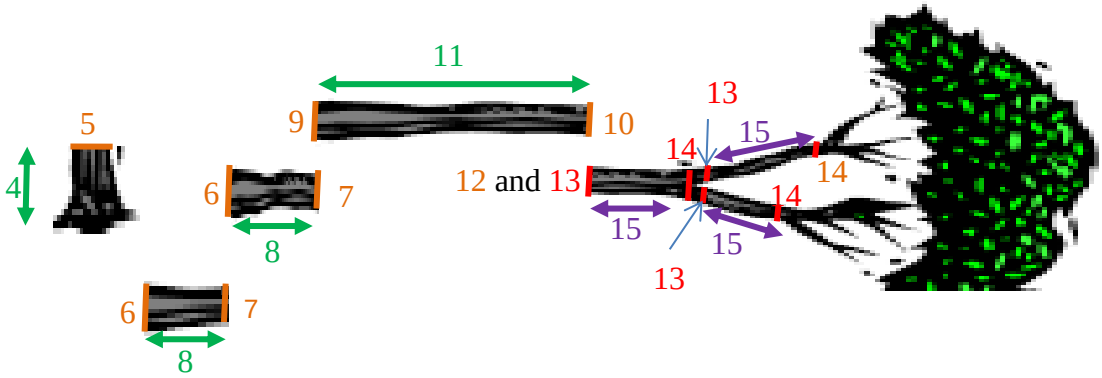
For density determination, cut 5 representative discs:

	Disc 1	Disc 2	Disc 3	Disc 4	Disc 5
Label					
L 1 (cm)					
L2 (cm)					
T1 (cm)					
T2 (cm)					

NOTES FOR DESTRUCTIVE SAMPLING MEASUREMENTS

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Measurements for timber tree:



Where:

1. DBH (cm)
2. Height at top of buttress (cm)
3. Diameter directly above buttress ($d_{buttress}$)
4. Height of the stump (H_{Stump}) (m)
5. Diameter of the top of stump (D_{Stump}) (cm)
6. Diameter of the bottom of piece *n* ($d_{Piece\text{-}B}$) (cm)
7. Diameter of the top of piece *n* ($d_{Piece\text{-}T}$) (cm)
8. Length of piece *n* (l_{Piece}) (cm)
9. Diameter of bottom of timber bole ($d_{Log\text{-}B}$) (cm)
10. Diameter of top of timber bole ($d_{Log\text{-}T}$) (cm)
11. Length of the bole (l_{Log}) (m)
12. Diameter at the top cut (d_{Top}) (cm)
13. Diameter at the bottom of the avoidable merchantable waste piece *n* ($d_{AMW\text{-}B,n}$) (cm)
14. Diameter at the top of the avoidable merchantable waste piece *n* ($d_{AMW\text{-}T,n}$) (cm)
15. Length of avoidable merchantable waste piece *n* ($l_{AMW,n}$) (m)

Classes of Damaged Trees:

Snapped (S): **Uprooted (U):** **Branch fallen off (B):**







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TIMBER TREE MEASUREMENTS

Date:_______________

Plot ID#:_____ Location: _____Coordinate System: _____

Crew chief: _____ Data recorded by: _____# of people in crew: _____

Start Time: _____End Time: _____ Total Time: _____minutes

Camera Number: _____Photo Number(s):_____

Forest Type: _____

Additional notes describing plot area (number of sections, number of logs, etc):

Timber Tree 1:

Species: _____GPS Accuracy: _____(m)

GPS Coordiantes: E/W: _____ N/S: _____

Tree Buttressed: ☐ Yes ☐ No

Height of the buttress ($H_{Buttress}$) _____ (cm)

Diameter of stump top (d_S): _____ (cm)

Height of the stump (H_S): _____ (cm)

DBH(DBH): _____ (cm)

Log Section 1:

Diam. bottom ($d_{Piece-B}$): _____ (cm)

Diam. top ($d_{Piece-T}$): _____ (cm)

Length (l_{Piece}): _____ (cm)

Log Section 2:

Diam. bottom ($d_{Piece-B}$): _____ (cm)

Diam. top ($d_{Piece-T}$): _____ (cm)

Length (l_{Piece}): _____ (cm)

Length of Log (l_{Log}): _____

Log: ☐ Present ☐ Absent

Diameter at top cut (d_T): _____ (cm)

Length of avoid. merchant waste (l_{AMW}): _____ (m)

Diam. Top of avoid. merchant waste (d_{AMW-T}): _____ (cm)

Timber Tree 2:

Species: _____ GPS Accuracy: _____(m)

GPS Coordinates: E/W: ___ N/S: _____

Tree Buttressed: ☐ Yes ☐ No

Height of the buttress ($H_{Buttress}$): _____ (cm)

Diameter of stump top (d_S): _____ (cm)

Height of the stump (H_S): _____ (cm)

DBH(DBH): _____ (cm)

Log Section 1:

Diam. bottom ($d_{Piece-B}$): _____ (cm)

Diam. top ($d_{Piece-T}$): _____ (cm)

Length (l_{Piece}): _____ (cm)

Log Section 2:

Diam. bottom ($d_{Piece-B}$): _____ (cm)

Diam. top ($d_{Piece-T}$): _____ (cm)

Length (l_{Piece}): _____ (cm)

Length of Log (l_{Log}): _____ (cm)

Log: ☐ Present ☐ Absent

Diameter at top cut (d_T): _____ (cm)

Length of avoid. merchant waste (l_{AMW}): _____ (m)

Diam. Top of avoid. merchant waste (d_{AMW-T}): _____ (cm)

Sketch of canopy gap: Canopy opening dimensions:

DAMAGED TREES MEASUREMENTS

Damage type: (S) snapped, (U) uprooted, or (B) branch (if larger than 10 cm in diameter)

Species	DBH	Type	Species	DBH	Type	Species	DBH	Type	Branches	D1	D2	Length

SKID TRAIL DATA SHEET

Skid Trail ID: _____ Location: _____ Date: _____/_____/_____

Crew Chief: _____ Coordinate System:_____

Skid Trail total length:_____

Area method:

Skid Trail width: (m)

Damage method:

Transect ID:_____

Fatally damaged trees: (S) snapped, (U) uprooted

Species	DBH	Type	Species	DBH	Type	Species	DBH	Type	Species	DBH	Type

---

Skid Trail ID: _____ Location: _____ Date: _____/_____/_____

Crew Chief: _____ Coordinate System:_____

Skid Trail total length:_____

Area method:

Skid Trail width: (m)

Damage method:

Transect ID:_____

Fatally damaged trees: (S) snapped, (U) uprooted

Species	DBH	Type	Species	DBH	Type	Species	DBH	Type	Species	DBH	Type

LOGGING DECK DATA SHEET

Date: _____/_____/_____

Logging Deck ID: _____ Location: _____

Polygon ID: (Using polygon feature of GPS) **OR**

Coordinate System: ____GPS Waypoint E/W: _____N/S:_____

Area method:

Logging Deck dimensions: _____Sketch of Logging Deck:

Damage method:

Fatally damaged trees: (S) snapped, (U) uprooted

Species	DBH	Type	Species	DBH	Type	Species	DBH	Type	Species	DBH	Type

Logging Deck ID: _____ Location: _____

Polygon ID: (Using polygon feature of GPS) **OR**

Coordinate System: ____GPS Waypoint E/W: _____N/S:_____

Area method:

Logging Deck dimensions: _____Sketch of Logging Deck:

Damage method:

Fatally damaged trees: (S) snapped, (U) uprooted

Species	DBH	Type	Species	DBH	Type	Species	DBH	Type	Species	DBH	Type

ROAD DATA SHEET

Road Track ID: _____Location: _____ Date: _____/_____/_____
Road Type: _____Crew Chief: _____
GPS Number: _____ Coordinate System:_____
Road Width: (m)

Road Track ID: _____Location: _____ Date: _____/_____/_____
Road Type: _____Crew Chief: _____
GPS Number: _____ Coordinate System:_____
Road Width: (m)

Road Track ID: _____Location: _____ Date: _____/_____/_____
Road Type: _____Crew Chief: _____
GPS Number: _____ Coordinate System:_____
Road Width: (m)

LOGGING REGROWTH PLOTS

Date: _____/_____/_____

Plot ID #:_____ Location: _____GPS Number: _____ Coordinate System: _____: E: _____ N: _____

Crew chief: _____ Data recorded by: _____ # people in crew: _____

Start Time: _____End time: _____Total Time: _____minutes

Approximate. Stump age: _____Slope (%): _____ Camera Number: _____

Photo Number(s):_____

Forest type (e.g. mixed, swamp)

Notes (including gap shape and size, and possibly measurements from densiometer):

SAPLINGS:

of Saplings: _____ Plot dimensions (m): _____

LIVE TREE MEASUREMENTS

Plot dimensions (m): L: _____W:_____ **Diameter break points (if relevant):**_____

←----------FOR TREES----------→←----------FOR PALMS, TREE FERNS, BAMBOO----------→

Species	DBH (cm)	Species	DBH (cm)	Species	DBH (cm)	Species	Height (m)	Clinometer angle +	Clinometer angle -	Eye to tree (m)	Equipment Used

CANOPY COVER DATA SHEET

Plot ID #:_____ Location:_____ GPS Number:_____ Lat:_____ Long:_____ Elev: _____
Land cover type:_____ Crew chief:_____ Date:_____/_____/_____
Notes:

Presence/Absence (P/A):

	1	2	3	4	5	6
1						
2						
3						
4						
5						
6						

Plot ID #:_____ Location:_____ GPS Number:_____ Lat:_____ Long:_____ Elev: _____
Land cover type:_____ Crew chief:_____ Date:_____/_____/_____
Notes:

Presence/Absence (P/A):

	1	2	3	4	5	6
1						
2						
3						
4						
5						
6						

Plot ID #:_____ Location:_____ GPS Number:_____ Lat:_____ Long:_____ Elev: _____
Land cover type:_____ Crew chief:_____ Date:_____/_____/_____
Notes:

Presence/Absence (P/A):

	1	2	3	4	5	6
1						
2						
3						
4						
5						
6						

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Pros and cons of different sampling techniques

Gaganpreet Sharma

Abstract
In the field of research different sampling technique are used for different fields. It is very essential to choose the adequate technique of sampling. In this paper first we clarify the proper meaning of sampling. Further we discus about the different techniques and types of sampling. We mainly concentrate on two types of probability and non- probability and their sub categories. Further we discus about the pros and cons of these techniques. Pros are the primary positive aspect of an idea process or thing. Cones are the primary negative aspects. It is very necessary to choose the write sampling technique for a specific research work. Before we choose the sampling technique it is necessary to know about the 'Pros' and 'Cons' of sampling technique. If the researcher know about the 'Pros' and 'Cons' he/she will select the adequate technique of sampling for his research work.

Keywords: Sampling, Pros, Cons.

Introduction

Pros and Cons

"Pros" are the primary positive aspects of an idea, process or thing; "Cons" are the primary negative aspects. The term Pros and Cons means both the primary positive and negative aspects of an idea, process or thing and is often used to clarify or decide whether that idea, process or thing is mainly positive or mainly negative.

Sampling

Sampling is a technique (procedure or device) employed by a researcher to systematically select a relatively smaller number of representative items or individuals (a subset) from a pre-defined population to serve as subjects (data source) for observation or experimentation as per objectives of his or her study. For example, if, by using some systematic device, you pick up a group of 100 undergraduates from out of a total of 1500 on the rolls of a college for testing their physical fitness, you have selected a desired sample from a particular population. Researchers usually use sampling for it is impossible to be testing every single individual in the population. Although it is a subset, it is representative of the population and suitable for research in terms of cost, convenience and time. Still, every researcher must keep in mind that the ideal scenario is to test all the individuals to obtain reliable, valid and accurate results. If testing all the individuals is impossible, that is the only time we rely on sampling techniques.

True to the science of research and statistics, the sampling procedures must be carried out in consideration of several important factors such as (a) population variance, (b) size of the universe or population, (c) objectives of the study, (d) precision in results desired, (e) nature of the universe i.e. homogeneity or heterogeneity in the constituent units, (f) financial implications of the study, (g) nature and objectives of the investigation, (h)techniques of the sampling employed, (i) accuracy needed in making inference about the population being studied, and so on.

Types of Sampling Techniques

1. **Probability Sampling**: - Probability sampling is any sampling scheme in which the probability of choosing each individual is the same (or at least known, so it can be readjusted mathematically). These are also called random sampling. They require more work, but are much more accurate.

2. **Non-Probability Sampling**: - Non-probability sampling technique is totally based on judgement.

Probability Sampling	Non-Probability Sampling
Simple Random Sampling	Quota Sampling
Systematic Sampling	Purposive Sampling
Stratified Sampling	Self-Selection Sampling
Cluster Sampling	Snowball Sampling

Probability Sampling

1. Simple Random Sampling

In this technique, each member of the population has an equal chance of being selected as subject. The entire process of sampling is done in a single step with each subject selected independently of the other members of the population.

Pros of Simple Random Sampling

- One of the best things about simple random sampling is the ease of assembling the sample. It is also considered as a fair way of selecting a sample from a given population since every member is given equal opportunities of being selected.
- Another key feature of simple random sampling is its representativeness of the population. Theoretically, the only thing that can compromise its representativeness is luck. If the sample is not representative of the population, the random variation is called sampling error.
- An unbiased random selection and a representative sample are important is drawing conclusions from the results of a study. Remember that one of the goals of research is to be able to make conclusions pertaining to the population from the results obtained from a sample. Due to the representativeness of a sample obtained by simple random sampling, it is reasonable to make generalizations from the results of the sample back to the population.

Cons of Simple Random Sampling

One of the most obvious limitations of simple random sampling method is its need of a complete list of all the members of the population. Please keep in mind that the list of the population must be complete and up-to-date. This list is usually not available for large populations. In cases as such, it is wiser to use other sampling technique.

2. Systematic Sampling

Suppose that the N units in the population are numbered 1 to N in some order. To select a sample on N units, we take a unit at random from the first K units and every kith unit thereafter. For instance, if K is 15 and if the first unit drawn is number 13, the subsequent units are numbers 28, 43, 58 and so on. The selection of the first unit determines the whole sample. This type is called an every kith systematic sample.

Pros of Systematic Sampling

- Spreads the sample more evenly over the population.
- Easier to conduct than a simple random sample.

Cons of Systematic Sampling

The process of selection can interact with a hidden periodic trait within the population. If the sampling technique coincides with the periodicity of the trait, the sampling technique will no longer be random and representativeness of the sample is compromised.

3. Stratified Sampling

A method of sampling that involves the division of a population into smaller groups known strata. In stratified random sampling, the strata are formed based on members shared attributes or characteristics. A random sample from each stratum is taken in a number proportional to the stratum's size when compared to the population. These subsets of the strata are then pooled to from a random sample.

Pros of Stratified Sampling

The aim of the stratified random sample is to reduce the potential for human bias in the selection of cases to be included in the sample. As a result, the stratified random sample provides us with a sample that is highly representative of the population being studied, assuming that there is limited missing data.

Since the units selected for inclusion in the sample are chosen using probabilistic methods, stratified random sampling allows us to make generalizations (i.e. statistical inferences) from the sample to the population. This is a major advantage because such generalizations are more likely to be considered to have external validity.

Cons of Stratified Sampling

Stratified sampling is not useful when the population cannot be exhaustively partitioned into disjoint subgroups. It would be misapplication of the technique to make subgroups sample sizes proportional to the amount of data available from the subgroups, rather than scaling sample sizes to subgroup sizes (or to their variances, if known to vary significantly e.g. by means of an F test). Date representing each subgroup is taken to be of equal importance if suspected variation among them warrants stratified sampling. If, on the other hand, the very variances vary so much, among subgroups that the data need to be stratified by variance, there is no way to make the subgroup sample sizes proportional (at the same time) to the subgroups sizes with in the total population. (What is the most efficient way to partition sampling resources among groups that vary in both their means and their variances?

4. Cluster Sampling or Multi-Stage Sampling

The naturally occurring groups are selected as samples in cluster sampling. All the other probabilistic sampling methods (like simple random sampling, stratified sampling) require sampling frames of all the sampling units, but cluster sampling does not require that. Once the clusters are selected, they are compiled into frames. Now, various probabilistic researches and observations are performed on these frames and require conclusions are drawn.

Pros of Cluster Sampling

- **Economy: -** The two major concerns of expenditure when it comes to sampling are travelling and listing. They are greatly reduced when it comes to cluster sampling. For example: Compiling research information about every house hold in the city would be a very difficult, whereas compiling information about

various blocks of the city will be easier. Here travelling as well as listing efforts will be greatly reduced.

- **Reduced Variability: -** When you considering the estimates by any other method of probabilistic sampling, reduced variability in results are observed. This may not be an ideal situation every time. Increased variability in results is observed in cluster sampling.

- **Feasibility: -** Again, as I mentioned before, cluster sampling is such a method of probabilistic sampling that takes into account large populations. Since these groups are so large, devploying any other sampling technique would be very difficult task. Cluster sampling is very feasible when you are dealing with large population.

Cons of Cluster Sampling

- **Biased Sampling: -** If the group in population that is chosen as a cluster sample has a biased opinion then the entire population is inferred to have the same opinion. This may not be the actual case. This is a major disadvantage as far as cluster sampling is concerned.

- **Sampling Errors: -** The other probabilistic methods give less error than cluster sampling. For this reason, cluster sampling is discouraged for beginners.

Non-Probability Sampling

1. Quota Sampling

With proportional quota sampling, the aim is to end up with a sample where the strata (groups) being studied (e.g. males vs. females students) are proportional to the population being studied. If we were to examine the differences in male and female students.

Pros of Quota Sampling

Quota sampling is particularly useful when you are unable to obtain a probability sample, but you are still trying to create a sample that is as representative as possible of the population being studied. In this respect, it is the non-probability based equivalent of the stratified random sample. Unlike probability sampling techniques, especially stratified random sampling, quota sampling is much quicker and easier to carry out because it does not require a sampling frame and the strict use of random sampling techniques (i.e. probability sampling techniques). This makes quota sampling popular in undergraduate and master's level dissertations where there is a need to divide the population being studied into strata (groups).

The quota sample improves the representations of particular strata (groups) within the population, as well as ensuring that these strata are not over-represented. For example, it would ensure that we have sufficient male students taking part in the research (60% of our sample size of 100; hence, 60 male students). It would also make sure we did not have more than 60 male students, which would result in an over-representation of male students in our research.

The use of quota sample, which leads to stratification of a sample (e.g. male and female students), allows us to more easily compare these groups (strata)

Cons of Cluster Sampling

In quota sampling, the sample has not been chosen using random selection, which makes it impossible to determine the possible sampling error. Indeed, it is possible that the selection of units to be included in the sample will be based on ease of access and cost considerations, resulting in sampling bias. It also means that it is not possible to make generalizations (i.e. statistical inferences) from the sample to the population. This can lead to problems of external validity.

Also, with quota sampling is must be possible to clearly divide the population into strata; that is, each unit from the population must only belong to one stratum. In our example, this would be fairly simple, since our strata are male and female students. Clearly, a student could only be classified as either male or female. No student could fit into both categories (ignoring transgender issues).

Furthermore, imagine extending the sampling requirements such that we were also interested in how career goals changed depending on whether a student was an undergraduate or postgraduate. Since the strata must be mutually exclusive, this means that we would need to sample four strata from the population: undergraduate males, undergraduate females, postgraduate males and postgraduate females. This will increase overall sample size required for the research, which can increase costs and time to carry out the research.

2. Purposive Sampling

Purposive sampling, also known as judgmental, selective or subjective sampling, reflects a group of sampling techniques that rely on the judgement of the researcher when it comes to selecting the units (e.g. people, case/organisations, events, pieces of data) that are to be studied. These purposive sampling techniques include maximum variation sampling, homogeneous sampling and typical case sampling; extreme (deviant) case sampling, total population sampling ad expert sampling.

Pros of Purposive Sampling

- Whilst the various purposive sampling techniques each have different goal, they can provide researchers with the justification to make generalisations from the sample that is being studied, whether such generalisations are theoretical, analytic and logical in nature. However, since each of these types of purposive sampling differs in terms of the nature and ability to make generalisations you should read the articles on each of these purposive sampling techniques to understand their relative advantages.
- Qualitative research designs can involve multiple phases, with each phase building on the previous one. In such instances different types of sampling techniques may be required at each phase. Purposive sampling is useful in these instances because it provides a wide range of non-probability sampling techniques for the researcher to draw on. For example critical case sampling may be used to investigate whether a phenomenon is worth investigating further, before adopting an expert sampling approach to examine specific issues further.

Cons of Purposive Sampling

- Purposive samples, irrespective of the type of purposive sampling used, can be highly prone to researcher bias. The idea that a purposive sample has been created based on the judgement of the researcher is not a good

defence when it comes to alleviating possible researcher biases, especially when compared with probability sampling techniques that are designed to reduce such biases. However, this judgemental subjective component of purpose sampling is only a major disadvantage when such judgements are ill-conceived or poorly considered; that is, where judgements have not been based on clear criteria, whether a theoretical framework, expert elicitation or some other accepted criteria.

- The subjectively and non-probability based nature of unit selection (i.e. selecting people, cases/organisations etc.) in purposive sampling means that it can be difficult to defend the representativeness of the sample. In other words, it can be difficult to convince the reader that the judgement you used to select units to study was appropriate. For this reason, it can also be difficult to convince the reader that research using purposive sampling achieved theoretical/analytic/logical generalisation. After all, if different units had been selected, would the results and any generalisations have been the same?

3. Self-Selection Sampling

Self-selection sampling is appropriate when we want to allow units or cases, whether individuals or organisations to choose to take part in research on their own accord. The key component is that research subjects volunteer to take part in the research rather than being approached by the researcher directly.

Pros of Self-selection Sampling

- This can reduce the amount of time necessary to search for appropriate units (or cases); that is, those individuals or organisations that meet the selection criteria needed for your sample.
- The potential units or cases are likely to be committed to take part in the study, which can help in improving attendance and greater willingness to provide more insight into the phenomenon being studied.

Cons of Self-selection Sampling

Since the potential research subjects (or organisations) volunteer to take part in the survey:

- There is likely to be a degree of self-selection bias. For example, the decision to participate in the study may reflect some inherent bias in the characteristics/traits of the participants (e.g. an employee with a 'chip of his shoulder' wanting to give an opinion).
- This can either lead to the sample not being representative of the population being studied or exaggerating some particular finding from the study.

4. Snowball Sampling

In sociology and statistics research, snowball sampling or chain sampling, chain-referral sampling is a non-probability sampling technique where existing study subjects recruit future subjects from among their acquaintances. Thus the sample group appears to grow like a rolling snowball. As the sample builds up, enough data is gathered to be useful for research. This sampling technique is often used in hidden populations which are difficult for researchers to access.

Pros of Snowball Sampling

- It can be difficult to identifying units to include in your sample, perhaps because there is no obvious list of the population you are interested in. For example, there are no lists of drug users or prostitutes that a researcher could get access to, especially lists that could be considered representative to the population of drug users or prostitutes.
- There may be no other way of accessing your sample, making snowball sapling the only viable choice of sampling strategy.

Cons of Snowball Sampling

Since snowball sampling does not select units for inclusion in the sample based on random selection, unlike probability sampling technique, it is impossible to determine the possible sampling error and make generalizations (i.e. statistical inferences) from the sample to the population. As such, snowball samples should not be considered to be representative of the population being studied.

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Module 4 – Project level field measurements related to REDD+ measurement, reporting and verification

This Module provides significant details on how to conduct field measurements to estimate indicators of carbon stock changes in forests. The methods described are based on two data collection protocols (Walker et al., 2018 and Huy eta al., 2013) which are explained and included in the reference material. *(Kindly find Walker et al., 2018 in Module 3 reference)*

The content presented in this Module is aimed to prepare participants for the field data collection day. This is achieved through a combination of explanations and demonstrations. A detailed description of the types of data to be collected and the methods and equipment used to collect the data are included.

The information and exercises presented as part of Module 4 aim to improve the participants' understanding of how to:

- Mark out a sample plot
- Use field equipment
- Conduct field measurements of carbon pools
- Record information in data sheets

Ensuring that the participants are familiar with all of these aspects is very important for a smooth and successful field trip.

The two exercises to be conducted at the end of this Module are aimed at ensuring that participants are also confident in the field data collection requirements they will need to complete during the field trip.

All measurement related questions should be answered before heading to the field as it is difficult to support multiple groups spread throughout the forest.

REMINDER: It is recommended that the facilitator prints copies of each of the protocols for each field crew and make sure they bring these during the fieldwork trip for their reference.

Module 4.1: Field Data Collection Protocol

Core Learning Outcome
Participants become familiar with the field protocol requirements for plot establishment

Core Message

- The field work is based on elements of two field work protocols.
    1. The PCM Manual (Walker et al., 2018) is a simple document describing the basics of above and below ground measurement.
    2. The Winrock SOP document is a more detailed set of operational description that cover all pools.

- All measurements are taken at the plot centre point or within the plot established around the centre point
- The plot for the field work is a concentric circular nested plot design
- This is established using various length of ropes as described in Huy et al, 2013. Noting that the dimensions of the concentric plot design is taken from Walker et al 2018.
- If there is a slope greater than 10% (measured using the clinometer) then the rope length needs to be adjusted according to the provided tables.

REMINDER:

- *For a more complete description, the Winrock SOP document should be followed.*
- *The plot design of the fieldwork for this training is based on the description in the Winrock SOP document.*
- *The core set of field equipment is listed with their uses. The participants should now be familiar with the equipment from the previous module; however, a refresher is useful here and in the context of the field work.*
- *During the fieldwork the participants will be asked to find the centre point of the plot using the GPS. At this point the GPS should be placed on the ground for as long as possible to triangulate with the satellites*.

Module 4.2: Measuring Changes in Forest Area and Status

Core Learning Outcome

Participants understand that qualitative information taken at the plot centre are useful for the classification of the land use occurring at the plot location.

Core Message

- At the centre point of the plot a number of observations should be taken
    - Record the location by entering the GPS co-ordinates in the field data sheet
    - Write down any knowledge of the eco-region (or biome) relevant to the country; Eco-regions can be based on ecology, soils, climate, and predominant vegetation for example: tropical, sub-tropical, mangroves, montane etc.
    - A description of land cover or land use. This should also be supported by photos at the 4 cardinal points; N/S/E/W

REMINDER: When going through this sub-module the facilitator should provide each participant a field data collection sheet. The participants should be familiar with the data to be collected for each part of the sheet.

Module 4.3: Measuring Forest Carbon Pools in Sample Plots

Core Learning Outcome
Quantitative information is collected by participants from within the plots or from quadrats or transects adjacent to the plot.

Core Message

- Measurements are taken from within the plots to make estimates of carbon within 5 pools.
- Above and below ground are most commonly measured, when combined they represent 77% of the carbon in the forest
- Deadwood, both lying and standing represent the next most measured pool
- Typically litter and soil organic carbon are not measured
    - Litter is very insignificant and has a fast turn over (decay rate)
    - Soil organic carbon is costly and difficult to measure as it is so variable and as such it is difficult to detect real change

REMINDER: The rest of the presentation focuses on presenting information contained in the Walker et al, 2018 SOP document. It is recommended that the facilitator read this protocol and become familiar with its contents to deliver the slides in the sub-module.

Module 4

Project level field measurements related to REDD+ measurement, reporting and verification

1

Module Outline

1. Field Data Collection Protocol
2. Measuring changes in forest area and status
3. Measuring forest carbon pools in sample plots

2

Module Outcomes

Understanding of how to:

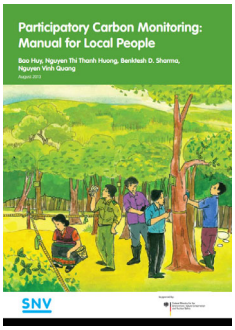
- conduct field observations and measurements to estimate forest carbon stocks

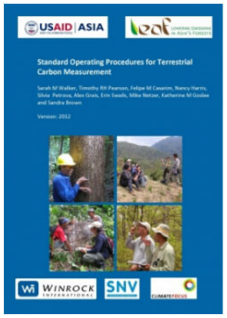
Field Data Collection Protocol

Module 4.1

Measurement of Forest Carbon Pools

- Many protocols available
- **Participatory Carbon Monitoring: Manual for Local People. Huy et al, 2013**
- **Winrock Standard Operating Procedures for Terrestrial Carbon Measurement. Walker et al., 2018**

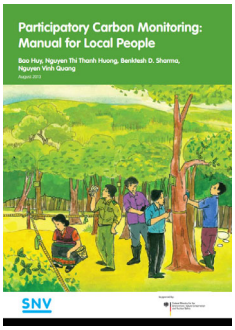


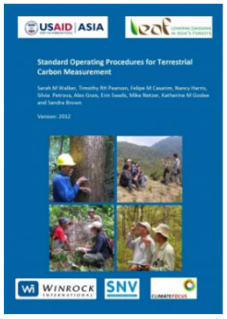


5

Measurement of Forest Carbon Pools

- Both have their bases in internationally recognised good practice
- Provide detailed step-wise procedures to measure changes in the forest area, forest status and forest carbon in the field using existing forest maps, the GPS and pre-determined plot locations.





6

Tools & Materials

Preparation will increase the likelihood of collecting good quality data.



Source: Huy et al, 2013

Tools & Materials

- **GPS –** used to find/record the latitude and longitude of the plot centre
- **Camera –** visual records of forest/land condition at the plot
- **Compass –** assist with navigation AND orientation of quadrats and deadwood transects
- **DBH tape –** measure diameter at breast height of the tree
- Clinometer – used to measure plot slope (%) and tree heights (m)
- **Caliper –** used to measure the diameter of lying deadwood



Source: Huy et al, 2013

Plot Based Measurements

All measurement are based on measurements taken at a GPS point.

Measurements are taken either:

- at the point OR
- from within a plot established at the point.

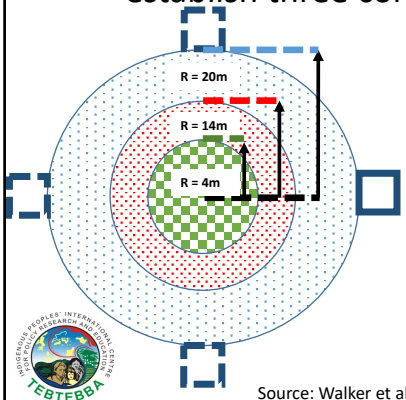


Source: Huy et al, 2013

Establishing a Plot

Procedure:

- For **evergreen, semi-deciduous, dipterocarp, and pine** forest, establish three concentric circular plots



Large plot
radius 20 m
trees> 50 cm dbh

Intermediate plot
radius 14 m
trees 20-50 cm dbh

Small plot
radius 4 m
trees 5-20 cm dbh

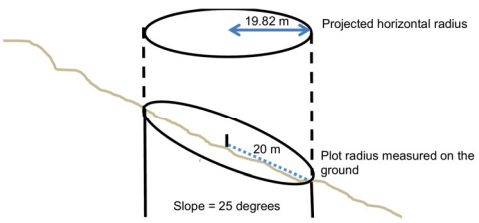
Source: Walker et al, 2018

Establishing a Plot

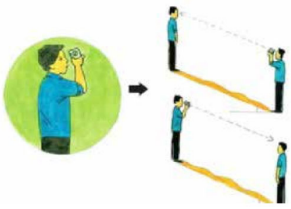
- Prepare a rope with several knots using different colours if possible.
- Make a knot at 4 m, 14m and 20 m.

Establishing a Plot

- If the plot falls on a slope that is greater than 10%, then slope angle should be measured using a clinometer so that an adjustment can be made to the subplot area.
- If slope is less than 10%, correction is not required



Source: Walker et al, 2018



Source: Huy et al, 2013

Establishing a Plot

- Use slope correction table and adjust position of knots accordingly
- The position of the knot should be:

radius + slope correction = corrected circle radius

Nested Tree plot Radius Correction Table – to correct area of plot based on slope

Slope (%)	Corrected Radii (m)																												
0	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
10	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0	14.0	15.0	16.0	17.0	18.0	19.0	20.0	21.1	22.1	23.1	24.1	25.1	26.1	27.1	28.1	29.1	30.1
15	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.1	10.1	11.1	12.1	13.1	14.1	15.1	16.1	17.1	18.1	19.1	20.1	21.1	22.1	23.1	24.1	25.1	26.1	27.2	28.2	29.2	30.2
20	2.0	3.0	4.0	5.0	6.1	7.1	8.1	9.1	10.1	11.1	12.1	13.1	14.1	15.1	16.2	17.2	18.2	19.2	20.2	21.2	22.2	23.2	24.2	25.2	26.3	27.3	28.3	29.3	30.3
25	2.0	3.0	4.1	5.1	6.1	7.1	8.1	9.1	10.2	11.2	12.2	13.2	14.2	15.2	16.2	17.3	18.3	19.3	20.3	21.3	22.3	23.4	24.4	25.4	26.4	27.4	28.4	29.4	30.5
30	2.0	3.1	4.1	5.1	6.1	7.2	8.2	9.2	10.2	11.2	12.3	13.3	14.3	15.3	16.3	17.4	18.4	19.4	20.4	21.5	22.5	23.5	24.5	25.5	26.6	27.6	28.6	29.6	30.7
35	2.1	3.1	4.1	5.1	6.2	7.2	8.2	9.3	10.3	11.3	12.4	13.4	14.4	15.4	16.5	17.5	18.5	19.6	20.6	21.6	22.6	23.7	24.7	25.7	26.8	27.8	28.8	29.9	30.9
40	2.1	3.1	4.2	5.2	6.2	7.3	8.3	9.3	10.4	11.4	12.5	13.5	14.5	15.6	16.6	17.6	18.7	19.7	20.8	21.8	22.8	23.9	24.9	25.9	27.0	28.0	29.1	30.1	31.1
45	2.1	3.1	4.2	5.2	6.3	7.3	8.4	9.4	10.5	11.5	12.6	13.6	14.7	15.7	16.8	17.8	18.8	19.9	20.9	22.0	23.0	24.1	25.1	26.2	27.2	28.3	29.3	30.4	31.4
50	2.1	3.2	4.2	5.3	6.3	7.4	8.5	9.5	10.6	11.6	12.7	13.7	14.8	15.9	16.9	18.0	19.0	20.1	21.1	22.2	23.3	24.3	25.4	26.4	27.5	28.5	29.6	30.7	31.7
55	2.1	3.2	4.3	5.3	6.4	7.5	8.5	9.6	10.7	11.8	12.8	13.9	15.0	16.0	17.1	18.2	19.2	20.3	21.4	22.4	23.5	24.6	25.6	26.7	27.8	28.8	29.9	31.0	32.0
60	2.2	3.2	4.3	5.4	6.5	7.6	8.6	9.7	10.8	11.9	13.0	14.0	15.1	16.2	17.3	18.4	19.4	20.5	21.6	22.7	23.8	24.8	25.9	27.0	28.1	29.2	30.2	31.3	32.4

Full table available from: Walker et al, 2018

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Establishing a Plot

- Example: If a plot is located at a slope of 30 degrees, then using the slope corrected distance of each radius would be:
  - 4m = 4.1m
  - 14m = 14.3
  - 20m = 20.4

Nested Tree plot Radius Correction Table – to correct area of plot based on slope

Slope (%)	Corrected Radii (m)																												
0	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
10	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0	14.0	15.0	16.0	17.0	18.0	19.0	20.0	21.1	22.1	23.1	24.1	25.1	26.1	27.1	28.1	29.1	30.1
15	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.1	10.1	11.1	12.1	13.1	14.1	15.1	16.1	17.1	18.1	19.1	20.1	21.1	22.1	23.1	24.1	25.1	26.1	27.2	28.2	29.2	30.2
20	2.0	3.0	4.0	5.0	6.1	7.1	8.1	9.1	10.1	11.1	12.1	13.1	14.1	15.1	16.2	17.2	18.2	19.2	20.2	21.2	22.2	23.2	24.2	25.2	26.3	27.3	28.3	29.3	30.3
25	2.0	3.0	4.1	5.1	6.1	7.1	8.1	9.1	10.2	11.2	12.2	13.2	14.2	15.2	16.2	17.3	18.3	19.3	20.3	21.3	22.3	23.4	24.4	25.4	26.4	27.4	28.4	29.4	30.5
30	2.0	3.1	4.1	5.1	6.1	7.2	8.2	9.2	10.2	11.2	12.3	13.3	14.3	15.3	16.3	17.4	18.4	19.4	20.4	21.5	22.5	23.5	24.5	25.5	26.6	27.6	28.6	29.6	30.7
35	2.1	3.1	4.1	5.1	6.2	7.2	8.2	9.3	10.3	11.3	12.4	13.4	14.4	15.4	16.5	17.5	18.5	19.6	20.6	21.6	22.6	23.7	24.7	25.7	26.8	27.8	28.8	29.9	30.9

Full table available from: Walker et al, 2018

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Measuring Changes in Forest Area and Status

Module 4.2

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Types of Data Collected

- **Location**
- **Eco-region**
- **Land Cover/Land Use description**
- Species
- Diameter
- Height
- Deadwood diameter/length
- Deadwood decay status
- Litter weight






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Monitoring changes in area and forest status

Expected outcomes:

- Complete information on change in area and status of forest
- Track data delimited in the GPS.

Materials required:

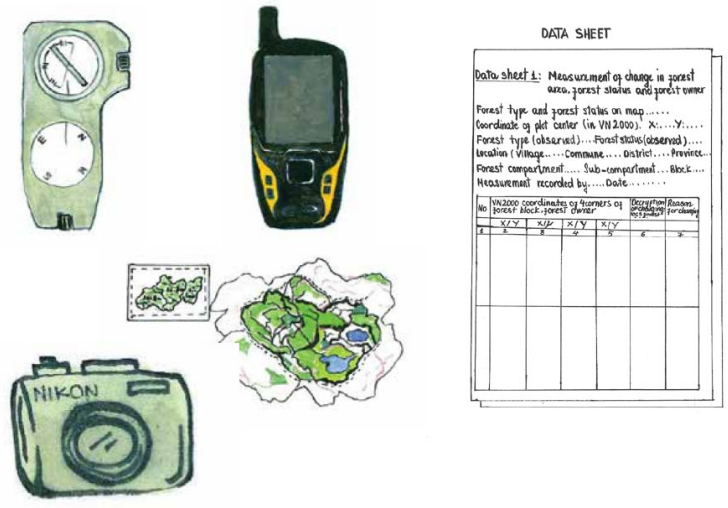
- Map showing the boundaries of forest owners
- GPS to check the boundaries of forest owners and forest change
- Suunto clinometer and compass
- Data recording sheet
- Digital camera

Procedure:

- Determine the forest blocks that were lost or changed in status.
- Use Track function of the GPS to delineate the area.
- Record information about change in area, forest status in field sheet.

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Changes in the forest area and forest status



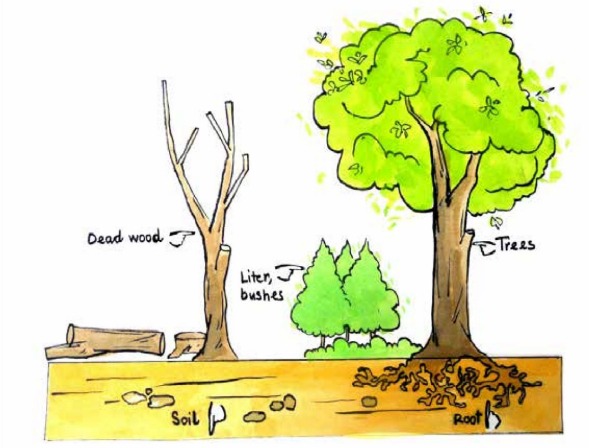
Source: Huy et al, 2013

18

Measuring Forest Carbon Pools in Sample Plots

Module 4.3

Forest Carbon Pools



Source: Huy et al, 2013

Which pools to measure?

Choosing which C pools to monitor depends on:

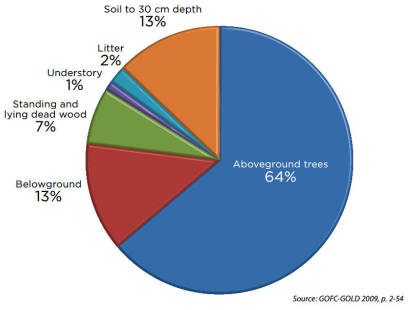
- Magnitude of pool
- Rate of change of pools in response to human disturbance
- Costs to measure
- Methods available to measure
- Attainable accuracy and precision

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Which pools to measure?

In general, all those pools representing 5% or more of total should be included:

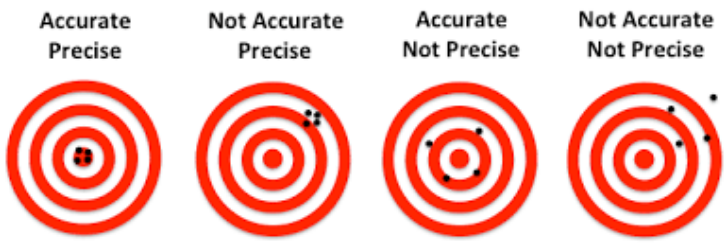
- **The aboveground and below ground tree carbon pool**
- **Standing and lying dead wood**
- Understory in a mature forest is often negligible—less than 2–3% of the total; in a secondary forest this can be a larger proportion—up to 5% of the total
- The soil carbon pool should be included if the forest conversion is to agriculture or roads or other land uses with high soil disturbance (e.g., mining); if converted to pasture soil, C pool can be ignored
- The soil C pool should be included if deforestation occurs on peat swamp forests



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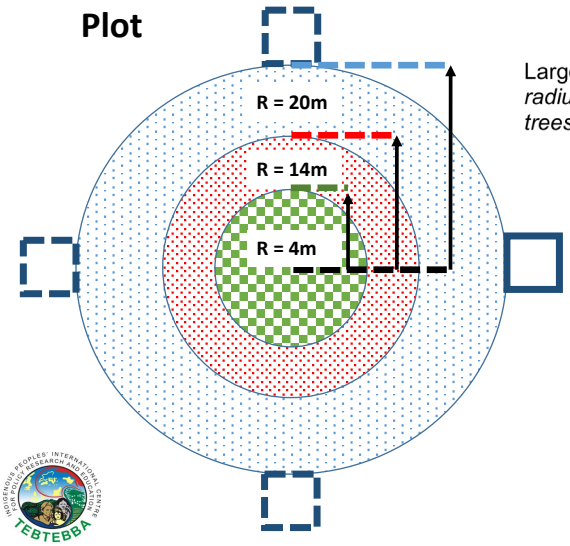
Accuracy vs precision

- **Precision** and **accuracy** are often used interchangeably, but in science they have very **different** meanings. Measurements that are close to the known value are said to be **accurate**, whereas measurements that are close to each other are said to be **precise**.



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Measure Forest Biomass



Large plot
radius 20 m
trees> 50 cm dbh

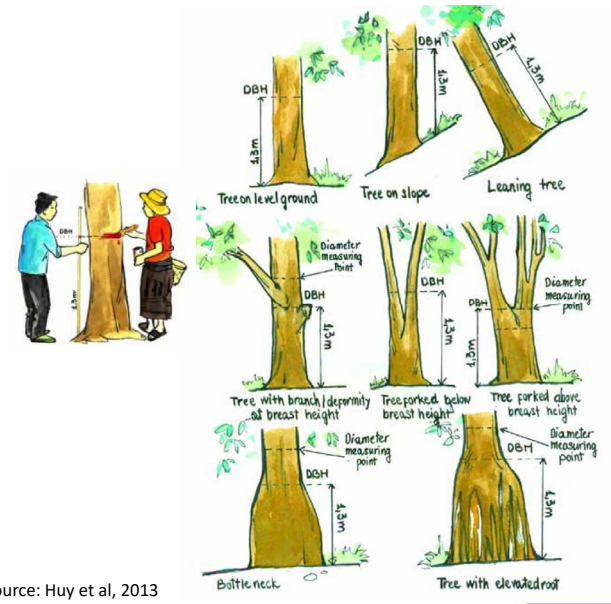
Intermediate plot
radius 14 m
trees 20-50 cm dbh

Small plot
radius 4 m
trees 5-20 cm dbh

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Measure Forest Biomass

- Record the tree species
- Diameter at breast height is measured using the DBH tape
- Tree characteristics impact where the measurement is taken.
- Paint/mark the tree at the point where the measurement is taken
- Tag the tree with a number



Source: Huy et al, 2013

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Measure Forest Biomass



Image Source: Walker et al, 2018

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Measure Forest Biomass

Measure tree height using the clinometer.

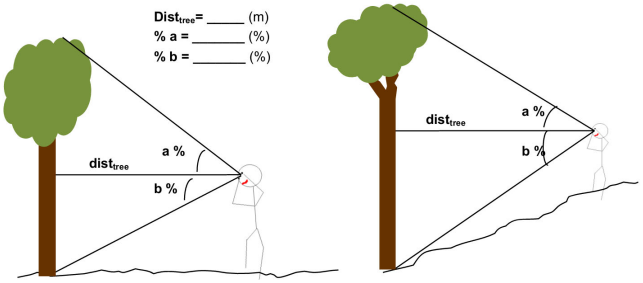
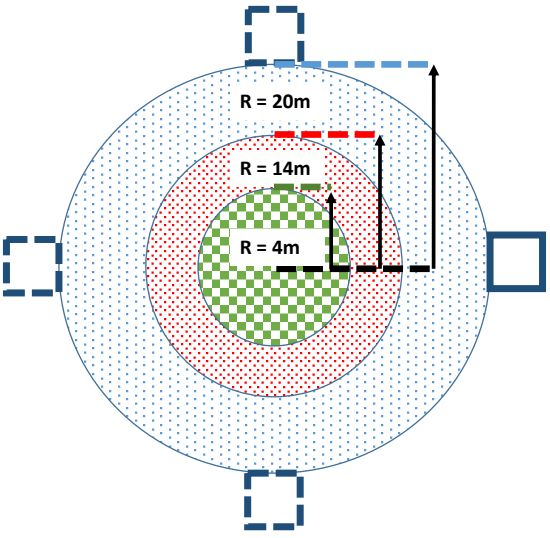


Image Source: Walker et al, 2018

27

Measure Undergrowth and Litter

- Take litter samples from quadrat immediately outside the largest radius plot
- Take 1 quadrat OR up to four if time/resources permit



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Measure Undergrowth and Litter

- Aboveground biomass and litter is measured using a 1m x 1m quadrat
- All undergrowth biomass is removed from within the quadrat
- Wet weight is measured in the field
- All litter is then removed from within the quadrat
- Wet weight is measured in the field



Image Source: Walker et al, 2018

29

Measure Undergrowth and Litter





Image Source: Walker et al, 2018



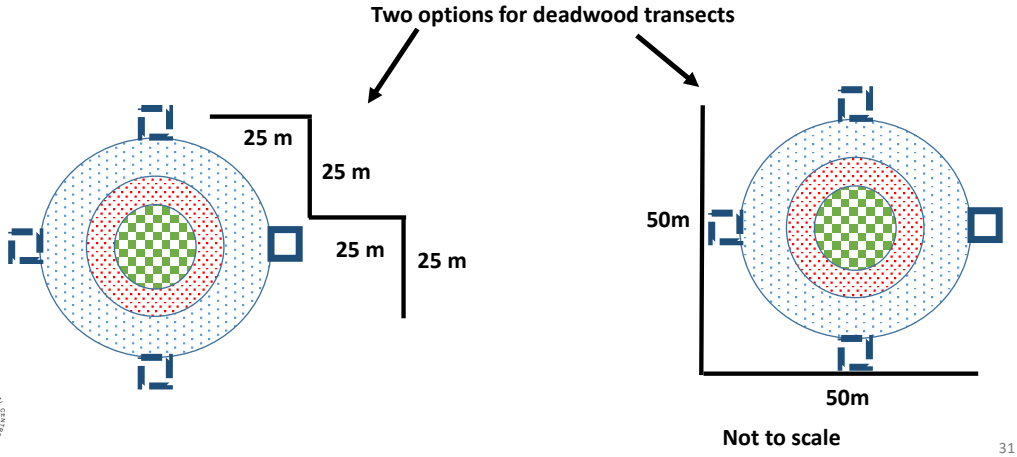


Image Source: Walker et al, 2018

30

Measuring Deadwood

- Standing deadwood is measured within the nested plots
- Lying deadwood along transects. Two options are presented below



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Measure Standing Deadwood

Measurements of standing dead wood take place concurrently with live tree measurements.

Each standing dead trees should be classified into two classes:

- Class 1: Dead tree with branches and twigs and resembles a live tree except for absence of leaves (make sure tree is dead and not deciduous)
- Class 2: Trees ranging from those containing small and large branches to those with bole only

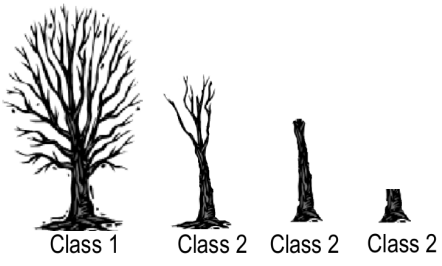


Image Source: Walker et al, 2018

32

Measure Standing Deadwood

Class 1 Trees

- Follow the same measurement protocols as for the measurement of live trees, including the measurement of tree variables (eg DBH, H)
- Mark tree as “Dead‘ on datasheet.

Class 2 Trees

- Measure the diameter at the base of the tree. (**Dbase**)
- Measure height of stem (H)
- Measure diameter at top of stump (**Dtop**) Alternatively, do not take a measurement at the top of the stump and write ‘None‘ or ‘NA‘ on datasheet.

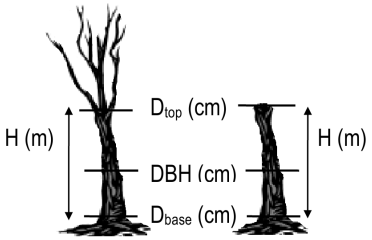


Image Source: Walker et al, 2018

33

Measure Lying Deadwood

- Starting at the tree plot center determine a random compass bearing.
- Using the compass bearing, walk 100 paces from the plot center.
- Walk 5 more steps
  - These additional steps reduce bias in choosing the sampling location
- Lay out two 50 m lines at right angles outside plot. Determine the direction of the first line using same random compass angle and place the other line at right angle to first. If necessary, 4 x 25 m lines can be laid out. However, the lines should not overlap or cross into tree plot.

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Measure Lying Deadwood

- Along the length of the line, measure the diameter of each intersecting piece of coarse dead wood (> 10 cm diameter)
- Calipers work best for measuring the diameter.
- When measuring the diameter of dead wood it is not always possible to place a tape around the log. It can also be dangerous because logs are usually home to snakes, spiders, etc.
- If you are going to measure the diameter of the piece of dead wood with a diameter tape, make sure the route is clear before placing your hand underneath the log.

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Measure Lying Deadwood



Image Source: Walker et al, 2018

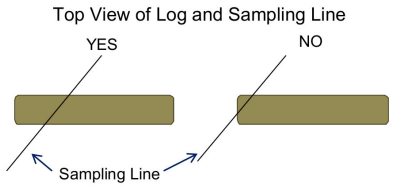
36

Measure Lying Deadwood

A piece of dead wood should only be measured if:

a) more than 50% of the log is aboveground

b) the sampling line crosses through at least 50% of the diameter of the piece



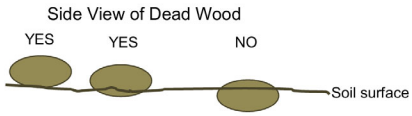


Image Source: Walker et al, 2018

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Measure Lying Deadwood

- If the log is hollow at the intersection point, measure the diameter of the hollow; the hollow portion in the volume estimates is excluded.
- Record one of three density states for each piece of deadwood: sound, intermediate, or rotten.
- To determine the density class, strike each piece with a machete
  - Machete bounces off – Sound
  - Machete partially sinks in – intermediate
  - Machete goes through the piece - rotten

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Measure Soil Organic Carbon

- Where litter and/or herbaceous vegetation samples have been taken, the same locations shall be used for soil sampling.
- Remove all vegetation and litter from the sampling location.
- Because the carbon concentration of organic materials is much higher than that of the mineral soil, including even a small amount of surface material can result in a serious overestimation of soil carbon stocks.

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Measure Soil Organic Carbon

- There are two options for sampling the soil: using a standard soil corer (option 1) or digging a small pit (option 2).
- Sampling forest soils with a standard soil corer can often present difficulties as the corer can hit roots frequently, which makes it difficult to extract a full core.

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Measure Soil Organic Carbon

Option 2- Soil pit method

- Four small pits 30cm deep, one at each of the four sampling locations are dug and aggregated into one sample.
- Using the shovel take a slice of soil from one of the walls of the soil pit.
- The slice should be uniform throughout the 30 cm profile, i.e. an equal amount of soil should be collected from the first 15 cm as the last 15 cm.
- Soil carbon usually decreases with depth, and if the slice collected contains more soil from the top of the pit versus the bottom the soil carbon estimate will be biased.
- Repeat steps at the other 3 sampling locations.






Measure Soil Organic Carbon

Option 2- Soil pit method

- Mix all four samples thoroughly to a uniform color and consistency. It is important to take special care to remove pieces of litter and charcoal from samples at any sites.
- Place one thoroughly mixed subsample into a labeled sample bag. Ensure total weight of soil in bag is greater than the minimum soil weight required by the soil laboratory

Measure Soil Organic Carbon

Bulk Density

- After removing the soil for carbon measurements, place the bulk density ring over the mid-point of the soil pit. This would normally be at 15 cm.
- Cover the ring with a piece of wood and hammer the ring into the side of the soil pit (avoid compacting the soil).
- When the ring is flush with the side of the soil pit dig around the ring until the soil ring can be removed along with all the soil inside. If soil falls out of the ring, the process must be repeated.
- Carefully place the soil contained in the bulk density ring into a sample bag and label
- Each sampling plot (e.g. tree plot) will have three soil samples: 1 bag for soil carbon estimation, 2 bags for bulk density estimation.

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Measure Soil Organic Carbon

Analysis

- It is allowed that there is a delay between field data collection and laboratory analysis. However, sample bags must be placed in a location that allows air drying to occur.

- Promptly send soil samples to a professional lab for analysis.

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Establishing a Plot

Exercise:

Mark and record the centre of a field plot
Simulate the establishment of concentric circular plots

Establishing a Plot

Expected Outcome:

Concentric circular plots of various size are established for different forest types or tree size.

Materials required:

- Suunto clinometer and compass
- Four ropes with a range of colours knots at specified intervals equivalent to the radius of the sub-plots
- Form for additional distances at different radius for plots located on slope
- Digital camera (optional).

Measuring Carbon Pools

Exercise:

Collect carbon pool measurements from the field.
Record information in the field sheets.

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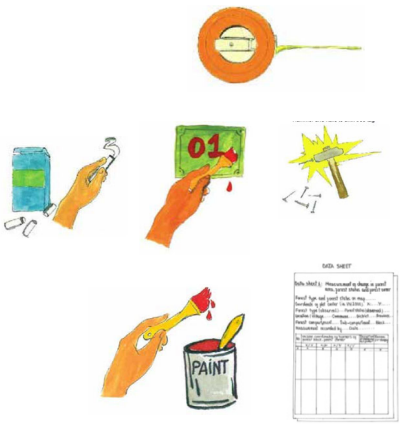
Measure Forest Biomass

Expected outcome

- Validated data about tree and forest resources.

Materials required:

- Diameter measurement tape (i.e. D tape)
- Clinometer to measure height
- Chalk, marker or paint for marking
- Tree tag for marking trees
- Hammer and nails to affix tree tag
- Paint to mark sign of tree
- Field sheet and pencil for recording inventory factors
- Digital camera for taking pictures.



Source: Huy et al, 2013

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Module 4 Exercises

Field Practice and Actual Field Data Collection

Description	There are two types of Exercises related to Module 4: • Field practice exercises • Actual Field Data Collection Both types of exercises should be conducted in teams. The teams should be the same as those that will work together on the field trip. Teams should be made up of 4 people at a minimum and it is recommended there are no more than 7 in a team. All participants should have a try at all tasks and at using all the different types of equipment. The **field practice exercises** are all aimed at familiarisation and practice prior to going to the field to conduct the actual tree plot measurements. One of the most challenging and time-consuming tasks is the establishment of field plots within the forest. It is very difficult to support the teams once they are in the field as they will be spread out in the forest. All participants need to be clear of what is expected of them prior to leaving for the field trip.
Materials	**Manual:** Walker et el, 2018 and Huy et al, 2013 **For documentation:** field sheets; pens/pencils **For navigation:** GPS, compass **For forest conditions:** camera **For establishing the plot:** stake, plot number tag, 1x50m measurement tape, clinometer, rope, coloured ribbons **For forest measurements:** paint/chalk, tree tags, DBH height stick, clinometer, 1 DBH tape; 1 x measurement calliper; 1xquadrat; 1xscales; 1xtarp/large bag; sample bags

Field Practice Exercise: Establish a Field Plot	All the equipment should be taken outside. Choose a location that is easy to work in. An outside area at least 30m in diameter is needed to simulate the establishment of a plot. If the group of participants is not more than 20 people it is recommended to conduct this exercise in 1 group. If the group is bigger, then split into 2 groups, but this will require 2 trained facilitators; one to work with each group. Get the participants to navigate to the plot using the GPS. This will require the facilitator to have collected the GPS co-ordinates of the location prior to the exercise and to share these with the participants who should entre them into the GPS and navigate to the location. The GPS point represents the plot centre and this should be marked (stake or similar). Once the centre point has been identified; the participants should be asked to fill in the information at the top of the field sheet. Demonstrate how to take photos at the 4 cardinal points of the compass. After this information is collected, the process of establishing the plot should commence. Follow the steps outlined in the Data Collection Protocol (Walker et al, 2018 ad Huy et al, 2013).
Expected Duration	1 hr
Field Practice Exercise: Measure Carbon Pools	This exercise should be conducted in the same teams as those allocated in **Exercise - Familiarisation with the Field Equipment.** This exercise is aimed to increase familiarisation with the field equipment by simulating some actual measurements and where possible outside. The proposed teams for the field work should work together. The teams should each have access to the Data Collection Protocol for this exercise to check they are doing the exercise properly (Walker et al, 2018 ad Huy et al, 2013). The facilitator could set up the following 'stations' which the teams can rotate around. The focus for each station may include: • *DBH tape station* – practice on trees or poles how to place the DBH tape and how to read the correct number from the tape. • Clinometer station – practice on trees or poles how to use the clinometer. A discussion on how to read the values and where to measure the distance between the location of the measurer and the item being measured • Deadwood measurement station – use of the caliper to measure the lying deadwood and a discussion on what would be considered 'in' or 'out' of the transect line • Litter collection station – discussion about how to weigh the litter in the field, how to determine the difference between litter and deadwood and soil.
Expected Duration	1.5 hrs

Actual Field Data Collection: Measure Carbon Pools	This exercise should be conducted in the same teams as those allocated in **Exercise - Familiarisation with the Field Equipment.** This exercise requires each team to establish a plot in the field exactly as was demonstrated in the Field Practice Exercises. Finding the plot centre can be done by either navigating to the plot (if the facilitator has prior access to the forest to enable the plot locations to be defined OR require the team to walk a set distance in a set direction and take a GPS point). Remind teams that all the information must be filled in on the field data sheets. Once the plot has been established the team should ask the facilitator to check the plot is established correctly before the team starts recording tree measurements. Once the check has been complete the teams should proceed with tree related measurements first and then conduct litter and deadwood measurements. If the teams are large enough then all pool measurements can be conducted at the same time, noting that there should be at least groups of 2 working together on the collection of data related to each carbon pool. The teams should follow the steps outlined in the Field Guidance Manual (Walker et al, 2018). Once all the measurements have been collected the Team Leader should do a final check of the data sheets to ensure there are no data gaps or obviously incorrect data. Once the group has made the field data sheet check all team should gather at a common point. All field equipment and samples should be collected and brought with the group; however, the plot and tree markings should not be removed at this point as they are still required for the QA/QC exercise.
Expected Duration	4-5 hours

Actual Field Data Collection: Conduct field QA/QC checks	Each team should have a clean Field Data sheet specifically for conducting independent QA/QC checks. Randomly allocate each team to another plot number and ask each team to remeasure the DBH of all the trees in their allocated QA/QC plot. The tree number and DBH should be recorded in the QA/QC field sheet. Once the team has remeasured all the trees in their QA/QC plot they should gather back at the common point. The field sheets should be handed to the facilitator. Once all teams are back, all teams should return to their original plot and collect the remaining equipment and prepare to leave the field. The outcomes of the field QA/QC checks will be explored back in the class room using an excel spreadsheet.
Expected Duration	1-2 hours

Sampling Data Sheet

Plot ID#:	
Date (DD / MM / YYYY):	
Land Cover type:	
Slope (%):	

Location:	Townsville		
GPS Coordinate	_____ :	Precision:	
	_____ :	Elevation:	

Crew chief:			
Start time:	End time:	Total time (h):	

Data recorded by:			
Photo Taken (Yes/No):		# people in crew:	

Notes:

Plot

Nested plot radius (m)	small:	4		medium:	14	large:	20
Measure all trees with diameter size (cm)	small:	>=	5.0	medium:	>= 20.0	large:	>= 50.0

Live Tree Measurements

Tree #	Species	(L / C)	DBH (cm)

Tree #	Species	(L / C)	DBH (cm)

Tree #	Species	(L / C)	DBH (cm)

Tree #	Species	(L / C)	DBH (cm)

Tree #	Species	(L / C)	DBH (cm)

Tree #	Species	(L / C)	DBH (cm)

Sampling Data Sheet

Plot ID#:	

Class 2 Standing Deadwood Measurements

Diameter (cm)				Height Measurement 1				Height Measurement 2			
Base (0.1m)	DBH (1.3m)	Top	Height (m)	Clinometer angle (%)		Distance from eye to tree (m)	Height of eye (m)	Clinometer angle (%)		Distance from eye to tree (m)	Height of eye (m)
				+	-			+	-		

Lying Deadwood Measurements

Transect length (m):	

(wood greater than 10cm diameter)

Diameter (cm)	Density Class (S, I, R)	Hollow diameter (cm)

Non-Tree Vegetation (Clip Plots)

Plot dimensions:	

Litter Plots

Plot dimensions:	

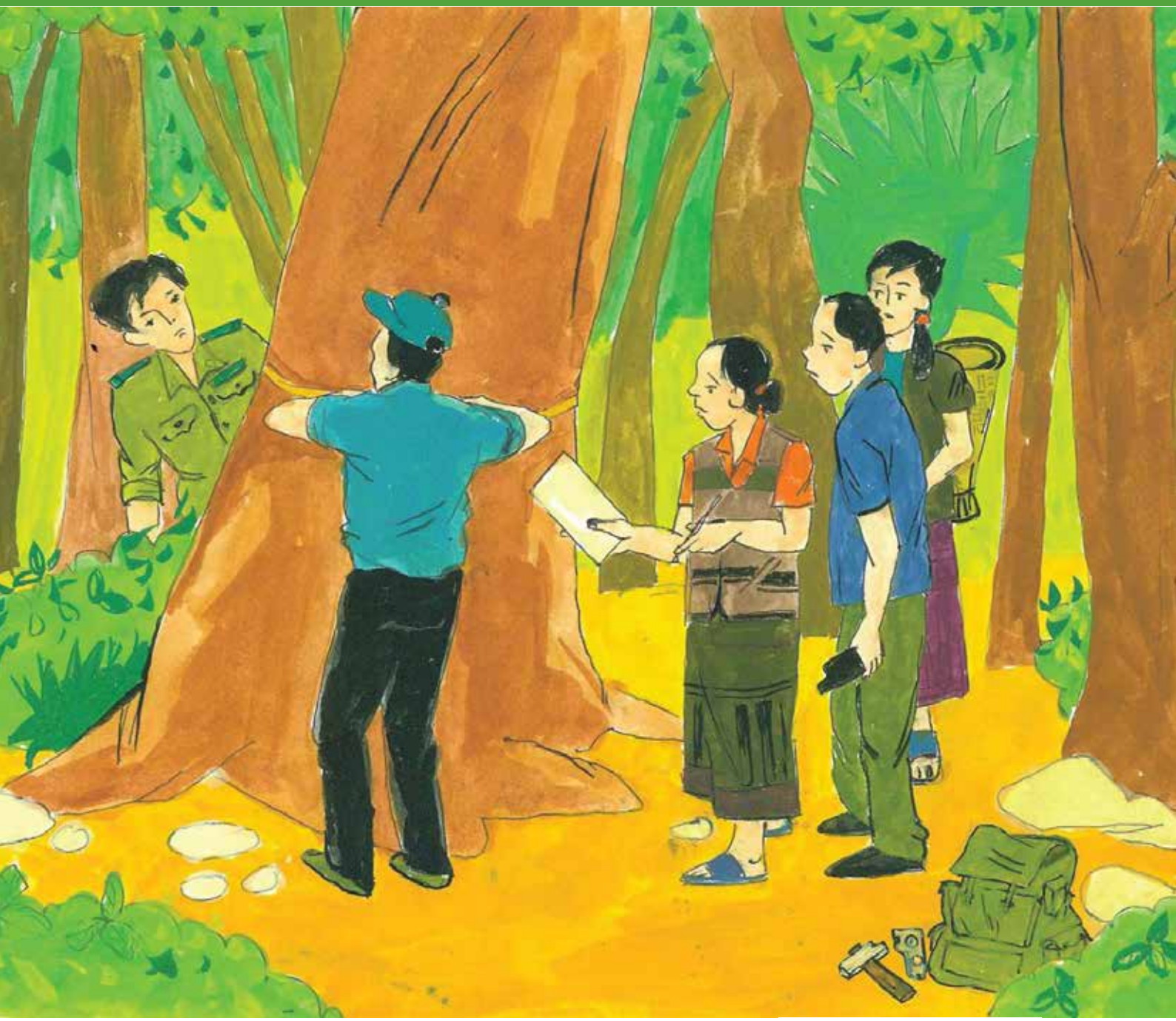
Sample ID #	Weight of (g)			
	bag or sheet	bag + material	subsample bag	subsample bag + subsample material

Sample ID #	Weight of (g)			
	bag or sheet	bag + material	subsample bag	subsample bag + subsample material

Participatory Carbon Monitoring: Manual for Field Reference

Bao Huy, Nguyen Thi Thanh Huong, Benktesh D. Sharma, Nguyen Vinh Quang

August 2013



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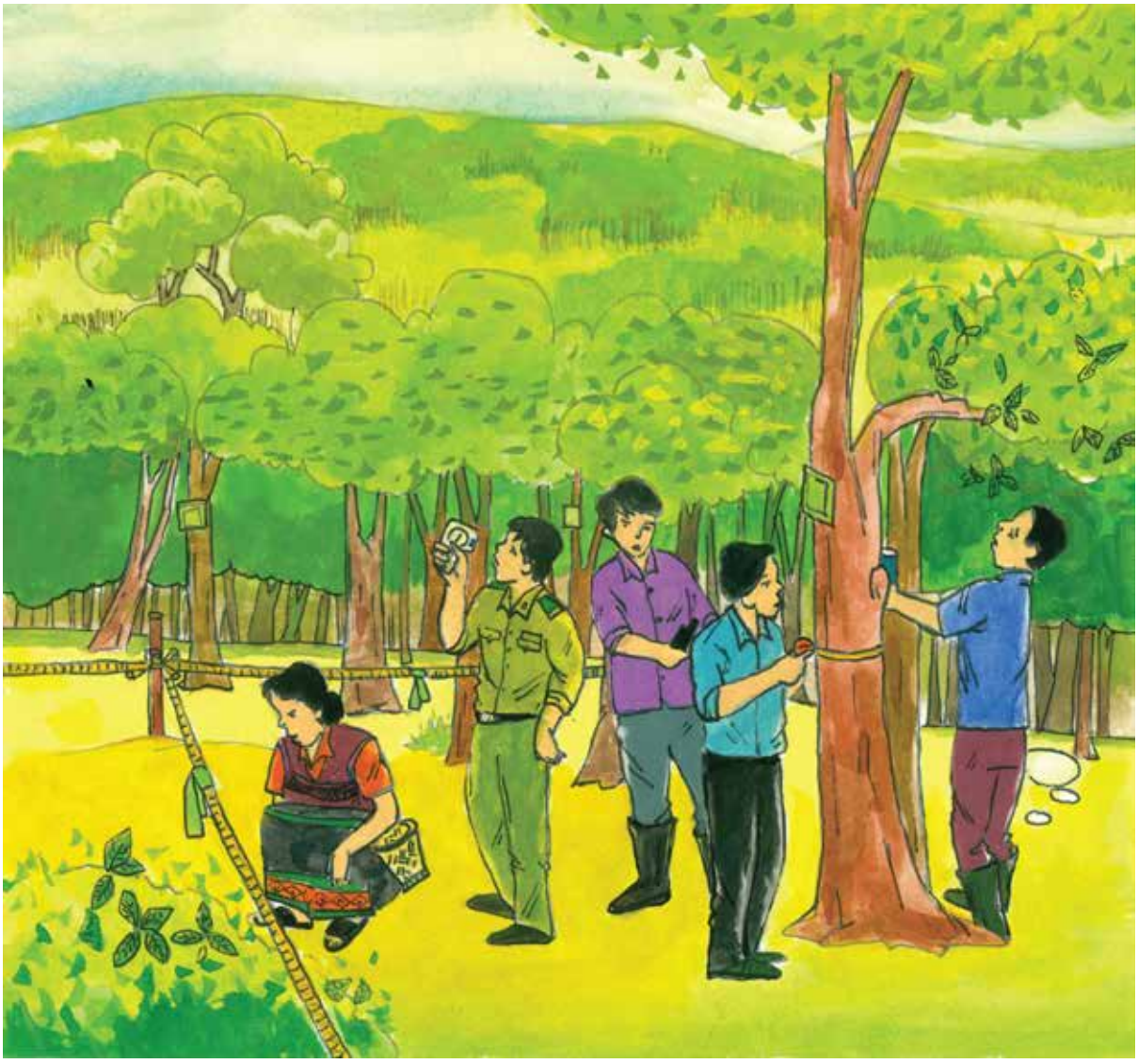
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Participatory carbon monitoring field task 1

This PCM manual, **Manual for Field Reference**, is one of three individual manuals designed to facilitate stakeholders' participation in carbon monitoring and is designed to be used in the field for quick reference. The **Manual for Local Technical Staff** is for use by local forestry staff for designing and implementing PCM activities in the field and for analysing PCM data. A third in the series, the **Manual for Local People**, is for use by local households and communities for collecting and monitoring field data.

This **Manual for Field Reference** is not a substitute for the other two manuals, but is to be used as a quick reference guide while performing the following PCM field tasks:

1. Monitoring changes in area and forest status
2. Determining position of sample plot
3. Establishing permanent sample plot
4. Measuring forest biomass and carbon in sample plot



Monitoring changes in area and forest status 2

Expected outcomes:

- Complete information on change in area and status of forest
- Track data delimited in the GPS.

Materials required:

- Map showing the boundaries of forest owners
- GPS to check the boundaries of forest owners and forest change
- Suunto clinometer and compass
- Data recording sheet (Form 1)
- Digital camera (optional).

Procedure:

When the forest status changes, such as from deforestation and selected exploitation, data on area and change is collected using the following approach:

- Determine the forest blocks that were lost or changed in status.
- Use Track function of the GPS to delineate the area.
- Record information about change in area, forest status in Form 1.

Determining position of sample plot 3

Expected Outcome:

- Each sample plot in the field is identified.

Materials required:

- Map of location of random sample plots
- Suunto clinometer and compass
- GPS with coordinates of random sample plots
- Table recording the list of sample plot codes and coordinates
- Iron boards to use as identification tags
- Hammer and nails to affix tree tags
- Permanent paint to mark identification tags
- Digital camera (optional).

Procedure:

- Use Goto function of the GPS to go to correct coordinate of each sample plot have been positioned on map and installed in the GPS.
- Fix landmark in the centre of the sample plot and affix iron board.

Establishing permanent sample plot 4

Expected Outcome:

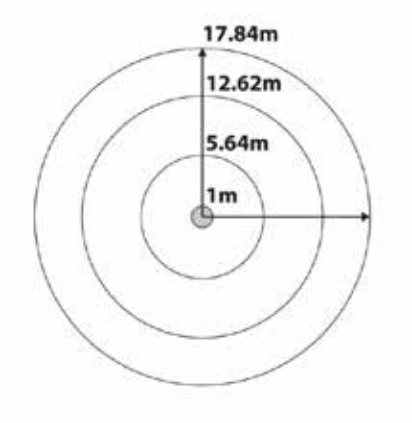
- Concentric circular plots of various size are established for different forest types or tree size.

Materials required:

- Suunto clinometer and compass
- Four ropes with a range of colours knots at specified intervals equivalent to the radius of the sub-plots
- Form for additional distances at different radius for plots located on slope
- Digital camera (optional).

Procedure:

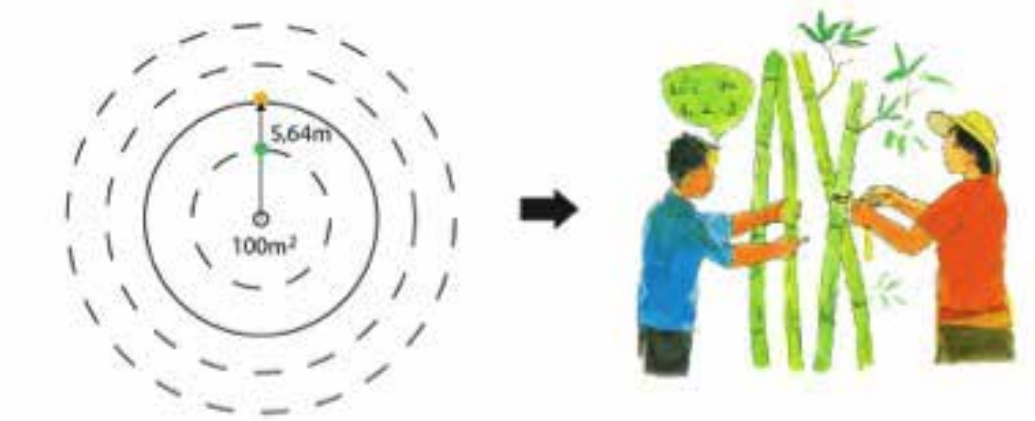
- For **evergreen, semi-deciduous, dipterocarp, and pine** forest, establish four concentric circular plots:



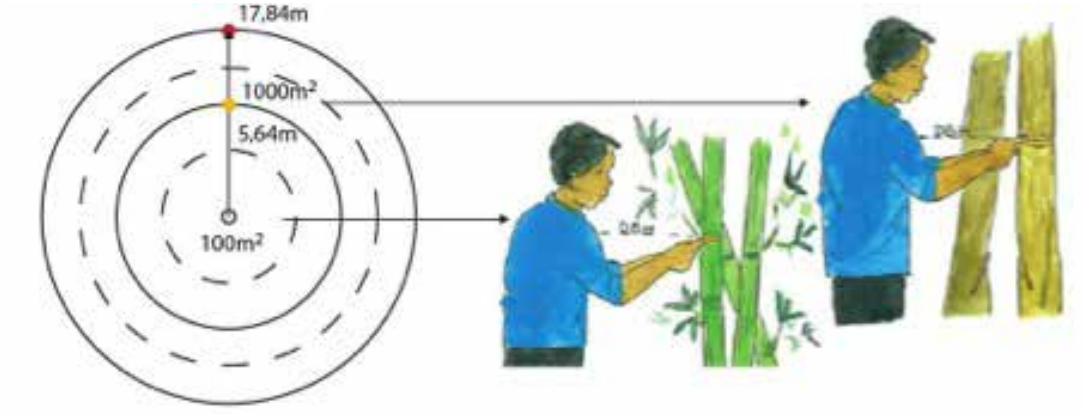
- Sub-plot 1: radius 1 m, area 3.64 m^2, measure regeneration with DBH < 6 cm and H > 1.3 m
- Sub-plot 2: radius 5.64 m, area 100 m^2, measure tree with 6 cm ≤ DBH ≤ 22 cm or bamboo
- Sub-plot 3: radius 12.62 m, area 500 m^2, measure tree with 22 cm ≤ DBH ≤ 42 cm
- Sub-plot 4: Radius 17.84 m, area 1000 m^2 to measure tree with DBH ≥ 4^2 cm

Figure 1. Layout of circular nested plot with four concentric sub-plots

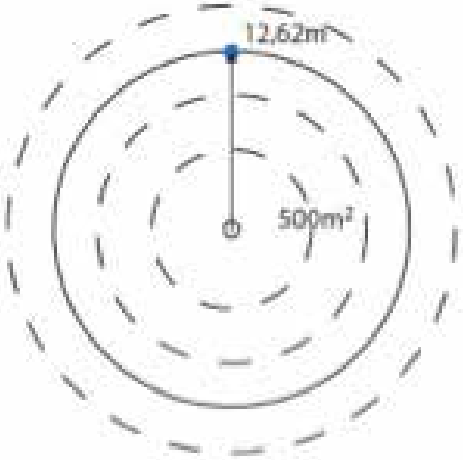
- For **bamboo forest**, the size of the sample plot is 100 m2 (sub-plot 2).

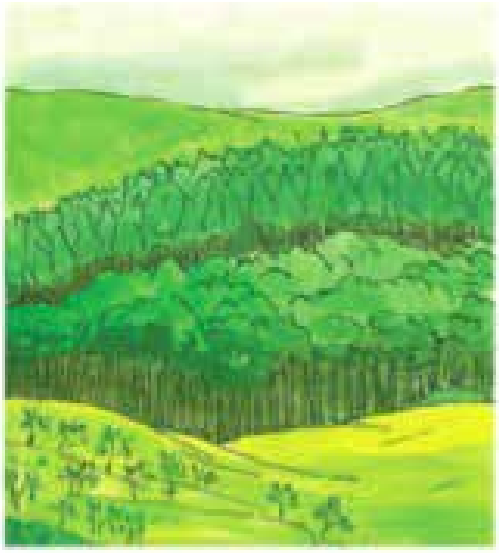


- For **mixed woody – bamboo forest**, measure trees as in the case of evergreen forest in four concentric sub-plots, but measure bamboo only in sub-plot 2.



- For **plantation forest**, establish three concentric plots i.e. sub-plot 3 as described for evergreen forest.





- Prepare a rope with several knots using different colours. Make a green knot at 1 m, a yellow knot 5.6 m, a blue knot at 12.62 m and a red knot at 17.8 m (Figure 5). Four ropes are needed.
- Measure slope of the ground at each plot using the clinometer in eight directions (i.e. every time rope is laid on the ground along the plot radius) (Figure 6). Use slope correction table (See Table 1) and adjust position of knots accordingly.

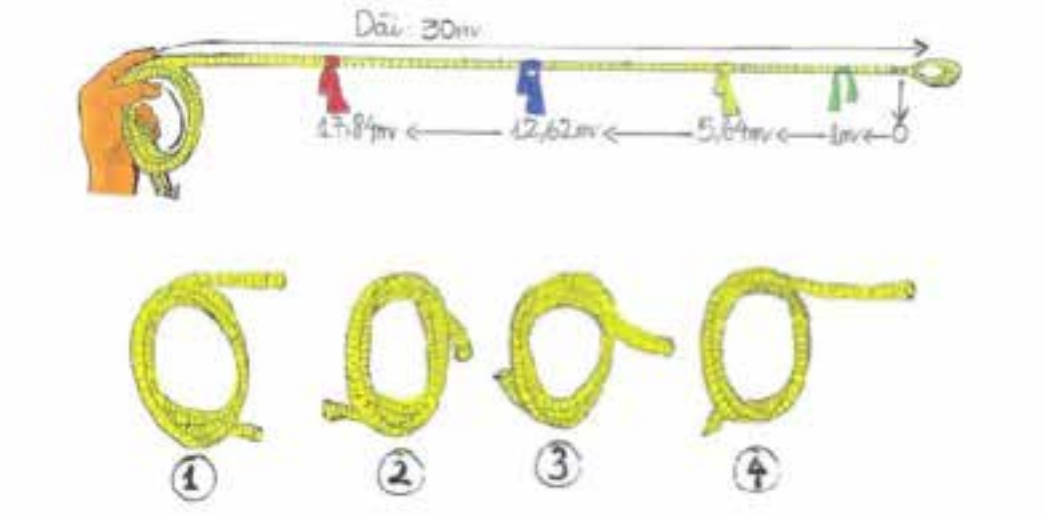


Figure 2. Making knots of different colours corresponding to radius of concentric sub-plot



Figure 3. Compass and clinometer and obtaining slope using clinometer

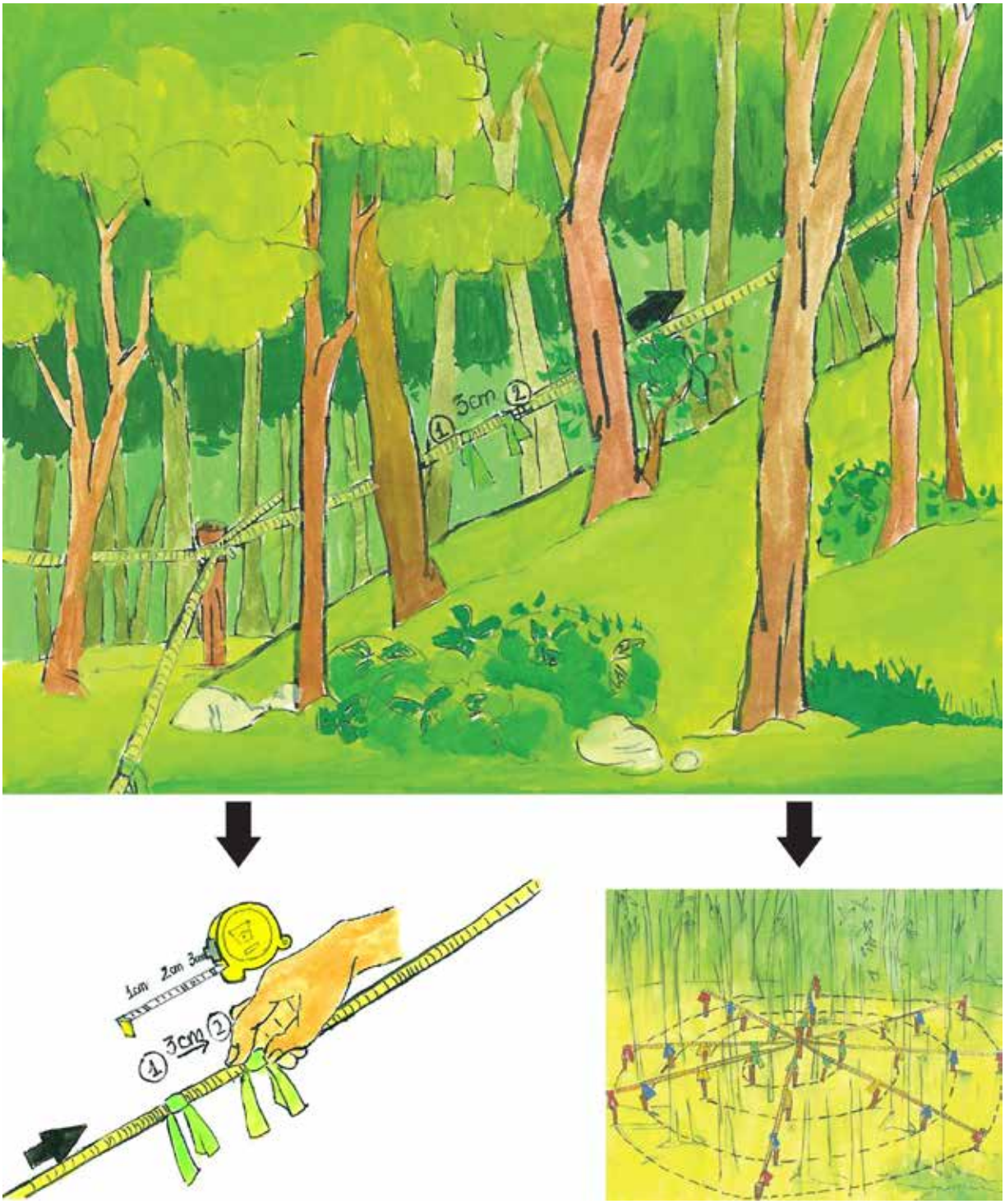

3cm
1cm 2cm 3cm
3cm

Table 1. Slope correction factors

Slope (degree)	Radius (m)			
	1.00 (Green)	5.64 (Yellow)	12.62 (Blue)	17.84 (Red)
0	0.00	0.00	0.00	0.00
2	0.00	0.00	0.01	0.01
4	0.00	0.01	0.03	0.04
6	0.01	0.03	0.07	0.10
8	0.01	0.06	0.12	0.18
10	0.02	0.09	0.19	0.28
12	0.02	0.13	0.28	0.40
14	0.03	0.17	0.39	0.55
16	0.04	0.23	0.51	0.72
18	0.05	0.29	0.65	0.92
20	0.06	0.36	0.81	1.14
22	0.08	0.44	0.99	1.40
24	0.09	0.53	1.19	1.69
26	0.11	0.64	1.42	2.01
28	0.13	0.75	1.67	2.37
30	0.15	0.87	1.95	2.76
32	0.18	1.01	2.26	3.20
34	0.21	1.16	2.60	3.68
36	0.24	1.33	2.98	4.21
38	0.27	1.52	3.40	4.80
40	0.31	1.72	3.85	5.45
42	0.35	1.95	4.36	6.17
44	0.39	2.20	4.92	6.96
46	0.44	2.48	5.55	7.84
48	0.49	2.79	6.24	8.82
50	0.56	3.13	7.01	9.91

- First, stretch one rope from centre towards the north. Stretch another rope to the east. Stretch a third rope at 45˚ N between the first and second ropes. As a result, two segments are established from north to east. Measure from left to right (i.e. clock-wise) and from the centre towards the sub-plot perimeter.

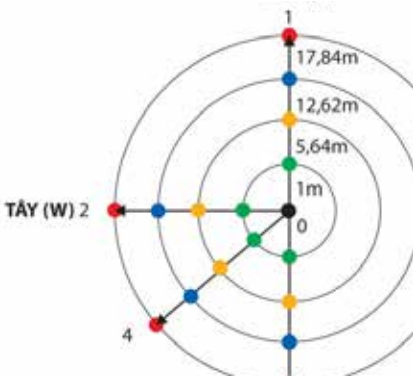


Figure 4. North-east section of plot

- Second, leave the north and east ropes fixed. Move the rope that was in between north and east to the south. Stretch a fourth rope between south and east creating two segments between south and the east. Start measuring from left to right and from the centre towards the plot perimeter

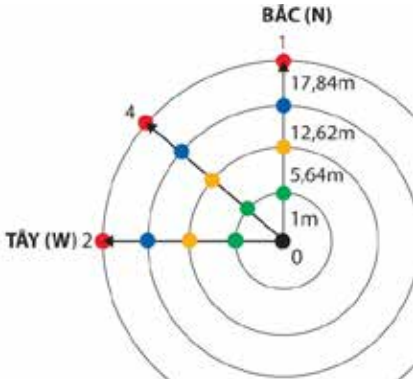


Figure 5. South-east section of plot

- Third, leave the north and south ropes are fixed and move the rope in the east to the west. Also move the rope that was between east and south to between south and west. Measure from left to right and from centre towards the plot perimeter.

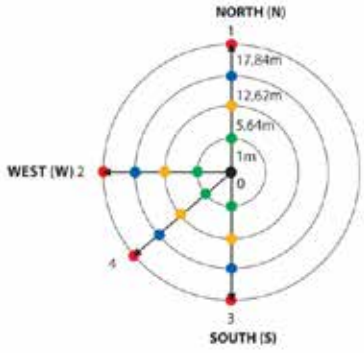


Figure 6. South-west section of plot

- Finally, leave the rope in the north and west and place another rope between west and north. Start measurement from left to right and from the centre towards the perimeter.
- Place a red wooden pillar at the north, east, south and west edges of the plot.

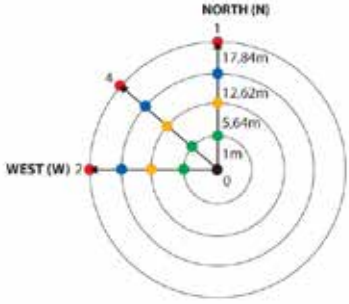


Figure 7. North-west section of plot

Measure forest biomass carbon in sample plot 5

Expected outcome:

- Validated data about tree, bamboo and forest resources.

Materials required:

- Diameter measurement tape (i.e. D tape)
- Chalk, marker or paint for marking
- Iron board or tree tag for marking trees
- Hammer and nails to affix tree tag
- Paint to mark sign of tree
- Spreadsheet for recording inventory factors
- Digital camera for taking pictures.

Procedure:

- Within 1 m radius sub-plot (green), measure all trees with DBH ≥ 6 cm and count regeneration trees with DBH < 6 cm and H ≥ 1.3 m.; within 1m - 5.54 m radius sub-plot (yellow), measure all trees with DBH ≥ 6 cm; within 5.64 m - 12.62 m radius sub-plot (blue), measures trees with DBH ≥ 22 cm; and within 12.62 m - 17.84 m radius sub-plot (red), measure trees DBH ≥ 42 cm (Figure 8)

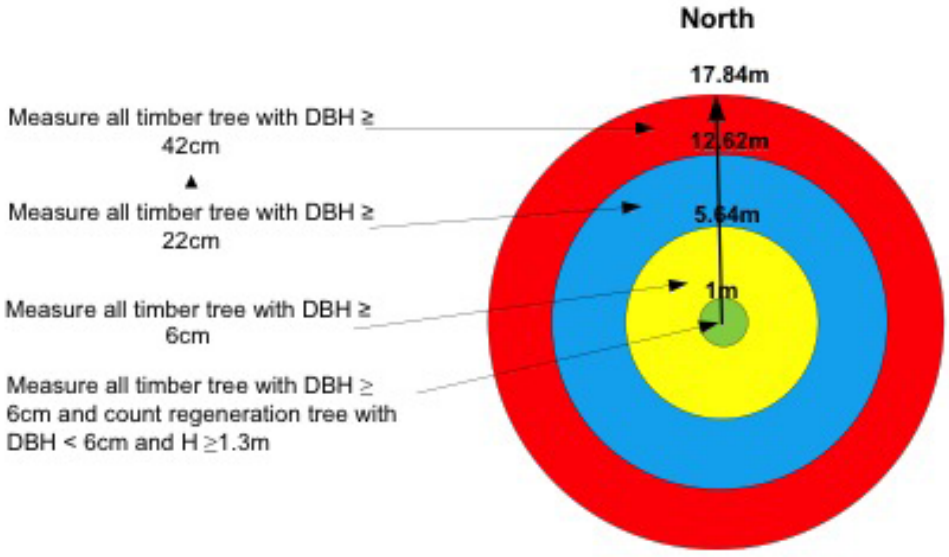


Figure 8. Measure diameter class according to radius of sample plot

- For woody tree, identify species and measure DBH if trees DBH is greater than 6 cm. For trees with DBH < 6 cm and height ≥ 1.3 m, count the number within the sub-plot 1
- Use tree tags to mark the trees
- For bamboo record age and average DBH
- Take picture of trees and of crews measuring trees.

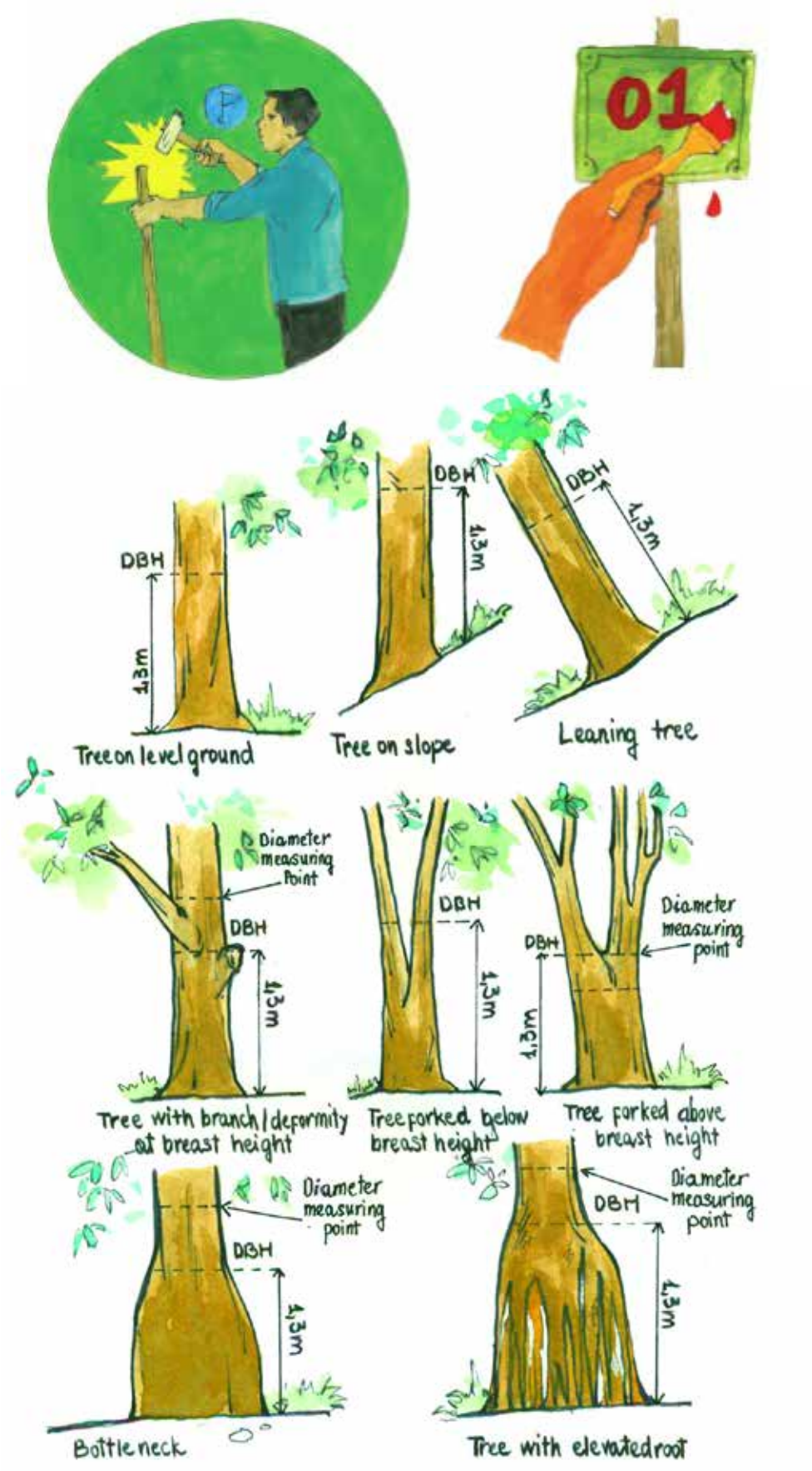


Figure 9. Measuring DBH tree

Method of bamboo age based on their aerial stem (Lam Xuan Sanh và Chau Quang Hien, 1984)

- ***First year of age:*** **a bamboo tree that finished its growth period in the previous rainy season is characterised by:**
  - Sheath still existing on stem, usually near root
  - Stem colour light green and covered by a layer of "white powder", but lichen has not developed
  - many small branches along the main stem but very few young branches on the upper stem.
- ***Second year of age:*** **Characterised by:**
  - Sheath is not present
  - Stem colour is green and is covered by a layer of "white powder", but less than that at the first year.
  - No, or minimal, lichen present near root
  - Many branches and may have young sub-branches.
- ***Third years of age:*** **Characterised by:**
  - Main stem colour is dark green, lichens cover 30-40% of stem surface creating white spots in the stem, green colour of stem is still visible
  - Branches are mainly on top of tree, old main branches are dark green with spotted lichen, sub-branches may show.
- ***Fourth years of age:*** **Characterised by**
  - Stem is white due to strong presence of lichen (accounts for 70-80% of stem surface)
  - Branches are limited to the upper stem, o main branches are dark green with spotted lichen.
- ***Five years and more:*** **Characterised by**
  - Stem colour changes to yellow, dense lichen develops along the stem
  - Decay and fall are apparent.

Appendix: Field Forms

Form 1: Measuring change in forest area, forest status and forest owner

Forest type and forest status on map:

Coordinate of plot centre (in VN2000): X: Y:

Forest type (observed): Forest status (Observed):

Forest owner: Contractor:

Location (village, commune, district, province):

Forest compartment:

Sub-compartment:

Block:

Measurement recorded by: Date: Time:

Picture: Yes/No (Circle Yes if pictures were taken. Circle No if pictures were not taken.)

No	VN2000 coordinates of foru corners of forest block, forest owner				Description of change, (i) Loss of forest cover, (ii) Change in forest type	Underlying causes or reasons for change
	X/Y	X/Y	X/Y	X/Y		
1	2	3	4	5	6	7

Note: Information on change in area and status are stored as tracks in the GPS and are named to follow the identification number of delineated area.

- Column 1: Identification number of delineated area. Numbers in serial order such as 1, 2, 3 can be used. Use separate form for each forest boundary. This identification number must be used to name the track in the GPS.
- Column 2, 3, 4 and 5: Record X, Y coordinates of the four corners using the GPS. On the GPS coordinates page the value for the x-coordinate is located at the top and the y-coordinate is at the bottom.
- Column 6: Description of change, either i) Forest loss, or ii) Reduced quality of forest, e.g. selected logging/exploitation.
- Column 7: Underlying causes or reason for change, e.g. logging forest for cropping, exploited as planned in 2013 etc.

Form 2: Data sheet form for forest inventory

Plot No.: Forest status on map:

Coordinates: X Y

Forest type: Forest stratum/status:

Forest owner: Contractor:

Location (village, commune, district, province):

Forest compartment: Altitude (m):

Forest sub-compartment: Canopy cover (%):

Forest block: Slope (degree):

Recorded by: Date:

Picture: Yes/No (Circle Yes if pictures were taken. Circle No if pictures were not taken.)

Measuring trees with DBH ≥ 6 cm in all sub-plots

No.	Species		DBH (cm)	Com-ment	No.	Species		DBH (cm)	Com-ment
	Local name	Com-mon name				Local name	Com-mon name		
1					26				
2					27				
3					28				
4					29				
5					30				
6					31				
7					32				
8					33				
9					34				
10					35				
11					36				
12					37				
13					38				
14					39				
15					40				
16					41				
17					42				
18					43				
19					44				
20					45				
21					46				
22					47				
23					48				
24					49				
25					50				

Form 3. Data Sheet for measuring DBH<6 cm and H≥1.3 m in 1 m radius sub-plot

Plot no.:

No.	Species		Number of tree	Comment	No.	Species		Number of trees	Comment
	Local name	Common name				Local name	Common name		
1					26				
2					27				
3					28				
4					29				
5					30				
6					31				
7					32				
8					33				
9					34				
10					35				
11					36				
12					37				
13					38				
14					39				
15					40				
16					41				
17					42				
18					43				
19					44				
20					45				
21					46				
22					47				
23					48				
24					49				
25					50				

Form 4. Data sheet for bamboo inventory

Plot No.: Forest status on map:

VN2000 Coordinates: X Y

Location (village, commune, district, province):

Forest type: Forest stratum/status:

Forest owner: Contractor:

Forest compartment: Altitude (m):

Forest sub-compartment: Canopy cover (%):

Forest block: Slope (degree):

Recorded by: Date:

Bamboo species: Height average (m):

Picture: Yes/No (Circle Yes if pictures were taken. Circle Noif pictures were not taken.)

For special bamboo: Every shoot is measured

Species: Average height (m)

Number of tree: Average DBH (cm):

No.	DBH (cm)	Age	Com-ment	No.	DBH (cm)	Age	Com-ment
1				26			
2				27			
3				28			
4				29			
5				30			
6				31			
7				32			
8				33			
9				34			
10				35			
11				36			
12				37			
13				38			
14				39			
15				40			
16				41			
17				42			
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21				46			
22				47			
23				48			
24				49			
25				50			

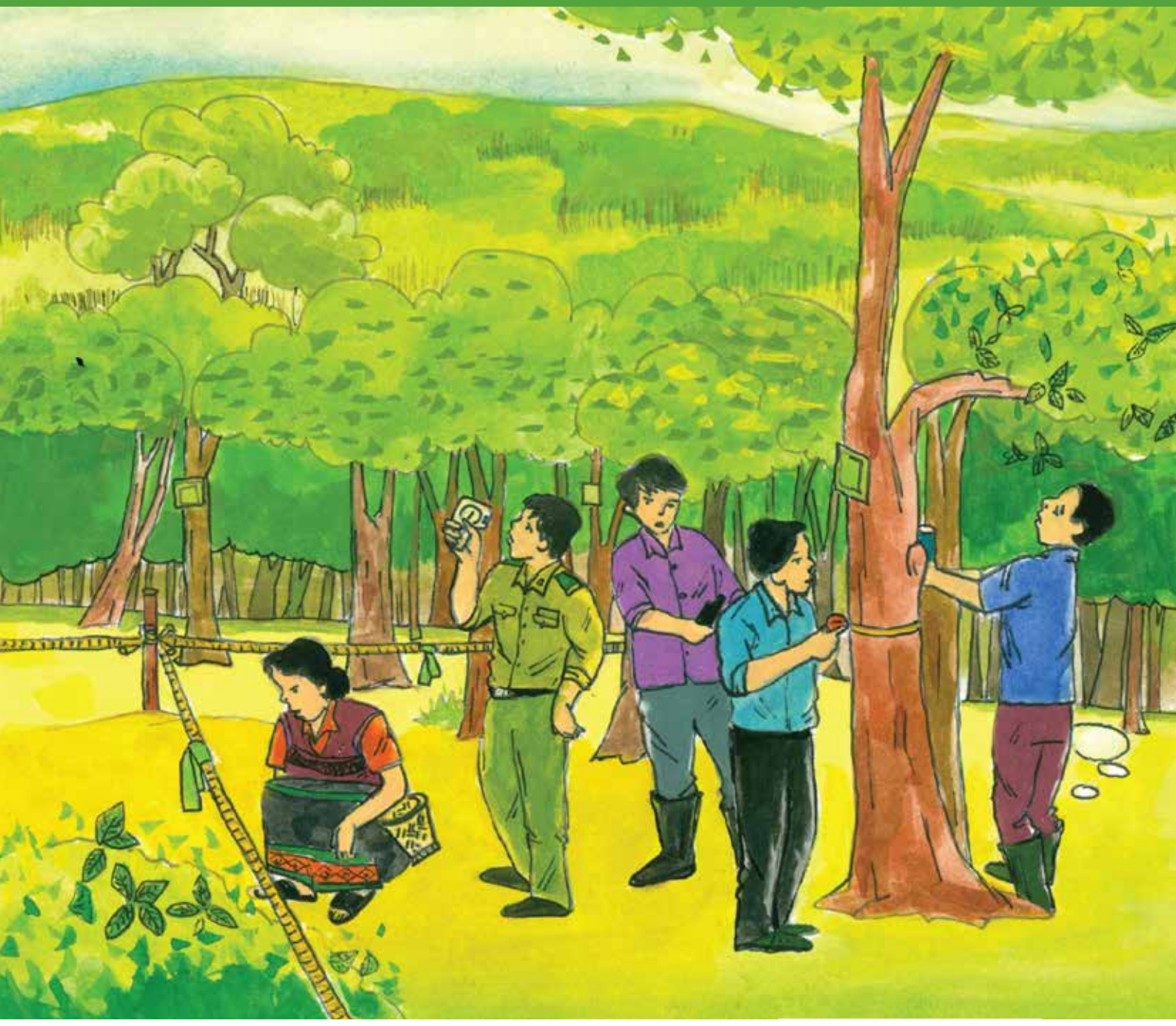
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Participatory Carbon Monitoring: Manual for Local People

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August 2013



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Introduction to participatory carbon monitoring (PCM) 1

The implementation of incentive based forestry programs such as Payment for Ecosystem Services (PES); Reducing Emissions from Deforestation and Forest Degradation (REDD+); and forestland allocation, management and protection under commitment contract with households, communities and forest owners needs a monitoring system to quantify the change in forest biomass and carbon for allocating incentives based on performance.

The monitoring system must involve local households and forest owners to ensure that local stakeholders actively participate in forest management and assist in gathering or providing qualitative and quantitative information on the forests allocated to them or managed under the contract with the forest owner. The participating households may receive a direct payment for labour invested during monitoring as well as other benefits such as payment, goods or services that accrue from the emissions reductions or emission removals achieved through the incentive based forestry activities such as from REDD+. A monitoring system that involves stakeholders in various steps of monitoring of forest carbon is called participatory carbon monitoring (PCM).

In order for local households and communities to undertake monitoring activities, the monitoring method must be simple and suitable for community and forest owner alike. Local stakeholders must be able to implement the monitoring activities with support of forestry staff to produce reliable data that meets the national and international expectations as well as quality standards.



This PCM manual, **Manual for Local People**, is one of the three individual manuals designed to facilitate stakeholders' participation in carbon monitoring and is designed for use by local households and communities for collecting and monitoring field data. In this manual, a quick review of forest parameters, i.e. carbon pools measured in the field using PCM, is covered.

This manual provides detailed step-wise procedures to measure changes in the forest area, forest status and forest carbon in the field using existing forest maps, the GPS and predetermined plot locations. The **Manual for Local Technical Staff** is for use by local forestry staff for designing and implementing PCM activities in the field and analysing PCM data. A third in the series, the **Manual for Field Reference**, is to be used in the field for quick reference.

Parameters measured in participatory carbon monitoring (PCM) 2

- Five forest carbon[1] pools can be measured using PCM (Figure 1). These are:
  i. above-ground
  ii. below-ground
  iii. litter
  iv. dead wood
  v. soil.

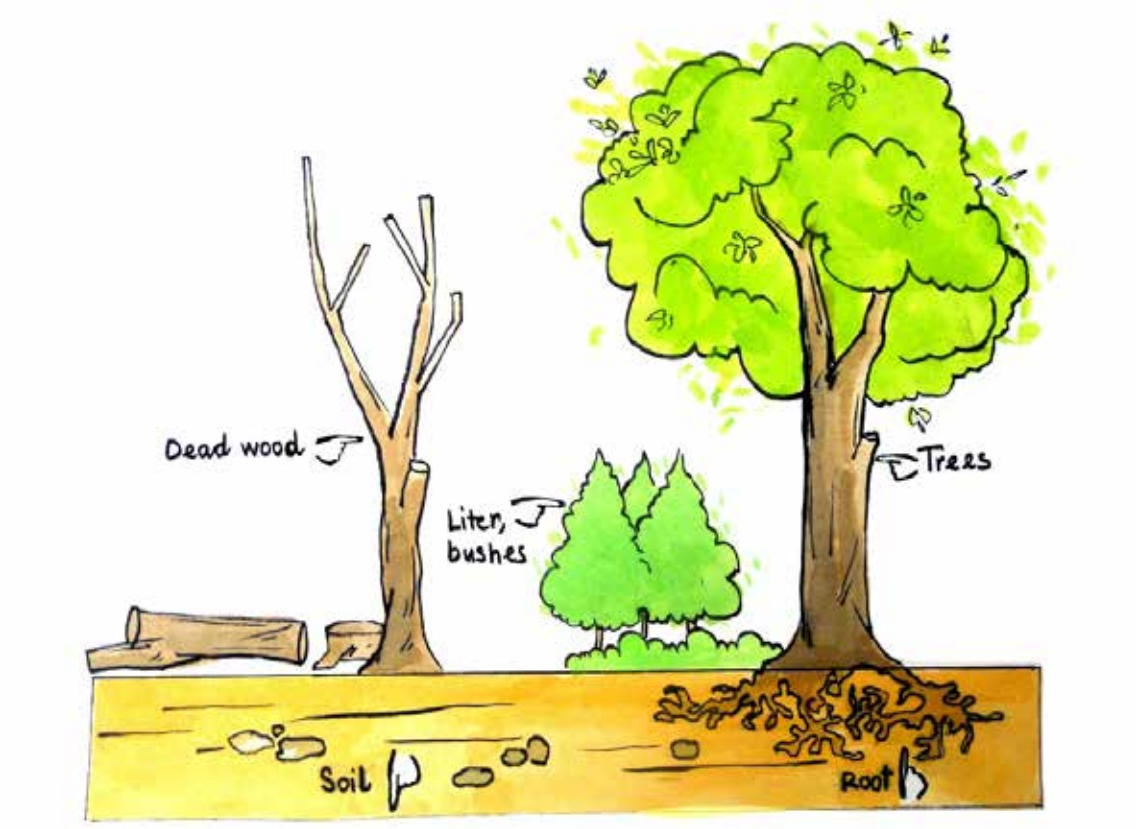


Figure 1. Carbon sinks in the forest

- PCM based monitoring of change in forest carbon includes the following two primary activities:
  - Measuring changes in the forest area and forest status
  - Measuring forest carbon pools and other attributes in sample plots,

This manual provides guidelines for measuring changes in forest area and forest status as well as for measuring forest attributes and carbon pools in forest. However, the scope of this manual is limited to the measurement of above-ground pools i.e. manual does not include guidelines for measuring below-ground, dead wood, litter and soil pools.

1 An additional carbon pool, wood product (HWP), is not measured in the forest and therefore related procedures are not included in this manual.



Figure 2. Necessary tools and materials for PCM activity

If the forest boundary or forest status is found to be different from that which is indicated on the forest map, the forest boundary must be delineated using the GPS tracking function. Upon delineating the boundary, update the boundary and forest status information.

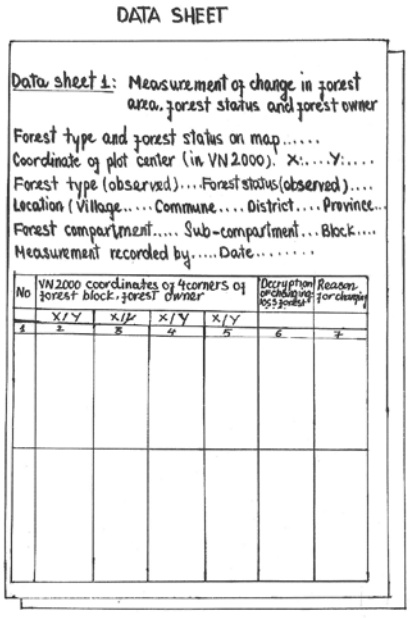
Expected outcome:

- Forest boundaries demarcated, changed area quantified and map prepared
- Status of forest change (e.g. past forest exploitation resulted in change of status from average to poor) indicated and deforestation rate in the forest management unit quantified
- Any change in area, boundary or status over a period (annual to period) recorded.

Materials required:

- Forest map showing the boundaries of forest owners
- GPS[2] for delineating forest boundary of forest owners and estimating forest area
- Suunto clinometer and compass
- Digital or other camera (optional)
- Data sheets to record forest area and status change (Form 1)




DATA SHEET

Data sheet 1: Measurement of change in forest area, forest status and forest owner

Forest type and forest status on map.....
Coordinate of plot center (in VN 2000): X:....Y:....
Forest type (observed)....Forest status (observed)....
Location (Village.....Commune....District....Province...
Forest compartment..... Sub-compartment...Block....
Measurement recorded by.....Date.....

No	VN2000 coordinates of 4 corners of forest block, forest owner				Description of changing: loss forest	Reason for change
	X/Y	X/Y	X/Y	X/Y		
1	2	3	4	5	6	7

2 The illustration contained in this manual is based on GPS 60CSx. For other model of GPS, refer to user's manual.

Procedure:

Step 1: Boundary delineation using GPS 60CSx

- Power on and press Menu twice to access Tracks, then press Enter
- Press Clear button to delete all old tracks
- Press Menu and select Area Calculation; press Enter two times to start track function
- Walk around the area while the GPS is still on
- When measurement is complete, press Enter twice to end the tracking
- Save and name the result, then press OK to finish the area delineation
- If a digital camera is available, take few pictures of the area. The name of the picture files must be similar to the name of the track for easy identification.







Make sure that the GPS is turned on while track function is active. Turn off the GPS upon completion of delineation of one area or forest parcel. If the GPS is on and track mode is active while moving to next forest parcel, the delineated areas could get connected together in the map, making the editing process time consuming and cumbersome.

Technical staff must lead the team and instruct local people about using the GPS. When local people feel comfortable about using the GPS, local people can lead this task.

Step 2: Record forest area change

Use Form 1 (see Appendix) to record the following information on forest area change in the field:

- Location, forest owners, date, time and person or team leader recording data leader
- VN2000 coordinates (X/Y) in four corners of the forest
- Description of changes and underlying causes.

Locate sample plot 4

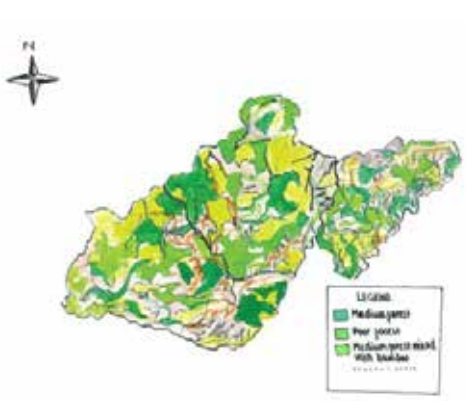
The random sample plots are shown on the map. The location of plots is pre-installed in the GPS by a technician. The locations of plots are identified in the forest.

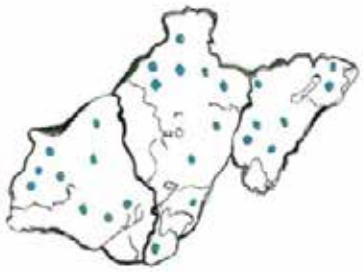
Expected outcome:

- The random permanent plots for collecting data on forest biomass and carbon are located in the forest and the centre of the plot is marked.

Materials required:

- Map of location of random sample plots
- Suunto clinometer and compass
- GPS with coordinates of random sample plots
- Sheet with recorded code and coordinates of sample plots
- Iron board for placing identification tags for plot and coordinates of sample plots
- Hammer and nails for affixing tree tags
- Permanent paint to mark identification tags on sample plots
- Digital camera (optional).













Procedure:

- Press Find, then press Enter to access Waypoint
- From the list of plots, select the correct plot to be sampled
- Press Goto and select Off road
- Walk to the destination shown on the GPS. The GPS will sound an alarm when the destination plot is reached
- The coordinates of the centre of the defined plot should be checked on the GPS and on the map
- If a camera is available, take a picture of the GPS while the GPS is showing the coordinate position
- End Goto function by pressing Menu and then selecting Stop Navigation
- At the centre of permanent sample plots, place the plot marker i.e. concrete or wooden pillar, and affix an iron board
- Write the identification number of sample plots and coordinates (i.e. VN2000 coordinates) directly on the iron board with permanent paint or marker
- The permanent marker on the field will be useful for locating plots for repeated measurements
- Take a picture of the plot centre with plot marker and iron board with plot information clearly visible.



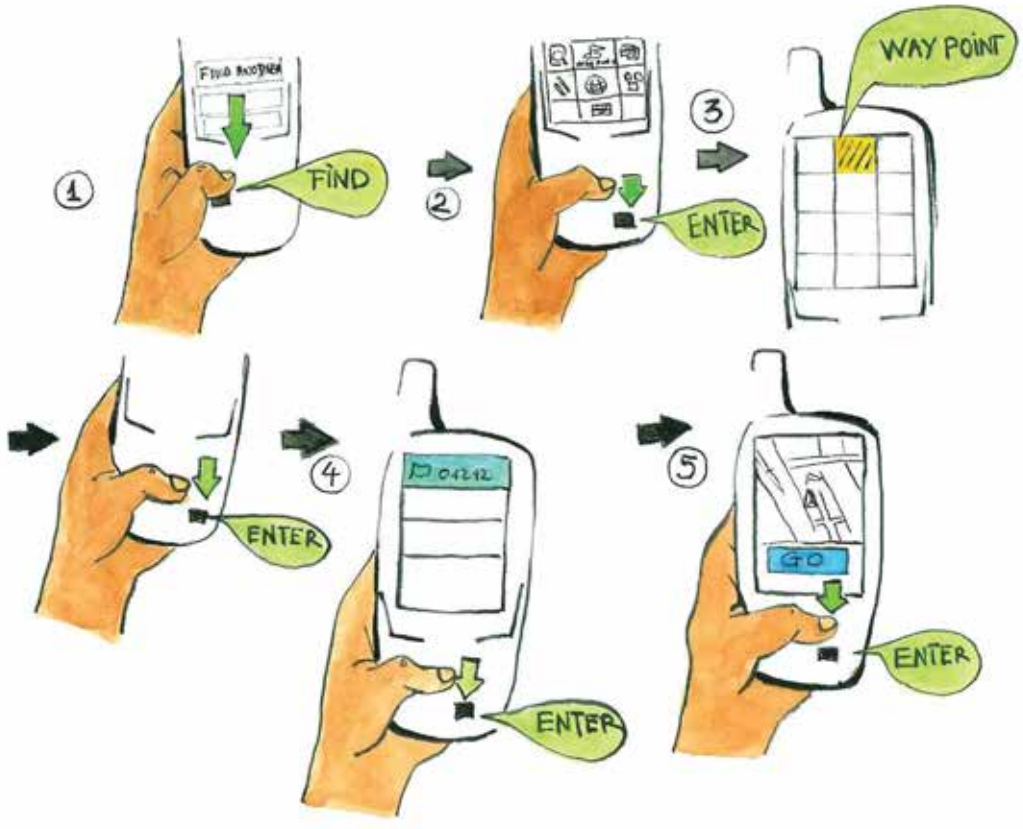

FIND
ENTER
WAY POINT
ENTER
ENTER
GO
ENTER



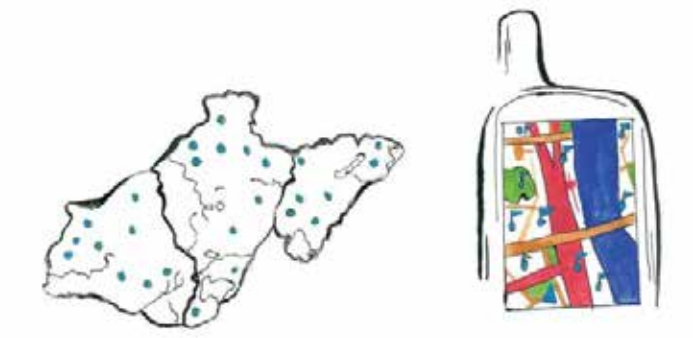
Figure 3. Locating position of a random plot by using GPS

Set up permanent sample plots 5

The shape of the plots can be rectangular, square or circular. In this document, circular sample plots are recommended for use, as they are relatively easy to establish in the field. Additionally, a plot is convenient for household and the community in locating plots in the field. Within the sample plot, trees of different sizes are measured in different sized sub-plots: larger trees are measured in larger sub-plots and smaller trees are measured in smaller sub-plots.

Expected outcome:

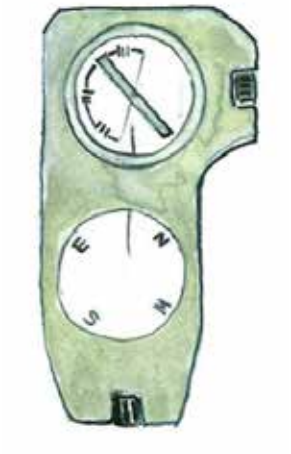
- Nested circular plots are established in the field.



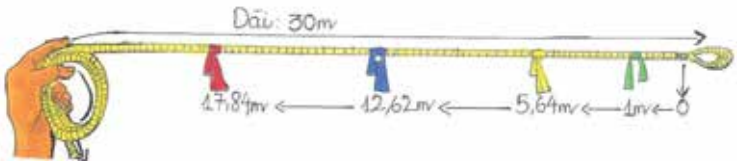
Materials required:

- Suunto clinometer
- Four ropes with a range of coloured knots at specified intervals equivalent to the radius of the sub-plots
- Form for additional distances at different radius for plots located on slope
- Digital camera (optional).





Slope Level (degrees)	SLOPE CORRECTION FACTOR SHEET RADIUS OF CIRCLE PLOT			
	1m	5,64m	12,62m	17,84m
0	0.00	0.00	0.00	0.00
2	0.00	0.00	0.01	0.01
4	0.00	0.01	0.03	0.04
6	0.01	0.03	0.07	0.10
8	0.01	0.06	0.12	0.18
10	0.02	0.09	0.19	0.28
12	0.02	0.13	0.28	0.40
14	0.03	0.17	0.39	0.55
16	0.04	0.23	0.51	0.72
18	0,05	0.29	0.65	0.92

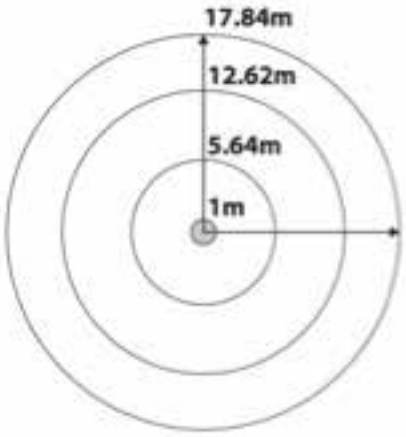


Procedure:

5.1 Design circular sample and sub-plot for different forest types:

Nested circular plot consisting of four concentric circles or sub-plots are used. Large trees are measured in larger circular plots while small trees are measured in smaller circular plots. The plot design also varies by forest types.

- For **evergreen, semi-deciduous, dipterocarp, and pine forest:**



- Sub-plot 1: radius 1 m, area 3.64 m^2, measure regeneration with DBH < 6 cm and H > 1.3 m
- Sub-plot 2: radius 5.64 m, area 100 m^2, measure tree 6 cm ≤ DBH < 22 cm or bamboo
- Sub-plot 3: radius 12.62 m, area 500 m^2, measure tree 22 cm ≤ DBH < 42 cm
- Sub-plot 4: Radius 17.84 m, area 1000 m^2 to measure tree ≥ 42 cm DBH

Figure 4. Layout of circular nested plot with four concentric sub-plots

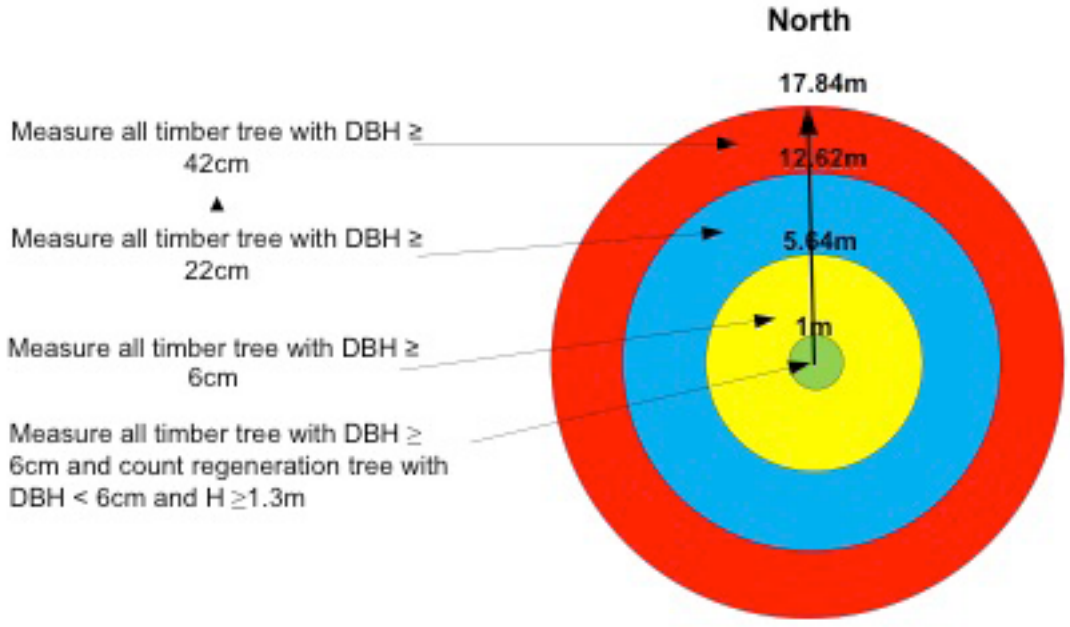
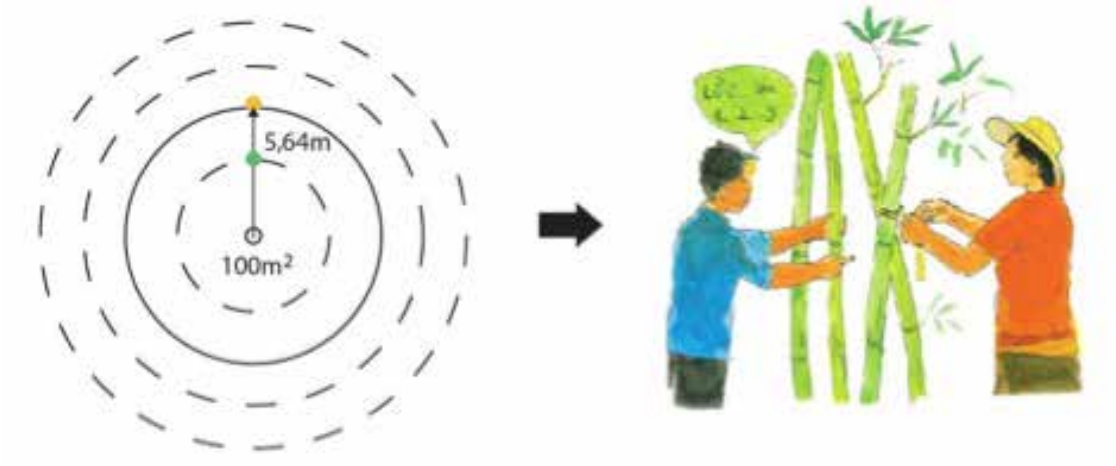
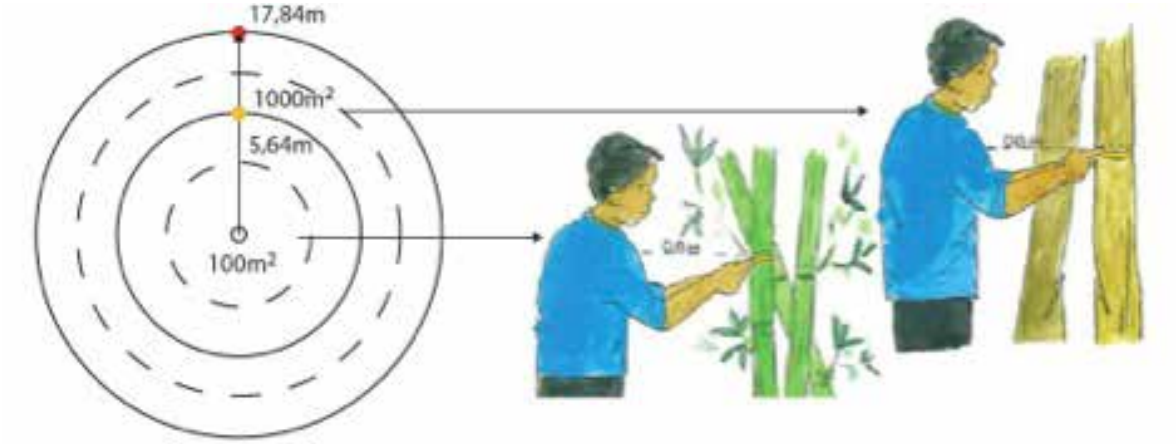


Figure 5. Measure diameter class according to radius of sample plot

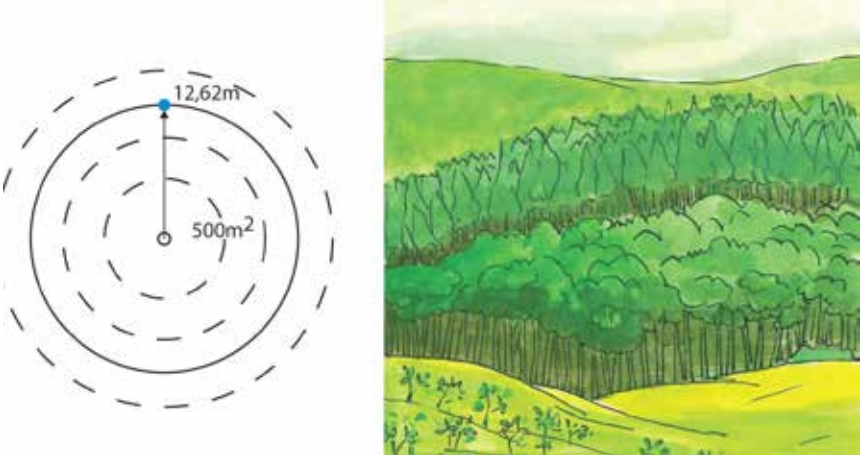
- For **bamboo forest**, the size of sample plot is 100 m^2



- For **mixed woody – bamboo forest**, measure trees as in the case of evergreen forest in four concentric sub-plots and measure bamboo only in sub-plot 2



- For **plantation forest**, the maximum diameter in plantation forest rarely exceeds 42 cm. Therefore, the measurement of the tree is conducted in sub-plot 3 i.e. in 500 m2 circular plot with a radius of 12.62 m.



Within 1m radius sub-plot (green), measure all trees with DBH ≥ 6 cm and count

regeneration trees with DBH < 6 cm and H ≥ 1.3 m; within 1 m - 5.54 m radius sub-plot (yellow), measure all trees with DBH ≥ 6 cm; within 5.64 m - 12.62 m radius sub-plot (blue), measures trees with DBH ≥ 22 cm; and within 12.62 m - 17.84 m radius sub-plot (red), measure trees DBH ≥ 42 cm (Figure 5).

5.2 Establish circular plot and sub-plots in the forest:

Prepare a rope with several knots. Use different colours for individual knots. Put knots at intervals equivalent to the radius of the sub-plots. For example, make a green knot at 1 m, a yellow knot 5.64 m, blue knot at 12.62 m and a red knot at 17.84 m (**Error! Reference source not found**. Figure). An additional rope may be needed for plots located on slopes. The length of rope should be about 30 m. Four ropes with colour knots need to be prepared. On each rope, at each colour knot add another same coloured knot that is movable along the rope to adjust for the radius of sub-plots on slope.

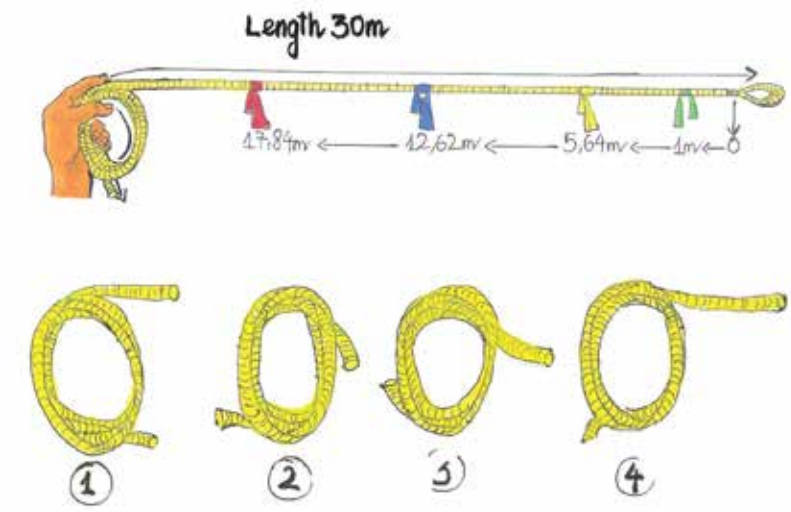


Figure 6. Making knots of different colours corresponding to radius of concentric sub-plot

- Measure slope of the ground every time the rope is laid out on the ground along the plot radius (eight times) using the clinometer (Figure).
- Ask one field crew member to stand on the slope. With the clinometer, aim at the head of the person standing above or below the slope to create the line of sight (Figure). The line of sight must be parallel to the slope surface. The indicator on the left of the clinometer shows the slope angle, which must be recorded.
- A table with slope corrected horizontal distances can be taken to the field (see Appendix). The knots representing the radius for the plot must be corrected. For example, if a plot is located at slope of 20 degrees, then using the slope corrected distance the green knot should be placed at 1.06 m, yellow knot at 6 m, blue knot at 13.43 m and red knot at placed at 18.98 m. Use linear tape to adjust the position of the knots in the field.



Figure 7. Compass and Clinometer

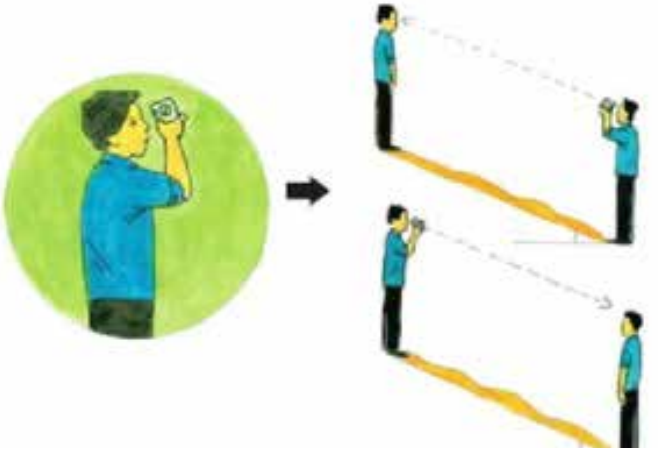
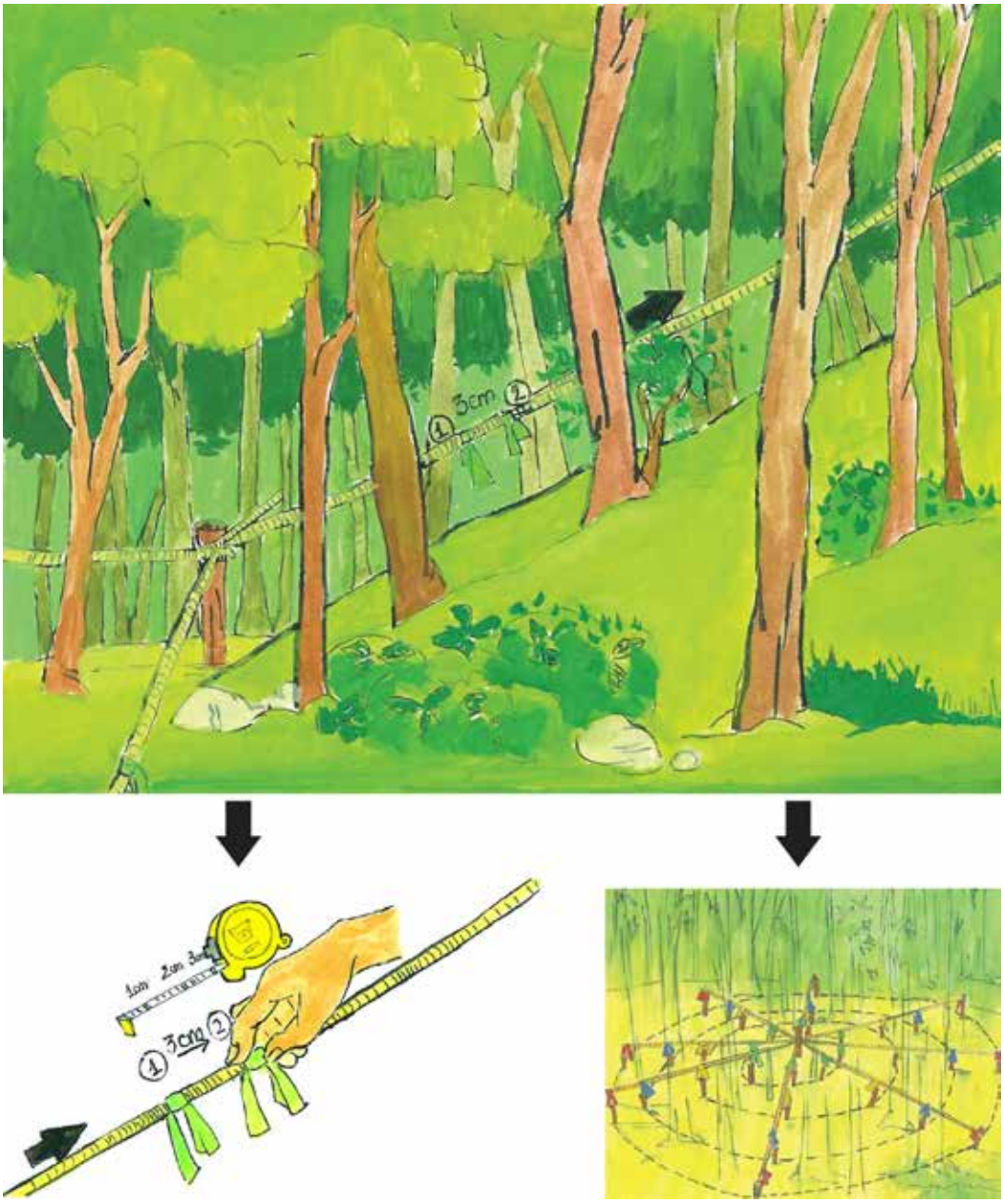


Figure 8. Obtaining slope using clinometer



Sheet of slope correction factors:

Slope level (degree)	Radius of cycle plot (m)			
	1.00 Green	5.64 Yelow	12.62 Blue	17.84 Red
0	0.00	0.00	0.00	0.00
2	0.00	0.00	0.01	0.01
4	0.00	0.01	0.03	0.04
6	0.01	0.03	0.07	0.10
8	0.01	0.06	0.12	0.18
10	0.02	0.09	0.19	0.28
12	0.02	0.13	0.28	0.40
14	0.03	0.17	0.39	0.55
16	0.04	0.23	0.51	0.72
18	0.05	0.29	0.65	0.92
20	0.06	0.36	0.81	1.14
22	0.08	0.44	0.99	1.40
24	0.09	0.53	1.19	1.69
26	0.11	0.64	1.42	2.01
28	0.13	0.75	1.67	2.37
30	0.15	0.87	1.95	2.76
32	0.18	1.01	2.26	3.20
34	0.21	1.16	2.60	3.68
36	0.24	1.33	2.98	4.21
38	0.27	1.52	3.40	4.80
40	0.31	1.72	3.85	5.45
42	0.35	1.95	4.36	6.17
44	0.39	2.20	4.92	6.96
46	0.44	2.48	5.55	7.84
48	0.49	2.79	6.24	8.82
50	0.56	3.13	7.01	9.91

- First, stretch one rope from the centre towards the north. Stretch another rope to the east. Stretch a third rope at 45˚ N between the first and second ropes. As a result, two segments are established from north to east. Measurement is carried out from the left to the right segment (i.e. clock-wise) and from the centre towards the sub-plot radius indicated by the coloured knots.

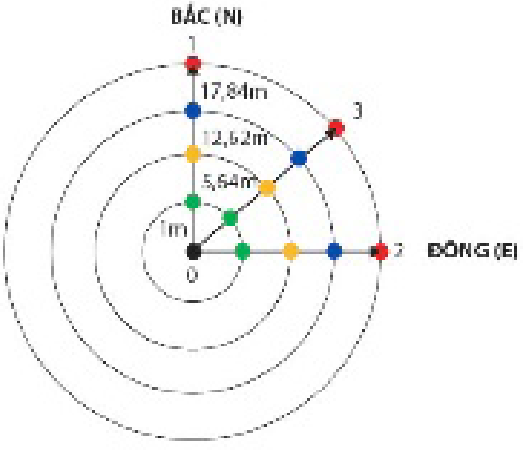


Figure 9. North-east section of plot

- Second, the north and east ropes are fixed while the rope that was in between is moved to the south (opposite to north). A fourth rope is stretched in between south and east. Two segments are created in the south east. Measurement is carried out from the left to the right segment and from the centre towards the sub-plot radius.

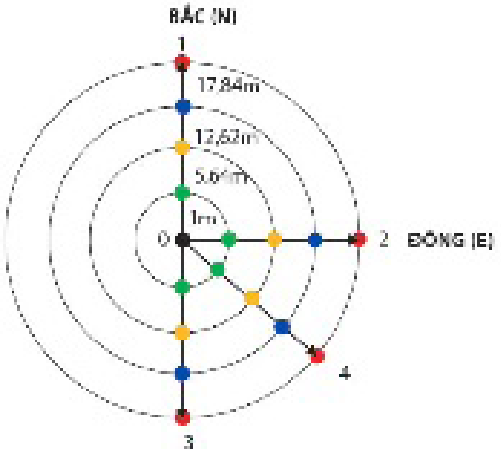


Figure 10. South-east section of plot

- Third, the north and south ropes are fixed while the rope in the east is moved to the west. The rope that was between east and south is moved in between south and west. Measurement is carried out from the left to the right segment and from the centre towards the sub-plot radius.

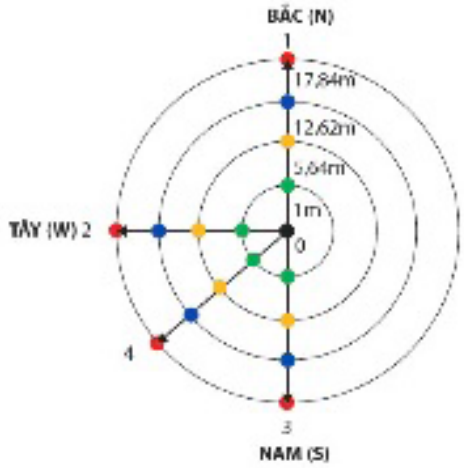


Figure 11. South-west section of plot

- Finally, the ropes in the north and west are fixed while another rope is placed between west and north. Measurement is carried out from the left to the right segment and from the centre towards sub-plot radius.

- At the four directions of north, east, south and west, red wooden pillars are positioned.

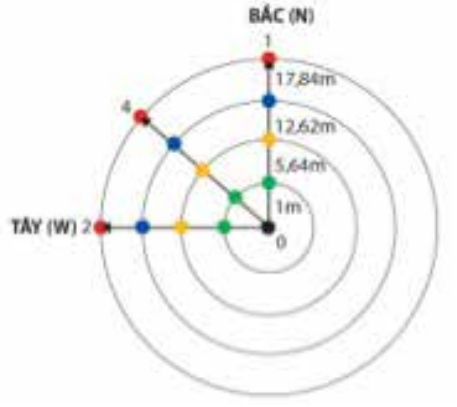


Figure 12. North-west section of plot

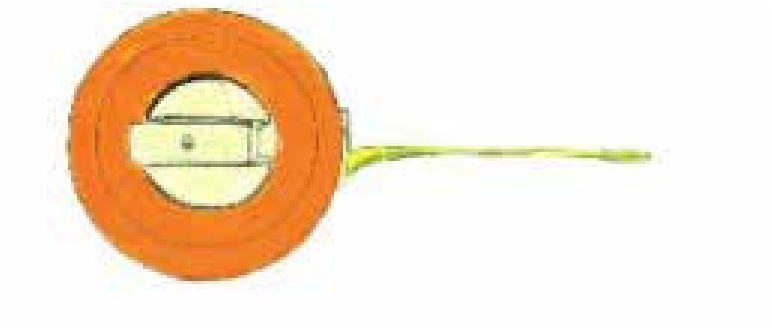
Measure within sample plot/sub-plot 6

In each sample plot, measure tree and other information.

Expected outcome: Validated data about trees and bamboo and forest resources.

Materials required:

- Diameter measurement tape (i.e. D tape)



- Chalk, marker, or paint for making on the tree



- Iron board or tree tag for marking trees



- Hammer and nails to affix tree tag



- Paint to mark sign of sample plots



- Spreadsheet for recording inventory factor



- Digital camera for taking picture (optional).

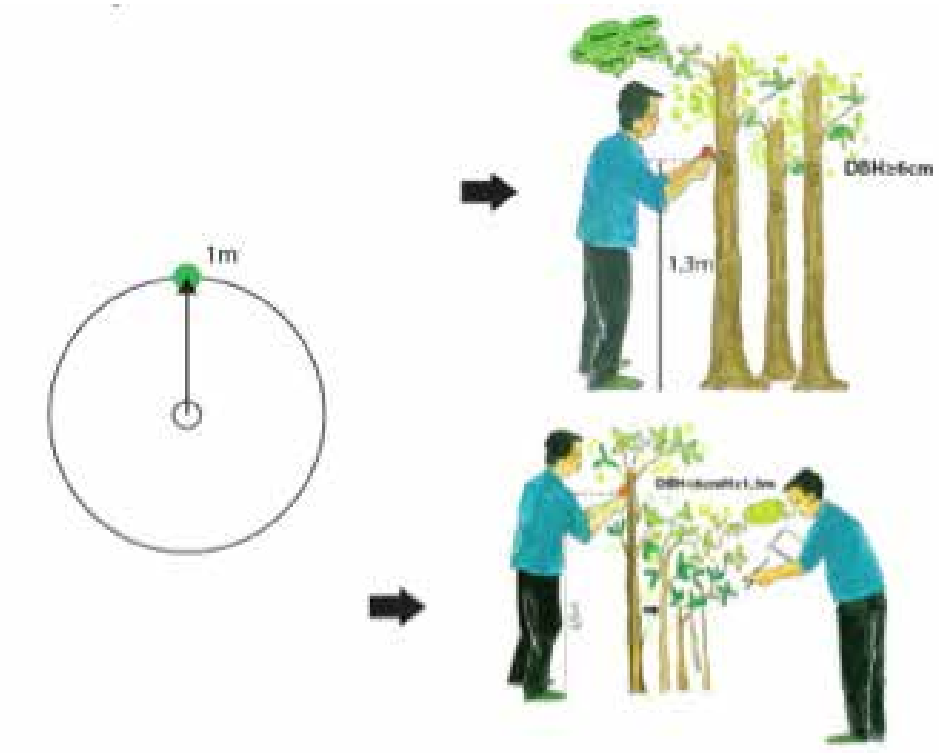




Procedure:

Measurement in sample plot to estimate forest biomass and carbon:

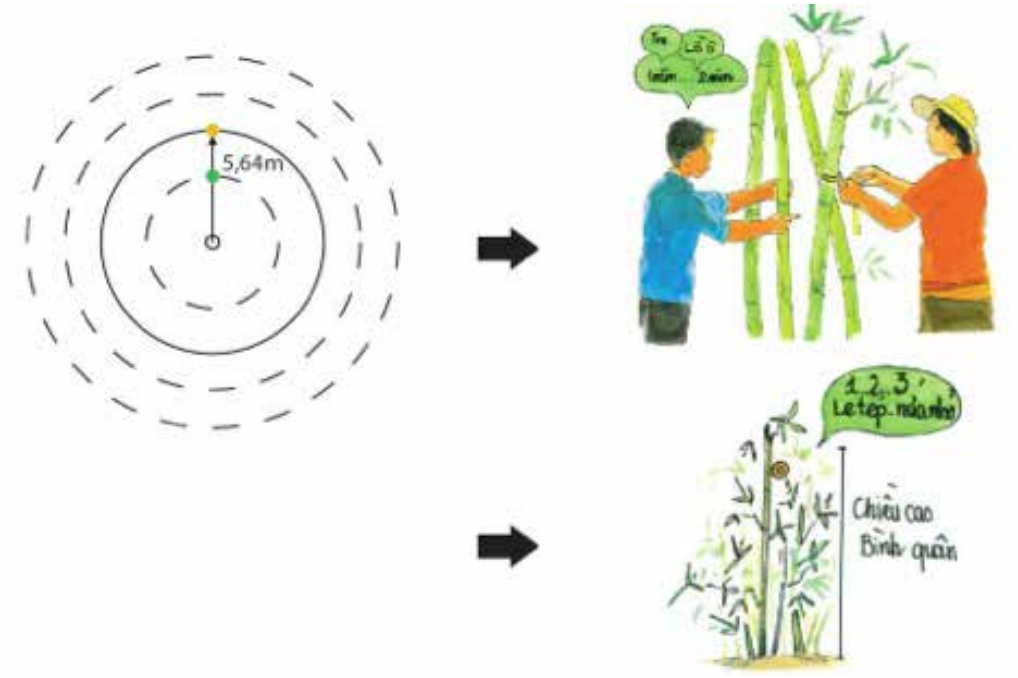
- For woody tree, identify species, measure DHB if trees DBH is greater than 6 cm. For trees with DBH < 6 cm and height > 1.3 m, count the number within the sub-plot 1



- Use tree tags to mark the trees



- **Bamboo** is measured in a 5.64 m radius plot. Age and individual DBH are measured. In the case of certain species of bamboo, such as neohouzeaua, the number of trees, average DBH and average height must also be estimated



- Use Figure 13 to determine the position of DBH on tree during DBH measurement for **irregular stems or for trees standing on slopes**
- If a tree falls on **the plot boundary** and over 50% of the stem is inside the plot, consider that tree to fall inside the plot. Otherwise, exclude boundary tree
- **Take pictures** of trees and crews measuring trees. Name picture files beginning with the plot name. For example, if plot id is 104, then name of picture can be "104_NorthWest".

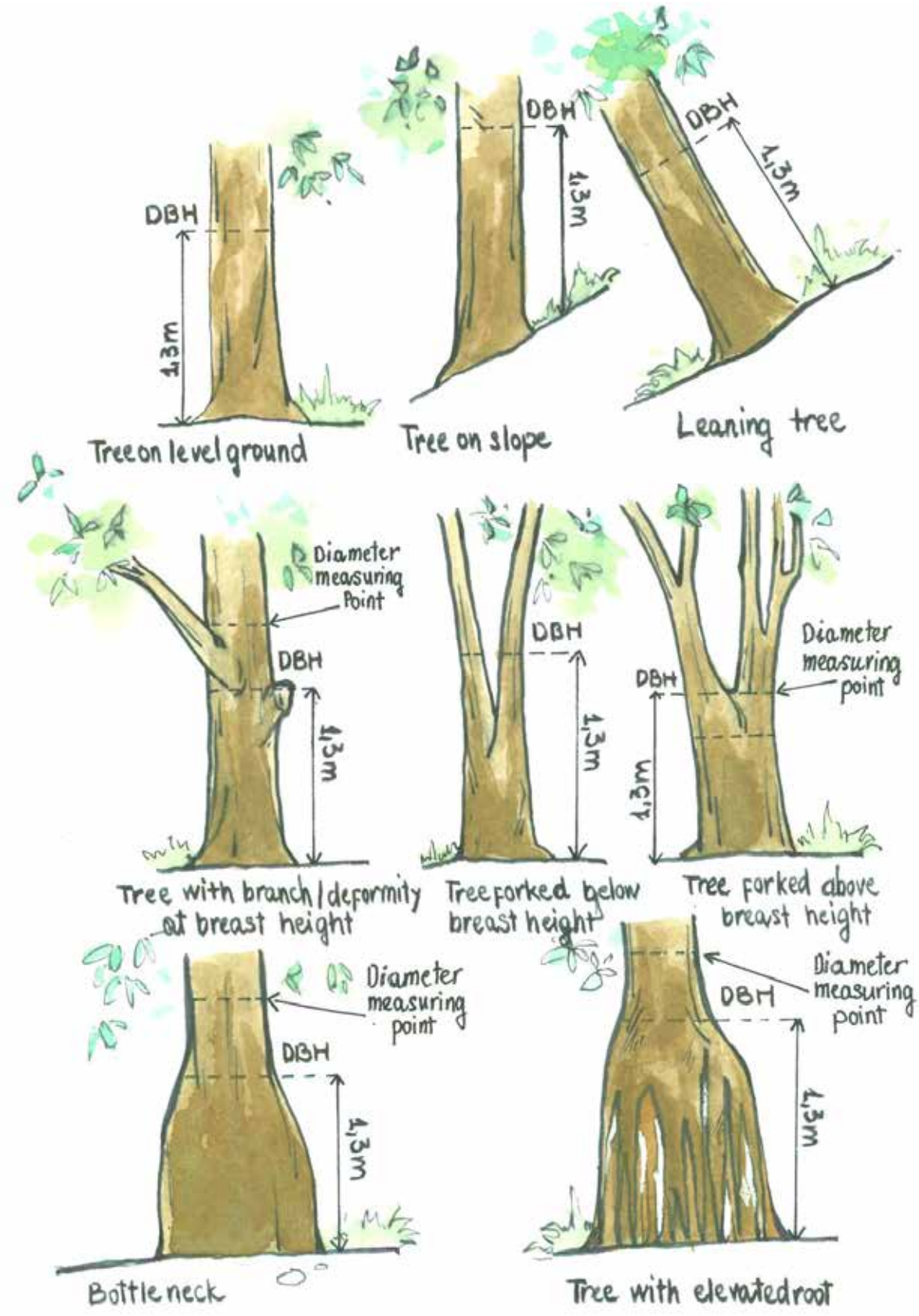


Figure 13. Measuring DBH tree of irregular stems or trees on slope

Appendix I: Field Form

Form 1: Measuring change in forest area, forest status, and forest owner

Forest type and forest status on map:

Coordinate of plot centre (in VN2000): X: Y:

Forest type (observed): Forest status (Observed):

Forest owner: Contractor:

Location (village, commune, district, province):

Forest compartment:

Sub-compartment:

Block:

Measurement recorded by: Date: Time:

Picture: Yes/No (Circle Yes if pictures were taken. Circle No if pictures were not taken.)

No	VN2000 coordinates of four corners of forest block, forest owner				Description of change, (i) Loss of forest cover, (ii) Change in forest type	Underlying causes or reasons for change
	X/Y	X/Y	X/Y	X/Y		
1	2	3	4	5	6	7

Note: Information on change in area and status are stored as tracks in the GPS and are named to follow the identification number of delineated area.

Column 1: Identification number of delineated area. Numbers in serial order such as 1, 2, 3 can be used. Use separate form for each forest boundary. This identification number must be used to name the track in the GPS.

Column 2, 3, 4 and 5: Record X, Y coordinates of the four corners from the GPS. On the GPS coordinates page the value for the x-coordinate is located at the top and the y-coordinate is at the bottom.

Column 6: Description of change, either i) Forest loss, or ii) Reduced quality of forest, e.g. selected logging/exploitation.

Column 7: Underlying causes or reason for change, e.g. logging forest for cropping, exploited as planned in 2013 etc.

Form 2: Data Sheet form for forest inventory

Plot No.: Forest status on map:

Coordinates: X Y

Forest type: Forest stratum/status:

Forest owner: Contractor:

Location (Village, Commune, District, Province):

Forest compartment: Altitude (m):

Forest sub-compartment: Canopy cover (%):

Forest block: Slope (degree):

Recorded by: Date:

Picture: Yes/No (Circle Yes if pictures were taken. Circle No if pictures were not taken.)

Measuring trees with DBH ≥ 6 cm in all sub-plots

No.	Species		DBH (cm)	Comment	No.	Species		DBH (cm)	Comment
	Local name	Common name				Local name	Common name		
1					26				
2					27				
3					28				
4					29				
5					30				
6					31				
7					32				
8					33				
9					34				
10					35				
11					36				
12					37				
13					38				
14					39				
15					40				
16					41				
17					42				
18					43				
19					44				
20					45				
21					46				
22					47				
23					48				
24					49				
25					50				

Form 3: Data Sheet for measuring DBH<6 cm and H>1.3 m in 1 m radius sub-plot

Plot no.:

No.	Species		Number of tree	Comment	No.	Species		Number of tree	Comment
	Local name	Common name				Local name	Common name		
1					26				
2					27				
3					28				
4					29				
5					30				
6					31				
7					32				
8					33				
9					34				
10					35				
11					36				
12					37				
13					38				
14					39				
15					40				
16					41				
17					42				
18					43				
19					44				
20					45				
21					46				
22					47				
23					48				
24					49				
25					50				

Form 4: Data Sheet form for bamboo inventory

Plot No.: **Forest status on map:**

VN2000 Coordinates: X Y

Location (Village, Commune, District, Province):

Forest type: Forest stratum/status:

Forest owner: Contractor:

Forest compartment: Altitude (m):

Forest sub-compartment: Canopy cover (%):

Forest block: Slope (degree):

Recorded by:

Date:

Picture: Yes/No (Circle Yes if pictures were taken. Circle No if pictures were not taken.)

For special bamboo:

Species: Average height(m)

Number of tree: Average DBH (cm):

No.	DBH (cm)	Age	Comment	No.	DBH (cm)	Age	Comment
1				26			
2				27			
3				28			
4				29			
5				30			
6				31			
7				32			
8				33			
9				34			
10				35			
11				36			
12				37			
13				38			
14				39			
15				40			
16				41			
17				42			
18				43			
19				44			
20				45			
21				46			
22				47			
23				48			
24				49			
25				50			

Appendix II. Tools and equipment needed for PCM/PFM for a technical group

No.	Item	Unit	Quality	Purpose
	Actual forest map with demarcation of boundaries of forest owner, household contracted to protect forest	Map	1	Monitor area of forest plot, forest owner
	Map with location of random sample plots	Map	1	Position sample plots on the field
	GPS	Unit	1	Define boundaries, change area, location of sample plots
	Battery for GPS	Unit	10	
	Digital camera	Unit	1	Take pictures
	Data sheet for measuring forest area (Form 1)	Form	50	Record of area change
	Rope for sub-plot with coloured knots for different sub-plot radii	Rope	4	Establish circular sample plot
	Compass, Sunnto clinometer	Equipment	1	Orientation, measuring tree height and slope angles
	Diameter	Equipment	2	Measure tree diameter
	Iron board to write plot number sign	Table	20	Record and fix plot number sign
	Paint	Box	5	To write plot number sign
	Paintbrush	Paintbrush	5	To write plot number sign
	Hammer	Hammer	1	Fix metal tags on tree
	Nail	kg	5	Place the tags
	Data sheet form for measuring timber forest, bamboo forest (Form 2, 3, 4)	Form	50	Record data of sample plot

Appendix III. Slope correction factors

No.	Item	Unit	Quality	Purpose
	Actual forest map with demarcation of boundaries of forest owner, household contracted to protect forest	Map	1	Monitor area of forest plot, forest owner
	Map with location of random sample plots	Map	1	Position sample plots on the field
	GPS	Unit	1	Define boundaries, change area, location of sample plots
	Battery for GPS	Unit	10	
	Digital camera	Unit	1	Take pictures
	Data sheet for measuring forest area (Form 1)	Form	50	Record of area change
	Rope for sub-plot with coloured knots for different sub-plot radii	Rope	4	Establish circular sample plot
	Compass, Sunnto clinometer	Equipment	1	Orientation, measuring tree height and slope angles
	Diameter	Equipment	2	Measure tree diameter
	Iron board to write plot number sign	Table	20	Record and fix plot number sign
	Paint	Box		To write plot number sign
	Paintbrush	Paintbrush		To write plot number sign
	Hammer	Hammer		Fix metal tags on tree
	Nail	Kg		Place the tags
	Data sheet form for measuring timber forest, bamboo forest (Form 2, 3, 4)	Form		Record data of sample plot

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LEAF TECHNICAL GUIDANCE SERIES FOR THE DEVELOPMENT OF A NATIONAL OR SUBNATIONAL FOREST MONITORING SYSTEM FOR REDD+

Module EF-D: Emission Factors for Deforestation



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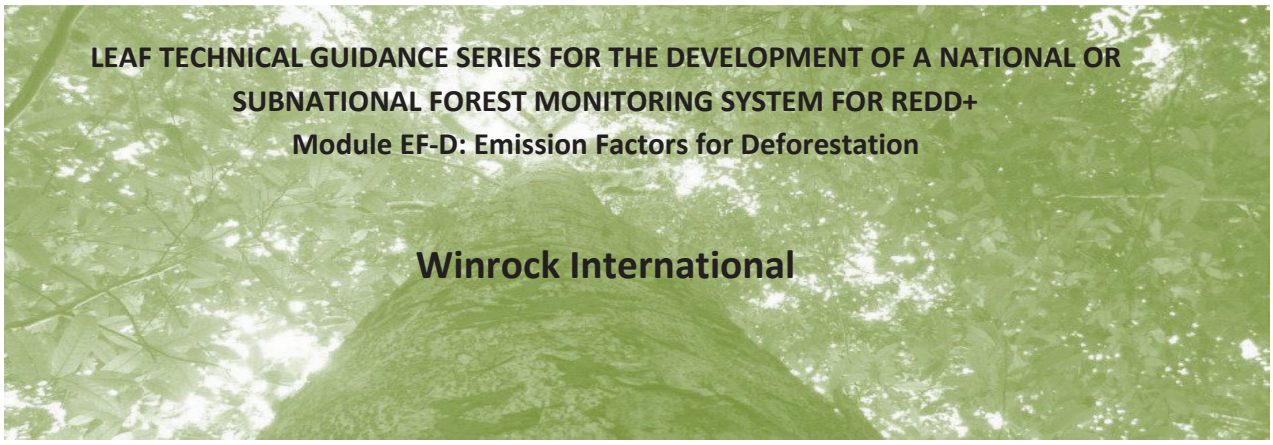


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ICONS WITHIN THE DOCUMENT

The icons below are found throughout the document and indicate areas that the reader should pay special interests to:

Icon	What does it signify?
	A key decision that must be made
	A key technical step that must be accomplished before moving forward
	The need for personnel with specified skill set
	An example
	A key term described in the framework
	A reference to relevant resource

1. SCOPE

This module describes the steps necessary to create emission factors (EF) for deforestation using existing carbon stock data. The output of this module is one component of a national or subnational forest monitoring system for REDD+.

An EF is an estimate of the change in carbon stocks in all carbon pools impacted by the land use change. Emissions resulting from deforestation are usually expressed on the emissions per unit area of change, e.g., tonnes of carbon dioxide per hectare (t CO_2e ha^{-1}).

2. APPLICABILITY

The module is applicable for estimating gross and net emissions per unit of activity resulting directly from the conversion of forests to non-forest land classes.

3. PRODUCTS

This module provides the methods and procedures to estimate EFs for deforestation by cause (or driver) and by stratum using the generic IPCC methods for land converted to a new land-use category, and the IPCC[1] methods for specific types of land-use conversions from forests. All carbon pools will be included and the EFs are calculated based on the IPCC stock-difference approach (see Section 5).

[1] 2006 AFOLU Guidelines

Users of this module will be able to produce all relevant emission factors for forests converted to non-forest land uses. These emission factors are then combined with activity data (as described in Module AD-D) to develop an estimate of the emissions from deforestation (Module EM-H). Use of AD from an historical period will result in emissions that can be used to develop a reference level and use of AD and EF from long-term monitoring will feed into the MRV system.

4. REQUIRED INPUTS

EFs are based on the field data collected from implementing the sampling plan and other factors and guidance in the IPCC (2006) AFOLU Guidelines for a National GHG Inventory.



To complete this module the following data must have been previously developed:

- Forest carbon strata and non-forest strata[2]
- Carbon stock estimates (mean and uncertainty) for all included carbon pools for each forest carbon strata and each non-forest carbon strata[3]
- Quantity and purpose of timber products removed from the forest prior to clearing

[2] For methods on stratification see: Pearson, T. et al. 2013. Guidelines for Stratification for REDD+ Using a National Inventory. An additional set of guidelines for stratification when there is no existing national inventory is forthcoming.

[3] For methods on field data collection see: Walker, SM, TRH Pearson, FM Casarim, N Harris, S Petrova, A Grais, E Swails, M Netzer, KM Goslee and S Brown. 2012. Standard Operating Procedures for Terrestrial Carbon Measurement: Version 2012. Winrock International

For methods on calculations needed to estimate carbon stocks see: Module C-CS, Calculations for Estimating Carbon Stocks

5. METHODS AND PROCEDURES

EFs from deforestation must be developed for each relevant stratum and by driver or cause of deforestation (e.g. conversion to cropland, conversion to mining). These EFs are estimated following the elements outlined in Figure 1 and described in detail in this module.

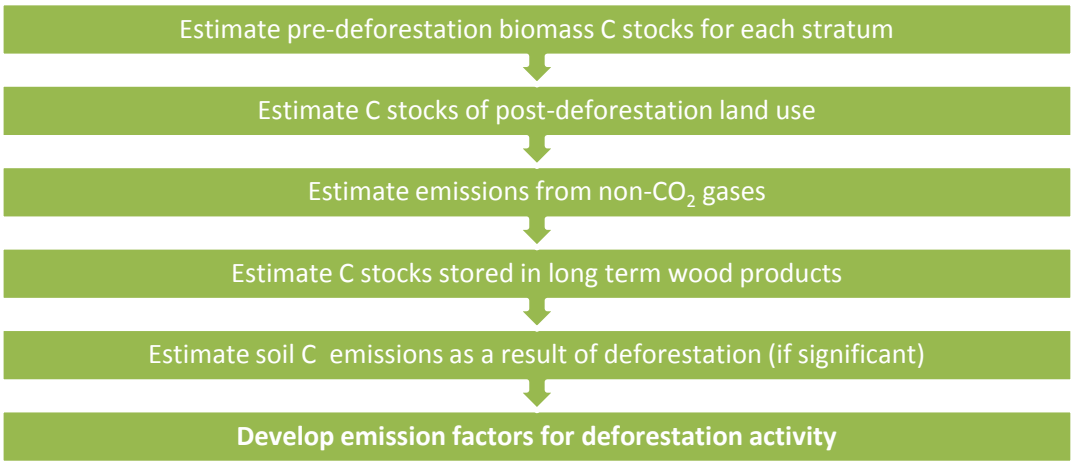


Figure 1. Required elements in the development of deforestation emission factors

Under the stock-difference[4] method, C emissions are estimated as the difference in carbon stocks before deforestation and the carbon stocks following deforestation, including carbon in living and dead biomass, carbon stored in harvested wood products, carbon released from the soil, and emissions of non-CO_2 gases. The emission factor is calculated using Equation 1:

$$EF_{def(t,x,y)} = (C_{bio.pre(x)} - C_{bio.post(t,y)} - C_{wp} + \Delta SOC_{(t)}) * 44/12 + L_{fire} \quad \text{Eq. 1}$$

Where:

$EF_{def(t,x,y)}$ = Emission factor for year t for deforestation for stratum *x* and driver *y*, $tCO_2e\ ha^{-1}$

$C_{bio.pre(x)}$ = Carbon stock in biomass in stratum *x,* prior to deforestation, $t\ C\ ha^{-1}$

$C_{bio.post(t,y)}$ = Carbon stock in biomass in year t post-deforestation, for driver *y*, $t\ C\ ha^{-1}$

C_{wp} = Carbon stock in long-term harvested wood products following deforestation, $t\ C\ ha^{-1}$

$\Delta SOC_{(t)}$ = Change in soil carbon stocks in year t following deforestation, $t\ C\ ha^{-1}$

44/12 = Conversion factor from carbon to CO_2

L_{fire} = Emissions from burning, including non-CO_2 gases such as methane and nitrous oxide, expressed in CO_2 equivalents, $tCO_2e\ ha^{-1}$

The remainder of this module will describe how to achieve the elements in the above equation, each represented by a box in Figure 1.

[4] 2006 AFOLU Guidelines, Chapter 2 Generic Methodologies Applicable to Multiple Land-Use Categories, http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_02_Ch2_Generic.pdf

Boundaries and Time

The methods described in this module do not account for emissions that occur from post-deforestation land uses. Such emissions are outside of the accounting boundary and are assumed to be accounted for in the appropriate sector. Where emissions result directly from deforestation but occur incrementally rather than immediately (e.g. decomposition of wood products), they are calculated over an appropriate time period or treated conservatively.

A. Estimate pre-deforestation biomass carbon stocks for each stratum

The total biomass carbon stock for each stratum is the sum of all carbon stocks from measured pools (Equation 2), excluding soil carbon pool, which is reported separately.

$$C_{bio.pre(x)} = (C_{agb(x)}+C_{bgb(x)}+C_{dw(x)}+C_{lit(x)}+C_{veg(x)}) \quad \text{Eq.2}$$

Where:

$C_{bio.pre(x)}$ = Carbon stock in biomass in stratum *x,* prior to deforestation, t C ha^{-1}

$C_{agb(x)}$ = Carbon stock in aboveground live tree biomass in stratum *x*, t C ha^{-1}

$C_{bgb(x)}$ = Carbon stock in belowground live tree biomass in stratum *x*, t C ha^{-1}

$C_{dw(x)}$ = Carbon stock in deadwood pools in stratum *x*, t C ha^{-1} (includes both standing and lying deadwood)

$C_{lit(x)}$ = Carbon stock in litter in stratum *x*, t C ha^{-1}

$C_{veg(x)}$ = Carbon stock in non-tree vegetation in stratum *x*, t C ha^{-1} (includes shrubs, sapling, and herbaceous understory)

Excluded pools can be counted as zero.

A Tier 1 estimate of total uncertainty uses simple error propagation (Equation 3 for adding or subtracting uncertainties). A Tier 2/3 estimate of uncertainty uses Monte Carlo analysis, which is described in a forthcoming data analysis module.

$$U_{total} = \frac{\sqrt{(U_1 * x_1)^2 + (U_2 * x_2)^2 + \cdots + (U_n * x_n)^2}}{|x_1 + x_2 + \cdots + x_n|} \quad \text{Eq.3}$$

Where:

U_{total} = the percentage uncertainty in the sum of the quantities

x_i U_i = the uncertain quantities (mean in each pool) and the percentage uncertainties (95% confidence interval as a percent of the mean) associated with them, respectively

A module addressing data analysis and uncertainty calculations in more depth is forthcoming, and will provide calculations for uncertainty of each pool, as well as Monte Carlo analysis.

As an example, the forest carbon stocks (with percent uncertainty) in each pool in moist tropical lowland unlogged forest in country A are as follows:

$C_{agb(x)}$ = 170.6 (±9.2%) t C ha^{-1}
$C_{bgb(x)}$ = 40.1 (±9.2%) t C ha^{-1}
$C_{dw(x)}$ = 11.5 (±19.8%) t C ha^{-1}
$C_{lit(x)}$ = 1.9 (±50.1%) t C ha^{-1}
$C_{veg(x)}$ = 3.8 (±34.4%) t C ha^{-1}

Therefore, the total carbon stocks are calculated as:

$C_{bio.pre(x)}$ = 170.6 + 40.1 + 11.5 + 1.9 + 23.8 = **227.9 t C ha^{-1}**

Tier 1[5] total uncertainty is calculated as:

$$\frac{\sqrt{(9.2\% * 170.6)^2 + (9.2\% * 40.1)^2 + (19.8\% * 11.5)^2 + (50.1\% * 1.9)^2 + (34.4\% * 3.8)^2}}{|170.6 + 40.1 + 11.5 + 1.9 + 3.8|} = \mathbf{7.3\%}$$

B. Estimate biomass carbon stocks of post-deforestation land use

In implementing REDD, each country must identify the type of post-deforestation land use(s), any land use cycle lengths (e.g. mean crop-fallow length, timber rotation), and determine an appropriate and defensible method to follow[6].

Equation 4 is appropriate for estimating post-deforestation biomass carbon stocks, although the tree biomass pool will often be zero. For post-deforestation land uses that have significant perennial and/or woody vegetation, it is recommended to use areas that reflect the projected post-deforestation land use, and conduct fieldwork to estimate carbon stocks of those land uses for use in estimating emission factors.

$$C_{bio.post(y,t)} = (C_{agb(y)}+C_{bgb(y,t)}+C_{dw(y)}+C_{lit(y)}+C_{veg(y)}) \quad \text{Eq.4}$$

Where:

$C_{bio.post(y,t)}$ = Carbon stock in biomass in land use y at time t, post-deforestation, t C ha^{-1}
$C_{agb(y)}$ = Carbon stock in aboveground live tree biomass in land use y, t C ha^{-1}
$C_{bgb(y,t)}$ = Carbon stock in belowground live tree biomass in land use y at time t[7], t C ha^{-1}
$C_{dw(y)}$ = Carbon stock in deadwood pools in land use y, t C ha^{-1} (includes both standing and lying deadwood)

[5] For the sake of simplicity, Tier 1 uncertainty calculations are used in the examples within this module. However, it is recommended that Tier 2 uncertainty estimates be used whenever possible.

[6] There are currently no UNFCCC required methods that must be followed to obtain post-deforestation carbon stocks.

[7] If roots remain following deforestation, pre-deforestation belowground carbon stocks are assumed to decompose over 10 years. Therefore post-deforestation below-ground carbon stocks are estimated as $C_{bgb(x,t-1)} - (C_{bgb(x)}/10)$, where t equals years following deforestation.

$C_{lit(y)}$ = Carbon stock in litter in land use y, t C ha^{-1}

$C_{veg(y)}$ = Carbon stock in non-tree vegetation in land use y, t C ha^{-1} (includes shrubs, sapling, and herbaceous understory)

If the post deforestation land-use is cyclical, as in the case of plantations or shifting agriculture, an approach commonly used is to estimate the carbon stocks as a time-weighted average of stocks in the cycle, particularly if the cycle is relatively short (≤10 years). For land uses that accumulate biomass, but are not cyclical, such as grasslands, carbon stocks may be assumed to be the mature stocks of the post-deforestation land use.

Where there is no woody vegetation, the post-deforestation carbon stocks can be based on default values, e.g. IPCC defaults, according to the post deforestation land use. Often the post deforestation carbon stocks in all vegetation pools are estimated to be zero for post deforestation land use classes such as annual croplands, mining areas, settlements, and roads. These defaults represent a Tier I approach under IPCC and it is therefore good practice to use national data for a Tier 2 or Tier 3 approach where possible.

Further guidance on default values for post deforestation carbon stocks based on land use and calculation of post deforestation carbon stocks for a Tier 2 or Tier 3 approach can be found in the 2006 IPCC AFOLU Guidelines for National Greenhouse Gas Inventories Volume 4 Agriculture, Forestry and Other Land Use. Default values based on land use are provided in the appropriate chapters available at: http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html.

As an example, if the post-deforestation land use is annual cropland (crop), the default biomass carbon stocks and uncertainty in country A after one year of growth are as follows, based on 2006 IPCC Guidelines, Vol. 4, Ch. 5, Table 5.9:

$C_{veg(crop)}$ = 5.0 (±75%) t C ha^{-1}

C. Estimate non-CO_2 emissions

Emissions from non-CO_2 gases in post-deforestation land uses result from fire, drainage of forested wetlands, and agricultural activities such as fertilizer application and grazing. This module is intended for estimating gross and net emissions per unit of activity resulting **directly** from the conversion of forests to other land uses. Therefore, the boundary is defined as the emissions occurring directly following conversion from forest to non-forest, and does not include emissions associated with the on-going activities following conversion; it is assumed that those will be addressed by other sectors.[8]

[8] This is an arbitrary distinction, and may be revised in the future. In addition, it is important to note that emissions from the long-term change in biomass are still considered to fall within this boundary.

The 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 4: Agriculture, Forestry and Other Land Use provide guidance on accounting for emissions of such non-CO_2 gases. An overview of non-CO_2 emission estimation is provided in Chapter 2, section 2.2.2, with references to other relevant sections.

For example, directly following deforestation, remaining biomass is often burned in preparation for the land use following conversion. The emission factor for fire, based on Equation 2.27 from the 2006 IPCC Guidelines for National GHG Inventories, is estimated as follows:

$$L_{fire} = M_B * C_f * G_{ef} * 10^{-3} \quad \text{Eq.5}$$

Where:

- L_{fire} = amount of greenhouse gas emissions from fire, t ha^{-1} of each GHG e.g., CO_2, CH_4, N_2O.
- M_B = mass of fuel available for combustion, t dry matter ha^{-1}. This includes aboveground biomass, ground litter and deadwood. (If not directly available, this can be estimated as t C ha^{-1} * 2.)
- C_f = combustion factor, dimensionless (default values in IPCC AFOLU GL Table 2.6[9])
- G_{ef} = emission factor, g kg-1 dry matter burnt (default values in IPCC AFOLU GL Table 2.5[9])

These are converted to carbon dioxide equivalents by multiplying by the appropriate global warming potential factor (21 for methane and 310 for nitrous oxide).

As an example, assuming the land was cleared by burning, the following factors are used:

- M_B = $(C_{agb(x)} + C_{dw(x)} + C_{lit(x)} + C_{veg(x)} +)*2 = (170.6 + 1.9 + 11.5 + 3.8) * 2 = 375.6$
- C_f = 0.36 (default value for all primary tropical forests, from IPCC GL Table 2.6)
- G_{ef} = 1580 for CO_2, 6.8 for CH_4, and 0.20 for N_2O (default values for tropical forest, from IPCC GL Table 2.5)

Therefore emissions from fire are calculated as follows:

L_{fire}	$CH_4 = 375.6*0.36*6.8*10^{-3}$	$= 0.9 * 21$	$= 19.3$
	$N_2O = 375.6*0.36*0.2*10^{-3}$	$= 0.03 * 310$	$= 8.4$
	Total emissions:		= **27.7 t CO_2e ha^{-1}**

Uncertainty is assumed to be 75%, due to use of default factors.

D. Estimate carbon stocks stored as wood products

[9] http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_02_Ch2_Generic.pdf

When trees removed during deforestation result in milled timber or exported logs, the carbon stocks stored in wood products following harvest, C_{wp}, are based on the efficiency of wood production, or the fraction of biomass effectively emitted to the atmosphere during production. This varies by wood product, location, and mill. It is therefore highly recommended that specific values be obtained for individual countries based on the country's mill efficiency and the proportion of specific wood products. In the absence of a country-specific value, it is recommended that a literature search be conducted to identify an appropriate figure. Alternately, a common conservative assumption is an overall efficiency of 50%.

Once obtained, the efficiency factors are multiplied by the volume that goes to each wood product class and the wood density:

$$C_{wp} = \sum (Vol_{wpc} * WD * EF_{wpc}) * 0.47 \qquad \text{Eq.6}$$

Where:

C_{wp}	= Carbon stock in wood products following deforestation, t C ha^{-1}
Vol_{wpc}	= Volume harvested (m^3/ha) by wood product class
WD	= Density of harvested wood (dimensionless)
EF_{wpc}	= Efficiency factor by wood product class (default of 50%, or justified by citation)
0.47	= carbon fraction

The method used here is conservative for wood products from deforestation. A less conservative, but more thorough accounting method would include a decay rate for wood products over time. This is briefly described in Appendix A.

For fuelwood and hand-milled timber 100% immediate emissions are assumed.

As an example, if deforestation results in a harvest of 15m^3/ha roundwood, with a wood density of 0.6, using the default efficiency factor the carbon stock stored in wood products is equal to:

C_{wp} = 15 * 0.6 *0.5 * 0.47 = **2.1 t C ha^{-1}**

Uncertainty is assumed to be 75%, due to use of default factors.

E. Determine soil carbon emitted as a result of deforestation

Changes in soil carbon stocks are related to the post deforestation land use, and it is recommended that the changes be estimated using the IPCC 2006 guidelines for this process. This IPCC method estimates the changes in soil carbon stocks based on the use of soil factors that account for how the soil is tilled, the method of management, and inputs in the post deforestation land use.

$$\Delta SOC = C_{soil} - (C_{soil} * F_{LU} * F_{MG} * F_I) \qquad \text{Eq.7}$$

Where:

ΔSOC = Soil carbon emitted, t C ha^{-1}

C_{soil} = Carbon stock in soil organic matter pool (to 30 cm); t C ha^{-1}

F_{LU} = Stock change factor for land-use systems for a particular land-use, dimensionless (IPCC AFOLU GL)

F_{MG} = Stock change factor for management regime, dimensionless (IPCC AFOLU GL)

F_I = Stock change factor for input of organic matter, dimensionless (IPCC AFOLU GL)

The change in soil carbon stocks is assumed to occur over a 20 year time period, at which time a new steady state for a given land use is reached. To account for this time period, $\Delta SOC_{(t)}$, as used in Equation 1, is estimated as ΔSOC / 20 for the first 20 years, and 0 thereafter.

Additional guidance on estimating change on soil carbon, suggested default time periods, and additional soil carbon factors can be found in in the 2006 IPCC AFOLU Guidelines for National Greenhouse Gas Inventories Volume 4 Agriculture, Forestry and Other Land Use.[10]

As an example, with hypothetical soil carbon stocks of 102 t C ha^{-1}, the moist tropical lowland forest in country A, converted to cropland uses the following IPCC soil carbon factors:

F_{LU}: 0.48
F_{MG}: 1.00
F_I: 1.00

And therefore has the following soil carbon emissions:

ΔSOC = 102 – (102 * 0.48 * 1.00 * 1.00) = 53.0 t C ha^{-1}

This must be divided by 20 to estimate annual change in soil carbon: **8.4** t C ha^{-1}
Uncertainty is assumed to be 75%, due to use of default factors.

F. Create emission factors for deforestation activity

After all of the individual elements have been calculated, Equation 1 can now be applied:

$$EF_{def(t,x,y)} = (C_{bio.pre(x)} - C_{bio.post(t,y)} - C_{wp} + \Delta SOC_{(t)}) * 44/12 + L_{fire} \quad \text{Eq. 8}$$

Combining all of the factors calculated in examples used in previous steps, the EF for the moist tropical lowland forest for country A is calculated as follows:

$$EF_{def(1,A,cropland)} = (227.9 - 5.0 - 2.1 + 8.4) * 44/12 + 27.7 = \mathbf{868.1\ tCO_2e\ ha^{-1}}$$

[10] IPCC (2006). Guidelines for National Greenhouse Gas Inventories. Volume 4, Agriculture, Forestry and Other Land Use. For soil carbon factors, see relevant chapters for post-deforestation land use: http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html

Uncertainty is calculated as described in Equation 3 (all factors converted to $tCO_2e\ ha^{-1}$):

$$\frac{\sqrt{(7.3\% * 835.6)^2 + (75\% * 18.3)^2 + (75\% * 7.7)^2 + (75\% * 30.8)^2 + (75\% * 27.7)^2}}{|835.6 + 18.3 + 7.7 + 30.8 + 241.3|} = \mathbf{7.6\%}$$

The end goal is to develop an emission factor look up table as in the example in table 3 below.

Table 3. Example of a look up table demonstrating emission factors (and uncertainties) for various deforestation scenarios.

From	To	
	Bare land	Cropland
	t CO_2e/ha	
Carbon stratum A	975 (13.2%)	**868 (7.6%)**
Carbon stratum B	450 (11.9%)	400 (13.0%)
Carbon stratum C	800 (12.2%)	760 (11.1%)
Carbon stratum D	1,050 (12.9%)	900 (12.5%)

APPENDIX A: ACCOUNTING FOR DECAY RATE OF WOOD PRODUCTS

The approach used to account for carbon stored in wood products in this module is conservative and is therefore acceptable. However, it would be more accurate to account for decay of wood products over time. The rate at which carbon is emitted from harvested wood products over time is a function of the rate of retirement of products from end uses and the various processes used to dispose of products:

- Carbon is emitted to the atmosphere when the product is retired and disposed of. How much is emitted and when is controlled by:
  - Carbon may be immediately emitted to the atmosphere through burning of wood products;
  - If wood products are burned for energy production, the carbon is emitted but the energy produced will displace some fossil fuel emissions that therefore remain in storage, resulting in emission reductions;
  - Retired wood products may also be recycled, extending the duration of carbon storage in end uses; and
  - When retired products are landfilled, the rate of decomposition is extremely slow and a proportion of carbon in the product is considered to be stored indefinitely.

The IPCC Tier 1 method uses default data and assumes a first order decay function for the in-use lifetime of products. Change in carbon stocks in in-use products may be estimated using the following equation, adapted from IPCC:

(A) $$C_{wp}(i+1) = e^{-k} * C_{wp}(i) + \left[\frac{(1-e^{-k})}{k}\right] * Inflow(i)$$ Eq.5

(B) $$\Delta C_{wp}(i) = C_{wp}(i+1) - C_{wp}(i)$$ Eq.6

Where:

i = year

$C_{wp}(i)$ = the carbon stock of the Harvested Wood Products (HWP) pool in the beginning of year i, t C

k = decay constant of first-order decay given in units, yr^{-1} (k=ln(2)/HL, where HL is half-life of the HWP pool in years. A half-life is the number of years it takes to lose one-half of the material currently in the pool.)

Inflow(i) = the inflow to the HWP pool during year i, t C yr^{-1}

$\Delta C_{wp}(i)$ = carbon stock change of the HWP pool during year i, t C yr^{-1}

Tier 2 requires using country-specific data, and Tier 3 entails developing a detailed, country-specific method to estimate relevant variables that may include use of a decay function other than first order decay.

More information is available from the IPCC 2006 Guidance for National Greenhouse Gas Inventories (Volume 4, Chapter 12)[11].

[11] http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_12_Ch12_HWP.pdf

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Module 5 – Recording field data and conducting quality assurance and quality control procedures

This Module focuses on practical techniques and skills required to achieve data quality. The facilitator should emphasize the need for data quality, that quality assurance and quality control (QA/QC) methods and techniques apply at all levels of the inventory process, and that those presented here are specific to the role that Participatory Carbon Monitoring takes in the National Forest Monitoring System for REDD+ Measurement, Reporting and Verification.

The content presented in this Module is supported by a number of exercises which rely on the collection of field data to be completed. Participants should understand all the exercises to be able to collect complete and accurate field data.

Module 5.1: Context of Quality Assurance and Quality Control

This module covers quality assurance and quality control (QA/QC) actions that relate directly to data used in the NFMS.

Core Learning Outcome
QA/QC methods and techniques apply at all levels of the inventory process.

Core Message

- QA/QC procedures should be conducted in every step of the national GHG accounting
    - Including review of protocols and sampling frame designs to ensure they are complete and without error
    - During data collection and data analysis and estimation of emissions and removals
    - Finally, the reports generated from the NFMS should be reviewed for completion and correctness prior to release.
- All NFMS stakeholders have a role in QA/QC

Module 5.2: QA/QC: Collecting field data

Core Learning Outcome
QA/QC is about minimizing errors in the data and identifying and correcting errors.

Core Message

- Training of field crew staff is fundamental to achieving the collection of quality data

- Field crews should be observed in the field and advised of things to look out for in collecting data, such as ensuring that the DBH tape is at 1.3m and that it is horizontal around the tree trunk and not up at the back and down at the front.
- Ways to maintain quality and consistency in field data collection is to regularly check the work. One good way of doing this is to swap team leaders around. However, this only works if you have consistency between team leaders as well.
- Regular group discussions between all field crews on interesting challenges they have come across and how they solved them also increase the likelihood the teams are all collecting data in a consistent way.
- Traceability is an important aspect of field data collection. Ensuring that details about the team members are on the data sheets enables questions regarding the data to be directed back to the team. Questions can arise when data entry commences and there may be some large or small or unusual data recorded. The teams may recall what happened at the plot and be able to explain the unusual data.
- Good communication in the field can also improve the likelihood of quality data collection. To ensure that the data recorder correctly notes down the numbers measured by the crew it is good practice for the team member measuring the data to call out the measurement. The data recorder then repeats the measurement heard as it is recorded in the sheet. If there are inconsistencies, they should be corrected immediately
- Team leaders should review the data collected on the datasheets before leaving the plot. This review should be for completeness of all data and also for any unusual data records. If there are any concerns, they should be checked prior to leaving. This step can sometimes be a challenge because the teams will be tired and wanting to finish. Maintaining the discipline to conduct these checks is an important trait of a good team leader. It can be a long way back to the plot to do the checks later!
- Independent checks of data collected within the plots is good practice. A different field crew, or QA/QC team re-measures a random sample of the measured plot. Typically, all measurements are re-measured within the plot. The plots to be re-measured should not be known as the teams conducting the original measurements may change their approach if they know someone is going to check that specific plot and they may be less careful on plots they know won't be re-measured.
- The results of the independent checks are used to quantitatively estimate measurement error
- This process requires that the two sets of data recorded on the plot are used to estimate biomass at the plot level and are compared.
- Calculating measurement error can assist in identifying areas of opportunity in the field data collection process
- Measurement error is one source of uncertainty related to biomass estimates. This error is combined with model error to represent the total uncertainty associated with the plot level estimates. This is described in more detail in Module 6.

Module 5.3: QA/QC - Processing field data

The material covered in this Sub-Module should familiarize participants with techniques to reduce errors when transferring field data to electronic formats. Proper training on the use of computers, specific software, and any other devices required for entering data should be carried out prior to data entry.

Core Learning Outcome
QA/QC provides an assessment of data accuracy to help identify any improvements that need to be made

Core Message

- As far as practicable, data entry should be conducted by the same team member who led the field data collection (i.e. field crew leader).
- Using the same participants for data entry as collected may reduce errors associated with transcribing field data.
- Quality control measures (i.e. QA/QC protocols) should be employed to ensure the accuracy of data entered. Some useful checks include random checks of data sheet records compared to electronic records. This could be done for an entire plot or for a random percentage of records per plot, depending on time and number of records to check.
- A good number of checks may be 10% of all data sheets or 10% of all records.
- Sorting data can be another good check. This can identify outliers (unusual large or small records) which may be errors or need some questions back to the field crew.
- All data sheets should also be reviewed for completeness to ensure all the records were entered into the electronic files.
- It is important to note that as technologies evolve, systems that automate data entry are being developed in which field data is directly collected in electronic format for later analysis.

This Module ends with an exercise to enter the data collected on the field sheets into the supplied excel spreadsheet training tool, incorporating QA/QC checks to ensure that the data is entered from the field sheets with no errors. This exercise cannot be completed until after the field trip has taken place.

Module 5

Recording field data and conducting quality assurance and quality control procedures

1

Module Outcomes

Understanding that quality assurance and quality control:

- methods and techniques apply at all levels of the inventory process.
- is about minimising errors getting in the data and identifying and correcting errors.
- provides an assessment of data accuracy to help identify any improvements that need to be made

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Module Outline

1. Context of Quality Assurance / Quality Control
2. QA/QC: Collecting field data
3. QA/QC: Processing field data

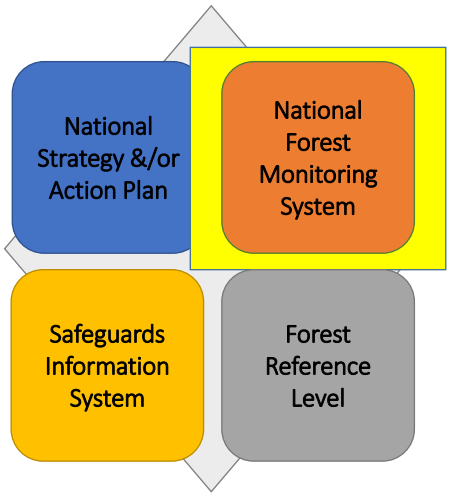
Context of Quality Assurance and Quality Control

Module 5.1

Four Elements of REDD+

National Forest Monitoring System

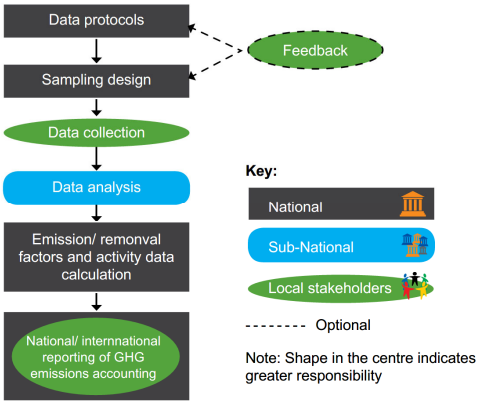
- National Forest Monitoring System (NFMS)
- This module covers QA/QC actions that relate directly to data used in the NFMS



5

Generic PCM operational framework for national REDD+ Emissions and Removals

National Forest Monitoring System



Source: Casarim et al., 2013

QA/QC procedures should be conducted in every step of the national GHG accounting

Leads to:

- improved accuracy and ensuring best practices
- strengthening confidence in the estimates produced

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National Forest Monitoring System

QA/QC: Collecting field data

Module 5.2

Field Crew Training

- Field crews should be well trained.
- Observations should be made of each field crew member during data collection of a field plot to verify measurement processes and correct any errors in techniques.
- It is recommended that the crew chiefs/field team leader regularly switch to a different crew to ensure data collection procedures are consistent across all field crews.
- Field crew observations should be repeated throughout the field measurement campaign to ensure data collection procedures are consistent over the whole duration of the campaign.

Field Crew Communication and Traceability

All data sheets should include a 'Data recorded by' field with the name of the crew member responsible for recording data

When collecting field data, the crew member responsible for recording must verbally repeat all measurements called by the crew member conducting the measurement.



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Data sheet review

Before leaving the plot all data sheets must be checked by team leaders to ensure that all the relevant information was collected.

If for some reason there is some information that seems odd or is missing, mistakes can be corrected in the field.

Reviewed/corrected data sheets shall be handed over to the person responsible for their safe keeping while the crew is still in the field.

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Independent checks

Certain percentage of the plots should be randomly or systematically chosen to be remeasured.

All measurements shall be remeasured in each plot.

Original field crews taking measurements should not be aware of which plots will be remeasured whenever possible.

The people involved in the independent assessment should be experienced in forest measurement and highly attentive to detail and be people other than the original field crew.

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Independent checks

- Field teams will be incentivized to maintain a consistent standard of work
- Gain insight into data quality issues by being able to check measurement errors
- Completeness checks at the final stage of data compilation should be conducted
- The assessments provide data to quantify the amount of error due to field measurement techniques.



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Estimating Measurement Error

After remeasurement, data analysis is conducted and biomass estimates are compared with estimates from the original data.

Any errors discovered could be expressed as a percentage of all plots that have been rechecked to provide an estimate of the Measurement Error (%) .

Measurement Error (%) as well as other uncertainty measurements will be included in the carbon stock reporting.

Estimating Measurement Error

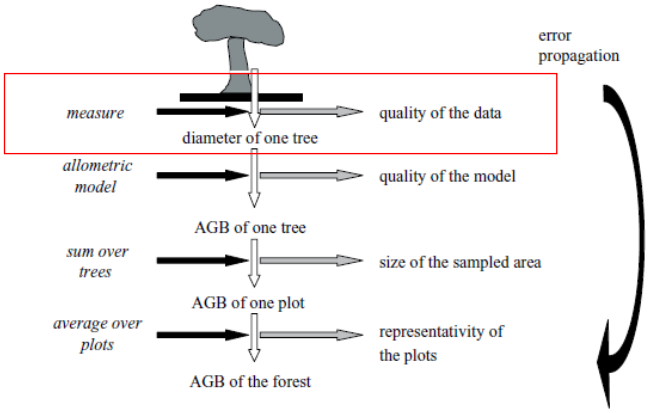


Figure 1. The error propagation for estimating the AGB of a tropical forest from permanent sampling plots.

In field QA/QC

Exercise:

Measurement Recording

- Person recording entries on field data sheets repeats measurement calls made by person measuring
- When a field crew is finished a person in the field crew not involved with writing entries on field data sheet reviews that the data sheet is clearly written and complete

Independent Assessment

- Field crew moves to the plot left of their plot
- Re-measure DBH for all measured/marked trees and record result on the independent assessment data sheet

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National Forest Monitoring System

QA/QC: Processing field data

Module 5.3

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Data Entry

After all data has been entered into computer file(s), a random check shall be conducted.

Data sheets shall be selected randomly for re-checks and compared with data entered.

Ten percent (10%) of all data sheets shall be checked for consistency and accuracy in data entry.

Data Entry

Other techniques such as data sorting and verification of resulting estimates shall be employed to ensure data entered properly corresponds to field sites visited.

Analysis should be done to identify errors such as unusually large or small records.

Data control and compilation of databases

In addition to consistency checks and assessment checks, it is important to perform completeness tests at the final stage of data compilation to ensure that all data has been collected.

Errors can be reduced if the entered data is reviewed using expert judgment and, if necessary, through comparison with independent data.



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Field data processing

Exercise:

Data Entry

- Enter the plot field data into the spread sheet
- Enter the verification data collected by the independent team into the spreadsheet

QA/QC

- Check that the largest and smallest value in the spread sheets matches the largest and smallest value on the field data sheet
- Randomly select 5 entries on the field data sheet and check that the values are entered correctly in the spread sheet

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Module 5 Exercises

There are three (3) exercises related to Module 5 which relate to QA/QC checks. Data from the field are used in combination with the Training Excel spreadsheet to complete the exercises.

Materials	Completed field data sheets Training Excel Spreadsheet Tool Field Data Tool Spreadsheet Manual

Exercise a: Actual Field Data Collection - Conducting field QA/QC checks

Guide	Each team should have a clean Field Data sheet specifically for conducting independent QA/QC checks. Randomly allocate each team to another plot number and ask them to re-measure the DBH of all the trees in their allocated QA/QC plot. The tree number and DBH should be recorded in the QA/QC field sheet. Once the team has re-measured all the trees in their QA/QC plot, they should gather back at the common point. The field sheets should be handed to the facilitator. Once all teams are back, all teams should return to their original plot and collect the remaining equipment and prepare to leave the field. The outcomes of the field QA/QC checks will be explored back in the class room using an excel spreadsheet.
Expected Duration	1 – 2 hours

Exercise b: Data Entry and QA/QC checks

Guide	Participants should work in the same groups as those in the field work. The data must be entered into the spreadsheet. The data entry requires two people: • 1 person should read out loud the records from the field sheets and • 1 person should type the data into the excel spreadsheet. Once the data has been inputted into the spreadsheet, it is good practice to conduct some QA/QC checks. The QA/QC checks should be done by two separate people. The following two checks should be conducted: 1. Check that the largest and smallest value in the spread sheets matches the largest and smallest value on the field data sheet 2. Randomly select 5 entries on the field data sheet and check that the values are entered correctly in the spread sheet Any identified errors should be noted and corrected. The teams should report back to the larger group what they found.
Expected Duration	1.5 hours

Exercise c: Field data processing

Guide	Participants should work in the same groups as those in the field work. The QA/QC data collected by an independent group for the team's plot should be provided to the team. The data should be entered into the QA/QC tab of the spreadsheet. This will mean that the team will have the plot data they measured and the data measured on the same plot by the independent team in their spreadsheet. The data entry requires two people: 1 person should read out load the data from the QA/QC field sheet and 1 person should type the data into the excel spreadsheet. The same data entry QA/QC checks as done in the previous

	exercise should be completed resulting in the following two checks being conducted: 1. Check that the largest and smallest value in the QA/QC field sheets matches the largest and smallest value on the field data sheet 2. Randomly select 5 entries on the QA/QC field data sheet and check that the values are entered correctly in the spread sheet Any identified errors should be noted and corrected. Once the data is entered into the spreadsheet, the carbon calculations are completed automatically. Teams should ccompare the results of the plot that they measured with the results of the re-measured QA/QC plot. A measurement error is automatically estimated in the excel spreadsheet. The teams should compare and discuss the results and measurement error with other teams by reporting back to the larger group what they found.
Expected Duration	1 hour

Module 6 – Analysing Field Data and Estimating Carbon Stocks

The material covered in this Module should familiarize participants with techniques to i) assess the quality of the collected field data; and ii) understand how the collected data contributes to calculations of carbon stocks in a National Forest Monitoring System.

As the data was entered in the previous session, the spreadsheet has automatically completed the calculations of aboveground biomass, below ground biomass and total biomass. Participants should not spend too much time at this point looking at the numbers but rather the facilitator should continue with the presentation of slides of Module 6.1 which presents an explanation of the numbers.

Once the presentation is completed then the facilitator should encourage the participants to return to the spreadsheet to allow them time to look over the numbers and calculations.

Module 6.1: Estimating carbon stocks in measured forest pools

Core Learning Outcome
Understand the calculations required to convert field data to forest carbon stock estimates

Core Message

- It is important to understand clearly the units of carbon accounting.
- Field measurements are typically applied in calculations that yield estimates of biomass which are in tonnes of dry matter per hectare (t.d.m. ha^{-1}).
- These units are then converted to carbon by multiplying by a default value of 0.47. The carbon stocks are then converted to the unit for reporting emissions and removals for carbon dioxide equivalents (t CO_2e) by multiplying the carbon stock and the molecular weight conversion factor of 44/12. These internationally recognised default values are provided by the IPCC.
- Although measurements of deadwood and litter were taken in the field, this training course only covers the techniques to estimate the main pools of above and below ground biomass.
- In a normal project or national level programme, average carbon stocks are estimated by measuring tree parameters in the field within plots. The carbon stock per plot is estimated and then an average and standard deviation is estimated from all the plots.
- In this training the estimates are made for each plot only. The combination and standard deviation are not done.
- Models known as allometric equations are used to estimate the above ground biomass of trees from field measurements of DBH, tree species (from which wood density is then known and used) as well as tree height.
- All natural things have allometry. Even humans. For example, a baby's birth weight can be estimated from a measure of the diameter of the head from an ultrasound. A teenager's foot size can be used to estimate their expected final height. For trees, a

measure of its DBH, height and species can be used to model total above ground biomass

- There are many allometric equations available. Some are country specific. Some have drawn on the many available equations to develop globally relevant equations.
- The calculations used in this training apply a version of the global equations published by a well-known author; Chave et al 2005. There are many global equations for different forest types which are provided in the slides for information only.
- The allometric equation in the spreadsheet uses DBH and wood density only.
- The IPCC also publishes default carbon stocks which you might expect in different forests globally. These numbers can be used as a check on the estimates generated from the field data. They should only be used as a guide because all forests are managed differently and contain different species, etc, but they can be a useful representation of the magnitude of the expected results.
- Some worked on calculations to demonstrate how to convert dry biomass to carbon and then to carbon dioxide using default values from the IPCC.

REMINDERS:
The slides in this module should be used in combination with the spreadsheet calculation tool and its supporting facilitator manual.

There are two slides at the end of this sub-Module (6.1) which describe the calculations being undertaken in the spreadsheet. There are some references to where the equations and default values are found. For wood density the FAO database can be used to source the value to input into the spreadsheet. If the wood density cannot be found for the recorded species then an average wood density value can be entered to ensure the spreadsheet can complete the calculations.

The last slide in this sub-module explains in point form the processes that happens in the spreadsheet and what can be done with the data when multiple plots for a project or national programme are completed.

Module 6.2: Estimating Emissions and Removals

Core Learning Outcome
Participants understand how plot level data are used to estimate emissions and removals.

Core Message

- REDD+ is based on the concept of avoiding emissions and enhancing removals from areas of forest.
- The data measured in the plot provide some indication of carbon stock; not emissions or removals
- The plot measurements provide an indication of carbon at 1 point in time. Emissions and removals represent the **difference** in carbon between two points in time.
- The IPCC describes two methods for estimating emissions and removals

- The stock difference method relies on estimates of carbon stock at two points in time. The difference between these two points in time represents the emissions or removals
- The gain loss method relies on estimates of gains such as growth and losses such as timber harvested. The difference between the INs and the OUTs represents the emissions or removals.
- Both methods should yield the same answer/result.
- The data collected from forest carbon plots can be used in the Stock -difference method to estimate emissions and removals.
- For example, the measurements taken in the field represent the carbon stock in the forest now (at time 1). If this land was to be deforested and converted to grassland tomorrow (at time 2) the emissions would be equivalent to the stock in the forest at time 1 less/minus the stock in the grassland at time 2.
- A work example is provided for the calculation including the unit conversions using IPCC default value for forests and grassland.
- Conducting this calculation results in the EMISSIONS FACTOR which is then multiplied by the area of change (or ACTIVITY DATA) and the product is the EMISSIONS from this deforestation event.
- This represents an example of how the field plot data is used in the NFMS in the context of reporting deforestation emissions
- For each emissions/removals estimate, uncertainty also needs to be estimated.
- Uncertainty can arise due to measurement error, data entry error and/or model error.
- These errors can be random or systematic and examples are clearly described in the slides.

Module 6

Analysing field data and estimating carbon stocks

Module Outcomes

Understanding of how:

- to conduct calculations of carbon stocks
- data collected in the field is used in National Forest Monitoring Systems for REDD+ MRV

Module Outline

1. Estimating carbon stocks in measured forest pools
2. Use of Data in National Forest Monitoring Systems

Estimating carbon stocks in measured forest pools

Module 6.1

Plot level calculations conducted

1. Calculate the aboveground biomass (AGB) in tons of carbon per hectare (t C/ha)
2. Estimate the belowground biomass (BGB) in tons of carbon per hectare (t C/ha)
3. Derive the total live tree t C/ha for each plot, by combining BGB and AGB estimates

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Units

- Tonnes of dry biomass – t d.m
- Tonnes of carbon – t C
- Tonnes of carbon dioxide equivalent – t CO_2e

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Unit Conversions

t C = t d.m x 0.47

0.47 is the default conversion factor to convert dry matter in trees to carbon

t CO_2e = t C x (44/12)

The atomic weight of *carbon* is 12 atomic mass units.

The weight of *carbon dioxide* is 44, because it includes an additional two oxygen atoms that each weigh 16.

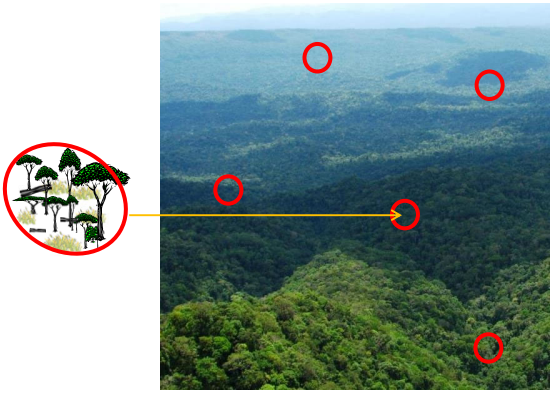
One ton of *carbon* equals *44/12* = 3.67 tons of *carbon dioxide*.

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Average carbon stock calculations

Calculate the mean value of the t C/ha for all the plots measured and find the standard deviation and confidence interval at 95%

If sampling is conducted at an appropriate scale, the average total live tree t C/ha could contribute to the development of an emission factor (EF) for the stratum

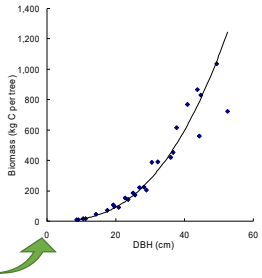


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Procedure for calculating average forest carbon stocks

- Measurements of carbon pools are recorded in the field.
- Models and conversion factors are used to estimate carbon stocks in each major pool based on field measurements.
- Statistical analysis is used to calculate average forest carbon stocks based on plot data.



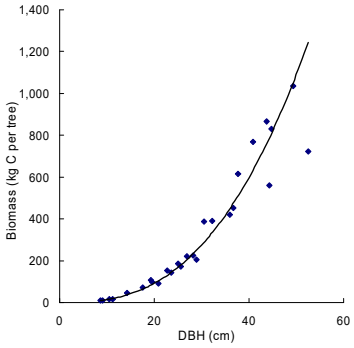



Data Analysis - Models

Trees often have predictable relationships among their height, diameter, and roots.

Mathematical formulas are available or can be developed to express these relationships (allometric models).

Forest field data can be applied to these mathematical formulas to indirectly estimate biomass.



Data Analysis – Allometic Models

An allometric model describes the relationship between a readily measurable variable (DBH) and mass (biomass) of the tree.

There are many models published for forests worldwide based on DBH or a combination of DBH, species wood density, and height.



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Data Analysis – Allometric Models

Global allometric models published by Chave are most commonly used.

Best-fit pantropical model - Chave 2014

$$AGB = 0.063 \times (\rho D^2 H)^{0.976}$$

Where;

$\rho = wood\ density$
$D = dimater\ at\ breast\ height$
$H = tree\ height$

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Allometric Models

Dry forest stands – Chave et. al., 2005

- With wood density, diameter and height

$$\langle AGB \rangle_{est} = \exp\left(-2.187 + 0.916 \times \ln\left(\rho D^2 H\right)\right)$$
$$\equiv 0.112 \times \left(\rho D^2 H\right)^{0.916}$$

- With wood density and diameter only

$$\langle AGB \rangle_{est} = \rho \times \exp(-0.667 + 1.784 \ln(D) + 0.207(\ln(D))^2 - 0.0281(\ln(D))^3)$$

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Allometric Models

Moist forest stands – Chave et. al., 2005

- With wood density, diameter and height

$$\langle AGB \rangle_{est} = \exp\left(-2.977 + \ln\left(\rho D^2 H\right)\right) \equiv 0.0509 \times \rho D^2 H$$

- With wood density and diameter only

$$\langle AGB \rangle_{est} = \rho \times \exp(-1.499 + 2.148 \ln(D) + 0.207(\ln(D))^2 - 0.0281(\ln(D))^3)$$

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Allometric Models

Wet forest stands – Chave et. al., 2005

- With wood density, diameter and height

$$\langle AGB \rangle_{est} = \exp\left(-2.557 + 0.940 \times \ln\left(\rho D^2 H\right)\right)$$
$$\equiv 0.0776 \times \left(\rho D^2 H\right)^{0.940}$$

- With wood density and diameter only

$$\langle AGB \rangle_{est} = \rho \times \exp(-1.239 + 1.980\ln(D) + 0.207(\ln(D))^2 - 0.0281(\ln(D))^3)$$

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Typical Carbon Stocks in Forests

TABLE 4.7
ABOVE-GROUND BIOMASS IN FORESTS

Domain	Ecological zone	Continent	Above-ground biomass (tonnes d.m. ha^{-1})	References
Tropical	Tropical rain forest	Africa	310 (130-510)	IPCC, 2003
		North and South America	300 (120-400)	Baker *et al.*, 2004a; Hughes *et al.*, 1999
		Asia (continental)	280 (120-680)	IPCC, 2003
		Asia (insular)	350 (280-520)	IPCC, 2003
	Tropical moist deciduous forest	Africa	260 (160-430)	IPCC, 2003
		North and South America	220 (210-280)	IPCC, 2003
		Asia (continental)	180 (10-560)	IPCC, 2003
		Asia (insular)	290	IPCC, 2003
	Tropical dry forest	Africa	120 (120-130)	IPCC, 2003
		North and South America	210 (200-410)	IPCC, 2003
		Asia (continental)	130 (100-160)	IPCC, 2003
		Asia (insular)	160	IPCC, 2003
	Tropical shrubland	Africa	70 (20-200)	IPCC, 2003
		North and South America	80 (40-90)	IPCC, 2003
		Asia (continental)	60	IPCC, 2003
		Asia (insular)	70	IPCC, 2003
	Tropical mountain systems	Africa	40-190	IPCC, 2003
		North and South America	60-230	IPCC, 2003
		Asia (continental)	50-220	IPCC, 2003
		Asia (insular)	50-360	IPCC, 2003

Source: IPCC, 2006 Default Aboveground Stocks in Natural Forests

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Typical Carbon Stocks in Forests

- Convert t d.m ha^{-1} to tC ha^{-1} then to tCO_2e ha^{-1}

Tropical Rainforest insular Asia

- Aboveground biomass = 350 t d.m ha^{-1}
- Aboveground carbon = 350 x 0.47 = 164.5 tC ha^{-1}
- Aboveground carbon dioxide equivalents = 136.5 x (44/12) = 603.2 tCO_2e ha^{-1}

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Data Analysis – Default Values

Belowground tree biomass (roots) is rarely measured.

A **root-to-shoot ratio** can be applied instead, such as those from IPCC.

Table 2.3.3. Root to shoot ratios modified* from Table 4.4. in IPCC GL AFOLU.

Domain	Ecological Zone	Above-ground biomass	Root-to-shoot ratio	Range
Tropical	Tropical rainforest or humid forest	<125 t.ha-1	0.20	0.09-0.25
		>125 t.ha-1	0.24	0.22-0.33
	Tropical dry forest	<20 t.ha-1	0.56	0.28-0.68
		>20 t.ha-1	0.28	0.27-0.28
Subtropical	Subtropical humid forest	<125 t.ha-1	0.20	0.09-0.25
		>125 t.ha-1	0.24	0.22-0.33
	Subtropical dry forest	<20 t.ha-1	0.56	0.28-0.68
		>20 t.ha-1	0.28	0.27-0.28

*the modification corrects an error in the table based on communications with Karel Mokany, the lead author of the peer reviewed paper from which the data were extracted.

Source: IPCC, 2006 Volume 4, Chapter 4

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Example of Plot Carbon Stock

A	B	C	D	E	F = D x E	G = D + F	H = G x 0.47	I = H x (44/12)
DBH	Species	Wood Density	Aboveground biomass (kg d.m. ha^{-1})	Root:shoot ratio	Belowground biomass (kg d.m. ha^{-1})	Total biomass (kg d.m. ha^{-1})	Total carbon (kg C ha^{-1})	Total (kg CO_2e ha^{-1})
15	*Dalbergia latifolia*	0.75	52.36	0.24	12.57	64.92	30.51	111.88
20	*Tectona grandis*	0.5	60.68	0.24	14.56	75.24	35.36	129.67
35	*Terminalia microcarpa*	0.53	188.83	0.24	45.32	234.15	110.05	403.52

A/B – Data collected from field plot (example only)

C - Wood Density sourced from FAO: http://www.fao.org/3/w4095e/w4095e0c.htm

D - Aboveground Biomass estimated using Chave et al 2005: $\langle AGB \rangle_{est} = \rho \times \exp(-1.239 + 1.980\ln(D) + 0.207(\ln(D))^2 - 0.0281(\ln(D))^3)$

E – IPCC 2006 Default Root: Root Ratio

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Example of Plot Carbon Stock

What the calculation spreadsheet tool does:

- Calculations are conducted for each tree per plot
- Total tree stock is summed for the plot
- Divided by the area of the plot
- Divided by 1000 to convert kilograms to tonnes
- Final result is an estimate of Total Carbon Stock for the plot

What can be done when multiple plots are measured:

- All the plot estimates are added then divided by the total number of plots to achieve a average of the plots.
- The standard deviation of the plots is used to estimate uncertainty.

20

Carbon Stock Calculations

Exercise:

Calculations

- Explore the spreadsheet calculations of carbon stocks in aboveground and belowground biomass

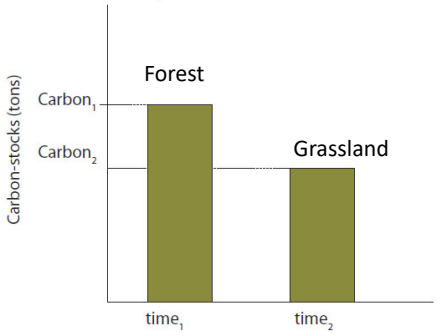
Estimating Emissions and Removals

Module 6.2

Methods for Estimating Emissions and Removals

METHOD 1

Stock-difference
The difference between carbon stocks gives carbon emissions



Carbon$_1$: Carbon stocks time$_1$
Carbon$_2$: Carbon stocks time$_2$

METHOD 2

Gain-loss
Carbon emissions are calculated from gain minus loss

Carbon uptake:
- Growth
- Enrichment

Forest Land

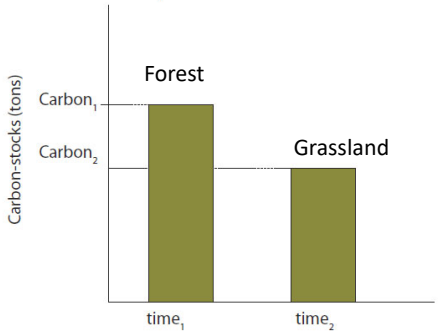
Carbon release:
- Timber harvests
- Fuelwood removals
- Charcoal production
- Sub-canopy fires
- Grazing

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Example of Carbon Stock Change

METHOD 1

Stock-difference
The difference between carbon stocks gives carbon emissions



Carbon$_1$: Carbon stocks time$_1$
Carbon$_2$: Carbon stocks time$_2$

METHOD 2

Gain-loss
Carbon emissions are calculated from gain minus loss

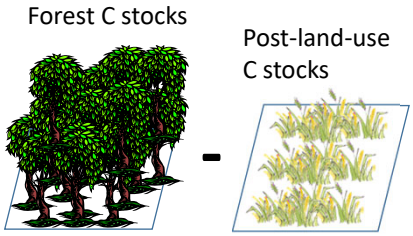
Carbon uptake:
- Growth
- Enrichment

Forest Land

Carbon release:
- Timber harvests
- Fuelwood removals
- Charcoal production
- Sub-canopy fires
- Grazing

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Example of Carbon Stock Change



Emissions Factor for Deforestation

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Example of Carbon Stock Change Estimates

The total measured carbon stock in the plots is them used to estimate the emission factor in the event that forest land is converted to annual cropland (Deforestation)

EXAMPLE

→ Assume all emissions occur at time of event

$$=(C_{forest}-C_{cropland})\times 44/12$$

$$=((164.5+(164.5x0.24))\ -3.0)\ x\ 44/12$$

$$=\ (204\ -\ 3)\ x\ 44/12$$

$$=\ \mathbf{737\ t\ CO_2e/ha}$$

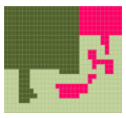
Default carbon stock from the IPCC

Estimate of belowground biomass using IPCC default value

IPCC default value for cropland in tropical zones

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Estimating Emissions and Removals

Area of change (AD)		Emissions unit of change (EFs)		Emissions from forest to cropland
1000 ha 	x	737 t CO_2e/ha 	=	737,000 t CO_2e

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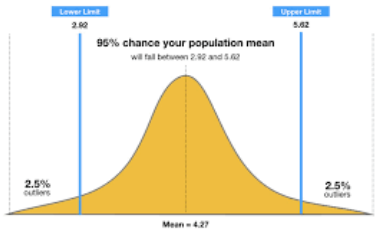
Uncertainty

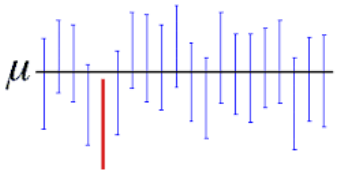
- Estimates should not be over- or underestimated (IPCC)
- Reporting uncertainties is transparent
- Uncertainty related to activity data, emissions factors, changes estimates all need to be considered
- Understanding key sources of uncertainties can assist in focusing resources for continuous improvement

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Uncertainty

How sure are you about the measured mean?





A 95% confidence interval indicates that 19 out of 20 samples (95%) from the same population will produce confidence intervals that contain the population parameter.

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Uncertainty

What are the sources of uncertainty?

- Measurement error (systematic or random)
- Recording/data entry error (systematic or random)
- Calculation error (model uncertainty)

Identify, quantify, discuss, reduce

30

Random Error

- **Random errors** are statistical fluctuations in the measured data due to the precision limitations of the measurement device
  - can be evaluated through statistical analysis and can be reduced by averaging over a large number of observations.
  - **Example –** the field crew measure the DBH of a tree to be 20.5cm. The first verification crew re-measure the tree and find it to be 21.2cm in diameter.

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Systematic Errors

- **Systematic errors** are errors that are not determined by chance but are introduced by an inaccuracy involving either the observation or measurement process
  - Systematic errors are difficult to detect and cannot be analyzed statistically, because all of the data is off in the same direction (either to high or too low). Spotting and correcting for systematic error takes a lot of care.
  - **Example -** the DBH tape used to measure the diameter of the tree has been stretched out from years of use. As a result, all of your measurements are smaller than the actual diameter.

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Random and Systematic Error

The main difference between **systematic and random errors** is that:

- **random errors** lead to fluctuations around the true value as a result of difficulty taking measurements,
- **systematic errors** lead to predictable and consistent departures from the true value due to problems with the calibration of your equipment.

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Measurement Error

Measurement Error is the difference between a measured quantity and its true value.

It can be estimated by compared two sets of measurements on the same population.

$$Measurement\ Error_{AGB}\ (\%) = \left|\frac{AGB_{measured} - AGB_{remeasured}}{AGB_{remeasured}}\right| \times 100$$

Source: Walker et al , 2018

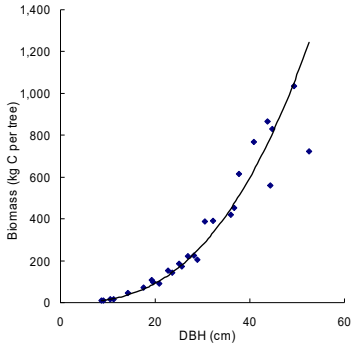
34

Model Error

Regression equations are developed specifically for a specific set of tree species within a specific DBH range.

A regression line generally does not go through all the data: approximating the data using the regression line entails some error.

Large regression errors can occur if field inventory DBH values are applied to an inappropriate regression formula for the DBH and species range.



Calculations

Exercise:

Measurement Error

- Enter the verification data collected by the independent team into the spreadsheet

Findings

- Compare your plot AGB measurement to the verified AGB measurement
- Compare and discuss your Measurement Error with other teams

Module 6 Exercise

The exercise related to Module 6 demonstrates how carbon stocks are estimated from field plot data.

Materials	Completed field data sheets Training Excel Spreadsheet Tool Field Data Tool Spreadsheet Manual

Exercise: Calculating carbon stocks in aboveground biomass

Guide	The carbon calculations are completed automatically in the spreadsheet once the field data are entered. This exercise should be completed following the delivery of presentation in Module 6.2. Participants are encouraged to explore the excel spreadsheet and the Field Data Tool Spreadsheet Manual to understand the calculations. The facilitator should walk around the room and answer any questions about the calculations. This exercise requires the facilitator to have a strong understanding of how above ground biomass estimates are calculated from the field data. The facilitator should read and understand the Field Data Tool Spreadsheet Manual.
Expected Duration	1.5 hours

Sampling Data Sheet

Plot ID#:	
Date (DD / MM / YYYY):	
Land Cover type:	
Slope (%):	

Location:	Townsville		
GPS Coordinate	_____ :	Precision:	
	_____ :	Elevation:	

Crew chief:					
Start time:		End time:		Total time (h):	

Data recorded by:			
Photo Taken (Yes/No):		# people in crew:	

Notes:

Plot

Nested plot radius (m)	small:	4		medium:	14	large:	20
Measure all trees with diameter size (cm)	small:	>=	5.0	medium:	>= 20.0	large:	>= 50.0

Live Tree Measurements

Tree #	Species	(L / C)	DBH (cm)

Tree #	Species	(L / C)	DBH (cm)

Tree #	Species	(L / C)	DBH (cm)

Sampling Data Sheet

Verification

Plot ID#:	
Date (DD / MM / YYYY):	
Land Cover type:	
Slope (%):	

Location:			
GPS Coordinate	_____ :	Precision:	
	_____ :	Elevation:	

Crew chief:			
Start time:	End time:	Total time (h):	

Data recorded by:			
Photo Taken (Yes/No):	# people in crew:		

Notes:

Plot

Nested plot radius (m)	small:	4		medium:	14	large:	20
Measure all trees with diameter size (cm)	small:	>=	5.0	medium:	>= 20.0	large:	>= 50.0

Live Tree Measurements

Tree #	Species	(L / C)	DBH (cm)

Tree #	Species	(L / C)	DBH (cm)

Tree #	Species	(L / C)	DBH (cm)

Sampling Data Sheet

Plot ID#:	

Class 2 Standing Deadwood Measurements

Diameter (cm)				Height Measurement 1				Height Measurement 2			
Base (0.1m)	DBH (1.3m)	Top	Height (m)	Clinometer angle (%)		Distance from eye to tree (m)	Height of eye (m)	Clinometer angle (%)		Distance from eye to tree (m)	Height of eye (m)
				+	-			+	-		

Lying Deadwood Measurements

Transect length (m):	

(wood greater than 10cm diameter)

Diameter (cm)	Density Class (S, I, R)	Hollow diameter (cm)

Non-Tree Vegetation (Clip Plots)

Plot dimensions:	

Sample ID #	Weight of (g)			
	bag or sheet	bag + material	subsample bag	subsample bag + subsample material

Litter Plots

Plot dimensions:	

Sample ID #	Weight of (g)			
	bag or sheet	bag + material	subsample bag	subsample bag + subsample material

Results

Plot ID#:	
Date (DD / MM / YYYY):	
Land Cover type:	

Main Plot Data

AGB

	Biomass	Biomass (t)	t d.m. / ha
small	0.00	0.00	0.00
medium	0.00	0.00	0.00
large	0.00	0.00	0.00
		Total t per ha	0.00

Carbon

	Cabon	Carbon (t)	t C / ha
small	0.00	0.00	0.00
medium	0.00	0.00	0.00
large	0.00	0.00	0.00
		Total t per ha	0.00

CO2e

	CO2e	CO2e (t)	t CO2e / ha
small	0.00	0.00	0.00
medium	0.00	0.00	0.00
large	0.00	0.00	0.00
		Total t per ha	0.00

BGB

	t CO2e / ha
Total t per ha	0.00

Verification Plot Data

AGB

	Biomass	Biomass (t)	t d.m. / ha
small	0.00	0.00	0.00
medium	0.00	0.00	0.00
large	0.00	0.00	0.00
		Total t per ha	0.00

Carbon

	Cabon	Carbon (t)	t C / ha
small	0.00	0.00	0.00
medium	0.00	0.00	0.00
large	0.00	0.00	0.00
		Total t per ha	0.00

CO2e

	CO2e	CO2e (t)	t CO2e / ha
small	0.00	0.00	0.00
medium	0.00	0.00	0.00
large	0.00	0.00	0.00
		Total t per ha	0.00

BGB

	t CO2e / ha
Total t per ha	0.00

Total (t CO2e / ha) - Mesurement Error 0%

Species Wood Density

Species	Wood Density

Field Data Tool Spreadsheet Manual

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Spreadsheet Tool Contents (Sheets)

SamplingDataSheet-LiveTree	Enter the plot data for the standing live tree data. This sheet also has all the location and field crew information. The data entered here is used to calculate the Aboveground Biomass on the Results sheet.
SamplingDataSheet-Verification	Use this sheet to add data collected for verification of the plot data collected on the LiveTree sheet. The data entered should be for the same plot as the Live Tree sheet. Use the plot location data and crew fields to record the verification team and any differences in GPS or other site specifics found by the verification team.
SamplingDataSheet-DW_NTV_LTR	This sheet is used to record the litter and deadwood carbon pool data. It is **not** used in the calculation on the Results sheet.
Results	This sheet calculates the carbon for the plot based on the data entered on the Live Tree sheet. It also estimates the measurement error based on the difference to the verification data entered on the Verification sheet.
SpeciesWoodDensity	To improve the carbon estimates the wood densities for each species can be entered in this sheet. If the species recorded in the LiveTree sheet does not match an entry on this sheet then a default wood density will be used in the calculation.
Calcs	This sheet contains all the calculations for the results sheet. It should not be edited unless the calculator defaults and plot design are being changed.

Enter location and plot information

Sampling Data Sheet

Plot ID#:		Location:			
Date (DD / MM / YYYY):		GPS Coordinate	_____ :	Precision:	
Land Cover type:					
Slope (%):			_____ :	Elevation:	
Crew chief:		Data recorded by:			
Start time:	End time:	Total time (h):	Photo Taken (Yes/No):	# people in crew:	
Notes:					

Figure 1[SamplingDataSheet-LiveTree] Plot Location

The basic plot location and field crew information is recorded in the green boxes of the spread sheet.

Consult the field manual for the required data formats and specified units to be used in these fields. Once data has been entered the cell colour will turn white.

Enter Tree Data

Live Tree Measurements

Tree #	Species	(L/C)	DBH (cm)	Tree #	Species	(L/C)	DBH (cm)	Tree #	Species	(L/C)	DBH (cm)

Figure 2[SamplingDataSheet-LiveTree] Live Tree Data

In the Live Tree sheet enter the standing live tree data collected. The “Tree #” column should be a whole number from 1 to the last tree data collected. The Species should be entered in the next column then in the next column enter a ‘L’ to indicate that the species is the local name OR a ‘C’ if it is a common name. Then in the last column enter the DBH in centimetres.

Entering Verification Plot data

Enter data from a verification team measurement of the plot on the SamplingDataSheet-Verification sheet.

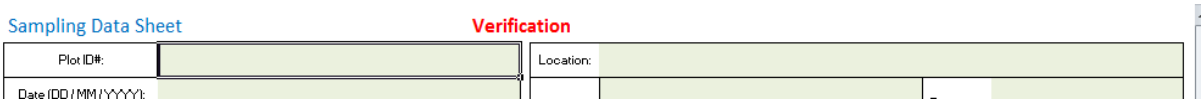


Figure 3Verification Indicator

Enter Deadwood, Non-Tree Vegetation, and Litter

Rnter the deadwood and litter data on the SamplingDataSheet-DW_NTV_LTR sheet. This information is **not** used in the calculations for the Results sheet.

The plot ID entered on this sheet should match the plot ID of the LiveTree sheet.

Figure 4[SamplingDataSheet-DW_NTV_LTR] Plot ID

When entering the sample information for the litter only enter the empty bag and sheet weight once. Only one space is provided as can be seen in the figure 5 below. The other boxes are blacked out. The one value should be used in all sample weight calculations.

Figure 5[SamplingDataSheet-DW_NTV_LTR] Sample Weights

Results

The results sheet display the plot calculations based on the Live Tree data entered. The green boxes will automatically fill in based on the values entered on the other sheet.

Results

Plot ID#:	
Date (DD / MM / YYYY):	
Land Cover type:	

Figure 6[Results] Plot Information

The results calculations for the plot are calculated for multiple units. To estimate the plot measurement error the verification plot data is used to calculate the same values and are then compared at the bottom of the spread sheet.

Main Plot Data

AGB

	Biomass	Biomass (t)	t d.m. / ha
small	0.00	0.00	0.00
medium	0.00	0.00	0.00
large	0.00	0.00	0.00
		Total t per ha	0.00

Verification Plot Data

AGB

	Biomass	Biomass (t)	t d.m. / ha
small	0.00	0.00	0.00
medium	0.00	0.00	0.00
large	0.00	0.00	0.00
		Total t per ha	0.00

Figure 7 Plot Results and Verification Plot Results

As can be seen in the Figure 7 above the main plot data and the verification plot can be compared for each subplot and unit.

Each unit calculation is displayed in a box with the unit type in blue above. As can be seen from the figure below the AGB, Carbon, CO_2e are calculated for each subplot; small, medium, and large.

Main Plot Data

AGB

	Biomass	Biomass (t)	t d.m. / ha
small	0.00	0.00	0.00
medium	0.00	0.00	0.00
large	0.00	0.00	0.00
		Total t per ha	0.00

Carbon

	Cabon	Carbon (t)	t C / ha
small	0.00	0.00	0.00
medium	0.00	0.00	0.00
large	0.00	0.00	0.00
		Total t per ha	0.00

CO2e

	CO2e	CO2e (t)	t CO2e / ha
small	0.00	0.00	0.00
medium	0.00	0.00	0.00
large	0.00	0.00	0.00
		Total t per ha	0.00

BGB

	t CO2e / ha
Total t per ha	0.00

Figure 8Plot Result Calculations

Total (t CO2e / ha)	-	Mesurement Error	0%

Figure 9Plot totals and Measurement Error

The total plot CO_2e is calculated at the bottom of the results sheet. The measurement error is also calculated using the verification data and reported as a (+/-) percentage.

To print extra field data sheets

If you need to print field sheets then print the SamplingDataSheet-LiveTree and SamplingDataSheet-DW_NTV_LTR sheet.

SamplingDataSheet-LiveTree is 2 pages. It is best printed front and back.
SamplingDataSheet-DW_NTV_LTR is only one page.

Three pdf files are also provided to print the extra pages as required.

- fielddatasheet-1b.pdf,
- fielddatasheet-1.pdf,
- fielddatasheet-2.pdf

Plot design

Plot									
	Nested plot radius (m)	small:	4		medium:	14		large:	20	
	Measure all trees with diameter size (cm)	small:	>=	5.0	medium:	>=	20.0	large:	>=	50.0

Figure 10Plot Design Display

The nested plot design is listed in a table on the LiveTree sheet. It shows the radius of the three sub plots and the tree DBH range to be collected in each plot. The diameter size listed is the lower bound of the plot and the upper bound is the diameter from the next plot size up. For example the DBH range of the small subplot is 5.0 and above to less than 20.0.

Wood Density and Species Table

To improve the carbon estimates the wood densities for each species can be entered in the Species Wood Density Sheet. If the species recorded in the LiveTree sheet does not match an entry on this sheet then a default wood density will be used in the calculation. The default and regional wood densities can be changed on the Calcs sheet. See the sections below for calculation modification.

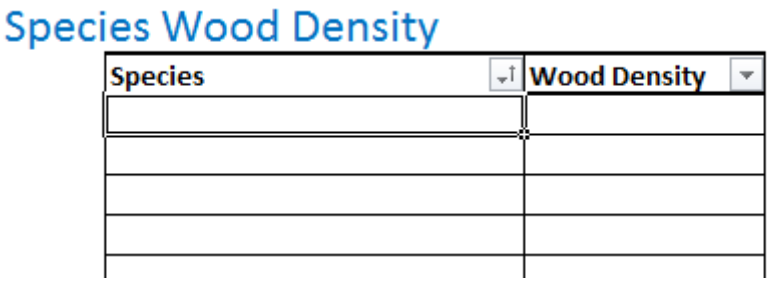


Figure 11Species and Wood Density Table

Unlocking and editing the tool

To change the sheets use the 'Unprotect' worksheet first. It does not require a password.

Formula Calculations

The formulas used in the Calcs cells bioToC, cToCo2e, unitToTone, m2ToHa, DBHtoBio, and CirlceArea are all named range formulas. These can be found in Name Manager on the Formulas tab of the ribbon.

Plot Design Changes

On the Calcs sheet all the configuration values for the calculations can be found.

Changes to the values in the green boxes changes can be made to the calculations to accommodate different regional and national systems.

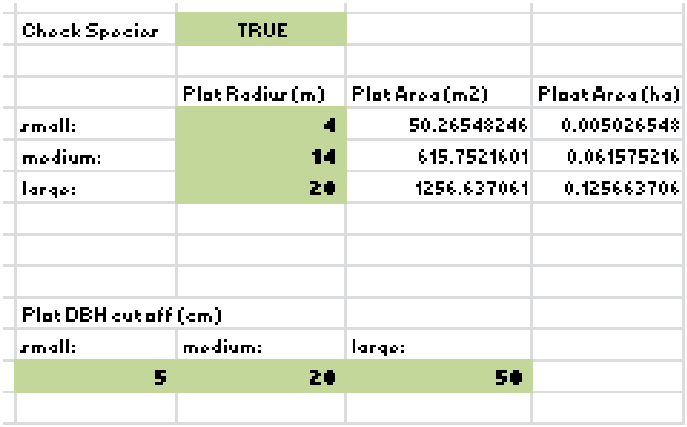


Figure 12[Calcs] Green boxes indicate where to change calculation defaults.

Nested Plot Dimensions

To change the size of the nested plots, change the values in E11, E12, and E13. The sheet will recalculate the area of each sub plot.

To change the ranges of the DBH edit the values in D19, E19, and F19. The DBH sizes form the lower and upper values of the DBH range for each sub plot. So if D19 is "5" and E19 is "20" then the first sub plot DBH range will be:

5 <= DBH Range sub plot small <50.

Plot DBH cut off (cm)		
small:	medium:	large:
5	**20**	**50**

Wood Density

To change the default wood density to another region change E37. This value is only used if the species is not found in the Species Wood Density Sheet.

Regional Default Wood Density

	Americas	0.6
	Asia	0.57
	Africa	0.5
Select Default Wood Density	Asia	0.57

AGB Root to Shoot Ratio

To change the AGB Root to Shoot Ratio to another Forest Type change F52. It can be either be Dry, Moist, or Wet.

The selected parameters are listed in the rows under the drop down box. These change as the selection changes in the drop down box.

Select the Forest Type	**Wet**			
Selected Parameters	-1.24	1.98	0.21	0.03
Selected Root Shoot Ratio	0.2	0.24		

Error Checking and Conditional Formatting

The spread sheets use colour to indicate data entry status information.

Once a field has been filled in it will change colour to white. This can be seen in the figure below.

Sampling Data Sheet

Plot ID#:	4		Location:	Townsville	
Date (DD / MM / YYYY):	10/05/2019		GPS Coordinate	S ____ : 19°15'38.0"	Precision: 3m
Land Cover type:	City			E ____ : 146°48'51.9"	Elevation: 54m
Slope (%):	0%				
Crew chief:	Tim		Data recorded by:	Tom	
Start time: 10:00	End time: 19:00	Total time (h): 9	Photo Taken (Yes/No): Yes	# people in crew: 1	
Notes: Great place to do a survey					

Figure 13Completed Fields

Indicator	Meaning
Empty Green	Fill in data
Orange border with spots	To stop the 'orange' box around species either change F8 to FALSE or enter the species into the Species Wood Density Sheet.
Dark orange	duplicate value
Warning Message	Number only in the Tree number column
Warning Message	decimal only greater than 5 in the DBH column
Warning Message	L/C only in the Local and common name column

Examples of the indicators can be seen in the figure below.

Live Tree Measurements

Tree #	Species	(L / C)	DBH (cm)
1	eucalyptus	C	50
2	Funny Tree	L	10
3	eucalyptus	C	12
3	eucalyptus	C	15

Figure 14Data Validation Colour Indication Example

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ECOSYSTEM ECOLOGY

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Abstract Tropical forests hold large stores of carbon, yet uncertainty remains regarding their quantitative contribution to the global carbon cycle. One approach to quantifying carbon biomass stores consists in inferring changes from long-term forest inventory plots. Regression models are used to convert inventory data into an estimate of aboveground biomass (AGB). We provide a critical reassessment of the quality and the robustness of these models across tropical forest types, using a large dataset of 2,410 trees ≥ 5 cm diameter, directly harvested in 27 study sites across the tropics. Proportional relationships between aboveground biomass and the product of wood density, trunk cross-sectional area, and total height are constructed. We also develop a regression model involving wood density and stem diameter only. Our models were tested for secondary and old-growth forests, for dry, moist and wet forests, for lowland and montane forests, and for mangrove forests. The most important predictors of AGB of a tree were, in decreasing order of importance, its trunk diameter, wood specific gravity, total height, and forest type (dry, moist, or wet). Overestimates prevailed, giving a bias of 0.5–6.5% when errors were averaged across all stands. Our regression models can be used reliably to predict aboveground tree biomass across a broad range of tropical forests. Because they are based on an unprecedented dataset, these models should improve the quality

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of tropical biomass estimates, and bring consensus about the contribution of the tropical forest biome and tropical deforestation to the global carbon cycle.

Keywords Biomass · Carbon · Plant allometry · Tropical forest

Introduction

The response of tropical forest ecosystems to natural or anthropogenic environmental changes is a central topic in ecology (Lugo and Brown 1986; Phillips et al. 1998; Houghton et al. 2001; Chambers et al. 2001a; Grace 2004). Long-term forest inventories are most useful in order to evaluate the magnitude of carbon fluxes between aboveground forest ecosystems and the atmosphere (Houghton 2003; Grace 2004). Guidelines have been published for setting up permanent plots, censusing trees correctly (Sheil 1995; Condit 1998), and for estimating aboveground biomass (AGB) stocks and changes from these datasets (Brown 1997; Clark et al. 2001; Phillips et al. 2002; Chave et al. 2004). However, one of the large sources of uncertainty in all estimates of carbon stocks in tropical forests is the lack of standard models for converting tree measurements to aboveground biomass estimates. Here, we directly appraise a critical step in the plot-based biomass estimation procedure, namely the conversion of plot census data into estimates of AGB.

The use of allometric regression models is a crucial step in estimating AGB, yet it is seldom directly tested (Crow 1978; Cunia 1987; Brown et al. 1989; Houghton et al. 2001; Chave et al. 2001). Because 1 ha of tropical forest may shelter as many as 300 different tree species (Oliveira and Mori 1999), one cannot use species-specific regression models, as in the temperate zone (Ter-Mikaelian and Korzukhin 1997; Shepashenko et al. 1998; Brown and Schroeder 1999). Instead, mixed species tree biomass regression models must be used. Moreover, published regression models are usually based on a small number of directly harvested trees and include very few large diameter trees, thus not well representing the forest at large. This explains why two models constructed for the same forest may yield different AGB estimates, a difference exacerbated for large trees, which imposes a great uncertainty on stand-level biomass estimates (Brown 1997; Nelson et al. 1999; Clark and Clark 2000; Houghton et al. 2001; Chave et al. 2004). Direct tree harvest data are difficult to acquire in the field, and few published studies are available. Therefore, it is often impossible to independently assess the model's quality.

A simple geometrical argument suggests that the total aboveground biomass (AGB, in kg) of a tree with diameter D should be proportional to the product of wood specific gravity (ρ, oven-dry wood over green volume), times trunk basal area ($BA = \pi D^2/4$), times total tree height (H). Hence, the following relationship should hold across forests:

$$\mathrm{AGB} = F \times \rho \times \left(\frac{\pi D^2}{4}\right) \times H \quad (1)$$

This model assumes taper does not change as trees get larger. The multiplicative coefficient F depends on tree taper only. In our measurement units (AGB, D in cm, ρ g/cm^3, H in m), Dawkins (1961) and Gray (1966) predicted a constant form factor F across broadleaf species, with $F = 0.06$ (Cannell 1984). If trees were assumed to be poles with no taper and uniform wood specific gravity, the form factor of Eq. 1 should be $F = 0.1$. If instead trees had a perfect conical shape (uniform taper), it should be $F = 0.0333$. This formula, originally developed by foresters, has seldom been used in the recent literature on the tropical carbon cycle. The first reason is that a comparison with available data shows that a relationship of the form

$$\mathrm{AGB} = F \times \left(\rho \times \left(\frac{\pi D^2}{4}\right) \times H\right)^{\beta} \quad (2)$$

with $\beta < 1$, may actually be a better model than Eq. 1 (Brown et al. 1989). The second reason is that formula 1 requires that total height be available on each tree, a variable difficult to measure in closed-canopy forests. Hence, models involving only trunk diameter are usually preferred. The most popular such models are constructed by assuming a power-law relationship between tree height and trunk diameter: $H \sim D^B$, where the symbol $\sim$ means that the two terms are proportional. Then, a model for the tree AGB may be obtained by substituting equation $H \sim D^B$ into Eq. 1:

$$\mathrm{AGB} = c\rho D^{2+B} \quad (3)$$

where c measures the taper of a mean tree. The exponent B can be derived from engineering considerations (McMahon and Kronauer 1976), and c measures the taper of a mean tree. In reality a power-law is not the best relationship for predicting height from diameter. Trees of large diameter show negative residuals, suggesting there are mechanical and/or physiological limits to height increase in large diameter trees (Niklas 1995; Midgley 2003). Hence, models slightly more complex than Eq. 2 should be used. We propose below a number of regression models constructed along the same lines, and we test their quality.

The predictive power of these models depends on how well they are validated using tree biomass data obtained directly from destructive harvest experiments. In the present work, we carry out the first among-site validation of biomass regression models with a large dataset collected at sites ranging from dry woodlands to hyperhumid closed-canopy forests, from highly seasonal to aseasonal climates, lowland to high-elevation forests, and secondary to old-growth forests. We also included two mangrove forest studies (e.g. Sherman et al. 2003).

This dataset considerably expands previous studies by including new data from Australia, Brazil, French Guiana, Guadeloupe, India, Indonesia, Malaysia, Mexico, and Venezuela. We use this database to test the generality of simple models, and ask whether common allometric patterns can be found for trees grown in different environments. We test the assumption that a single pan-tropical allometry can be used in AGB estimation procedures. Specifically, we ask to what extent the observed differences among site-derived allometries are due to the limited sample size used to construct the allometry. Our approach relies on model selection based on penalized likelihood. This enables us to construct a general procedure for estimating the AGB held in tropical forest trees.

Materials and methods

Study sites

Our analysis relies upon a compilation of tree harvest studies carried out since the 1950s. Our compilation comprises 27 published and unpublished datasets, from tropical forests in three continents: America, Asia, and Oceania (Fig. 1), for a total of 2,410 trees ≥5 cm in dbh (Table 1). Details on site geographical location, climate, altitude, successional status, and forest type, are provided in Table 1. These sites encompass a broad array of environmental conditions. We restricted ourselves to forests growing in tropical climates, and that regenerate naturally, thus excluding plantations or managed forests. Further details on these sites and datasets are available as Electronic Supplementary Materials. We further partitioned forests into young, or 'successional' (S) and 'old-growth' (OG) forests. Forests where evapotranspiration exceeds rainfall during less than a month were classified as 'wet forests'. Practically, this corresponds to high-rainfall lowland forests (rainfall greater than 3,500 mm/year and no seasonality), and montane cloud forests. Forests where evapotranspiration exceeds rainfall during more than a month (climatological average over many years), but less than 5 month were classified as 'moist forests'. These are forests with a marked dry season (one to 4 months), sometimes with a semi-deciduous canopy, and corresponding to ca. 1,500–3,500 mm/year in rainfall for lowland forests. Finally, forests with a pronounced dry season, during which the plants suffer serious water stresses, are classified as 'dry forests' (below 1,500 mm/year, over 5 months dry season).

For each harvested tree, our dataset reports biometric variables (trunk diameter at 130 cm aboveground or above buttresses, total tree height), and wood specific gravity (oven-dry weight over green volume). For identified trees that lacked a direct measurement of specific gravity, species-level, or genus-level averages were used wherever possible (see details in ''Electronic Supplementary Material''). In a few cases a site-averaged value of wood specific gravity had to be used. It was deduced from available floristic censuses in nearby plots.

Regression models

We compared a number of statistical models commonly used to estimate AGB in the forestry literature. A large number of regression models have already been published, and we only selected a limited subset of these, based on their mathematical simplicity and their applied relevance.

Biomass-diameter-height regression (model I)

Biomass regression models may include information on trunk diameter D (in cm), total tree height H (in m) and wood specific gravity ρ (in g/cm^3). Dawkins' regression model (Eq. 1) is a simple version of a more general model, first proposed by Schumacher and Hall (1933), and henceforth referred to as our *model I*:

$$\ln(\mathrm{AGB}) = \alpha + \beta_1 \ln(D) + \beta_2 \ln(H) + \beta_3 \ln(\rho) \qquad (4)$$

Indeed, if $\beta_1 = 2$, $\beta_2 = 1$, $\beta_3 = 1$, the above formula is equivalent to $\mathrm{AGB} = \exp(\alpha) \times \rho D^2 H$. We now define six versions of this model, based on additional assumptions on the parameters. Model I.1 is the full model, with all four parameter independently fitted for the different forest types. Model I.2 is like model I.1, but it assumes that the four parameters do not vary across forest types. In the remaining four models, the compound variable $\rho\ D^2\ H$ is the only predictor of AGB, like in Eqs. 1 and 2 above. The model described in Eq. 2, henceforth our model I.3, is rewritten as $\ln(\mathrm{AGB}) = \alpha + \beta_2 \ln(D^2 H \rho)$. Here, again, model I.4 is like model I.3, but it assumes that the two parameters α and β_2 do not vary across forest types. Finally, the



Fig. 1 Location of the study sites. All of the experiments were carried out in the Neotropics and in South-East Asia or Oceania. Notice the absence of study sites in Africa

Table 1 Description of the study sites included in this study. The first column provides the site label used in the text. Successional status was categorized into old growth forests (OG) and secondary forests (S). Three forest types (dry, moist, and wet) were based on potential evapotranspiration, function of rainfall and elevation. Supplementary information on the sites and on the data is provided in the Appendix

Label	Country	Site	Latitude, longitude	Max dbh	Trees, ≥5 cm	Trees, ≥10 cm	Rainfall	Altitude	Dry months	Succ status	Forest type
Australia	Australia	Darwin	12°30′S,132°00′E	52.4	133	82	1,700	20	8	OG	Dry
BraMan1	Brazil	Manaus	2°57′S, 60°12′W	120.0	315	161	2,200	100	3	OG	Moist
BraMan2	Brazil	Manaus	2°30′S, 60°00′W	38.2	123	83	2,700	100	3	S	Moist
BraMatoG	Brazil	Mato Grosso	9°52′S, 56°06′W	93.0	34	34	2,300	100	5	OG	Moist
BraPara1	Brazil	Tomé Acu, Para	2°30′S, 48°08′W	138.0	127	127	2,200	100	4	OG	Moist
BraPara2	Brazil	Jari, Para	NA	38.0	15	15	2,200	100	4	OG	Moist
BraPara3	Brazil	Belem	1°30′S, 48°30′W	55.0	21	20	3,000	20	0	S	Moist
BraRond	Brazil	Rondônia	8°45′S, 63°23′W	89.0	8	8	2,300	110	4	OG	Moist
Cambodia	Cambodia	Cheko	10°56′N, 103°2′E	133.2	72	20	3,726	20	3	OG	Wet
Colombia	Colombia	Araracuara	0°38′S, 72°22′W	98.2	52	51	3,000	200	0	OG	Wet
CostaRica	Costa Rica	La Selva	10°43′N, 83°98′W	116.0	96	92	3,824	42	0	OG	Wet
FrenchGu	French Guiana	Piste St Elie	5°20′N, 53°00′W	117.8	363	187	3,125	50	2	OG	Moist
IndiaCha	India	Uttar Pradesh	25°20′N, 83°00′E	34.7	23	23	1,200	350	7	S	Dry
IndiaKarna	India	Karnataka	12°50′N, 75°20′E	61.2	188	182	6,000	500	5	OG	Moist
Jamaica	Jamaica	J Crow Ridge	18°08′N, 76°65′W	52.4	86	55	2,335	1,572	1	OG	Wet
Kaliman1	Indonesia	Kalimantan, Balikpapan	0°40′S, 116°45′E	77.6	23	23	2,200	250	2	OG	Moist
Kaliman2	Indonesia	Kalimantan, Sebulu	1°50′S, 116°58′E	130.5	69	38	1,862	50	1	OG	Moist
Llanosec	Venezuela	Llanos secondary	7°26′N, 70°55′W	23.3	24	18	1,800	100	4	S	Moist
Llanosold	Venezuela	Llanos old-growth	7°26′N, 70°55′W	156.0	27	27	1,800	100	4	OG	Moist
Malaysia	Malaysia	Pasoh	2°98′N, 102°31′E	101.6	139	78	2,054	100	1	OG	Moist
MfrenchG	French Guiana	Cayenne	4°52′N, 52°19′W								
		Sinnamary	5°28′N, 53°00′W	42.0	29	11	3,200	0	2	OG	Moist-Mangrove
		Iracoubo	5°30′N, 53°10′W								
Mguadel	Guadeloupe	Grand Cul-De-Sac Marin	16°19′N, 61°32′W	40.7	55	41	1,800	0	4	OG	Moist-Mangrove
NewGuinea	New Guinea	Marafunga	6°00′S, 145°18′E	110.1	42	42	3,936	2,450	0	OG	Wet
PuertoRi	Puerto Rico	El Verde	18°32′N, 65°82′W	45.7	30	16	3,500	510	1	OG	Wet
Sumatra	Indonesia	Sumatra	1°29′S, 102°14′E	48.1	29	24	3,000	100	2	S	Moist
Venezuela	Venezuela	San Carlos	1°93′N, 67°05′W	67.5	41	30	3,500	120	0	OG	Wet
Yucatan	Mexico	La Pantera	20°00′N, 88°00′W	63.4	248	177	1,200	20	5	OG	Dry

model described in Eq. 1: $\ln(\mathrm{AGB}) = \alpha + \ln(D^2 H \rho)$ is our model I.5 if α varies across forest types, and I.6 if it does not. This last model provides a null hypothesis: $\beta_1 = 2$, $\beta_2 = 1$, $\beta_3 = 1$, with just one parameter (cf. Eq. 1). An alternative hypothesis, namely that AGB does not depend on wood specific gravity, was also tested ($\beta_3 = 0$). These models are written down explicitly in Table 2. Roughly, this suite of models defines a decreasing sequence of complexity, and they are compared following the approach of the model selection procedure (e.g. Burnham and Anderson 2002, Johnson and Omland 2004, Wirth et al. 2004). Both regressions and tests are implemented using linear models (lm() function of the R software, see http://www.r-project.org).

Biomass-diameter regression (model II)

Total tree height is not always available in field inventories, and it may sometimes be better not to include it in biomass estimation procedures (Williams and Schreuder 2000). A concave shaped relationship is observed when the logarithm of height, $\ln(H)$, is plotted against the logarithm of diameter, $\ln(D)$. This indicates a progressive departure from the ideal allometry during the tree's ontogeny. A polynomial model relating $\ln(H)$ and $\ln(D)$ provides a reasonable generalization of the power-law model (Niklas 1995, 1997). Assuming such a polynomial relationship between $\ln(H)$ and $\ln(D)$ together with Eq. 4, it is easy to deduce the following equation, which is our *model II*:

$$\ln(\mathrm{AGB}) = a + b\ln(D) + c(\ln(D))^2 + d(\ln(D))^3 + \beta_3 \ln(\rho) \quad (5)$$

In this model, the power-law relationship is parameterized by $c = d = 0$. As in model I, we tested six alternative hypotheses based on this model. Our model II.1 was the most complex model, with all the parameters being separately fitted for the different forest types, while model II.2 assumed that the five parameters did not depend on forest type. Model II.3 was like model II.1,

Table 2 Results of the regression analyses with model I, assuming that all four parameters depend on the type of forest, or that some of them are fixed. Only six alternative models are reported, corresponding to the most parsimonious ones

Model	Forest type	α	β_1	β_2	β_3	df	RSE	r^2	AIC
$\ln(AGB) = \alpha + \beta_1 \ln(D) + \beta_2 \ln(H) + \beta_3 \ln(\rho)$									
I.1	Dry	−2.680	1.805	1.038	0.377	312			
	Moist	−2.994	2.135	0.824	0.809	1344	0.302	0.996	818
	Wet	−2.408	2.040	0.659	0.746	139			
I.2	All types	−2.801	2.115	0.780	0.809	1,804	0.316	0.969	971
$\ln(AGB) = \alpha + \beta_2 \ln(D^2 H\rho)$									
I.3	Dry	−2.235	–	0.916	–	314			
	Moist	−3.080	–	1.007	–	1,346	0.311	0.996	913
	Wet	−2.605	–	0.940	–	141			
I.4	All types	−2.922	–	0.990	–	1,806	0.323	0.967	1,050
$\ln(AGB) = \alpha + \ln(D^2 H\rho)$									
I.5	Dry	−2.843	–	–	–	316			
	Moist	−3.027	–	–	–	1,349	0.316	0.989	972
	Wet	−3.024	–	–	–	143			
I.6	All types	−2.994	–	–	–	1,808	0.324	–	1,053

Parameters α, β_1, β_2, and β_3 are the model's fitted parameters. The best-fit parameters are reported for each model, together with the degrees of freedom (df), residual standard error (RSE), squared coefficient of regression, and Akaike Information Criterion (AIC)

and model II.4 like model II.2, but they both assumed $\beta_3 = 1$. Finally, model II.5 was like model II.3 and model II.6 like model II.4, but they both assumed no quadratic and cubic terms in Eq. 5, that is: $c = d = 0$. In all models II.1, II.3, and II.5, the parameters were independently fitted for different forest types, while in models II.2, II.4, and II.6 they were assumed constant. These models are written down explicitly in Table 4.

Model selection

To select the best statistical model we used a penalized likelihood criterion (Burnham and Anderson 2002; Johnson and Omland 2004). Specifically, we used a penalization on the number of parameters, the Akaike information criterion (AIC):

$$\mathrm{AIC} = -2\ln(L) + 2p \tag{6}$$

In this formula, L is the likelihood of the fitted model, p is the total number of parameters in the model. The best statistical model minimizes the value of AIC. As an alternative statistic, we also reported residual standard error (RSE), the standard error of the residuals. All statistical analyses were carried out with the R software package (http://www.r-project.org/). More complex regression procedures, such as weighted regression, have been proposed but they do not conclusively provide much better fits than classical regressions (Cormier et al. 1992). Various statistics for evaluating goodness-of-fit have also been advocated in the literature (reviewed in Parresol 1999), but AIC and RSE reported together provide sufficient information on the quality of a statistical fit for a mixed-species regression model. Besides goodness of fit measures, we evaluate a posteriori the performance of the regression model by measuring the deviation of the predicted versus measured total AGB at each site: $\mathrm{Error} = 100 \times (\mathrm{AGB}_{\mathrm{predict}} - \mathrm{AGB}_{\mathrm{measured}})/\mathrm{AGB}_{\mathrm{measured}}$. The mean across all sites was called the mean error (or bias, in %), and the standard deviation of *Error* across sites was the standard error (also expressed in %), and represented the overall predictive power of the regression.

Model prediction

Models I and II can, in principle, be used to estimate plant AGB, so long as their residuals are normally distributed. The log-transformation of the data entails a bias in the final biomass estimation (Baskerville 1972; Duan 1983; Parresol 1999), and uncorrected biomass estimates are theoretically expected to underestimate the real value. A simple, first order, correction for this effect consists of multiplying the estimate by the correction factor:

$$\mathrm{CF} = \exp\left(\frac{\mathrm{RSE}^2}{2}\right) \tag{7}$$

which is always a number greater than 1, and where, here again, RSE is obtained from the model regression procedure. The larger RSE is, the poorer the regression model, and the larger the correction factor. To show the tendency of the final regression model, we plotted the model's relative error against AGB, and we smoothed this plot using a lowess procedure (locally weighted scatterplot smoothing, Cleveland 1979; Nelson et al. 1999).

Results

Biomass-diameter-height regression (model I)

We tested model I for 20 sites, and 1,808 trees (Fig. 2). We tested the following explanatory variables: D, H, and ρ, forest type, successional status, and regional location. The most important predictive variables were D, H, ρ,

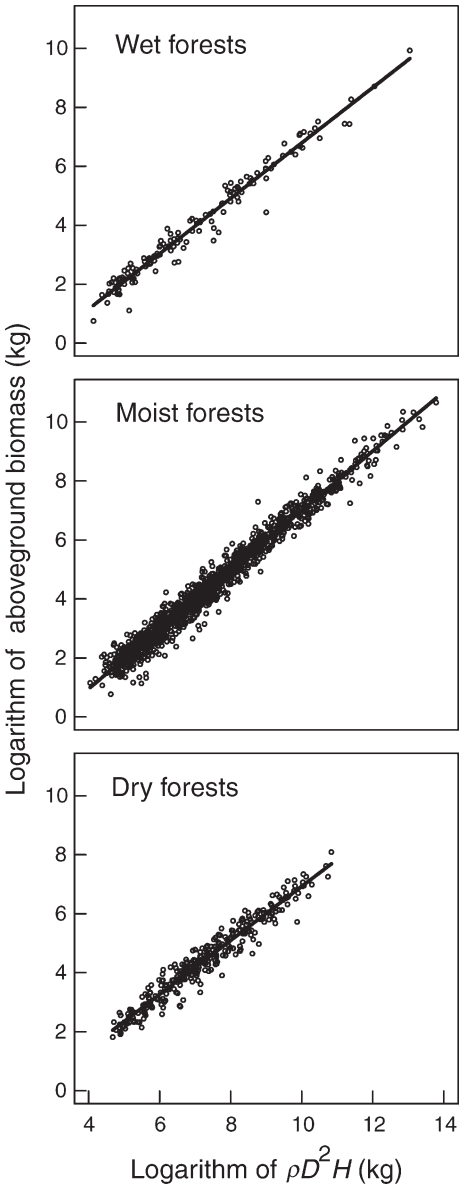


Fig. 2 Regression between the logarithm of $\rho D^2 H$ and the logarithm of aboveground biomass (AGB) for the three forest types (wet, moist and dry forests). Each dot corresponds to an individually weighed tree. The corresponding regression models are summarized in Table 2

and forest type. Including site, successional status, continent, or forest type did not improve the quality of the fit. Results for the six variants of model I are summarized in Table 2. The model including all four predictive variables performed best in all cases, but the simpler models $\ln(\mathrm{AGB}) = \alpha + \beta_2 \ln(D^2 H \rho)$, and $\ln(\mathrm{AGB}) = \alpha + \ln(D^2 H \rho)$ gave good fits. Wood specific gravity was an important predictive variable in all regressions.

To test the consistency of our model, we compared the summed AGB as measured at each site and as estimated by our regression models (Table 3). All models tended to overestimate the true biomass by 0.5–6.5% when averaged across sites. The models' predictions made an error over ±20% at five sites out of 21: BraRond, Kaliman1, Llanosol, NewGuinea, and PuertoRi. Small sample size and the presence of a few very large trees may help explain some of this overall poor performance at these sites. The model that best predicted the stand level AGB was model I.3, similar to that of Brown et al. (1989). In the case of moist forests, the predicted value for β was very close to 1, and model I.5 was chosen instead. The standard deviation of all divergences between observed and predicted stand biomass, was within 11.8–15.6%, and complex models did not produce better results than simpler ones. For trees ≥20 cm only, the models were also correct to within 15% with a bias of −1–6.2% (results not shown).

Biomass-diameter regression (model II)

Model II was tested for 27 sites, and 2,410 trees (Fig. 3). The most important predictive variables were D, ρ, and forest type. In this case, the model's predictive power was improved if mangrove forests were considered as a fourth group. Forest type was an important predictive variable, as it contributed to significantly reduce both RSE and AIC. The most parsimonious model was obtained when the parameters a and b varied with forest type, but not c and d. As for models of type I, we provided a comparison with simpler models (Table 4). Averaged across sites, the models all overestimated the true AGB by 5.5–16.4%, and the standard deviation of error was 19–30.7%, substantially larger than for models of type I (Table 5). The six models predicted site-level AGB with an error of over ±20% for 8–14 sites out of 27, depending on the model. Models that did not include forest type as a predictive variable (models II.2, II.4, and II.6) systematically overestimated the AGB of wet forest sites, sometimes by over 50%. Models that did not include higher order polynomial terms in D (models II.5 and II.6) led to the most serious overestimation in AGB, due to an overestimation of the biomass of the largest trees (results not shown).

Choice of the best predictive models

The overall best model, depending on whether total tree height H is available, was: Dry forest stands:

$$\langle AGB \rangle_{est} = \exp\left(-2.187 + 0.916 \times \ln\left(\rho D^2 H\right)\right) \equiv 0.112 \times \left(\rho D^2 H\right)^{0.916}$$

$$\langle AGB \rangle_{est} = \rho \times \exp(-0.667 + 1.784 \ln(D) + 0.207(\ln(D))^2 - 0.0281(\ln(D))^3)$$

Moist forest stands:

$$\langle AGB \rangle_{est} = \exp\left(-2.977 + \ln\left(\rho D^2 H\right)\right) \equiv 0.0509 \times \rho D^2 H$$

$$\langle AGB \rangle_{est} = \rho \times \exp(-1.499 + 2.148 \ln(D) + 0.207(\ln(D))^2 - 0.0281(\ln(D))^3)$$

Table 3 Validation of model I. Total aboveground biomass (AGB) was estimated for each of the six models summarized in Table 2 (model I.1–I.6), and the departure between estimated and measured was reported (in %)

Site	Nb trees	Total biomass	I.1	I.2	I.3	I.4	I.5	I.6
Australia	46	3240	9.66	0.76	8.81	−3.63	12.30	−3.20
BraMan1	315	147,928	10.16	6.76	9.75	7.35	7.44	11.33
BraMan2	123	13,004	−0.56	1.11	−8.70	−6.28	−8.82	−5.52
BraPara1	127	105,147	5.07	0.77	3.29	0.09	0.73	4.38
BraPara3	21	15,982	0.27	−1.96	0.42	−0.70	−1.24	2.33
BraRond	8	20,117	−25.58	−28.78	−27.18	−29.60	−29.05	−26.48
Cambodia	71	25,739	−17.20	18.10	−18.04	9.89	11.90	15.61
FrenchGu	360	138,029	−0.50	−3.63	−2.75	−4.71	−4.72	−1.27
IndiaCha	23	5,954	−4.01	6.94	−0.39	−3.69	13.56	−2.10
Kaliman1	23	44,376	27.73	21.50	26.56	22.56	23.39	27.86
Kaliman2	69	99,027	13.17	5.81	16.00	9.77	12.03	16.08
Llanosec	24	1,040	16.99	19.78	−6.11	−1.83	−5.52	−2.10
Llanosol	27	119,886	−9.84	−14.99	−22.08	−25.76	−24.54	−21.80
Malaysia	139	121,488	4.43	−0.40	5.21	1.93	2.60	6.31
MfrenchG	29	5,495	7.28	7.03	9.15	9.35	7.92	11.83
MGuadel	55	9,110	11.05	12.99	10.27	12.12	9.70	13.67
NewGuinea	42	27,640	12.84	49.21	9.46	36.67	37.11	41.65
PuertoRi	30	3,506	2.41	21.02	−0.81	12.79	11.05	14.73
Sumatra	29	9,477	6.41	5.37	−1.85	−1.72	−2.98	0.53
Yucatan	247	51,438	1.99	4.34	0.49	−0.09	18.29	1.98
Mean error			3.59	6.59	0.57	2.23	4.56	5.29
Standard error			11.85	15.63	12.82	14.58	15.21	15.26

Moist mangrove forest stands:

$$\langle AGB\rangle_{est} = \exp\left(-2.977 + \ln\left(\rho D^2 H\right)\right) \equiv 0.0509 \times \rho D^2 H$$

$$\langle AGB\rangle_{est} = \rho \times \exp(-1.349 + 1.980\ln(D) + 0.207(\ln(D))^2 - 0.0281(\ln(D))^3)$$

Wet forest stands:

$$\langle AGB\rangle_{est} = \exp\left(-2.557 + 0.940 \times \ln\left(\rho D^2 H\right)\right) \equiv 0.0776 \times \left(\rho D^2 H\right)^{0.940}$$

$$\langle AGB\rangle_{est} = \rho \times \exp(-1.239 + 1.980\ln(D) + 0.207(\ln(D))^2 - 0.0281(\ln(D))^3)$$

These equations already include the correction factor (Eq. 7). The symbol ≡ means a mathematical identity: both formulas can be used in the biomass estimation procedure. The standard error in estimating stand biomass was 12.5% if H is available, and 19.5% if H is not available. For these two models, smoothed residuals with the lowess method were plotted in Fig. 4. We found that locally, the error on the estimation of a tree's biomass was on the order of ±5%.

Discussion

AGB regression models with tree height

A number of previous studies have attempted to produce general biomass regression models for the tropics. Dawkins (1961) collected data from forests in Trinidad, Puerto Rico, and Honduras. He used 38 trees from 8 different species. He predicted that a single biomass equation, $\langle \text{AGB} \rangle_{\text{est}} \approx 0.0694\ (\rho D^2 H)$, should hold across these species. Later, Ogawa et al. (1965), contrasted results from four forests stands in Thailand, a dry monsoon forest, a mixed savanna-monsoon forest, a savanna forest, and a tropical rain forest. They found that the variable $D^2\ H$ was a suitable predictor of total tree AGB across this gradient and proposed the general equation $\langle \text{AGB} \rangle_{\text{est}} = 0.0430\ (D^2\ H)^{0.950}$ ($n = 119$). More recently, Brown et al. (1989) constructed two different models including dbh and height as predictive variables, one for moist forests ($n = 168$, RSE = 0.341), and one for wet forests ($n = 69$, RSE = 0.459). They also proposed an equation including wood specific gravity, only for moist forests ($n = 94$, RSE = 0.247). This last model had a much smaller RSE. This suggests, that including wood specific gravity leads to an important improvement for AGB estimation models, as confirmed in the present study. We should also mention Cannell's (1984) model relating stand level basal area and maximal tree height to stand level AGB. This model was validated with a large compilation of studies published across broadly variable vegetation types. Malhi et al. (2004) recently followed a strategy similar to Cannell's and developed a stand-level regression model. This approach is potentially very useful, but it also needs to be calibrated across regions with tree-level studies.

The present work generalizes these previous results in several ways. We assessed the validity of the regression model $\ln(\text{AGB}) = \alpha + \beta_1 \ln(D) + \beta_2 \ln(H) + \beta_3 \ln(\rho)$ across a number of different forests, and asked whether a single model could be used across all sites. Based on criteria of goodness of fit and of parsimony, we selected a regression model using the compound variable $\rho\ D^2\ H$

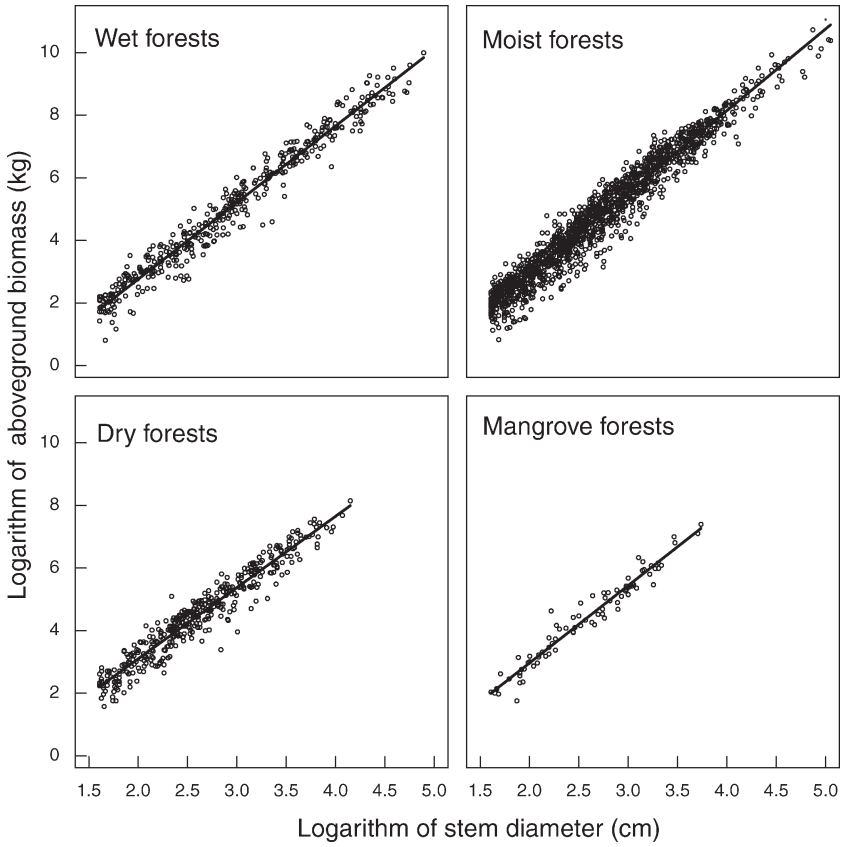


Fig. 3 Regression between the logarithm of D and the logarithm AGB for the four forest types (wet, moist, dry, and mangrove forests). *Each dot* corresponds to an individually weighed tree. The corresponding regression models are summarized in Table 4

as a single predictor. The goodness of fit of our model was measured by the residual standard error of the fit (RSE), and by a penalized likelihood criterion (AIC). This model estimated accurately the AGB at most sites, although they encompassed dry, moist, and wet forests, lowland and montane forests, and secondary and old-growth forests. Hence, provided that diameter, total height and wood specific gravity of a tree are available, its AGB is easily estimated, irrespective of the tree species and of the stand location. We emphasize that the site name was not a significant factor in the linear model. This shows that there was no detectable investigator's effect in our dataset (see Wirth et al. 2004 for a related discussion).

Table 4 Results of the regression analyses with model II, assuming that all five parameters depend on the type of forest, or that some of them are fixed

Model	Forest type	a	b	c	d	β_3	df	RSE	r^2	AIC
$\ln(AGB) = a + b\ln(D) + c(\ln(D))^2 + d(\ln(D))^3 + \beta_3 \ln(\rho)$										
II.1	Dry	−1.023	1.821	0.198	−0.0272	0.388	401			
	Moist	−1.576	2.179			1.036	1,501	0.353	0.995	1,837
	Wet	−1.362	2.013			0.956	415			
	Mangrove	−1.265	2.009			1.700	81			
II.2	All types	−1.602	2.266	0.136	−0.0206	0.809	2,405	0.377	0.958	2,145
$\ln(AGB) = a + b\ln(D) + c(\ln(D))^2 + d(\ln(D))^3 + \ln(\rho)$										
II.3	Dry	−0.730	1.784	0.207	−0.0281	–	402			
	Moist	−1.562	2.148			–	1,502	0.356	0.996	1,869
	Wet	−1.302	1.980			–	416			
	Mangrove	−1.412	1.980			–	82			
II.4	All types	−1.589	2.284	0.129	−0.0197	–	2,408	0.377	0.958	2,146
$\ln(AGB) = a + b\ln(D) + \ln(\rho)$										
II.5	Dry	−1.083	2.266	–	–	–	402			
	Moist	−1.864	2.608	–	–	–	1,502	0.357	0.996	1,883
	Wet	−1.554	2.420	–	–	–	416			
	Mangrove	−1.786	2.471				82			
II.6	All types	−1.667	2.510	–	–	–	2,408	0.378	0.957	2,159

Parameters a, b, c, d, and β_3 are the model's fitted parameters. The best fit parameters are reported for each model, together with the degrees of freedom (df), residual standard error (RSE), squared coefficient of regression, and Akaike Information Criterion (AIC)

Table 5 Validation of model II. Total AGB was estimated for each of the six models summarized in Table 4 (model II.1 to II.6), and the departure between estimated and measured was reported (in %)

Site	Nb trees	Total biomass	II.1	II.2	II.3	II.4	II.5	II.6
Australia	133	26847	0.57	1.41	1.58	33.61	2.81	34.69
BraMan1	315	147928	18.39	22.99	17.26	−1.43	25.10	5.96
BraMan2	123	13004	20.70	17.63	21.37	10.83	18.88	12.62
BraMatoG	34	26158	34.89	38.38	34.23	13.46	40.49	20.70
BraPara1	127	105147	4.98	14.64	4.10	−13.19	16.55	−2.77
BraPara2	15	5741	−18.41	−21.11	−18.67	−28.20	−19.97	−27.48
BraPara3	21	15982	5.15	2.25	4.45	−10.24	3.88	−8.80
BraRond	8	20117	−23.94	−18.18	−24.55	−37.94	−16.83	−31.01
Cambodia	71	25739	−24.37	−10.56	−25.30	−0.39	−10.70	24.66
Colombia	52	136122	−28.18	−25.52	−28.76	−8.81	−25.52	0.61
CostaRica	96	177466	17.33	24.18	16.32	50.17	24.18	69.06
FrenchGu	362	138048	1.78	6.25	1.25	−14.57	7.87	−7.69
IndiaCha	23	5954	32.62	31.67	34.66	72.51	34.21	71.31
IndiaKarna	188	125855	14.67	10.22	13.44	−1.31	12.17	−0.95
Jamaica	86	6109	52.89	48.35	51.58	78.94	47.94	82.24
Kaliman1	23	44376	8.48	13.24	8.24	−10.61	14.85	−2.97
Kaliman2	69	99027	−5.55	11.80	−6.81	−24.76	13.90	−9.30
Llanosec	24	1040	21.05	22.03	24.48	16.22	22.14	22.02
Llanosol	27	119886	−11.89	14.27	−11.73	−29.38	15.60	−7.52
Malaysia	139	121488	−7.81	−3.36	−8.36	−23.87	−1.84	−17.28
MfrenchG	29	5495	−12.34	26.48	−12.74	16.23	−11.60	15.65
MGuadel	55	9110	9.88	51.80	9.21	43.39	9.46	41.94
NewGuinea	42	27640	8.67	12.06	6.70	35.25	11.08	50.35
PuertoRi	30	3506	17.72	13.67	16.81	39.60	13.47	42.00
Sumatra	29	9477	21.80	19.21	22.22	6.36	20.60	8.81
Venezuela	41	27379	−0.90	−2.65	−0.92	22.46	−2.11	26.44
Yucatan	248	51937	−1.26	−0.28	−1.17	29.42	0.11	30.72
Mean error			5.81	11.88	5.51	9.77	9.88	16.44
Standard error			19.28	19.05	19.48	30.67	17.66	29.46

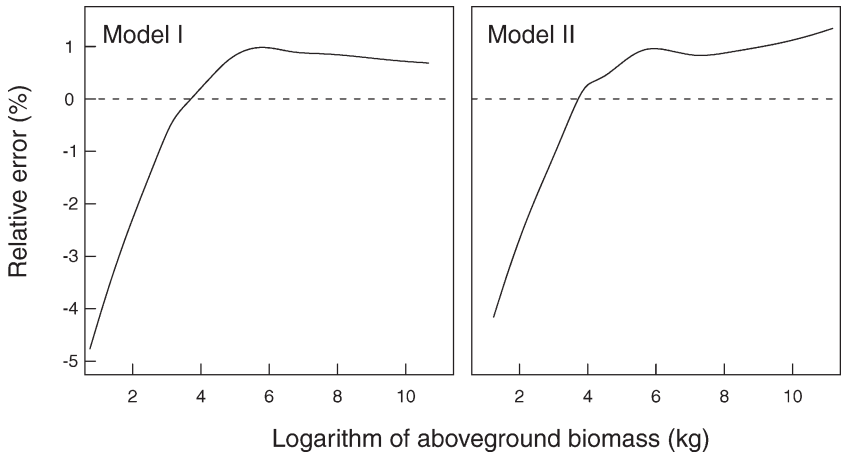


Fig. 4 Structure of the residuals (percent difference between real and predicted biomass for individual trees) plotted against the logarithm of predicted AGB, smoothed by a lowess method. *Left panel* shows results of the best type I model including ρ, D, and H as predictors and coefficients tailored to four forest types; *right panel* corresponds to the best type II model, which includes ρ, and D as predictors and coefficients by forest type

The simplest predictive model was: $\langle AGB \rangle_{est} = 0.0509 \times \rho\ D^2\ H$ (model I.6). We did not select this model because our statistical analyses showed that this model should depend on forest type. Yet, it is interesting to discuss this very simple model in detail. According to our result, the form factor F in Eq. 1 should be equal to 0.0648, close to the predictions of Dawkins (1961) and Gray (1966) for broadleaf tree species. Engineering arguments (MacMahon and Kronauer 1976) suggest that trees taper as a power law along the main stem: that is, trunk diameter at height z should be $D_z = D_0\ (1-z/H)^{\gamma}$. The exponent γ characterizes the stem shape, being 0 in the case of a pole, and 1 in the case of a perfectly conical stem. It is a simple matter of calculus to show that F and γ are related through $F = 0.1/(2\gamma+1)$, and that for our model, $\gamma = 0.271$. This result should be compared to the area-preserving branching hypothesis of West et al. (1999), which would amount to setting $\gamma = 0$ (no taper), and to ignoring structural considerations. Our regressions were not improved by the inclusion of a cross-continent variation. Thus, we have shown that tree allometry is

conserved across sites on different continents. These sites typically contained no species in common, thus this character is highly conserved across the phylogeny of self-supporting woody plants. Plant form is strongly selected, as photosynthetic production should be allocated optimally into construction features. It would be important to further test this model for temperate broadleaf trees. Published single-species regression models suggest that this is indeed the case (Tritton and Hornbeck 1982).

AGB regression models without tree height

Tree height measurements are often difficult to make because treetops are hidden by the canopy layer. Also, historical tree inventories are very valuable in ecological research, but they may not have recorded tree height. For these various reasons, it has often been claimed that it was better to simply use the trunk diameter as a predictive variable for the AGB (cf. for instance Ter-Mikaelian and Khozurkhin 1997, and references therein, however see Wirth et al. 2004 for different conclusions). Here, we show that the situation is more complex for the tropical forest biome, where mixed-species regression models should be used, than the temperate forest biome, where single species models are used. The best predictive models were forest type-dependent. Also, as previously noted by Chambers et al. (2001b), AGB does not follow a simple power-law scaling relation with stem diameter alone. The 'universal' power-law allometry proposed by West et al. (1999) considerably overestimates the mass of the largest trees. The polynomial terms in our model II, although yielding only small improvements in the goodness of fit measures (RSE and AIC), enable us to offset the overestimation observed with West et al.'s (1999) power-law model.

This departure from ideal power-law allometry can be interpreted as follows. The largest trees in an old-growth moist tropical forest can be older than 100–200 years (indeed some trees have been ^{14}C dated over 1,000 years, Chambers et al. 1998). These trees tend to be smaller and lighter than predicted by the ideal model because throughout life span they have been subject to the 'forces of nature', that often cause them to develop hollow trunks and/or lose large branches. Further, contrary to understory trees, canopy trees have no incentive to outgrow but continue to increase their crown size to maximize light interception.

On finding the 'best' statistical model

A considerable amount of literature has sought to find the 'best' biomass regression model for mixed-species forests (c.f. Brown et al. 1989; Shepashenko et al. 1998), or for single-species forests (c.f. Wirth et al. 2004). Most of these studies constructed complex models, with many fitted parameters, in order to minimize the goodness of fit measures. However, the principle of parsimony stipulates that the quality of a fit should depend on the model complexity, as measured by the number of parameters in the models (Burnham and Anderson 2002). To account for this principle, we selected only two sets of nested models (I and II) based on their mathematical simplicity, and discussed the performance of these models using the AIC as a selection criterion. However, it is important to realize that no simple statistical procedure permits to unambiguously decide which model is the best in the case of complex, inhomogeneous datasets (Burnham and Anderson 2002). Our dataset is almost certainly not free of measurement error, and it is not homogeneous either, being a collection of independent studies led by different investigators, and collected during a time span of over 40 years. These limitations usually tend to favor complex models over simple ones: simple model may be incorrectly rejected. Therefore, we do not exclude that more parsimonious models than the ones we recommend here, may in fact predict correctly the AGB of tropical trees. Our models represent a consensus among many studies, and the current state of knowledge; further field work should be carried out for improving their quality and their regional coverage.

Among type II models, the simplest relationship is II.6: $\ln(AGB) = a + \ln(\rho) + b\ln(D)$, with a and b constant across forest types. However, not only was this model a poor fit of the data (RSE = 0.378), it also poorly estimated the aboveground stand biomass of over 50% of the sites. That the model parameters should vary across forests is easily interpretable, because forest types with similar diametric structure may vary considerably in canopy height.

During the validation procedure, the predicted total aboveground stand biomass differed by over 20% from the measured value in several sites. Most of these sites had less than 30 trees, and in such small samples, only a few trees may bias the overall prediction. Our models tend to overestimate the AGB by 0–5%. Several authors have already noticed that such models tend to overestimate aboveground biomass (Magdewick and Satoo 1975). We believe that this overestimation cannot be offset without explicitly accounting for the log-transform correction factor $CF = \exp(RSE^2/2)$ (Saldarriaga et al. 1988). Indeed, a regression model should account for as many known sources of bias as possible, even if they result in a slightly worse fit. We therefore included this correction term in our final statistical model. Duan (1983) suggested an even better correction procedure for back-transforming the data (see Wirth et al. 2004). This could be another way of improving the models reported here.

Recommendations for measuring AGB in tropical forest stands

The motivation for this study was to provide consensus mixed-species AGB regression models for a broad range

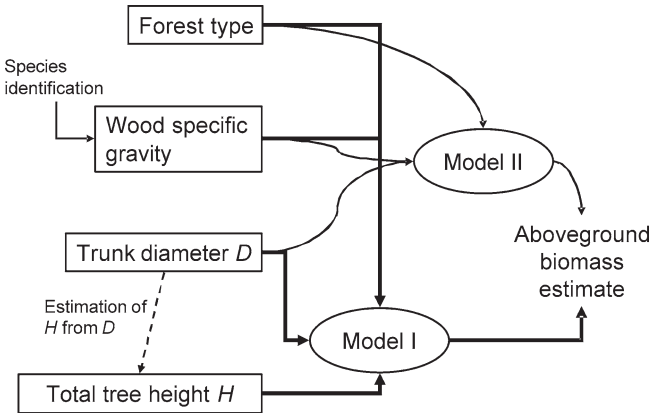


Fig. 5 Estimation of the AGB of tropical trees. Predicting variables are forest type, wood specific gravity, trunk diameter and total tree height. Models I and II differ in that Model II does not assume any knowledge of total tree height. Wood specific gravity may be estimated from species-specific literature values

of forest types, and to reduce the likelihood of estimation errors due to the use of improper models. Here, we focused only on total AGB. Models for belowground biomass estimation can be found in Cairns et al. (1997). It should also be mentioned that most studies are concerned with evaluating forest carbon pools, not biomass pools. It has traditionally been assumed that the carbon content of dry biomass of a tree was 50% (Brown and Lugo 1982; Roy et al. 2001; Malhi et al. 2004), however it should be emphasized that wood carbon fraction may exhibit some small across species variation (Elias and Potvin 2003).

The general method for estimating AGB from tropical forest stands and for assessing error in these protocols is described in Chave et al. (2004), and Fig. 5 summarizes the necessary information for this procedure. We assume here that the forest plots have been correctly designed, are large enough, and the tree diameters are measured accurately (above buttresses, if necessary). Depending on the data available, one of the two models presented above should be used. If D, H, and ρ are available for each tree, then the model using $\rho D^2 H$ as a predictive compound variable should be used (three different models for dry, moist, or wet forest types). If total tree height is missing, then a model using ρ and D as predictive variables should be used instead, with four different models for dry, moist, mangrove, or wet forest types. The AGB estimate should be accompanied by an estimation of the error due to both data measurement and model uncertainty (Cunia 1987; Chave et al. 2004). The error due to the measurement of dbh, height, or wood density can be factored in just one error term (Chave et al. 2004, Appendix A). The standard deviation measuring the error due to the regression model is given by $\sqrt{CF^2 - 1} \times \langle AGB \rangle$, where CF is the correction factor and $\langle AGB \rangle$ is the AGB estimate (Parresol 1999; Chave et al. 2004).

Wood specific gravity is an important predictive variable in all of these models. Its importance may not be obvious if one is interested in estimating the biomass in an old-growth forest dominated by hardwood species, spanning a narrow range of wood densities. However, Baker et al. (2004) have shown that ignoring variations in wood density should result in poor overall prediction of the stand AGB. Direct wood density measurements are seldom available for the trees in permanent forest stands. It is recommended to use a species-level average (Brown et al. 1989; Nelson et al. 1999; Chave et al. 2003), or, if detailed floristic information is unavailable, a stand-level average (Baker et al. 2004). Compilations of species-specific wood specific gravity are being made available to facilitate this procedure (Reyes et al. 1992; Wood Density database http://www.worldagroforestry.org/sea/Products/AFDbases/WD; J. Chave et al. in preparation).

The use of tree height as a predictive variable also improved the quality of the model. However, this variable is usually not available for censused trees. While models ignoring total tree height should be applicable in most forests, caution should be exerted when using them. For instance, the wet forest equation II.3 predicted a very large AGB stock for the montane forest at Blue Mountains, Jamaica (see Table 5). This forest is regularly impacted by hurricanes and is dominated by short trees. In this case, height is a crucial variable, and ignoring it would result in an overestimation of the forest AGB. The alternative solution is to construct a stand-specific diameter-height allometry between dbh and total height to estimate the total height of each tree in permanent plots (Ogawa et al. 1965; Brown et al 1989). The estimated tree height could in turn be used in the biomass regression model I.3 (cf. Fig. 5) although this of course will increase the regression error in the biomass estimate.

Regression models should not be used beyond their range of validity. The models proposed here are valid in the range 5–156 cm for D, and 50–1,000,000 for $\rho D^2 H$. We stress that in the models presented here, D should be measured in centimeter, H in meter, and ρ in grams per cubic meter. The resulting AGB estimated from the equation is then in kilograms. Moreover, ρ should represent an oven dry mass (103°C) divided by green volume, not an air-dry wood density. Finally, these equations should in principle only be used for broadleaf tree species, and different models should hold for conifers, palms, and lianas. We are hoping that these will improve the quality of tropical biomass estimates, and bring consensus regarding the contribution of this biome to the global carbon cycle.

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Improved allometric models to estimate the aboveground biomass of tropical trees

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Abstract

Terrestrial carbon stock mapping is important for the successful implementation of climate change mitigation policies. Its accuracy depends on the availability of reliable allometric models to infer oven-dry aboveground biomass of trees from census data. The degree of uncertainty associated with previously published pantropical aboveground biomass allometries is large. We analyzed a global database of directly harvested trees at 58 sites, spanning a wide range of climatic conditions and vegetation types (4004 trees ≥ 5 cm trunk diameter). When trunk diameter, total tree height, and wood specific gravity were included in the aboveground biomass model as covariates, a single model was found to hold across tropical vegetation types, with no detectable effect of region or environmental factors. The mean percent bias and variance of this model was only slightly higher than that of locally fitted models. Wood specific gravity was an important predictor of aboveground biomass, especially when including a much broader range of vegetation types than previous studies. The generic tree diameter–height relationship depended linearly on a bioclimatic stress variable *E*, which compounds indices of temperature variability, precipitation variability, and drought intensity. For cases in which total tree height is unavailable for aboveground biomass estimation, a pantropical model incorporating wood density, trunk diameter, and the variable *E* outperformed previously published models without height. However, to minimize bias, the development of locally derived diameter–height relationships is advised whenever possible. Both new allometric models should contribute to improve the accuracy of biomass assessment protocols in tropical vegetation types, and to advancing our understanding of architectural and evolutionary constraints on woody plant development.

Keywords: carbon, forest inventory, global carbon cycling, plant allometry, tree height, tropics

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Introduction

Over the past two decades, tropical land-use change, especially deforestation and forest degradation, has accounted for 12–20% of global anthropogenic greenhouse gas (GHG) emissions (Harris *et al*., 2012; le Quéré *et al*., 2012). Economic incentives to favor carbon sequestration in forests have been devised, commonly referred to as REDD (Reducing Emissions from Deforestation and Forest Degradation; Miles & Kapos,

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2008; Agrawal *et al*., 2011). Aside from the serious political challenge in establishing a global mechanism to fund climate change mitigation activities (Fearnside, 2012; Tirole, 2012; Tulyasuwan *et al*., 2012), its implementation critically depends on reliable ground-based monitoring, reporting, and verification (MRV) protocols of carbon storage. In the future, carbon MRV protocols will be increasingly based on remote-sensing techniques, yet their calibration will still rely on the accuracy of ground-based carbon storage estimation (Asner *et al*., 2010; Saatchi *et al*., 2011; le Toan *et al*., 2011; Baccini *et al*., 2012; Clark & Kellner, 2012). In tree-dominated ecosystems, the stock of aboveground biomass (henceforth denoted AGB; in kg of oven-dry matter) held in vegetation is usually inferred from ground census data. Tree biometric measurements are converted into biomass values using an empirical allometric model (Brown, 1997). However, the quality of these allometric models represents one of the most important limitations in assessing AGB stocks (Chave *et al*., 2004; Skole *et al*., 2011; Clark & Kellner, 2012; Baccini & Asner, 2013). The goal of this contribution is to describe a new generation of pantropical tree allometric models and to evaluate the uncertainty associated to them.

The development and testing of biomass allometric models depend on the availability of direct destructive harvest data, which are enormously time-consuming and expensive to acquire. Previously published studies have made progress toward addressing this problem. Brown (1997) proposed a scheme where different allometric models should be used depending on vegetation type and on the availability of total tree height information. As a compromise between environmental variation and data availability at the time, Brown (1997) proposed a classification of tropical forests into three forest types, dry, moist, and wet, following the Holdridge life zone system (Holdridge, 1967; Brown & Lugo, 1982). This seminal study was restricted to a few destructive harvest datasets. Chave *et al*. (2005) included many more datasets and a consistent statistical scheme of model selection. The Chave *et al*. (2005) models represented a major step forward in tropical forest carbon accounting, and they are currently being proposed for inclusion in the IPCC Emission Factor Database also used by REDD protocols.

However, one major issue with the Chave *et al*. (2005) allometries relates to the importance of direct tree height measurements in AGB stock estimation. If total tree height is available, allometric models usually yield less biased estimates. However, tree height has often been ignored in carbon-accounting programs because measuring tree height accurately is difficult in closed-canopy forests (Hunter *et al*., 2013; Larjavaara & Muller-Landau, 2013). Whether or not to include tree height as a predictor of AGB has generated serious controversies in the global change community (Baccini *et al*., 2012; Harris *et al*., 2012; Baccini & Asner, 2013). Better calibration and analysis of tropical tree allometric equations are needed to avoid mismatches of otherwise convergent studies, whether from plot inventory or plot-inventory-calibrated remote sensing. Second, the Chave *et al*. (2005) models may lead to biased AGB stock estimates in some undersampled vegetation types. Over the past few years, numerous new tree harvest datasets have been produced, notably in Africa (Djomo *et al*., 2010; Henry *et al*., 2010; Ebuy *et al*., 2011; Ryan *et al*., 2011; Fayolle *et al*., 2013; Mugasha *et al*., 2013a), in dry forests and open woodlands (Nogueira *et al*., 2008a; Vieilledent *et al*., 2012; Colgan *et al*., 2013), and in previously undersampled regions in South America (Martinez-Yrizar *et al*., 1992; Alvarez *et al*., 2012; Lima *et al*., 2012; Goodman *et al*., 2014).

Here, we analyze a globally distributed database of direct-harvest tree experiments in tropical forests, subtropical forests, and woodland savannas. Our dataset includes 53 undisturbed vegetation and five secondary forest sites spanning a wide range of vegetation types, for a total of 4004 trees with trunk diameter ranging from 5 to 212 cm. We address the following questions: (i) What is the best pantropical AGB model incorporating wood specific gravity, trunk diameter, and total height? (ii) How does our pantropical AGB model compare in performance with locally fitted AGB models? (iii) If only diameter and wood specific gravity (and not total tree height) are available, does the inclusion of environmental variables improve AGB estimation?

Materials and methods

Site locations and climates

The destructive harvest dataset assembled for the present study was distributed across the tropics and across vegetation types (Fig. 1). Local climatic information was extracted from global gridded climatologies, which interpolate data from available meteorological stations (New *et al*., 2002; Hijmans *et al*., 2005). Temperature and rainfall variables were acquired from the WorldClim database (Hijmans *et al*., 2005), which reports gridded mean climate values from the 1950–2000 period. We downloaded the dataset at 2.5 arc min resolution, or about 5 km spatial resolution along the equator (http://www.worldclim.org/current). This product includes elevation as available from a digital elevation model produced by NASA's Shuttle Radar Topography Mission at ca. 90 m spatial resolution (Farr *et al*., 2007). Because water stress is important in predicting the shape of local allometric equations, we also extracted monthly values of reference evapotranspiration (ET), as computed by the FAO Penman–Monteith equation (Allen *et al*., 1998) at a 10 arc min resolution from a mean

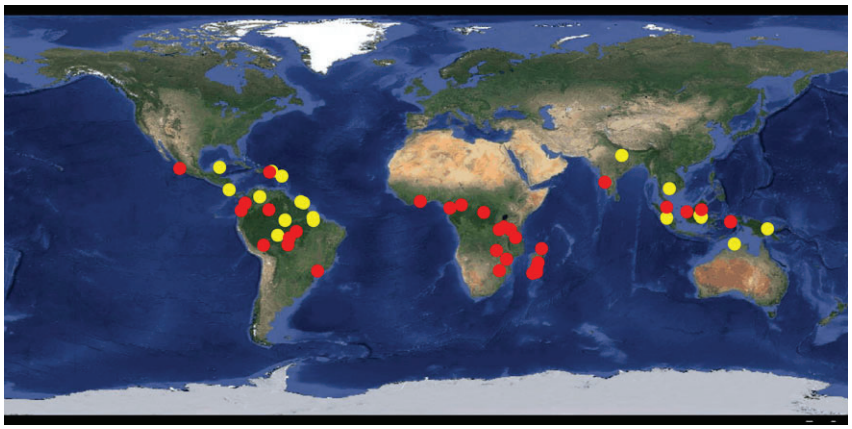


Fig. 1 Geographical locations of the study sites. Yellow circles indicate 20 studies included in Chave *et al.* (2005); red circles indicate 38 sites added to the present study. (Color in the online version)

monthly climatology developed by the Climate Research Unit (New *et al.*, 2002) over the 1960–1990 period (downloaded from http://www.fao.org/geonetwork/srv/en/ on 21 November 2012).

Preliminary analyses led us to focus on three bioclimatic variables: temperature seasonality, the maximum climatological water deficit, and precipitation seasonality. Temperature seasonality (TS), is the standard deviation (SD) of the monthly mean temperature over a year, expressed in degrees Celsius multiplied by 100. Temperature seasonality increases polewards from the equator, and also increases with altitude. The maximum climatological water deficit (CWD) is computed by summing the difference between monthly rainfall P_i and monthly evapotranspiration ET_i only when this difference is negative (water deficit): $CWD = \sum_{i=1}^{12} \mathrm{Min}(0, P_i - ET_i)$. This definition differs slightly from that of Aragão *et al.* (2007) and Malhi *et al.* (2009) because in this study, we assume that CWD is caused by a single drought season. Also, we used the Climate Research Unit dataset value for ET instead of assuming a constant ET of 100 mm month^{-1}, because ET shows strong patterns of geographical variation even in the tropics (Jung *et al.*, 2010; Wang & Dickinson, 2012). A global gridded layer of CWD at 2.5 arc sec resolution is available at http://chave.ups-tlse.fr/pantropical_allometry.htm. Finally, precipitation seasonality (PS) is the coefficient of variation in monthly rainfall values, or the SD expressed in percent of the mean value.

To explore whether the sites included in the database were representative of the environmental conditions of tropical woody vegetation, we compared them with sites selected at random. We defined as tropical woody vegetation sites between the two tropics with at least 50% of canopy cover in the FAO forest-cover map (included in the Food Insecurity, Poverty and Environment Global GIS Database, Huddleston *et al.*, 2006). We randomly selected ca. 80 000 locations that fit the above criteria. For these locations, we extracted climate variables to define a realized range of climate values across tropical woody vegetation. We then graphically compared the distribution of environmental conditions at the study sites with the distribution observed over all selected sites. The result of this analysis is reported in Figure S1.

Harvest dataset compilation

We compiled tree harvest studies that had been carried out in old-growth or secondary woody vegetation, excluding plantations and agroforestry systems. The rationale for this choice is that the natural variability in plant allometry tends to be minimized in plantations. We considered only studies in which fieldwork was conducted by experienced ecologists or foresters.

To be included in the compilation, the following measurements had to be available for each tree: trunk diameter D (cm), total tree height H (m), wood specific gravity ρ (g cm^{-3}), and total oven-dry AGB (kg). We excluded trees with $D < 5$ cm because such trees hold a small fraction of AGB in forests and woodlands (Chidumayo, 2002; fig. 3), and would otherwise dominate the signal in regression models. The common practice for measuring D is to measure trunk diameter at 130 cm aboveground (diameter at breast height). Buttressed or irregular-shaped trees are measured above buttresses or trunk deformities. It was impossible to confirm that this convention had been followed, especially for the older datasets (e.g. Hozumi *et al.*, 1969), but the trunk diameter size structure was carefully checked and the retained datasets were those without obvious diameter measurement error. Measuring total height accurately may also be an issue in closed-canopy forests (Hunter *et al.*, 2013; Larjavaara & Muller-Landau, 2013). The compiled studies usually did not report how tree height was measured. However, it is likely that more effort was put into measuring tree height correctly in destructive harvest experiments than in nondestructive forest surveys.

Each tree was felled at ground level, and different sections were weighed fresh or their fresh volume measured. The fresh wood weight was then converted into oven-dry weight by directly measuring the moisture content in the different parts of the plant. In the largest trees, it was usually not practical to weigh the entire individual, so wood volume was often inferred from geometrical considerations (see e.g. Henry *et al.*, 2010; Fayolle *et al.*, 2013), and wood volume was converted into oven-dry weight by multiplying the volume by the wood specific gravity (Chave *et al.*, 2009; Williamson & Wiemann, 2010).

In many studies, the mass of the main stem (merchantable bole before the first branching), branches, and leaves were measured separately. In seasonally dry forests, it was often difficult to measure leaf biomass because of deciduousness, but leaf biomass usually contributes less than 5% of total AGB (Delitti *et al.*, 2006). Thus, we analyze only total oven-dry above ground biomass (the sum of the above ground biomass compartments).

Our dataset includes 58 study sites, from published and unpublished sources, for a total of 4004 individually harvested trees (see Data S2). The previous compilation, reported in Chave *et al.* (2005), included 20 study sites and 1481 individually harvested trees for which trunk diameter, total tree height, AGB, and wood specific gravity were all available. A few studies were removed from the Chave *et al.* (2005) compilation because the criteria for inclusion chosen here were more stringent (see Data S3). Sites included in this database comprise the first destructive harvest experiments reported from the Afro-tropical realm (n = 1429, including Madagascar), data from Latin America (n = 1794), and from Southeast Asia and Australia (n = 781). This also includes many new sites from woodlands and dry tropical forest types, both in Africa and Latin America. This compilation was carried out between 2008 and 2013. In a recent article, Feldpausch *et al.* (2012) published a reanalysis of the Chave *et al.* (2005) dataset, to which they added six datasets (349 trees). Of these additional datasets, we retained five in the present compilation. Because we also removed and corrected some data from Chave *et al.* (2005), the dataset analyzed here is more conservative than that of Feldpausch *et al.* (2012), but is also more than twice as large.

Wood specific gravity (here defined as the oven-dry wood mass divided by its green volume, and denoted ρ) is an important predictor of stand-level AGB (Baker *et al.*, 2004). In the field, green volume was measured from freshly cut wood samples. The samples were subsequently weighed after having been left in a drying oven until constant weight is reached. However, it should be acknowledged that even direct ρ measurement is prone to error (for a comprehensive review, see Williamson & Wiemann, 2010), and not all individuals had ρ directly measured in the field. The alternative is to assume that the ρ of a tree is equal to its species-mean value. The majority of the trees in our dataset were identified to species (81%). Taxonomic information was carefully checked for consistency (Boyle *et al.*, 2013). In case of inconsistencies, the most likely name was selected. In a few cases, trees were identified using a vernacular name, and we attempted to assign them to the most precise relevant taxonomic level, often to genus, based on expert knowledge. For those trees lacking direct ρ measurement but identified taxonomically, we extracted the species-mean from the comprehensive global wood density database (Chave *et al.*, 2009; Zanne *et al.*, 2009). In that database, wood specific gravity values are typically means across several individuals of the same species, and measurements were conducted in highly qualified wood science laboratories. In total, ρ was directly measured for 59% of the trees, and species-mean ρ was assumed for an additional 26% of the trees. For the remaining 15% of the trees, we assumed genus-mean (13%) or family mean (2%) wood specific gravity values as computed from the global database.

To test a possible bias in the selection of ρ from global compilations, we compared the values obtained directly from field values and from the global database for a total of 1194 trees. Because the errors are expected to be of the same magnitude in both variables, we used a reduced major axis regression and found that database values explained 67% of the variance in the field values, and the slope of the regression was of 0.993, very close to the expected slope of 1. Thus, we conclude that assigning species-mean wood specific gravity values to the trees of our database may introduce random errors but did not bias the analyses.

The tree harvest database used in the present study is available at http://chave.ups-tlse.fr/pantropical_allometry.htm.

Statistical analyses

Estimating AGB when tree height is available. Allometric model construction is based on regressing a dependent variable (i.e. AGB), against one or several independent variables. The possible independent variables included here were trunk diameter D (cm), wood specific gravity ρ (g cm^{-3}), total tree height H (m), or a combination thereof. We fitted the following log-log model relating AGB to the compound variable $\rho \times D^2 \times H$.

$$\ln(\mathrm{AGB}) = \alpha + \beta \ln(\rho \times D^2 \times H) + \varepsilon \quad (1)$$

where α and β are model coefficients (derived from least-squares regression), ε is an error term, which we assume to be normally distributed with zero mean and SD σ [i.e. the random variables are identically independently distributed with a distribution N (0, σ^2)]. If a model such as Model 1 has p parameters, σ is defined by

$$\sigma = \sqrt{\frac{1}{N-p}\sum_{i=1}^{N}\varepsilon_i^2}$$

where N is the sample size. In the statistical literature, σ is also called residual standard error or RSE. Technically, the above formula is the residual maximum likelihood estimate for σ, and it may be shown to be unbiased (Harville, 1977). If $\beta = 1$, an isometric relationship exists between AGB and $\rho D^2 H$. In a likelihood-based framework, testing the hypothesis that $\beta = 1$ may be implemented by comparing the Akaike Information Criterion (AIC) of Model 1 with the nested model ln (AGB) = α + ln ($\rho \times D^2 \times H$) + ε. The AIC is a measure of the goodness-of-fit that penalizes parameter-rich models, as required by the principle of parsimony (Burnham & Anderson, 2002).

Model 1 may be used to infer the value of AGB for an individually measured tree. The estimated value $\mathrm{AGB}_{\mathrm{est}}$ can be written as:

$$\begin{aligned}\mathrm{AGB}_{\mathrm{est}} &= \overline{\exp[\alpha + \beta \ln(\rho D^2 H) + \varepsilon]} \\ &= \overline{\exp[\varepsilon]} \times \exp[\alpha + \beta \ln(\rho D^2 H)]\end{aligned}$$

where $\overline{\exp[\varepsilon]} = \int \exp(\varepsilon) N(\varepsilon) d\varepsilon$ and $N(\varepsilon)$ is the distribution of errors [assumed to be a normal distribution, N(0, σ^2)]. As first shown by Baskerville (1972), a simple algebraic manipulation

yields $\overline{\exp[\varepsilon]} = \exp(\sigma^2/2)$. From this it follows that Model 1 may be used to give an unbiased estimate of AGB using the following equation:

$$\mathrm{AGB}_{\mathrm{est}} = \exp[\sigma^2/2 + \alpha + \beta \ln(\rho D^2 H)] \quad (2)$$

Improvements to this formula are possible, especially accounting for the fact that the estimator of σ itself has uncertainty (Shen & Zhu, 2008). Recently, Clifford *et al.* (2013) have reviewed this issue and provided routines to implement corrections. We also tested this approach using our dataset. However, as our sample size is large, we found that applying the correction of Shen & Zhu (2008) to our data yielded AGB estimates within 0.5% of the values obtained with the Baskerville correction [Eqn (2)]. We therefore decided to retain the simpler [Eqn (2)] for the present study.

While the importance of trunk diameter in inferring AGB has been acknowledged since the development of tropical forestry (Dawkins, 1961; Ogawa *et al.*, 1965), the importance of ρ as a predictor of AGB has been debated only recently. Wood specific gravity varies greatly within individuals (Patiño *et al.*, 2009) and existing pantropical wood specific gravity compilations are incomplete (Clark & Kellner, 2012). Therefore, it has been argued that ρ may not be a useful variable in AGB estimation (Lima *et al.*, 2012). To test this hypothesis, we conducted a comparison of Model 1 with a similar model, but from which wood specific gravity was excluded, namely $\ln(\mathrm{AGB}) = \alpha + \beta \ln(D^2 \times H) + \varepsilon$. We asked whether this alternative model yields a goodness-of-fit comparable to that of Model 1, as evaluated by AIC.

For each of the 58 sites, we calculated measures of average systematic error (bias) and of total tree-level coefficient of variation (CV). As in Chave *et al.* (2005), the bias at individual sites was evaluated by comparing the empirical mean AGB at site j B_{obs} (j) to the estimated value B_{est} (j). The model bias was defined as follows:

$$\mathrm{Bias}(j) = [B_{\mathrm{est}}(j) - B_{\mathrm{obs}}(j)]/B_{\mathrm{obs}}(j)$$

To measure total error, including random error, we also computed the tree-level coefficient of variation in AGB for site j defined as

$$\mathrm{RSE}(j) = \sqrt{\frac{1}{N_j - p}\sum_{i\in[j]}[\mathrm{AGB}_{\mathrm{est}}(i,j) - \mathrm{AGB}_{\mathrm{obs}}(i,j)]^2}$$

$$\mathrm{MAGB}(j) = \frac{1}{N_j}\sum_{i\in[j]}\mathrm{AGB}_{\mathrm{obs}}(i,j),$$

$$\mathrm{CV}(j) = \frac{\mathrm{RSE}(j)}{\mathrm{MAGB}(j)}$$

as in Colgan *et al.* (2013). $\mathrm{AGB}_{\mathrm{obs}}$ (i, j) is the observed AGB of tree i belonging to site j, and $\mathrm{AGB}_{\mathrm{est}}$ (i, j) is the estimated AGB value for the same tree. The first equation defines the residual standard error (RSE), the second defines the mean AGB at site j MAGB(j). Then, CV(j) is simply defined as the ratio of these two terms. CV(j) measures the typical relative error at site j that should be expected in the estimate of a single tree. A large value of CV(j) would be acceptable so long as the bias is low, because in general the model is applied to many trees within a site and thus random errors will tend to cancel.

The tree-level coefficient of variation (CV) and the bias were used to compare the performance of the model summarized in Model 1 with that of alternative models. We performed the analysis in three stages. First, at each study site we fitted Model 1 using all study sites except that of the focal site. We then computed the CV and the bias of the focal site with this model, ensuring that the calibration and validation datasets are independent. Second, we tested the hypothesis that local models perform significantly better than pantropical models. To this end, we constructed a local allometry excluding all study sites but the focal one, again using Model 1. We then computed the CV(j) and Bias(j) of the focal site based on the local model. We expect that the local models will have lower bias and variance (hence smaller CVs). However for local models (but not for the pantropical model), the same dataset is used to calibrate the model and to compute errors (validation stage). Thirdly, we repeated the same procedure as in stage 1, but using the predictor variable $D^2 \times H$ instead of $\rho \times D^2 \times H$ to test the hypothesis that wood density is an important predictor of AGB. We again compared the performance of the two models based on the CV and bias at each study site.

Estimating AGB when tree height is unavailable. When tree height is unavailable to estimate AGB, the inference is thought to be less accurate, and allometric equations are more likely to vary across vegetation types, as diameter–height allometry depends on environmental conditions. Pantropical or regional allometric equations to predict AGB based on only D and ρ have been developed previously (Brown, 1997; Ketterings *et al.*, 2001; Chave *et al.*, 2005; Feldpausch *et al.*, 2012), but here we provide a simpler framework. We seek a general model relating total tree height to trunk diameter and bioclimatic variables. We selected the relevant bioclimatic variables using a forward model selection approach where all possible combinations of bioclimatic variables were compared. If such a model does exist, then it should be possible to infer height from trunk diameter at each site. Here, we propose the following functional form:

$$\ln(H) = a + a' \times E + b \times \ln(D) + c \times \ln(D)^2 + \varepsilon' \quad (3)$$

The quadratic dependence of $\ln(H)$ on $\ln(D)$ was implicitly assumed in previous studies (Chambers *et al.*, 2001; Chave *et al.*, 2005), but to our knowledge it has never been tested directly as a diameter–height equation. In Eqn (3), E denotes an environmental variable, and model error is described by the SD of the residuals denoted σ' to avoid confusion with the σ of Model 1. More general models may be constructed similarly, assuming that all of the model parameters depend on E, but we here privileged the simplicity and consistency of the present approach. To select the environmental variable E, we performed a forward selection by sequentially including the bioclimatic variables that led to the greatest decline in model RSE.

Once total tree height has been estimated from Eqn (3), Eqn (1) can be used to estimate AGB even for trees without field measurements of H. Further, the mathematical form of

the resulting AGB model is equivalent to that proposed in Chambers *et al.* (2001) and used by Chave *et al.* (2005). More precisely, using Eqn (3) to express ln(H) as a function of ln(D) and using this estimate in Eqn (1), yields a new pantropical allometric model

$$\mathrm{AGB_{est}} = \exp\left[\frac{\sigma^2}{2} + \beta^2\frac{\sigma'^2}{2} + \alpha + \beta\ln(\rho D^2) + \beta\{\ln(\mathrm{H})\}_{\mathrm{est}}\right]$$

where $\{ln(H)\}_{\mathrm{est}} = a + a' \times E + b \times ln(D) + c \times ln(D)^2$ is obtained directly from Eqn (3), and depends explicitly on the local bioclimatic variable E. We also compared the performance of Eqn (3) with the height equations proposed by Feldpausch *et al.* (2012).

Because of the quadratic form of Eqn (3), it would be theoretically possible that for large values of D, H would decrease when D increases. We therefore tested whether this regime was likely to be reached empirically. The function reaches a maximum at $D = \exp[-b/(2c)]$, and we verified that this maximum is never reached in practical applications.

All statistical analyses were performed with the R statistical software (R Development Core Team, version 3.0.3).

Results

When we regressed tree AGB (kg) against the product $\rho \times D^2 \times H$, we found the best-fit pantropical model to be:

$$\mathrm{AGB_{est}} = 0.0673 \times (\rho D^2 H)^{0.976} \quad (\sigma = 0.357, \mathrm{AIC} = 3130, \mathrm{df} = 4002) \qquad (4)$$

where D is in cm, H is in m, and ρ is in g cm^{-3}. This model performed well across forest types and bioclimatic conditions (Figures S2 and S3). The alternative model where the exponent was constrained to one:

$$\mathrm{AGB_{est}} = 0.0559 \times (\rho D^2 H) \quad (\sigma = 0.361, \mathrm{AIC} = 3211, \mathrm{df} = 4003) \qquad (5)$$

gave a slightly poorer performance (greater σ and AIC). Model 4 tends to underestimate AGB by 20% for individual trees with observed AGB exceeding 30 Mg (n = 14; Fig. 2). The trend disappeared for trees in the range 10–30 Mg (2.7% overestimation, n = 94). Because of the spread of values for $\rho D^2 H$, we did not find suitable models to accommodate this bias.

In comparison to Model 4, the best-fit model excluding wood specific gravity as a predictor had an AIC = 3983 and σ = 0.418, which are significantly poorer than Model 4. Thus, we conclude that wood specific gravity is an important predictor of AGB, especially when a broad range of vegetation types is considered.

Compared with local models, average total tree-level prediction error was only modestly higher in the pantropical model (Fig. 3a), but the spread of systematic error across sites was more than three times higher

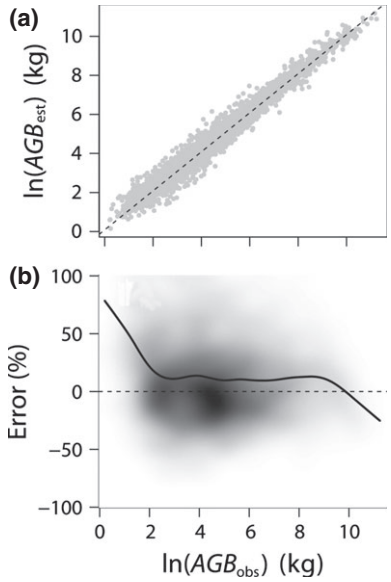


Fig. 2 Goodness-of-fit for Model 4. (a) AGB as estimated from the model vs. observed AGB (n = 4004, gray points), compared with the 1 : 1 line (dashed line). (b) Relative error (estimated minus observed AGB, divided by observed AGB, in%); the thick black line represents a spline regression of the data points, illustrating a slight negative bias at large AGB values (values >30 Mg). The background represents data-point density.

(Fig. 3b). The mean of CV(j) across sites was 56.5% using the pantropical allometric Model 4 vs. 47.4% using the local allometric models. The mean bias was +5.31% across all sites for Model 4, vs. +0.38% for the locally developed models. The pantropical model tended to substantially overestimate the measured total, site-level AGB at seven sites (bias > 30%) and underestimate it (bias< −30%) at one site (Fig. 3b). This bias was not explained by vegetation type or by bioclimatic conditions (Figures S2 and S3). The site-mean form factor (AGB divided by $\rho \times D^2 \times H$) displayed a trend with forest type and bioclimatic factors, but this trend was significant only with CWD (climatic water deficit, R^2 = 0.17, P = 0.02, Figure S4).

To compare more directly the influence of vegetation type and site on Model 4, we also conducted a nested analysis of variance on the relative residuals $100 \times \frac{\mathrm{AGB_{est}} - \mathrm{AGB_{obs}}}{\mathrm{AGB_{obs}}}$. The vegetation type factor explained 0.6% of the relative residual variance, the site factor explained 21.4%, and the within site variation explained 78%. Thus, most of the residual variation in the dataset was among trees within sites. Model 4 was plotted for each site in Data S2.

For cases in which total tree height is unavailable, we developed a diameter–height allometric equation of the form of Eqn (3). Using forward selection (see Methods), we found that among-site variation in diameter–height

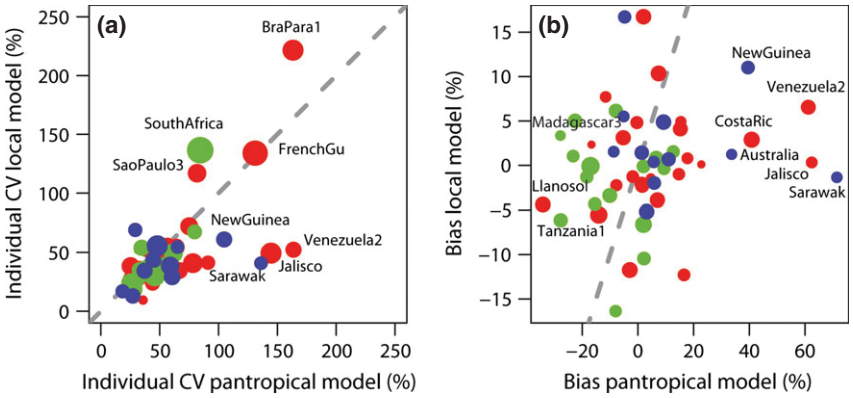


Fig. 3 Comparison of model performance between the pantropical allometric AGB Model 4 and local allometric models. (a) Individual coefficient of variation at each site for both types of allometries. Point size is proportional to sample size, red dots indicate Latin American sites, green African sites, and blue Southeast Asian and Australian sites. Outlying sites are labeled (sites such that CV >100% in any one direction). (b) Individual bias at each site for both types of allometries. Point color as in Panel (a), point size proportional to total AGB at the site. In color in the online version. Outlying sites – sites such that the absolute value of the bias exceeds 30% – have been labeled. (Color in the online version)

allometries was best explained by TS (temperature seasonality), CWD (climatic water deficit), and PS (precipitation seasonality), with only small further declines in model RSE with the sequential inclusion of additional bioclimatic variables (Figure S5). We thus propose the following pantropical diameter–height allometric model

$$\ln(H) = 0.893 - E + 0.760\ln(D) - 0.0340[\ln(D)]^2 \quad (6a)$$

(AIC = 47, RSE = 0.243, df = 3998), where E is defined as

$$E = (0.178 \times \mathrm{TS} - 0.938 \times \mathrm{CWD} - 6.61 \times \mathrm{PS}) \times 10^{-3} \quad (6b)$$

Equation (6b) has an intuitive interpretation. E is a measure of environmental stress. Indeed, E increases with temperature seasonality, which relates to the amount of time a plant is exposed to stressful temperature, and CWD (a negative quantity) increases in magnitude with increasing annualized water stress. The dependence of E on PS (precipitation seasonality) is less obvious but appears to be mostly driven by monsoon-dominated rainfall regime (Nemani *et al.*, 2003). The dependence of diameter–height allometry on E is illustrated in Fig. 4. A global gridded layer of E at 2.5 arc sec resolution is available at http://chave.ups-tlse.fr/pantropical_allometry.htm. Equation (6a) predicts that the log-transform of tree height for a given diameter declines with both water and temperature stress. We also verified that the functional form of Eqn (3) is biologically consistent: for all E, the quadratic function in $\ln(D)$ reaches a maximum that far exceeds biologically realistic values for D. Combining Eqns (4) and (6a) directly, AGB can be inferred in the absence of height measurements (RSE = 0.431, df = 3999). Here, we prefer to fit the data directly, yielding the following model:

$$\mathrm{AGB}_{\mathrm{est}} = \exp[-1.803 - 0.976E + 0.976\ln(\rho) + 2.673\ln(D) - 0.0299[\ln(D)]^2] \quad (7)$$

which yields a slightly lower RSE (AIC = 4293, σ = 0.413, df = 3999). The mean CV across sites and the bias were 71.5% and 9.71%, respectively. We therefore propose Model 7 for estimating AGB in the absence of height measurements. The performance of Model 7 was clearly worse than Model 4, as observed from a comparison of the AIC, and as would be expected (Model 7 vs. Model 4; CV: 71.5% vs. 56.5%; bias: 9.71% vs. 5.31%;

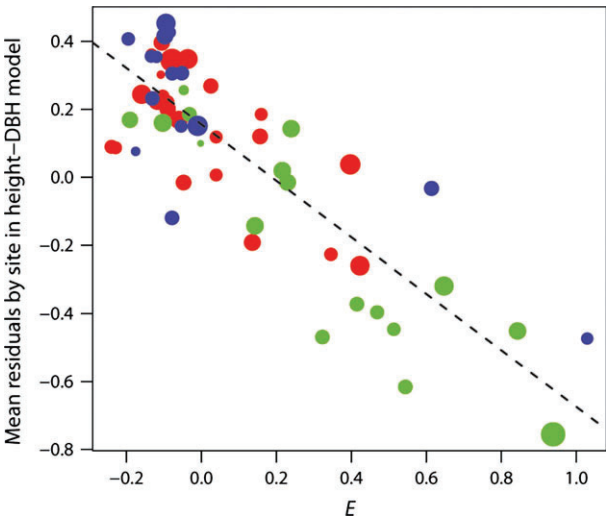


Fig. 4 Dependence of the diameter–height model on the environmental variable [E; Eqn (6b)]. Point color and size are as in Fig. 3. (Color in the online version)

Fig. 5a, b). We also verified that if the regional diameter–height models of Feldpausch *et al.* (2012) had been used instead of Model 6a, the bias would have been much larger (mean bias: +22.41%; Figure S6).

Finally, we compared the performance of the models proposed in this study with that developed in Chave *et al.* (2005). Model 4 predicted results very similar to those obtained with Model I.3 of Chave *et al.* (2005). Across our sites, the mean CV(*j*) of Model I.3 was 56.2%, and the mean bias was −2.24%, and these values were similar to that obtained for Model 4. When tree height is unavailable, Chave *et al.* (2005) proposed model II.3. The mean CV(*j*) of Model II.2 was 80.5%, and the mean bias was +5.78%. Although it is simpler, our new Model 7 thus performed much better than the Chave *et al.* (2005) models.

Discussion

On estimating AGB when tree height is available

We here propose a single allometric equation to estimate tree AGB across vegetation types when wood specific gravity, trunk diameter, and total tree height are available (Model 4). Most of the variation was found within vegetation types, and the apparent variation among vegetation types appears to mostly reflect small sample sizes. This interpretation is supported by the fact that the form factor (ratio of AGB divided by $\rho D^2 H$) varies weakly across vegetation types (Figure S4). This convergence of tropical tree biomass allometries across biomes and continents is striking. The causes of variation in trunk tapering coefficient have been studied in depth (Dawkins, 1961; Niklas, 1994; Chave *et al.*, 2005), but the form factor depends also on the size and shape of the crown. One possible interpretation of our finding is that although trunk taper varies consistently across vegetation types, biomechanical design both of the hydraulic plant system and of the organism strongly constrains the overall architecture of self-supporting plants.

It is useful to contrast this result with the previous analysis of Chave *et al.* (2005). Here, we greatly increased the sampling effort in both dry and wet vegetation types. In the 2005 analysis, only three dry forest sites where tree height was measured were included to form the basis of the dry forest equation (Australia: 46 trees, Yucatan: 175 trees, IndiaCha: 23 trees). In comparison, the present study includes 22 dry vegetation sites, and 1891 trees. Likewise, Chave *et al.* (2005) included only three wet forest sites having height data (NewGuinea: 42 trees, PuertoRi: 30 trees, Cambodia: 72 trees), while the present analysis now includes 12 wet forest sites and 681 trees.

Although our dataset represents a significant improvement over previously published intercomparisons of tree harvest data, they are still limited in size, especially compared with those developed for temperate forests (Chojnacky *et al.*, 2014) or plantations (Paul *et al.*, 2013). One option for assembling whole-tree AGB measurements without harvesting the tree is to use terrestrial LiDAR to estimate the volume of individual branches and stems (Hildebrandt & Iost, 2012). With additional wood specific gravity measurements, it should be possible to estimate tree AGB to a good accuracy without felling the tree. This approach should accelerate the acquisition of tree biometric data.

Based on the data now available, it appears that separate regression parameters for the dry, moist, and wet vegetation types do not improve the statistical performance of the model. Our analysis thus suggests that it is more parsimonious to retain a single allometric

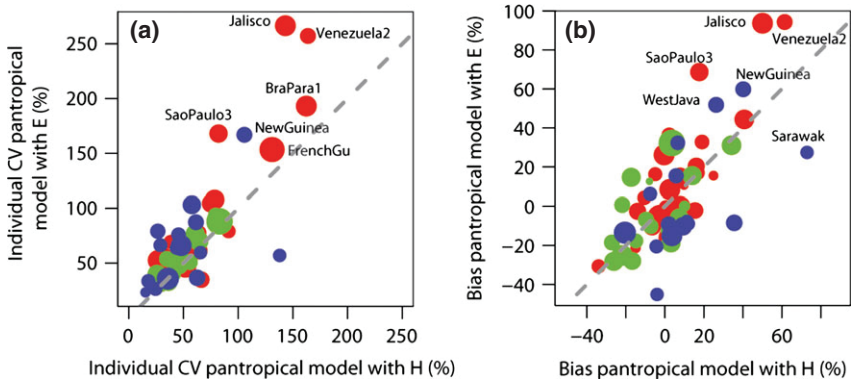


Fig. 5 Comparison between the pantropical allometric AGB Model 7 and pantropical allometric AGB Model 4. Panel (a) Individual coefficient of variation at each site for both types of allometries. Outlying sites are labeled (sites with an individual CV >150%). Panel (b) Comparison of the bias between Model 7 and Model 4. Point color and size are as in Fig. 3. Outlying sites are labeled (sites with an absolute bias >50%). (Color in the online version)

model. Previously published estimates for moist forests using Chave *et al.* (2005)'s Model I.3 are very close to estimates obtained using Model 4, as may be evidenced in Table 1. This is important because most of the tropical forest carbon sequestration occurs in moist tropical forests and the corresponding Chave *et al.* (2005) allometry has been used frequently in the published literature (see e.g. Asner *et al.*, 2010 and the related discussion in Skole *et al.*, 2011). Thus, it is likely that the present equation will not drastically change AGB stock estimates for moist tropical forests. We also note that this new model holds for both old-growth and secondary vegetation types.

The previous classification of harvest experiments into forest types was based on the sparse bioclimatic information available at the time, and possible inconsistency in climatic measurements, which led to a misclassification of some of the sites. For instance, the Cambodia dataset is a forest close to the current locality of Thma Sa in the Kingdom of Cambodia. It was previously classified as ever-wet forest because annual rainfall exceeds 3300 mm yr^{-1}. However, it is a monsoonal climatic regime (ET exceeds rainfall during 6 months of the year and CWD is less than -400 mm yr^{-1}); thus, this site was now reclassified as dry forest for comparison with previous studies. This illustrates the importance of accurate estimates of bioclimatic variables, and of relying on quantitative climatic metrics, rather than on an *a priori* classification into vegetation types. Because global climatic compilations have greatly improved over the past decade (Hijmans *et al.*, 2005), it is now possible to obtain far better bioclimatic descriptors at ecological study sites than the ones derived from the Holdridge life zone system.

In a recent study, Goodman *et al.* (2014) emphasized that pantropical allometric models may underestimate the AGB of very large trees in areas where trees are shorter but have large crowns. We did detect a departure between observations and predictions for individual trees with an AGB greater than 30 Mg. For these very large trees, Model 4 underestimated AGB by an average of 20% (note that this bias vanishes for trees in the range 10–30 Mg). This is an issue given that these large trees may contribute a large fraction of the AGB stock in a tropical forest stand. However, we here suggest that sampling bias in the harvest dataset may also in part explain this pattern. Because harvesting very large trees is a laborious endeavor, we hypothesize that well-formed boles may have been preferentially selected over partly broken, or senescent large trees, especially when the study was conducted in relation to logging activity (as is the case for the Cameroon3 site, which includes eight of the 14 trees with AGB $\geq$ 30 Mg in our dataset). We therefore believe that the discrepancy of our model in these extreme values of AGB should not necessarily be interpreted as a failure of the model. In a recent essay, Clark & Kellner (2012) provided a constructive critique of current strategies for AGB model development, and they suggest that harvested trees are probably never selected at random, and that poorly conformed trees are seldom included in analyses. Models with few parameters are robust to biases generated by individual harvest datasets, and they are therefore an advantage in this situation.

It has often been argued that local allometric equations should be constructed in as many sites and for as many species as possible. In the same line of reasoning, many authors have contended that previous pantropical AGB allometries could not be used in Africa because no African site had been included in previous efforts for constructing pantropical AGB models (Chave *et al.*, 2005). However, our results show that once variation in diameter–height allometries are accounted for, pantropical AGB allometries are

Table 1 Estimation of the AGB (kg) when tree height is available, for trees of typical dimensions and for the four largest trees in the dataset. Four models are used: the three models called Model I.3 in table 2 of Chave *et al.* (2005), and Model 4 of the present study. The last four lines represent the parameters of trees in the dataset reported to have measured *AGB* over 50 Mg. Their measured *AGBs* are 51.7 Mg (*Cyclodiscus gabunensis* (Taub.) Harms), 60.5 Mg (*Entandrophragma cylindricum* (Sprague) Sprague), 70.2 Mg (*Tieghemella heckelii* (A.Chev), Pierre, ex Dubard), and 76.1 Mg (*Dipteryx micrantha* Harms), respectively

Trunk diameter (cm)	Height (m)	Wood specific gravity (g cm^{-3})	Model I.3 dry forests	Model I.3 moist forests	Model I.3 wet forests	This study model 4
10	9	0.7	41	32	33	36
30	25	0.6	680	687	592	723
70	40	0.6	4940	5986	4529	5980
100	45	0.5	8950	11 453	8335	11 265
136	48.5	0.78	25 302	35 615	24 215	34 092
178	52.4	0.57	33 364	48 169	32 162	45 776
180	61	0.62	42 274	62 371	41 005	58 906
158	44.1	0.83	32 310	46 510	31 120	44 237

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consistent across sites. To quantify this claim, we compared error metrics between our pantropical equation and locally fitted equations. The pantropical approach was based on the estimation of two parameters (Model 4), while the local approach required the estimation of two parameters per site, i.e. 116 parameters in total. We found that the AGB of single trees was estimated to within 56.5% of the mean using the pantropical model and to within 47.4% of the mean with local allometric models (coefficient of variation; Fig. 3a). Thus, local allometric models do not perform much better than pantropical models in terms of model uncertainty: in both cases, the error in estimation of AGB for any single tree is on the order of 50% of the mean. Mean bias across sites was higher for the pantropical equation, averaging +5.31% vs. +0.38%. However, this is in part a simple consequence of the fact that, in the local case, fitting and evaluation are performed on exactly the same dataset. Indeed, if we measured bias as mean deviations in ln(AGB), then we would have zero bias for the local models by the very nature of the model fitting procedure, which minimizes the sum of squared errors in ln (AGB). Because we measure bias instead as the mean error in AGB, the local models have nonzero bias, but this bias is still inherently small.

Much of the increase in bias between the local and the pantropical allometries was contributed by six outlying sites (three moist forests and three wet forests; Fig. 3b). For these outlying sites, Model 4 tends to overestimate AGB. A number of interpretations could be put forward to explain this discrepancy. The dimensions of wet forest trees are difficult to measure because many trees are buttressed. Yet the majority of wet forest sites comply with the pantropical model (eight of 11). Also, methodological inconsistencies with the other studies included in the present compilation cannot be excluded. However, as several of these studies were conducted decades ago (NewGuinea, Venezuela2, Jalisco), it would be difficult to trace back such inconsistencies, if any. Thus, it is important to continue generating primary data with careful quality control/quality assurance procedures.

Tree-level uncertainty in AGB estimation from our model is about of 50% the mean, thus individual-tree AGB cannot be estimated precisely with any such model. However, assuming an average of 500 trees with $D \geq 10$ cm per ha, then the plot-based uncertainty in AGB can be computed as follows. If, as previously, we denote $AGB_{est}(i)$ the estimated value of AGB for tree i, and the SD for this tree $\sigma(i)$, then $\sigma(i) = CV \times AGB_{est}(i)$, and CV = 50%. A simple calculation shows that plot-based uncertainty, CV_{plot} is such that

$$CV_{plot} = CV \times \frac{\sqrt{\Sigma_i [AGB_{est}(i)]^2}}{\Sigma_i AGB_{est}(i)} \quad (8)$$

where the sum runs over all the trees in the plot. Computing this for typical AGB distributions shows that plot-level uncertainty due to the allometric equation drops to ca. 10–15% for a ¼ ha plot and ca. 5–10% for a 1 ha plot. This plot-based uncertainty is larger than expected from a simple averaging because a few large trees contribute disproportionately to stand-level AGB (Chave *et al.*, 2004). However, even accounting for these terms, model-based uncertainty is typically less than 10% of the mean at the 1 ha scale, and the equation for CV_{plot} allows to compute this uncertainty for any plot.

On inferring tree height from trunk diameter and bioclimatic variables

A large body of literature in forestry suggests that the diameter–height relations in trees depend on a range of physiological and environmental factors (Ryan & Yoder, 1997; Falster & Westoby, 2005; Ryan *et al.*, 2006; Niklas, 2007; Kempes *et al.*, 2011; Mugasha *et al.*, 2013a,b). These include climatic conditions (Wang *et al.*, 2006; Nogueira *et al.*, 2008b; Lines *et al.*, 2012) and altitude (Grubb, 1977; Aiba & Kitayama, 1999; Lines *et al.*, 2012; Marshall *et al.*, 2012), but also local edaphic factors (Aiba & Kitayama, 1999; Kempes *et al.*, 2011), evolutionary and architectural constraints (King, 1990; Niklas, 1994; Falster & Westoby, 2005; Goodman *et al.*, 2014), and competition for space (Henry & Aarssen, 1999). For instance, Lines *et al.* (2012) showed that in temperature- and/or water-stressed environments, tree height is typically much smaller than expected under a purely mechanical model, confirming the primary role of hydraulics in regulating the height of trees at a given trunk diameter (see also Kempes *et al.*, 2011).

Recently, Feldpausch *et al.* (2011) conducted a pantropical analysis of diameter–height tree allometries and concluded that regional variation in this allometry was an important source of variation in tree AGB. They then developed a set of region-specific diameter–height allometries to minimize bias due to the variation in canopy height across tropical forest regions (see also Banin *et al.*, 2012). They investigated whether some of the climatic variables in the WorldClim database may predict a significant fraction of the variation in the diameter–height relationship. For a given trunk diameter, they found a positive correlation between tree height and precipitation seasonality only. Their finding is counter-intuitive because height should peak at intermediate precipitation seasonality values, and be lower in both

dry and ever-wet forests (see e.g. Hall & Swaine, 1981; figure 5.1; Wang *et al.*, 2006). This is probably because the Feldpausch *et al.* (2011) database did not include many dry vegetation sites.

Here, we readdressed the question of the bioclimatic dependency of the diameter–height relationship in tropical trees. Our dataset had only a limited overlap with that used in Feldpausch *et al.* (2011) and Banin *et al.* (2012), and we found different results. Our major finding is that the diameter–height relationship depends linearly on a compound bioclimatic variable E, which itself is a linear function of climatic water deficit, temperature seasonality, and precipitation seasonality. Indeed, we found that a large fraction of the residual variation in the diameter–height relationship is attributable to the variable E, and that a single model (Eqn 6) may be used to predict total tree height from trunk diameter and E across the tropics.

Our finding that the tree diameter–height relationship reflects the effect of drought tolerance and tolerance to temperature variability is consistent with a number of classic results in plant physiology. For instance, drought and temperature are known to modulate tree physiology and especially carbon assimilation (reviewed in Lloyd & Farquhar, 2008) but also ecosystem productivity (Nemani *et al.*, 2003; Gatti *et al.*, 2014). Also, our findings confirm those of Aiba & Kitayama (1999), Lines *et al.* (2012), and Kempes *et al.* (2011), but over a much larger geographical and environmental scale.

Carbon accounting and relevance to global change

The finding that AGB may be reliably inferred from wood specific gravity, trunk diameter, and the environmental variable E, has obvious consequences for Measurement, Reporting, and Verification (MRV) applications and carbon accounting activities. Indeed, many countries are currently implementing forest inventories where total tree height is not directly measured, because of logistical and financial consideration. Our Model 7 shows that information on wood specific gravity (as inferred from the taxonomic determination of the tree), trunk diameter, and the variable E (as inferred from the geolocation of the plot) is sufficient to provide a robust AGB estimate of this tree. We assessed the performance of Model 7 compared with our best Model 4 and found that it gave reliable results at most sites. We also quantified the performance in terms of the model's RSE, and this performance can be used in future error propagation studies (Eqn (8)). We conclude that the present strategy for AGB estimation is more robust than Model II.3 of Chave *et al.* (2005), and that it outperforms the strategy proposed by Feldpausch *et al.* (2012), as evidenced in Figure S6.

However, it cannot be overstated that this method provides estimates – not direct measurements – and model error should always be carefully examined and propagated through to the quantity of interest. Although Model 7 is an improvement over previously published generic biomass allometries, it is likely to provide unreliable results in some situations. For instance, some low-stature vegetation types in the tropics are driven not by the climate but by soil type (heath forests). Because these vegetation types may occur in limited areas, the diameter–height allometry may vary significantly at the landscape scale. Thus, we advise, whenever possible, developing a local diameter–height allometry, by measuring total height on a subsample of the trees stratified by trunk diameter and by forest type. In such projects, the accuracy of total tree height measurement is critical. We strongly advise using direct measurements of tree height. The most reliable method for large trees is to climb the tree and measure the distance from the top branch to the ground using a laser rangefinder with decimetric accuracy (such as the Laserace 1000, Trimble Navigation Limited, Sunnyvale, CA, USA, or the TruePulse Series, Laser Technology, Centennial, CO, USA). These instruments could also be used from the ground as classical hypsometers, or directly from the base of the tree, by aiming at the highest branch and taking repeated measurements. Whenever this approach is implemented, it should be preceded by a training session when operators can crosscheck their measurements.

Because the proposed models are applicable to already acquired datasets, we foresee that they will be broadly applicable to tree-dominated vegetation types in the tropics. For the UN Framework Convention on Climate Change to implement a Reduced Emissions from Deforestation and Degradation (REDD+) scheme, more accurate and precise country-based carbon inventories are needed (Pelletier *et al.*, 2011). This method should also be complemented with belowground biomass estimation methods (Mokany *et al.*, 2006; Niiyama, *et al.*, 2010). Our allometric equations typically achieve 90% accuracy in AGB stock estimation at a 0.25 ha scale in a moist tropical forest, and the bias is on the order of 10%, on average. The recently published global cover maps for AGB stocks (Saatchi *et al.*, 2011), and for changes in AGB stocks (Harris *et al.*, 2012) could be then updated based on this new methodology. Specifically, we predict that the Harris *et al.* (2012) map may be modified in drier vegetation types, which harbor some of the highest carbon emission rates, such as the Brazilian arc of deforestation or the Indochinese peninsula. We hope that the present study will help advance the implementation of sound practices to devise a global mechanism to fund climate change mitigation activities.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Data S1. Figures.
Data S2. Description of the study sites.
Data S3. Details about the database construction.
Data S4. Illustration of the goodness of fit at each of the 58 study sites. The full dataset is plotted in the background (black). The foreground points and regression line represent the best-fit regression for local datasets.
Figure S1. Distribution of the 58 study sites in environmental space of altitude, mean annual temperature, mean annual evapotranspiration (ET, mm yr^{-1}), mean annual rainfall, and temperature seasonality (TS). The gray shades in the background represent the range of observed variation in currently forested areas in the tropical belt. Red dots indicate Latin American sites, green African sites, and blue Southeast Asian and Australian sites.
Figure S2. Among-site relationship of the individual coefficient of variation to bioclimatic variables (TS: temperature seasonality; CWD: climatic water deficit) across study sites, for Model 4. Each point represents the individual coefficient of variation CV(j) of a study site j, as inferred from Model 4. Point color and size are as in Fig. 3.
Figure S3. Among-site relationship of the site-level bias with bioclimatic variables (TS: temperature seasonality; CWD: climatic water deficit) for Model 4. Each point represents the Bias(j) for site j as inferred from Model 4. Point color and size are as in Fig. 3.
Figure S4. Among-site relationship of the form factor (ratio AGB $/\rho D^2 H$ with bioclimatic variables (TS: temperature seasonality; CWD: climatic water deficit). Each point represents the mean form factor of a study site (equivalent to the fitted parameter of Model 5). Correlation tests were performed on each dataset. In panel (a) $P = 0.09$ (Bartlett test); in panels (b) to (d), $P < 10^{-3}$, $P = 0.08$, $P < 10^{-3}$ (Spearman correlation). Point color and size are as in Fig. 3.
Figure S5. Forward selection for bioclimatic variables in Eqn (3). The first selected variable is TS (temperature seasonality), and including it results in a decline of the residual standard error (σ', noted RSE in the ordinate axis) from 0.430 to 0.292. The second selected variable is CWD (climatic water deficit), and including it results in a decline of the RSE from 0.292 to 0.272. The third selected variable is PS (precipitation seasonality), and including it results in a further decline of the RSE from 0.272 to 0.243. Additional environmental variables induced comparatively very little further decline in RSE (a gain of 0.022).
Figure S6. Comparison between the pantropical allometric AGB Model 7 and a model in which Feldpausch *et al.* (2012) regional diameter–height equations were used. (a) Individual coefficient of variation at each site for both types of allometries. (b) Bias at each site for both types of allometries. Point color and size are as in Fig. 3. The outlying sites are labeled.
Table S1. Study sites and their characteristics.
Table S2. Description of the variables included in the dataset ($n = 4004$).

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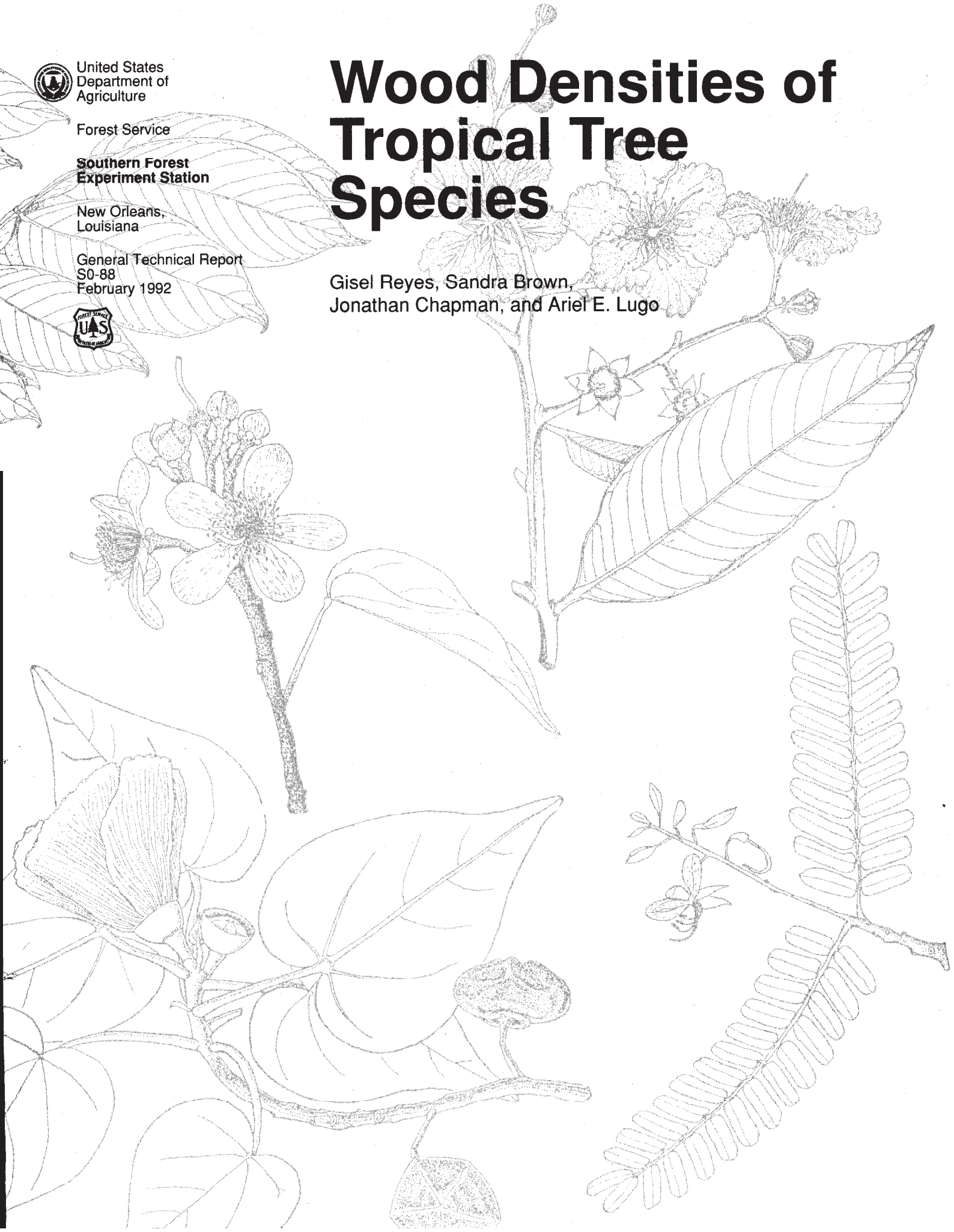
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Wood Densities of Tropical Tree Species

Gisel Reyes, Sandra Brown,
Jonathan Chapman, and Ariel E. Lugo



SUMMARY

Wood density information for a large number of tropical tree species is presented in units of ovendry weight in grams per cubic centimeter of green volume. The data base includes 1,280 entries from tropical America (40 percent), tropical Asia (36 percent), and tropical Africa (24 percent). The most frequent wood densities were 0.5 to 0.8 g/cm^3. In all three tropical continents, the most frequent class was the 0.5 to 0.6 g/cm^3. These data are useful for a wide variety of practical and scientific applications, including the estimation of forest stand biomass from wood volume data.

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Wood Densities of Tropical Tree Species

Gisel Reyes, Sandra Brown, Jonathan Chapman,
and
Ariel E. Lugo

INTRODUCTION

Information on the biomass of tropical forests is critical in order to answer many questions on the role of these forests in global phenomena, including the global carbon and other nutrient cycles, and on the magnitude of the global wood resources.

The biomass of tropical forests has been measured for a few sites scattered around the tropical world, but the area represented by these studies is extremely small (<30 ha) compared with the total area of tropical forests (about 18 million km^2) (Brown and Lugo 1982). Furthermore, there is strong evidence that the selection of these few sites was biased toward high biomass forests (Brown and Lugo 1984). A vast quantity of forest inventory data is available for the tropics. These data often report stand and stock tables (number of trees per unit area and volume per unit area, respectively) by diameter class or total volume for areas that are representative of thousands of hectares of forests. The data are useful for estimating forest biomass by a variety of techniques (Brown and others 1989; Gillespie and others in press).

To use forest inventory data for biomass estimation, wood density values for species or species groups are often needed. For example, the product of gross commercial volume and wood density, by species or species groups, gives the biomass of the commercial wood. Total biomass can then be estimated using biomass expansion factors (total biomass/commercial wood biomass) as reported in Brown and others (1989). Wood density data may also be useful for the study of forest structure and response to environmental factors (e.g., Chudnoff 1984). However, Chudnoffs (1984) analysis of patterns in wood densities of tropical trees according to life zone was not conclusive because the data base was small. Weaver (1987) demonstrated that the average wood density of montane forest stands in Puerto Rico increased with increasing age of the stand. Similar analyses for other ecologically contrasting conditions are not possible because wood density data are normally not readily available to ecologists and foresters.

In studies of tropical forest biomass (Brown and Lugo 1982, 1984; Brown and others 1989; Lugo and others 1988), a large data base has been assembled on wood density of tropical tree species. Because wood volume data, as reported in forest inventories, are given in units of green volume, and because volumes needed to be converted to oven dry weights, wood density is reported in ovendry weight grams per cubic 'centimeter of green volume. This information is summarized here to help others in need of it. Readers are encouraged to make the authors aware of additional sources of information so that the data base can be updated and disseminated periodically. The information is stored at the Institute of Tropical Forestry and can be obtained from the senior author.

METHODS

The list of species for which wood densities were gathered is based on the species encountered in inventories of the following regions and countries:

1. Tropical America
   a. Lowland moist forests of Brazil
   b. Lowland to upland and wet, moist, and dry forests (as described in Holdridge 1967) of Venezuela
   c. Guyana
   d. Surinam
2. Tropical Asia
   a. Malaysia
   b. Sri Lanka

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c. Tropical forest regions of east India

3. Tropical Africa

a. Cameroon
b. Gabon

The sources used for wood densities are listed by each region (table 1). Difficulties were encountered in finding sufficient wood density data in the desired units for forests of tropical Africa and Asia. Most of the data for these regions were in lb/ft^3 volume at la-percent moisture (air-dry weight). Because of this limitation, a regression equation was developed using data in Chudnoff (1984) for wood density with volume at 12-percent moisture versus wood density at green volume. There were no significant differences among the regression equations for the three tropical regions; thus, only the equation based on all species is used. The regression equation, based on data for 379 trees, is as follows:

$$Y = 0.0134 + 0.800X \quad (r^2 = 0.988)$$

where

Y = wood density at ovendry weight/green volume; g/cm^3

X = wood density at air-dry weight/volume at 12-percent moisture; g/cm^3

All density data adjusted by this regression equation are indicated in the data set (table 2) with an asterisk (*).

RESULTS AND DISCUSSION

Table 2 lists the species as identified in the original source and the reported wood density (g/cm^3) for each species. All values cited in the sources (table 1) are reported without comment, although age of tree from which the sample was derived may be a factor for differences between bibliographic sources for the same species (indicated by a plus sign [+] in table 2). However, it is likely that most determinations are based on mature trees.

There are a total of 1,180 species listed in table 2. Tropical Asia, tropical America, and tropical Africa are represented, respectively, by 428, 470, and 282 species or 36, 40, and 24 percent of the record.

The data set is summarized in figure 1 according to continent and frequency of occurence of wood density classes. The most frequent wood densities are the 0.4 to.0.8 g/cm^3 classes. The 0.5 to 0.6 class is dominant in the data sets of all three continents. The wood density of trees in the tropical America data set were more evenly distributed across four classes (0.4-0.5 to 0.7-0.8). This data set has the broadest range of wood densities (0.1 to 1.0) and the highest frequency of dense wood (>0.8); however, this range may be partly, due to the larger data set for this region.

The patterns in figure 1 most likely reflect the smallness and bias of the sources toward commercial forests and species. Clearly, more data of this type are needed before conclusions regarding the ecological meaning of the patterns can be reached.

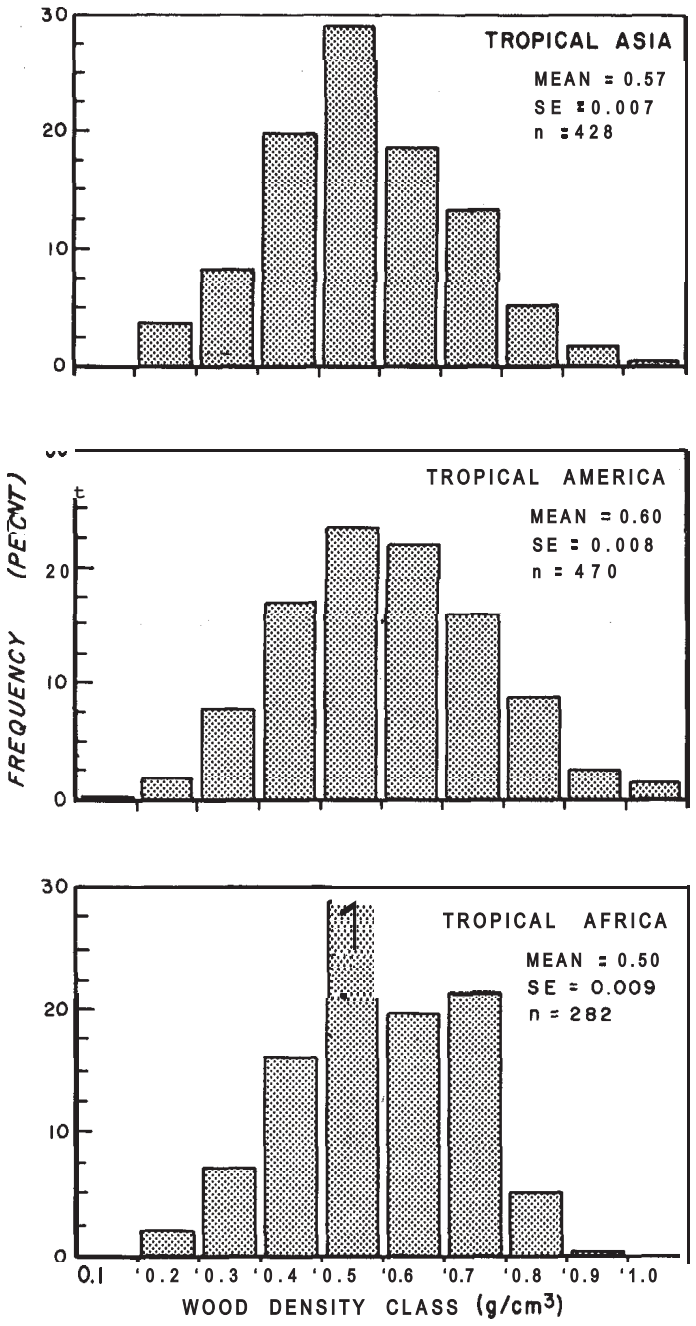


Figure *I.-Frequency distribution of tropical forest species by wood density class for three tropical regions encompassing parts of nine tropical countries.*

Table 1.Sources of *wood density data* bv *tropical region*

Asia

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Chudnoff, Martin. 1984. Tropical timbers of the world. Agric. Handb. 607. Washington, DC: U.S. Department of Agriculture. 464 p.

Food and Agriculture Organization. 1980. Guidelines for the improved utilization and marketing of tropical wood species. Laguna, Philippines: Forest Products Research and Industries Development Commission (FORPRIDECOM), National Science Development Board. 153 p.

Howard, L.A. 1951. A manual of the timbers of the world: their characteristics and uses. London: MacMillan. 751 p.

Singh, K.D. 1978. Informations on the industrial raw material catchments for pulp and paper (unpublished report for the Hindustan Paper Corp., personal communication, March 1987, on file with the wood density data for regions of Southeast Asia).

Trotter, H. 1944. The common commercial timbers of India and their uses. Dehra Dun, India: Vasant Press. 289 p.

America

Berni, C.A.; Bolza, E.; Christensen, F.J. 1979. South American timbers: the properties, uses and characteristics of 190 species. Ivory House, Melbourne, Australia: Commonwealth Scientific and Industrial Research Organization, Division of Building Research. 229 p.

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Dickinson, F.E.; Hess, R.W.; Wangaard, F.F. 1949. Properties and uses of tropical woods, I. Tropical Woods 95. 145 p.

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Hess, R.W.; Wangaard, F.F.; Dickinson, F.E. 1950. Properties and uses of tropical woods, II. Tropical Woods 97. 132 p.

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Howard, L.A. 1951. A manual of the timbers of the world: their characteristics and uses. London: MacMillan. 751 p.

Instituto Brasileiro de Desenvolvimento Florestal. 1981. Madeiras da Amazonia. Caracteristicas e utilizacao. Floresta Nacional da Tapajos. Brasilia, Brazil: Conselho Nacional de Desenvolvimento Cientifico e Tecnologico. 113 p. Vol. 1.

Table 1-Sources *of wood density data by tropical region-(Continued)*

Ladrach, W.E. 1951. Recapitulation of the taxonomy band establishment of a wood library of commercial species for the region of Bajo Calima. In: Ladrach, W.E., ed. Forest Research in the Bajo Calima Concession. Ninth Annual Report. Cali, Colombia: Carton de Colombia: 17– 38.

Longwood, Franklin. R. 1961. Puerto Rican woods. Agric. Handb. 205. Washington, DC: U.S. Department of Agriculture. 98 p.

Ministerio de Agricultura y Cria. 1969. Estudio tecnologico de 144 maderas de la Guyana Venezolana. Merida, Venezuela: Ministerio de Agricultura y Cria, Universidad de los Andes. Laboratorio Nacional de Productos Forestales.

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Table 2.-*Wood densities (g/cm^3) of tree species for tropical regions of three continents*

Species	Wood density	Species	Wood density
Tropical Asia			
Acacia arabica	0.70*	*Bombycidendron vidalianum*	0.53
Acacia catechu	0.88	*Boswellia serrata*	0.50
Acacia confusa	0.75	*Bridelia retusa*	0.50
Acacia leucophloea	0.76	*Bridelia squamosa*	0.50
Acacia richii	0.69	*Buchanania lanzan*	0.45
Adina cordifolia	0.58, 0.59+	*Buchanania latifolia*	0.45
Aegle marmelo	0.75	*Bursera serrata*	0.59
Agathis dammara	0.41	*Butea monosperma*	0.48
Agathis spp.	0.44	*Calophyllum blancoi*	0.51
Agathis uitiensis	0.45	*Calophyllum inophyllum*	0.57
Aglaia diffusa	0.70	*Calophyllum neo-ebudicum*	0.50
Aglaia iloilo	0.53	*Calophyllum obliquinervium*	0.58
Aglaia llanosiana	0.89	*Calophyllum* spp.	0.53
Alangium longiflorum	0.65	*Calophyllum vitiense*	0.50
Alangium meyeri	0.63	*Calycarpa arborea*	0.53
Albizzia amara	0.70*	*Cananga odorata*	0.29
Albizzia falcataria	0.25	*Canarium asperum* var. *asperum*	0.50, 0.60+
Albizzia lebbek	0.55, 0.66+	*Canarium hirsutum* forma *scabrum*	0.40
Albizzia odoratissima	0.76	*Canarium luzonicum*	0.51
Albizzia procera	0.52*, 0.59+	*Canarium* spp.	0.44
Aleurites moluccana	0.25	*Canarium vanikoroense*	0.54
Aleurites trisperma	0.43	*Canarium vitiense*	0.54
Alnus japonica	0.43	*Canarium vrieseanum* forma *stenophyllum*	0.56
Alphitonia philippinensis	0.40	*Canthium monstrosum*	0.42
Alphitonia zizyphoides	0.50	Carallia calycina	0.66*
Alphonsea arborea	0.69	*Cassia fistula*	0.71
Alseodaphne longipes	0.49	*Cassia javanica*	0.69
Alstonia macrophylla	0.62	*Cassia spectabilis*	0.48
Alstonia scholaris	0.36	*Castanopsis philippensis*	0.51
Alstonia spp.	0.37	*Casuarina equisetifolia*	0.83
Amoora aherniana	0.58	*Casuarina nodiflora*	0.85
Amoora macrocarpa	0.55	*Cedrela odorata*	0.38
Amoora spp.	0.60	*Cedrela* spp.	0.42
Anisophyllea zeylanica	0.46*	*Cedrela toona*	0.43
Anisoptera aurea.	0.53	*Ceiba pentandra*	0.23
Anisoptera spp.	0.54	*Celtis luzonica*	0.49
Anisoptera thurifera	0.54	*Chisocheton cumingianus*	0.52
Anogeissus latifolia	0.78, 0.79+	*Chisocheton pentandrus*	0.52
Anthocephalus chinensis	0.36, 0.33+	*Chloroxylon swietenia*	0.76, 0.79, 0.80+
Antidesma pleuricum	0.59	*Chukrassia tabularis*	0.57
Aphanamixis cumingiana	0.58	*Cinnamomum mercadoi*	0.65
Aphanamiris perrottetiana	0.52	*Cinnamomum* spp.	0.43
Araucaria bidwillii	0.43	*Citrus grandis*	0.59
Artocarpus blancoi	0.43	*Cleidion speciflorum*	0.50
Artocarpus heterophylla	0.60	*Cleistanthus collinus*	0.88
Artocarpus lakoocha	0.53*	*Cleistocalyx operculatus*	0.66
Artocarpus ovata	0.47	*Cleistocalyx* spp.	0.76
Artocarpus spp.	0.58	*Cochlospermum gossypium+religiosum*	0.27
Azadirachta indica	0.69	*Cocos nucifera*	0.50
Azadirachta spp.	0.52	*Colona serratifolia*	0.33
Balanocarpus spp.	0.76	*Combretodendron quadrialatum*	0.57
Barringtonia edulis	0.48	*Cordia* spp.	0.53
Bauhinia spp.	0.67	*Cotylelobium* spp.	0.69
Beilschmiedia tawa	0.58	*Crataeva religiosa*	0.53*
Berrya cordifolia	0.78*	*Cratoxylon arborescens*	0.40
Bischofia javanica	0.54, 0.58, 0.62+	*Cryptocarya* spp.	0.59
Bleasdalea vitiensis	0.43	*Cubilia cubili*	0.49
Bombax ceiba	0.33	*Cullenia excelsa*	0.53

Table 2.-*Wood densities (g/cm^3) of tree species for tropical regions of three continents—(Continued)*

Species	Wood density
Cynometra insularis	0.76, 0.91+
Cynometra ramiflora	0.70
Cynometra spp.	0.80
Dacrycarpus imbricatus	0.45, 0.47+
Dacrydium elatum	0.48
Dacrydium nausoriensis	0.52
Dacrydium nidulum	0.52
Dacrydium spp.	0.46
Dacryodes spp.	0.61
Dalbergia latifolia	0.75
Dalbergia paniculata	0.64
Decussocarpus philippinensis	0.50
Decussocarpus vitiensis	0.37
Degeneria vitiensis	0.35
Dehaasia triandra	0.64
Dialium spp.	0.80
Dillenia luzoniensis	0.69
Dillenia megalantha	0.69
Dillenia pentagyna	0.53
Dillenia philippinensis	0.61
Dillenia spp.	0.59
Diospyros embryopteris	0.63*
Diospyros inclusa	0.68
Diospyros melanoxylon	0.68
Diospyros mindanaensis	0.69
Diospyros nitida	0.71
Diospyrosphilippensis	0.81
Diospyros pilosanthera	0.80
Diospyros poncei	0.81
Diospyros pyrrhocarpa	0.60
Diospyros spp.	0.70
Diplodiscus paniculatus	0.63
Dipterocarpus caudatus	0.61
Dipterocarpus eurynchus	0.56
Dipterocarpus gracilis	0.61
Dipterocarpus grandiflorus	0.62
Dipterocarpus kerrii	0.56
Dipterocarpus kunstlerii	0.57
Dipterocarpus spp.	0.61
Dipterocarpus warburgii	0.52
Dracontomelon dao	0.52
Dracontomelon edule	0.46
Dracontomelon spp.	0.50
Dryobalanops spp.	0.61
Drypetes bordenii	0.75
Durio spp.	0.53
Durio zibethinus	0.44, 0.53+
Dyera costulata	0.36
Dysoxylum altissimum	0.42
Dysoxylum decandrum	0.51
Dysoxylum euphlebium	0.63
Dysoxylum quercifolium	0.49
Dysoxylum richii	0.49
Elaeocarpus serratus	0.40*
Emblica officinalis	0.80
Endiandra laxiflora	0.54
Endospermum macrophyllum	0.40
Endospermum peltatum	0.31
Endospermum spp.	0.38
Enterolobium cyclocarpum	0.35
Epicharis cumingiana	0.73
Erythrina fusca	0.25
Erythrina suberosa	0.32
Erythrina subumbrans	0.24
Erythrophloeum densiflorum	0.65
Eucalyptus citriodora	0.64
Eucalyptus deglupta	0.34
Eugenia spp.	0.65
Fagraea gracilipes	0.84
Fagraea spp.	0.73
Ficus benjamina	0.65
Ficus botryocarpa	0.43
Ficus minahassae	0.42
Ficus spp.	0.39
Ficus variegata	0.28
Ganua obovatifolia	0.59
Garcinia myrtifolia	0.65
Garcinia spp.	0.75
Gardenia latifolia	0.64
Gardenia turgida	0.64
Garuga pinnata	0.51
Gluta spp.	0.63
Gmelina arborea	0.41, 0.45+
Gmelina vitiensis	0.54
Gonocaryum calleryanum	0.64
Gonystylus bancanus	0.52
Gonystylus macrophyllus	0.52
Gonystylus punctatus	0.57
Grewia multiflora	0.46
Grewia tiliaefolia	0.68
Hardwickia binata	0.73
Harpullia arborea	0.62
Heritiera ornithocephala	0.68
Heritiera spp.	0.56
Heritiera sylvatica	0.77
Hevea brasiliensis	0.53
Hibiscus tiliaceus	0.57
Homalanthus populneus	0.38
Homalium spp.	0.76
Hopea acuminata	0.62
Hopea foxworthyi	0.64
Hopea plagata	0.88
Hopea spp.	0.64
Intsia bijuga	0.61, 0.68, 0.74+
Intsia palembanica	0.68
Kayea garciae	0.53
Kingiodendron alternifolium	0.48
Kleinhovia hospita	0.36
Knema spp.	0.53
Koompassia excelsa	0.63
Koompassia malaccensis	0.72
Koordersiodendron pinnatum	0.65, 0.69+
Kydia calycina	0.72
Lagerstroemia parviflora	0.62
Lagerstroemia piriformis	0.50
Lagerstroemia speciosa	0.53
Lagerstroemia spp.	0.55
Lannea coromandelica	0.54
Lannea grandis	0.50

Table 2.-*Wood densities (g/cm^3) of tree species for tropical regions of three continents—(Continued)*

Species	Wood density
Leucaena leucocephala	0.64
Litchi chinensis ssp. *philippinensis*	0.88
Lithocarpus celebica	0.68
Lithocarpus llanosii	0.63
Lithocarpus soleriana	0.63
Litsea garciae	0.34
Litsea leytensis	0.35
Litsea perrottetii	0.45
Litsea spp.	0.40
Lophopetalum spp.	0.46
Macaranga bicolor	0.29
Macaranga denticulata	0.53
Madhuca fulva	0.53
Madhuca longifolia var. *latifolia*	0.74
Madhuca oblongifolia	0.53
Mallotus multiglandulosus	0.42
Mallotus philippensis	0.64
Mangifera altissima	0.55
Mangifera indica	0.52, 0.59+
Mangifera merrillii	0.52
Mangifera spp.	0.52
Maniltoa grandiflora	0.76
Maniltoa minor	0.76
Mastixia philippinensis	0.47
Melanorrhea spp.	0.63
Melia dubia	0.40
Melicope triphylla	0.37
Meliosma macrophylla	0.27
Melochia umbellata	0.25
Mesua ferrea	0.83, 0.85+
Metrosideros collina	0.70, 0.76+
Michelia platyphylla	0.51
Michelia spp.	0.43
Microcos stylocarpa	0.40
Micromelum compressum	0.64
Milliusa velutina	0.63
Mimusops elengi	0.72*
Mitragyna parviflora	0.56
Myristica castaneifolia	0.49
Myristica chartacea	0.49
Myristica gillespieana	0.49
Myristica spp.	0.53
Neesia spp.	0.53
Neonauclea bernardoi	0.62
Neotrewia cumingii	0.55
Ochna foxworthyi	0.86
Ochroma pyramidale	0.30
Octomeles sumatrana	0.27, 0.32+
Oroxylon indicum	0.32
Ougenia dalbergiodes	0.70
Palaquium fidjiense	0.48
Palaquium hornei	0.70
Palaquium lanceolatum	0.55
Palaquium luzoniense	0.45
Palaquium philippense	0.41
Palaquium spp.	0.55
Palaquium tenuipetiolatum	0.50
Palaquium vitilevuense	0.48
Pangium edule	0.50
Parashorea malaanonan	0.51
Parashorea spp.	0.44
Parashorea stellata	0.59
Paratrophis glabra	0.77
Parinari corymbosa	0.76
Parinari insularum	0.65
Parinari spp.	0.68
Parkia roxburghii	0.34
Payena spp.	0.55
Peltophorum pterocarpum	0.62
Pentace spp.	0.56
Phaeanthus ebracteolatus	0.56
Phyllocladus hypophyllus	0.53
Pinus caribaea	0.48
Pinus insularis	0.47, 0.48+
Pinus merkusii	0.54
Pisonia umbellifera	0.21
Pittosporum pentandrum	0.51
Planchonella vitiensis	0.77
Planchonia spectabilis	0.58
Planchonia spp.	0.59
Podocarpus neriifolius	0.52
Podocarpus spp.	0.43
Polyalthia flava	0.51
Polyscias nodosa	0.38
Pometia pinnata forma pinnata	0.58
Pometia spp.	0.54
Pouteria villamilii	0.47
Premna tomentosa	0.96
Pterocarpus indicus	0.52
Pterocarpus marsupium	0.67
Pterocymbium macrorater	0.47
Pterocymbium tinctorium	0.28
Pyge'um vulgare	0.57
Quercus spp.	0.70
Radermachera pinnata	0.51
Salmalia malabarica	0.32, 0.33+
Samanea saman	0.45, 0.46+
Sandoricum koetjape	0.44
Sandoricum vidalii	0.43
Sapindus saponaria	0.58
Sapium luzontcum	0.40
Schleichera oleosa	0.96
Schrebera swietenoides	0.82
Semicarpus anacardium	0.64
Serialbizia acle	0.57
Serianthes melanesica	0.48
Sesbania grandiflora	0.40
Shorea agsaboensis	0.35
Shorea almon	0.42
Shorea assamica forma *philippinensis*	0.41
Shorea astylosa	0.73
Shorea ciliata	0.75
Shorea contorta	0.44
Shorea gisok	0.76
Shorea guiso	0.68
Shorea hopeifolia	0.44
Shorea malibato	0.78
Shorea negrosensis	0.44
Shorea palosapis	0.39
Shorea plagata	0.70

Table 2. -*Wood densities (g/cm³) of tree species for tropical regions of three continents—(Continued)*

Species	Wood density
Shorea polita	0.47
Shorea polysperma	0.47
Shorea robusta	0.72
Shorea spp. *balau group*	0.70
Shorea spp. *dark red meranti*	0.55
Shorea spp. *light red meranti*	0.40
Shorea spp. *white meranti*	0.48
Shorea spp. *yellow meranti*	0.46
Shorea virescens	0.42
Sloanea javanica	0.53
Soymida febrifuga	0.97
Spathodea campanulata	0.25
Stemonurus luzoniensis	0.37
Sterculia ceramica	0.27
Sterculia foetida	0.47*
Sterculia urens	0.67
Sterculia vitiensis	0.31
Stereospermum suaveolens	0.62
Strombosia philippinensis	0.71
Strychnos potatorum	0.88
Swietenia macrophylla	0.49, 0.53+
Swintonia foxworthyi	0.62
Swintonia spp.	0.61
Sycopsis dunni	0.63
Syzygium cumini	0.70
Syzygium luzoniense	0.63
Syzygium *nitidum*	0.74
Syzygium simile	0.56
Syzygium spp.	0.69, 0.76+
Tamarindus indica	0.75
Tectona grandis	0.50, 0.55+
Teijsmanniodendron ahernianum	0.90
Terminalia arjuna	0.68
Terminalia belerica	0.72
Terminalia catappa	0.52
Terminalia chebula	0.96
Terminalia citrina	0.71
Terminalia copelandii	0.46
Terminalia foetidissima	0.55
Terminalia microcarpa	0.53
Terminalia nitens	0.58
Terminalia pterocarpa	0.48
Terminalia tomentosa	0.73, 0.76, 0.77+
Ternstroemia megacarpa	0.53
Tetrameles nudiflora	0.30
Tetramerista glabra	0.61
Thespesia populnea	0.52
Toona calantas	0.29
Trema orientalis	0.31
Trichospermum richii	0.32
Tristania decorticata	0.91
Tristania micrantha	0.89
Tristania spp.	0.80
Turpinia ovalifolia	0.36
Vateria indica	0.47*
Vatica mangachapoi	0.65
Vatica obscura	1.04*
Vatica pachyphylla	0.78
Vatica spp.	0.69
Vitex parviflora	0.70
Vitex peduncularis	0.96
Vitex spp.	0.65
Vitex turczaninowii	0.49
Wallaceodendron celebicum	0.55, 0.57+
Weinmannia luzoniensis	0.49
Wrightia tinctorea	0.75
Xanthophyllum excelsum	0.63
Xanthostemon verdugonianus	1.04
Xylia xylocarpa	0.73, 0.81+
Zanthoxylum rhetsa	0.33
Zizyphus spp.	0.76
Zizyphus talanai	0.53
Zizyphus xylopyra	0.85
Tropical America	
Albizzia caribaea	0.64
Albizzia spp.	0.52
Alcornea latifolia	0.49
Alcornea spp.	0.34
Alexa grandiflora	0.60
Alexa imperatricis	0.41, 0.51+
Alnus ferruginea	0.38
Alnus jorullensis	0.38
Anacardium excelsum	0.41
Anacardium spruceanum	0.42
Anadenanthera macrocarpa	0.86
Anadenanthera rigida	0.63
Andira inermis	0.63, 0.64+
Andira retusa	0.67
Aniba perutilis	0.50
Aniba riparia lduckei	0.62
Aniba spp.	0.38, 0.60+
Antiaris africana	0.38
Apeiba aspera	0.23
Apeiba echinata	0.36
Apeiba spp.	0.20, 0.24+
Apeiba tibourbon	0.12
Artocarpus comunis	0.70
Aspidosperma album	0.68
Aspidosperma cruentum	0.71
Aspidosperma dugandii	0.77
Aspidosperma marchravianum	0.68
Aspidosperma megalocarpum	0.71, 0.81+
Aspidosperma spp. (**araracanga** group)	0.75
Aspidosperma spp. (peroba group)	0.62, 0.65+
Astronium graveolens	0.75, 0.80, 0.84, 0.89+
Astronium lecointei	0.73
Bagassa guianensis	0.68, 0.69+
Banara guianensis	0.61
Basiloxylon exelsum	0.58
Beilschmiedia pendula	0.54
Beilschmiedia sp.	0.61
Berthollettia excelsa	0.59, 0.63+
Bixa arborea	0.32
Bombacopsis quinatum	0.38, 0.45, 0.51+
Bombacopsis sepium	0.39
Borojoa patinoi	0.52
Bowdichia nitida	0.77
Bowdichia spp.	0.74
Brosimum acutifolium	0.55

Table 2.—*Wood densities (g/cm^3) of tree species for tropical regions of three continents—(Continued)*

Species	Wood density	Species	Wood density
Brosimum parinarioides	0.57	*Cordia apurensis*	0.66
Brosimum potabile	0.53	*Cordia bicolor*	0.43, 0.49+
Brosimum rubescens	0.73	*Cordia borinquensis*	0.70
Brosimum sp.	0.64, 0.84+	*Cordia collococca*	0.47
Brosimum spp. (alicastrum group)	0.64, 0.66+	*Cordia exaltata*	0.41
Brosimum spp. (utile group)	0.43	*Cordia fallax*	0.36
Brosimum utile	0.41, 0.46+	*Cordia goeldiana*	0.50
Brysenia adenophylla	0.54	*Cordia sagotii*	0.50
Buchenauia capitata	0.61, 0.63+	*Cordia* spp. (gerascanthus group)	0.74
Buchenavia huberi	0.59, 0.79+	*Cordia* spp. (alliodora group)	0.48
Bucida buceras	0.93	*Cordia sulcata*	0.60
Bulnesia arborea	1.00	*Couepia* sp.	0.70
Bursera simaruba	0.29, 0.34+	*Couma macrocarpa*	0.50, 0.53+
Byrsonima aerugo	0.62	*Couratari pulchra*	0.50, 0.54+
Byrsonima coriacea	0.64	*Couratari* spp.	0.50
Byrsonima coriacea var. *spicata*	0.61	*Couratari stellata*	0.65, 0.78+
Byrsonima spp.	0.61, 0.64, 0.75+	*Croton xanthochloros*	0.48
Cabralea cangerana	0.55	*Cupressus lusitanica*	0.43, 0.44+
Caesalpinia spp.	1.05	*Cyrilla racemiflora*	0.53
Calophyllum brasiliense	0.51, 0.54, 0.55+	*Dactyodes colombiana*	0.51
Calophyllum mariae	0.46	*Dacryodes excelsa*	0.52, 0.53+
Calophyllum sp.	0.65	*Dalbergia nigra*	0.68
Calycophyllum candidisimum	0.67	*Dalbergia retusa.*	0.89
Campnosperma panamensis	0.33, 0.50+	*Dalbergia stevensonii*	0.82
Carapa guianensis	0.56	*Declinanona calycina*	0.47
Carapa sp.	0.47	*Dialium guianensis*	0.87
Caryocar nr. *barbinerve*	0.62	*Dialyanthera* spp.	0.36, 0.48+
Caryocar spp.	0.69, 0.72+	*Dicorynia guianensis*	0.60, 0.65+
Caryocar villosum	0.72	*Dicorynia paraensis*	0.60
Casearia arborea	0.53	*Didymopanax morototoni*	0.36, 0.40, 0.45+
Casearia guianensis	0.70	*Didymopanaxpittieri*	0.43
Casearia praecox	0.69*	*Didymopanax* sp.	0.74
Casearia sp.	0.62	*Dimorphandra mora*	0.99*
Cassia moschata	0.71	*Diplotropis purpurea*	0.76, 0.77, 0.78+
Cassia *multijuga*	0.57	*Dipterix odorata*	0.81, 0.86, 0.89+
Casuarina equisetifolia	0.81	*Drypetes variabilis*	0.69
Catostemma commune	0.51	*Dussia lehmannii*	0.59
Catostemma spp.	0.55	*Ecclinusa guianensis*	0.63
Cecropia *peltata*	0.29, 0.30, 0.36+	*Endlicheria cocvirey*	0.39
Cecropia spp.	0.36	*Enterolobium cyclocarpum*	0.34, 0.45+
Cedrela angustifolia	0.36	*Enterolobium schomburgkii*	0.82
Cedrela huberi	0.38	*Eperua* spp.	0.78
Cedrela odorata	0.43, 0.44, 0.45+	*Eriotheca longipedicellatum*	0.45
Cedrela spp.	0.40, 0.46+	*Eriotheca* sp.	0.40
Cedrelinga catenaeformis	0.41, 0.53+	*Erisma uncinatum*	0.42, 0.48+
Ceiba pentandra	0.23, 0.24, 0.25, 0.29+	*Erythrina* sp.	0.23
Centrolobium paraense var. *orinocensis*	0.69	*Eschweilera amara*	0.85
Centrolobium spp.	0.65	*Eschweilera corrugata*	0.66
Cespedesia macrophylla	0.63	*Eschweilera grata*	0.88
Chaetocarpus schomburgkianus	0.80	*Eschweilera hologyne*	0.76
Chlorophora tinctoria	0.71, 0.75+	*Eschweilera odora*	0.81, 0.85+
Clarisia racemosa	0.53, 0.57+	*Eschweilera sagotiana*	0.82
Clathrotropis brunnea	0.82	*Eschweilera* spp.	0.71, 0.79, 0.95+
Clathrotropis spp.	0.89	*Eschweilera subglandulosa*	0.87, 0.89+
Clusia rosea	0.67	*Eschweilera tenax*	0.62
Cochlospermum orinocensis	0.26	*Eschweilera trinitensis*	0.77
Copaifera duckeilreticulata	0.62	*Eucalyptus robusta*	0.51
Copaifera officinalis	0.59	*Eugenia compta*	0.68
Copaifera spp.	0.46, 0.55+	*Eugenia pseudosidium*	0.62
Cordia alliodora	0.42, 0.47, 0.50, 0.57+	*Eugenia stahlii*	0.73

Table 2.—*Wood densities (g/cm³) of tree species for tropical regions of three continents—(Continued)*

Species	Wood density
Euxylophora paraensis	0.68, 0.70+
Fagara aff. F. *martinicense*	0.41
Fagara sp.	0.57
Fagara spp.	0.69
Ficus *citrifolia*	0.40
Ficus sp.	0.32
Genipa americana	0.57, 0.58, 0.66+
Genipa spp.	0.75
Goupia glabra	0.67, 0.72+
Guarea *chalde*	0.52
Guarea spp.	0.52
Guarea trichiloides	0.51, 0.52+
Guatteria spp.	0.36
Guazuma ulmifolia	0.52, 0.50+
Guettarda scabra	0.65
Guillielma gasipae	0.95, 1.25+
Gwtavia sp.	0.56
Helicostylis tomentosa	0.68, 0.72+
Hernandia sonora	0.29
Hevea brasiliense	0.49
Himatanthus articulata	0.40, 0.54+
Hirtella davisii	0.74
Humiria balsamifera	0.66, 0.67+
Humiriastrum melanocarpum	0.60
Humiriastrum procera	0.70
Hura crepitans	0.36, 0.37, 0.38+
Hyeronima alchorneoides	0.60, 0.64+
Hyeronima laxiflora	0.59
Hymenaea courbaril	0.54, 0.76, 0.77+
Hymenaea davisii	0.67
Hymenolobium excelsum	0.63
Hymenolobium sp.	0.64
lnga alba	0.53
Inga capitata	0.64
Inga coruscans	0.72
Inga floribunda	0.56
Inga ingoides	0.50
Inga laurina	0.62
Inga marginata	0.72
Inga sp.	0.49, 0.52, 0.58, 0.64+
Inga splendens	0.55
Inga vera	0.59
Iryanthera grandis	0.63
Iryanthera hostmanii	0.50
Iryanthera spp.	0.46
Jacaranda copaia	0.35
Jacaranda hesperia	0.35
Jacaranda sp.	0.55
Joannesia heveoides	0.39
Lachmellea speciosa	0.73
Laetia procera	0.68
Lecythis davisii	0.82
Lecythis ollaria	0.72
Lecythis paraensis	0.88
Lecythis sp.	0.83
Lecythis spp.	0.77
Licania aff. *micrantha*	0.86
Licania alba	0.91
Licania apetala	0.64, 0.78+
Licania densiflora	0.80
Licania hypoleuca	0.90
Licania macrophylla	0.76
Licania parviflora	0.76
Licania sp.	0.61, 0.79+
Licania spp.	0.78
Licaria cayennensis	0.99
Licaria spp.	0.82
Lindackeria sp.	0.41
Linociera domingensis	0.81
Lonchocarpus sericens	0.78
Lonchocarpus spp.	0.69
Lonchocarpus straminens	0.75
Loxopterygium sagotii	0.56
Lucuma spp.	0.79
Luehea cymulosa	0.55
Luehea spp.	0.50
Lueheopsis duckeana	0.64
Mabea piriri	0.59
Machaerium spp.	0.70
Macoubea guianensis	0.40*
Magnolia *sororum*	0.50
Magnolia splendens	0.59
Magnolia spp.	0.52
Maguira sclerophylla	0.57
Mammea americana	0.62
Mangifera indica	0.55
Manilkara bidentata	0.82, 0.84, 0.85+
Manilkara sp.	0.89
Marila sp.	0.63
Marmaroxylon racemosum	0.78*
Matayba domingensis	0.70
Matisia hirta	0.61
Maytenus ficiformis	0.67
Maytenus spp.	0.71
Mezilaurus itauba	0.68
Mezilaurus lindaviana	0.68
Michropholis garciniaefolia	0.64
Michropholis spp.	0.61
Minquartia guianensis	0.76, 0.79+
Mora excelsa	0.80
Mora gonggrijpi	0.80
Mora magistosperma	0.88
Mora sp.	0.71
Mouriria guianensis	0.80
Mouriria huberi	0.75
Mouriria pseudo-germinata	0.65
Mouriria sideroxylon	0.88
Myrcia paivae	0.73
Myrcia splendens	0.80
Myrciaria floribunda	0.73
Myristica spp.	0.46
Myroxylon balsamum	0.74, 0.76, 0.78+
Nectandra antillana	0.42
Nectandra concinna	0.54, 0.56+
Nectandra coriacea	0.51
Nectandra rigida	0.59
Nectandra rodioei	0.91
Nectandra rubra	0.55
Nectandra sp.	0.43, 0.48, 0.72+

Table 2.-*Wood densities (g/cm³) of tree species for tropical regions of three continents—(Continued)*

Species	Wood density
Nectandra spp.	0.52
Ocotea glandulosa	0.46
Ocotea leucoxylon	0.45
Ocotea moschata	0.61
Ocotea rodioei	0.85, 0.86+
Ocotea rubra	0.54, 0.55, 0.56+
Ocotea *spathulata*	0.62
Ocotea spp.	0.51
Onychopetalum amazonicum	0.64
Ormosia krugii	0.50
Ormosia lignivalvis	0.58
Ormosia spp.	0.59
Ouratea sp.	0.66
Pachira acuatica	0.43
Paratecoma peroba	0.60
Parinari campestris	0.69
Parinari excelsa	0.64
Parinari rodolfi	0.72
Parinari spp.	0 . 6 8
Parkia belutina	0.42
Parkia multijuga	0.38
Parkia oppositifolia	0.24
Parkia pendula	0.51
Parkia spp.	0.39
Peltogyne porphyrocardia	0.92
Peltogyne spp.	0.79
Pentaclethra macroloba	0.65, 0.68+
Peru *glabrata*	0.65
Peru schomburgkiana	0.59
Persea spp.	0.40, 0.47, 0.52+
Petitia domingensis	0.66
Pinus caribaea	0.51
Pinus oocarpa	0.55
Pinus patula	0.45
Piptadenia communis	0.68
Piptadenia macrocarpa	0.83*
Piptadenia pittieri	0.62, 0.76+
Piptadenia psilostachya	0.67
Piptadenia rigida	0.73
Piptadenia sp.	0.58
Piptadenia suaveolens	0.72
Piranhea longepedunculata	0.90
Piratinera guianensis	0.96
Pithecellobium guachapele (syn. Pseudosamea)	0.56
Pithecellobium saman	0.48
Platonia insignis	0.70'
Platymiscium pinnatum	0.80, 0.81+
Platymiscium polystachium	0.73
Platymiscium spp.	0.71, 0.84+
Podocarpus oleifolius	0.46
Podocarpus rospigliossi	0.40
Podocarpus spp.	0.46
Pourouma aff. *apiculata*	0.45
Pourouma aspera	0.28
Pourouma aff. *guianensis*	0.33
Pourouma aff. *melinonii*	0.32
Pouteria carabobensis	0.68
Pouteria egregia	0.89
Pouteria eugeniifolia	1.08
Pouteria gonggrijpii	0.84
Pouteria melinonii	0.63*
Pouteria multiflora	0.74
Pouteria pomifera	0.76
Pouteria sp.	0.73
Pouteria spp.	0.64, 0.67+
Prioria copaifera	0.40, 0.41+
Protium crenatum	0.54
Protium decandrum	0.56
Protium heptaphyllum	0.40, 0.55+
Protium neglectum	0.58, 0.64+
Protium sp.	0.73
Protium spp.	0.53, 0.64+
Protium tenuifolium	0.60
Pseudolmedia laevigata	0.64
Pterocarpus officinalis	0.32, 0.50+
Pterocarpus rohrii	0.41
Pterocarpus sp.	0.46, 0.50+
Pterocarpus spp.	0.44
Pterocarpus vernalis	0.59
Pterogyne nitens	0.66
Pterygota excelsa	0.58
Qualea albiflora	0.50
Qualea cf. *lancifolia*	0.58
Qualea dinizii	0.58
Qualea spp.	0.55
Quararibaea guianensis	0.54
Quercus *alata*	0.71
Quercus *costaricensis*	0.61
Quercus eugeniaefolia	0.67
Quercus spp.	0.70
Raputia sp.	0.55
Rheedia spp.	0.72
Rollinia exsucca	0.32
Rollinia sp.	0.34, 0.36+
Rollinia spp.	0.36
Saccoglottis cydonioides	0.72
Sapium biglandulosum	0.45
Sapium cf. *jenmanni*	0.41
Sapium laurocerasus	0.38
Sapium sp.	0.38, 0.48+
Sapium ssp.	0.47, 0.72+
Schinopsis spp.	1.00
Sclerobium aff. *chrysophyllum*	0.62
Sclerobium guianensis	0.56
Sclerobium paniculatum	0.34
Sclerobium spp.	0.47
Sickingia spp.	0.52
Simaba multiflora	0.51
Simarouba amara	0.32, 0.34, 0.38+
Sloanea berteriana	0.80
Sloanea grandiflora	0.80
Sloanea guianensis	0.79
Spondias lutea	0.38
Spondias mombin	0.30, 0.40, 0.41+
Sterculia apetala	0.33, 0.36
Sterculia pilosa /speciosa	0.53
Sterculia pruriens	0.46
Sterculia spp.	0.55
Stryphnodendron polystachum	0.52
Stylogyne spp.	0.69

Table 2.-*Wood densities (g/cm^3) of tree species for tropical regions of three continents—(Continued)*

Species	Wood density
Swartzia spp.	0.95
Swietenia macrophylla	0.42, 0.45, 0.46, 0.54+
Symphonia globulifera	0.68
Tabebuia guayacan	0.82
Tabebuia heterophylla	0.58
Tabebuia heterotricha	0.82
Tabebuia pentaphylla	0.51
Tabebuia rosea	0.54
Tabebuia serratifolia	0.92, 0.95, 0.99+
Tabebuia spectabilis	1.07
Tabebuia spp. (lapacho group)	0.91
Tabebuia spp. (roble)	0.52
Tabebuia spp. (white cedar)	0.57
Tabebuia stenocalyx	0.55, 0.57+
Tachigalia myrmecophylla	0.56
Talisia sp.	0.84
Tapirira guianensis	0.47*
Terminalia amatonia	0.66
Terminalia catappa	0.59
Terminalia guianensis	0.63
Terminalia lucida	0.65
Terminalia sp.	0.50, 0.51, 0.58+
Tetragastris altisima	0.61
Tetragastris balsamifera	0.63, 0.67+
Tetragastris panamensis	0.71
Tetragastris spp.	0.71
Toluifera balsamum	0.74
Torrubia cuspidata	0.47
Torrubia sp.	0.52
Toulicia pulvinata	0.63
Tovomita guianensis	0.60
Trattinickia burserifolia	0.44
Trattinickia rhoifolia	0.37
Trattinickia sp.	0.38
Trichilia propingua	0.58
Trichosperma mexicanum	0.41
Triplaris sp.	0.64
Triplaris spp.	0.56
Triplaris surinamensis	0.51
Trophis sp.	0.54
Vatairea lundellii	0.64
Vatairea spp.	0.60
Virola sebifera	0.48
Virola spp.	0.40, 0.44, 0.48+
Virola surinamensis	0.37, 0.42+
Vismia spp.	0.41
Vitex divaricata	0.62
Vitex gaumeri	0.56
Vitex orinocensis	0.53
Vitex spp.	0.52, 0.56, 0.57+
Vitex stahelii	0.60
Vochysia ferruginea	0.42, 0.47+
Vochysia guianensis	0.45
Vochysia hondurensis	0.33
Vochysia lehmannii	0.48
Vochysia maxima	0.46
Vochysia spp.	0.40, 0.47, 0.79+
Vochysia tetraphylla	0.48
Vochysia tomentosa	0.36
Vouacapoua americana	0.79
Warszewicsia coccinea	0.56
Xanthoxylum martinicensis	0.46
Xanthoxylum spp.	0.44
Xylopia columbiana	0.51
Xylopia emarginata	0.59
Xylopia frutescens	0 64"
Tropical Africa	
Afzelia bipindensis	0.66"
Afzelia pachyloba	0.63*
Afzelia spp.	0.67
Aidia ochroleuca	0.78*
Albizia ferruginea	0.47*
Albizia glaberrima	0.52"
Albizia gummifera	0.51*
Albizia spp.	0.52
Albizia zygia	0.46*
Allanblackia floribunda	0.63*
Allophyllus africanus f. *acuminatus*	0.45
Alstonia congensis	0.33
Amphimas ferrugineus	0.63*
Amphimas pterocarpoides	0.63*
Anisophyllea obtusifolia	0.63*
Annonidium mannii	0.29*
Anopyxis klaineana	0.74*
Anthocleista keniensis	0.50*
Anthonotha macrophylla	0.78*
Anthostemma aubryanum	0.32*
Antiaris africana	0.37
Antiaris spp.	0.38
Antrocaryon klaineanum	0.50*
Aucoumea klaineana	0.37
Autranella congolensis	0.78
Baillonella toxisperma	0.71
Balanites aegyptiaca	0.63*
Baphia kirkii	0.93*
Beilschmiedia corbisieri	0.63*
Beilschmiedia diversiflora	0.63*
Beilschmiedia kweo	0.56*
Beilschmiedia louisii	0.70*
Beilschmiedia membranifolia	0.50*
Beilschmiedia nitida	0.50*
Berlinia bracteosa	0.60*
Berlinia confusa	0.56*
Berlinia spp.	0.58
Blighia welwitschii	0.74*
Bombax buonopozense	0.32*
Bombax chevalieri	0.41*
Bombax rhodognaphalon	0.36*
Bombax spp.	0.40
Brachystegia cynometroides	0.56*
Brachystegia laurentii	0.45*
Brachystegia mildbraedii	0.50*
Brachystegia spp.	0.52
Bridelia grandis	0.50*
Bridelia micrantha	0.47*
Calpocalyx heitzii	0.66*
Calpocalyx klainei	0.63*
Canarium schweinfurthii	0.40*
Canthium rubrocostratum	0.63*

Table 2.—*Wood densities (g / cm³) of tree species for tropical regions of three continents—(Continued)*

Species	Wood density	Species	Wood density
Carapa procera	0.59	*Enantia chlorantha*	0.42"
Casearia battiscombei	0.50	*Endodesmia calophylloides*	0.66"
Cassipourea euryoides	0.70*	*Entandrophragma angolensis*	0.45
Cassipourea malosana	0.59*	*Entandrophragma candollei*	0.59
Ceiba pentandra	0.26	*Entandrophragma cylindricum*	0.55
Celtis brieyi	0.50"	*Entandrophragma utile*	0.53
Celtis mildbraedii	0.56*	*Eribroma oblongum*	0.60*
Celtis spp.	0.59	*Eriocoelum microspermum*	0.50"
Celtis zenkeri	0.59"	*Erismadelphus exsul*	0.56*
Chlorophora ercelsa	0.55	*Erythrina vogelii*	0.25"
Chrysophyllum albidum	0.56*	*Erythrophleum ivorense*	0.72
Cleistanthus mildbraedii	0.87*	*Erythroxylum mannii*	0.50
Cleistopholis patens	0.36*	*Fagara heitzii*	0.41*
Coelocaryon preussii	0.56"	*Fagara macrophylla*	0.69
Cola cordifolia	0.50*	*Ficus iteophylla*	0.40"
Cola gigantea	0.46"	*Ficus mucuso*	0.39*
Cola gigantea var. *glabrescens*	0.46*	*Funtumia africana*	0.40*
Cola natalensis	0.70"	*Fumtumia latifolia*	0.45*
Cola sp.	0.70"	*Gambeya africana*	0.63
Combretodendron macrocarpum	0.70	*Gambeya lacourtiana*	0.63*
Conopharyngia holstii	0.50*	*Gambeya madagascariensis*	0.56*
Copaifera mildbraedii	0.63*	*Gambeya* spp.	0.56*
Copaifera religiosa .	0.50"	*Garcinia gerardii*	0.66*
Cordia africana	0.40*	*Garcinia mannii*	0.78"
Cordia millenii	0.34	*Garcinia punctata*	0.78"
Cordia platythyrsa	0.36"	*Gilbertiodendron dewevrei*	0.65"
Corynanthe gabonensis	0.56"	*Gilbertiodendron grandiflorum*	0.66"
Corynanthe pachyceras	0.63"	*Gilbertiodendron mayombense*	0.63"
Coda edulis	0.78*	*Gilletiodendron mildbraedii*	0.87"
Croton macrostachyus	0.50*	*Gossweilerodendron balsamiferum*	0.40
Croton megalocarpus	0.57	*Guarea cedrata*	0.48
Cryptosepalum staudtii	0.70*	*Guarea laurentii*	0.56"
Ctenolophon englerianus	0.78*	*Guarea thompsonii*	0.55"
Cylicodiscus gabonensis	0.80	*Guibourtia arnoldiana*	0.64
Cynometra alexandri	0.74	*Guibourtia demeusei*	0.70"
Dacryodes buettneri	0.53"	*Guibourtia ehie*	0.67
Dacryodes edulis	0.50"	*Guibourtia pellegriniana*	0.74"
Dacryodes igaganga	0.53"	*Guibourtia* spp.	0.72
Dacryodes klaineana	0.70"	*Guibourtia tessmannii*	0.74*
Dacryodes le-testui	0.50"	*Hannoa klaineana*	0.28"
Dacryodes normandii	0.50*	*Harungana madagascariensis*	0.45"
Dacryodes spp.	0.61	*Hexalobus crispiflorus*	0.48"
Daniellia klainei	0.45*	*Holoptelea grandis*	0.59"
Daniellia ogea	0.40*	*Homalium letestui*	0.66*
Daniellia soyaunii	0.45"	*Homalium* spp.	0.70
Desbordesia pierreana	0.87"	*Hylodendron gabonense.*	0.78"
Detarium senegalensis	0.63*	*Hymenostegia afzelii*	0.78"
Dialium bipindense	0.83"	*Hymenostegia pellegrini*	0.78"
Dialium dinklagei	0.72	*Irvingia gabonensis*	0.71
Dialium excelsum	0.78*	*Irvingia grandifolia*	0.78"
Didelotia africana	0.78"	*Julbernardia globiflora*	0.78
Didelotia brevipaniculata	0.53	*Khaya grandifoliola*	0.60
Didelotia letouzeyi	0.50	*Khaya ivorensis*	0.44
Diospyros kamerunensis	0.78*	*Khaya senegalensis*	0.60
Diospyros spp.	0.82	*Klainedoxa gabonensis*	0.87
Discoglypremna caloneura	0.32*	*Lannea welwitschii*	0.45"
Distemonanthus benthamianus	0.58	*Lecomtedoxa klainenna*	0.78"
Drypetes gossweilleri	0.63*	*Letestua durissima*	0.87"
Drypetes sp.	0.63*	*Lophira alata*	0.87"
Ehretia acuminata	0.51*	*Lovoa trichilioides*	0.45"

Table 2.-*Wood densities (g/cm³) of tree species for tropical regions of three continents—(Continued)*

Species	Wood density
Macaranga conglomerata	0.40*
Macaranga kilimandscharica	0.40*
Maesopsis eminii	0.41
Malacantha sp. aff. *alnifolia*	0.45"
Mammea africana	0.62
Manilkara cuneifolia	0.81*
Manilkara lacera	0.78"
Markhamia hildebrandtii	0.50*
Markhamia platycalyx	0.45*
Memecylon capitellatum	0.77"
Microberlinia bisulcata	0.63"
Microberlinia brazzavillensis	0.70
Microcos coriaceus	0.42"
Milletia laurentii	0.70"
Milletia spp.	0.72
Mitragyna ciliata	0.45
Mitragyna stipulosa	0.47
Monopetalanthus coriaceus	0.45*
Monopetalanthus durandii	0.50*
Monopetalanthus heitzii	0.39
Monopetalanthus letestui	0.50"
Monopetalanthus pellegrinii	0.47"
Musanga cecropioides	0.23
Nauclea diderrichii	0.63
Neopoutonia macrocalyx	0.32"
Nesogordonia fouassieri	0.70"
Nesogordonia papaverifera	0.65
Newtonia buchananii	0.48*
Newtonia glandulifera	0.74"
Ochtocosmus africanus	0.78'
Odyendea gabonensis	0.32"
Odyendea spp.	0.32
Oldfieldia africana	0.78*
Ongokea gore	0.72
Oxystigma oxyphyllum	0.53
Pachyelasma tessmannii	0.70"
Pachypodanthium confine	0.58*
Pachypodanthium staudtii	0.58"
Paraberlinia bifoliolata	0.56"
Parinari excelsa	0.69
Parinari glabra	0.87"
Parinari goetzeniana	0.78"
Parkia bicolor	0.36"
Pausinystalia brachythyrsa	0.56"
Pausinystalia cf. *talbotii*	0.56"
Pentaclethra eetveldeana	0.63"
Pentaclethra macrophylla	0.78"
Pentadesma butyracea	0.78"
Phyllanthus discoideus	0.76"
Pierreodendron africanum	0.70;"
Piptadenia gabunensis	0.70*
Piptadeniastrum africanum	0.56
Plagiostyles africana	0.70"
Poga oleosa	0.36
Polyalthia suaveolens	0.66"
Premna angolensis	0.63"

Species	Wood density
Pteleopsis hylodendron	0.63*
Pterocarpus angolensis	0.59
Pterocarpus soyauxii	0.61
Pterygota bequaertii	0.56*
Pterygota spp.	0.52
Pycnanthus angolensis	0.40
Randia cladantha	0.78*
Rauwolfia macrophylla	0.47*
Ricinodendron heudelotii	0.20
Saccoglottis gabonensis	0.74"
Santiria trimera	0.53*
Sapium ellipticum	0.50*
Schrebera arborea	0.63*
Sclorodophloeus zenkeri	0.68*
Scottellia chevalieri	0.50*
Scottellia coriacea	0.56
Scyphocephalium ochocoa	0.48
Scytopetalum tieghemii	0.56"
Sindoropsis letestui	0.56*
Staudtia stipitata	0.75
Stemonocoleus micranthus	0.56"
Sterculia oblonga	0.61
Sterculia rhinopetala	0.64
Strephonema pseudocola	0.56*
Strombosia glaucescens	0.80
Strombosia grandifolia	0.74*
Strombosiopsis tetrandra	0.63"
Swartzia fistuloides	0.82
Symphonia globulifera	0.58"
Syzygium cordatum	0.59*
Tarrietia densiflora	0.63
Tarrietia utilis	0.54"
Terminalia superba	0.45
Tessmania africana	0.85"
Testulea gabonensis	0.60
Tetraberlinia bifoliolata	0.54*
Tetraberlinia tubmaniana	0.60"
Tetrapleura tetraptera	0.50"
Tieghemella africana	0.55
Tieghemella heckelii	0.55"
Trema guineensis	0.40"
Trema sp.	0.40*
Trichilia heudelotii	0.50"
Trichilia prieureana	0.63"
Trichoscypha arborea	0.59"
Triplochiton scleroxylon.	0.32
Uapaca spp.	0.60
Vepris undulata	0.70"
Vitex doniana	0.40
Xylopia aethiopica	0.50"
Xylopia chrysophylla	0.70*
Xylopia hypolambra	0.63"
Xylopia quintasii	0.70"
Xylopia staudtii	0.36*

+The wood densities specified pertain to more than one bibliographic source.

* Wood density value is derived from the regression equation given in the text,

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Wood densities of a number of tree species for tropical America, tropical Asia, and tropical Africa have been compiled.

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Module 7 – Preparing for verification

This Module builds on previous content in the workshop relating to independent external review (i.e. external validation/verification). The main message to get across to the participants is that independent review is a part of the REDD+ process. The review is conducted to identify what is working well and might identify areas for improvement. **External validation/ verification is not a test. It is an opportunity to demonstrate skills, experiences, things that are working well and things that remain a challenge.**

A number of improvements may be identified from external validation/verification which may lead to new skills and techniques and improved quality outcomes.
The Module material explores the role of indigenous peoples and forest dependent communities in external validation/verification through two role playing exercises.

Module 7.1: What is verification

Core Learning Outcome

Participants understand that verification is conducted by an independent team. It is not a pass or fail test.

Core Message

- Techniques are based on inspection of documents, records and processes and reports **may identify improvement opportunities.** It is good practice to assess and improve.
- Verification is an assessment process which can be internal or external.
- Internal verification is more of an informal process. External verification is a more formal process.
- In the context of REDD+, external verification is required to confirm the emissions reductions submitted for results based payments estimated in a way consistent with the fund requirements
- A team of verifiers usually conduct the assessment over the period of a few months.
- The assessment requires a review of documentation, interviews with stakeholders, field trips, demonstration of data collections and processing techniques.
- The participants have the opportunity to make improvements/corrections or to present a plan to do so.
- For REDD+, the outcomes of the verification are publicly made available in a report published on line.
- It is a good idea to build capacity in verification to boost confidence internally and externally in roles and responsibilities in the work being done to improve quality of outcomes.

Module 7

Preparation for verification

Module Outcomes

Understanding that:

- verification is conducted by an independent team
- verification is not a pass or fail test
- techniques are based on inspection of documents, records and process
- reports may identify improvement opportunities

Module Outline

1. What is verification
2. Role Play



3



National Forest Monitoring System

What is verification

Module 7.1



4



The 'V' in MRV

National Forest Monitoring System

Measurement
Reporting
Verification

- Conducted by an independent **team of people**
- It is **not a pass or fail** test
- Techniques are based on **inspection** of documents, records and process
- Reports may **identify improvement opportunities**

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The 'V' in MRV: Who





- **Verification** – is the process of assessing the data and information submitted
- **Internal Verification** - approach to quality assurance based on peer support and review that enables you to integrate quality into internal assessment from start to finish.
- **External Verification** - confirmation of estimates and supporting documents by **an independent third party**

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Independent Third Party

- Typically a team of people make up the verification team (usually between 2-4 people)
- Team members generally have a broad range of skills including knowledge of:
  - the program / agency requirements to which you are reporting
  - carbon accounting and data collection methods
  - processes and system design and operation
  - Safeguards
- Examples:
  - UNFCCC technical assessment process includes experts (i.e. national GHG inventory compilers from both developing and developed countries)
  - World Bank FCPF technical assessment panel offer a wide range of technical and policy expertise and knowledge of specific country conditions

Verification Overview

Effective verification processes require:

- establishment of national capacity and good communication between the national institutions involved.
- transparent, consistent, complete and accurate data and information
- sufficient information provided to enable third parties to be able to assess whether requirements have been met.

Verification Capacity

In the context of REDD+ internal and external verification capacity building is required at both the:

- Individual level
- Institutional level

Capacity building refers to activities which strengthen the knowledge, abilities, skills and behaviour of individuals and improve institutional structures and processes

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Verification Capacity

Capacity Building is much more than training and includes:

- Human resource development - the process of equipping individuals with the understanding, skills and access to information, knowledge and training that enables them to perform effectively.
- Organizational development - the elaboration of management structures, processes and procedures, not only within organizations but also the management of relationships between the different organizations and sectors (public, private and community).
- Partnership development - strengthening relationships regionally and internationally with countries and organisations working in the same field to share experiences

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Verification Outcomes

Outcomes from the verification process can be shared internally and externally

- **Internal Use –** Findings can be used to identify opportunities for improvement such as training or process efficiencies
- **External Use –** Used in the context of results based payments

National Forest Monitoring System

Verification Role Play

Module 7.2

V: Do people know how to do the tasks ?



Focus:

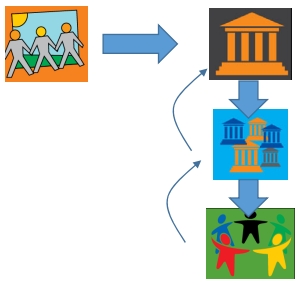
- Instructions
- Training
- Methods of evaluation and review of skills

Evidence:

- Demonstration of skills
- Attendance sheets in training
- Improvements and changes resulting in updated skills and instructions

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V: Is the system working?



Focus:

- Operational and Management effectiveness
- Plans and tasks have been executed
- Follow the path from reports to data collected

Evidence:

- Demonstrate that process records exist and can be found
- Records capture required operational information and feedback

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Verification

Exercise:

Role Play:
Use the scenario sheets provided and enact the role play in groups.

Role Play 1 : Do people know how to do the tasks?
Role Play 2 : Is the system working?

Module 7 Exercises

External validation/verification role play

Materials	Script

Exercise a: Do people know how to do the task?

Guide	This exercise should be conducted as a whole group in a 'fish bowl' type environment. Two "cast members" (volunteers) are required. Preferably these "cast members" should stand/sit in the middle of the group with the rest of the workshop participants in a circle around them. Alternatively, they can stand at the front of the room. The two cast should work through the script. The facilitator can act as the "Director". At the end of the role play, the following items should be discussed with the group: • The focus of the verifier's questions related to the field crew's capacity to undertake the tasks related to his role and responsibility. • The verifier will be looking for evidence of skills and this may be through asking the field crew member to demonstrate how he undertakes his job • Evidence of attendance at any training events Evidence that any changes or improvements to field data collection protocols are carried through to the training
Expected Duration	**30 minutes**

Role Play: Do people know how to do the tasks?

Cast:

Assessor: Member of verification team from the Independent Auditor appointed by the country to verify operations of the NFMS.

IPs / forest dependent community representative: Someone who was involved in the tasks performed by the field crews. Maybe randomly selected from field crew names or nominated by senior staff.

Scene:

Assessor and IPs/forest dependent community representatives are both standing and talking after navigating and arriving at the field plot where data had been measured as part of the inventory. The equipment used by the field crew is in a bag on the ground next to a tree with a numbered tag.

<Director: Assessor is asking questions while the rest of the verification team are walking around the plot.>

Assessor: You found this plot very easily. Have you ever had trouble finding other plots?

IPs / forest dependent community representative: Thanks. I am quite skilled with the GPS. It's my favourite part of the job. Some plots are hard to find but we have a procedure to handle the case if we can't find it.

Assessor: When we get back to the office can you show me where the procedure is for that?

IPs / forest dependent community representative: Sure thing. We have the updated printed copy at our office and I can also access it online through the website when I am in town.

<Director: Assessor opens the bag of field equipment>

Assessor: Can you run me though some of the tools you use for the field measurements?

IPs / forest dependent community representative: I mainly do the DBH measurements with the DBH tape once the tree has been marked. Bill does the tree height and Tom fills in the data sheet.

< **IPs / forest dependent community representative** picks up the tape and demonstrates how he measures DBH.>

Assessor: That's great. Thanks for showing me that. How did you learn how to use a DBH tape?

IPs / forest dependent community representative: Initially we all participated in the field crew training program. This included some theory in a class room and then some practice at a managed forest outside of town. When I first started I always would read the field manual before I went out into the field. But now I am pretty confident in how to do it so I don't need to read the manual as much. The senior field crew officer sometimes comes in to do a plot to just check up on how we are going.

Assessor: What happens if you are unsure about what to do when you get to a plot. Maybe there is something different such as a terrain feature that makes it hard to do the measurements?

IPs / forest dependent community representative: We talk amongst the team to see if someone has experienced it before. We record the issue in the notes and take a photo and then proceed with doing the measurements if we can.

Assessor: Do you have any suggestions on how the field work or measurements can be done better?

IPs / forest dependent community representative: Just last month at the field crew meeting, we talked about how to handle batteries of the laser height finder going flat during field work whether it would be better to go back to the old clinometers or carry a power bank to recharge while in the field. I think they are going to do a trial next week with a couple of brands of power banks. We will know more after the next field crew meeting.

Exercise b: Is the system working?

Guide	This exercise should be conducted as a whole group in a 'fish bowl' type environment. Three "cast members" (volunteers) are required. Preferably these "cast members' should be different people from those who performed the first role play. The two cast should work through the script. The facilitator can act as the "Director". At the end of the role play, the following items should be discussed with the group: • The focus of the verifier's questions related to assessing operational and management effectiveness and in confirming that plans and tasks have been executed. • Some types of evidence that the verifier may be looking for include: • Demonstration that process records exist and can be found • Evidence that records capture the required operational information and feedback.
Expected Duration	30 minutes

Role Play: Is the system working?

Cast:

Assessor: Member of the verification team from the Independent Auditor appointed by the country to verify operations of the NFMS.

Ministry of Forestry Officer: National Government NFMS staff member responsible for inventory standards and data collection.

Regional Extension Staff: Regional office staff member responsible for field crew coordination and data collation.

IPs/forest dependent community representative: Someone who was involved in the field crew tasks.

Scene:
The Assessor and the IPs/forest dependent community representative has just returned to the village hall where the Ministry of Forestry Officer and the Regional Extension Staff are waiting at a table with cups of tea.

<Director: Assessor and IPs/forest dependent community representative drop their bags and sit down with the others at the table.>

Assessor: It was great today. We got through a lot in a short time. I really enjoyed seeing the forest and talking with the crews about the experiences in the field. We heard so many bird calls which I have not heard before.

IPs/forest dependent community representative: It was great to be out in the forest and sharing our environment with you.

Assessor: Can you explain what happens with the field sheets once you return from the plots?

IPs/forest dependent community representative: I check them over amongst the crew and if there are no obvious mistakes or odd things that should be corrected, we hand them to the regional staff here at the office.

<Director: IPs/forest dependent community representative hands the field data sheets to the Regional Extension Staff. >

Regional Extension Staff: We check all the data sheets against a check list for common mistakes and then each month we hand the collected field data sheets with our monthly progress report to the Ministry of Forestry each

<Director: Regional Extension Staff hands the field data sheets to the Ministry of Forestry Officer. >

Ministry of Forestry Officer: We enter all the data from the field data sheets collected over the last month and analyse the data and location information and perform our internal assessment.

Assessor: What if you find errors on the field data sheets. How do you resolve or correct the errors?

Ministry of Forestry Officer: We contact the regional staff to see if they can clear up the issue from their experience or if not resolved they will then contact the field crew to see if they can help.

Assessor: While we were at the plot the field crew member mentioned that you are trialling power banks in the field. Can you explain the process for implementing improvements?

IPs/forest dependent community representative: In our monthly field crew meetings we reported that the laser height finder was going flat after 2 days. We thought the most practical way would be getting power banks.

Regional Extension Staff: We reported back to the Ministry of Forestry the issue about the laser height finders going flat and the suggestions of either going back to the clinometer or provide power banks. But during discussion with the Ministry of Forestry Officer it was realised that changing tools at this point may affect the consistency of the data. So it was decided to supply more batteries because not all villages have electricity to recharge the power banks.

Ministry of Forestry Officer: So we have included the cost of supplying more batteries in next month's budget.

Regional Extension Staff: The process for purchasing and supplying the new batteries has been updated in the SOP.

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