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PARTNERSHIP FOR LAND USE SCIENCE (FOREST-PLUS) PROGRAM

Resource Material for Training of Trainers on Forest Carbon Measurement, including Community-Based Carbon Measurement

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PARTNERSHIP FOR LAND USE SCIENCE (Forest-PLUS) PROGRAM

RESOURCE MATERIAL FOR TRAINING OF TRAINERS ON FOREST CARBON MEASUREMENT, INCLUDING COMMUNITY-BASED CARBON MEASUREMENT

April 2017

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ACRONYMS

AD	Activity Data
AFOLU	Agriculture, Forestry, and Other Land Use
AGB	Above-Ground biomass
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
AWiFS	Advanced Wide Field Sensor
BEF	Biomass Expansion Factor
BGB	Below-Ground biomass
B_h	Historical Baseline
B_t	Business-as-Usual Baseline
C	Carbon
CAMPA	Compensatory Afforestation Fund Management and Planning Authority
CBFM	Community Based Forest Management
CCBA	Climate, Community & Biodiversity Alliance
Cf	Carbon Fraction of Biomass
CFM	Community Forest Management
CO_2	Carbon Dioxide
COP	Conference of the Parties
CS	Carbon stock
CSV	Comma-Separated Values
DBH	Diameter at Breast Height
DEM	Digital Elevation Model – Topographic
DMS	Data Management System
DW	Dry Weight
EAFM	Ecosystem approach to forest management
EF	Emission Factors
ERDAS	Earth Resource Development Assessment System
fC	Fractional Cover
fDMS	Forest Data Management System
Forest-PLUS	Partnership for Land Use Science
FPIC	Free Prior and Informed Consent
FSI	Forest Survey of India
FW	Fresh Weight
G	Biomass
GHG	Greenhouse Gas
GIM	National Mission for a Green India
GIS	Geographic Information System
GOI	Government of India
GPS	Global Positioning System
IDMS	Inventory Data Management System
IPCC	Intergovernmental Panel on Climate Change
JFM	Joint Forest Management
JNR	Jurisdictional and Nested REDD+
LISS	Linear Imaging Self-Scanning
MoEFCC	Ministry of Environment Forest and Climate Change
MRV	Monitoring, Reporting and Verification
NAPCC	India's National Plan of Action on Climate Change

NATCOM	National Communication
NTFP	Non-timber Forest Products
OS	Operating System
P	Plot
PES	Payments for Ecosystem Services
PMRV	Participatory Measurement, Reporting & Verification
REDD+	Reducing Emissions from Deforestation and forest Degradation
RS	Remote Sensing
SES	Social & Environmental Standards
SOC	Soil Organic Carbon
tC^{-ha}	Tons of Carbon per Hectare
TNA	Training Needs Assessment
TTM	Tools, Techniques, and Methods
UNFCCC	United Nations Framework Convention on Climate Change
USAID	United States Agency for International Development
USDA	United States Department of Agriculture
UTM	Universal Transverse Mercator
V	Volume
VNIR	Visible Near Infra-Red
WD	Wood density

ABOUT FOREST-PLUS

The Partnership for Land Use Science (Forest-PLUS) program is a five-year initiative between the United States Agency for International Development (USAID)/India and Government of India (GOI). Forest-PLUS contributes to USAID/India's Development Objective of accelerating India's transition to a low emissions economy by providing technical assistance to develop, demonstrate, and institutionalize forest management practices. These practices:

- Reduce Green House Gas (GHG) emissions from forested landscapes;
- Increase sequestration of atmospheric carbon in forests;
- Protect forest biodiversity health; and
- Protect and/or enhance forest-based livelihoods, forest ecosystem services, and other social contributions of forests in India.

Forest-PLUS will help position India to participate in any final Reducing Emissions from Deforestation and forest Degradation (REDD+) mechanism.

Forest-PLUS develops improved tools, techniques, and methods (TTMs) for forest management with climate change mitigation benefits. Forest-PLUS Component I develops TTMs by facilitating scientific exchange and technical cooperation between India and the United States.

Forest-PLUS Component II deploys these TTMs in pilot landscapes to demonstrate and validate their effectiveness. Across both Components, Forest-PLUS develops and deploys TTMs in three general technical areas:

- Ecosystem approach to forest management (EAFM);
- Scientific data acquisition and analysis; and
- Forest governance and institutional structures.

Forest-PLUS includes capacity building and communications programs that develop and deploy TTMs for training and public awareness in all three technical areas. Forest-PLUS coordinates its work with the Ministry of Environment, Forests, and Climate Change (MoEFCC) and State Forest Departments.

TRAINING MODULES SYNOPSIS

Notes on the Resource Material

This document contains resource material for training Indian master trainers on the principles of forest carbon measurement, with an emphasis on involving community members. It was developed and deployed by the Forest-PLUS program, with the goal of training Indian Forest Service and State Forest Service officers in the principles of community engagement and forest carbon measurement so that they can engage community members through Joint Forest Management Committees or other institutions on forest measurement for carbon. Beyond that audience and purpose, the curriculum can be used by anyone working in Indian forestry with an interest in community carbon measurement.

The material is divided into three modules or main sections, with the first module explaining principles of training in a rural community, the second covering principles of forest carbon accounting using Forest-PLUS tools, and the third covering an application and field practicum. The material is designed to support a three-day training, to be used with the Forest-PLUS tools and protocols for remote sensing, inventory analysis, and data collection using mobile smartphone applications.

Module 1: Community Training Concepts

Module 1 combines community engagement approaches with basic elements related to carbon and REDD+. Effective participation for community involvement in forest carbon measurement starts, fundamentally, with communication and building a partnership with communities. This is not dissimilar to the basic tenets of Joint Forest Management (JFM) and Community Forest Management (CFM). Module 1 starts with these basic, yet important, fundamentals. Trainees will also learn the fundamental principles of REDD+ safeguards and community benefits. Understanding carbon not as an abstract concept but as another forest resource is also essential to developing collaborative, participatory engagement with communities in measuring forest carbon. Trainees will build a foundation of these core elements that support effective cooperation and co-development with communities.

Module 2: Principles of Forest Carbon Accounting Using Forest-PLUS Tools for Community Forest Carbon Measurement

Module 2 trains participants in the basic principles of forest carbon accounting, the two Forest-PLUS Protocols, and the deployment of the mForest App tools. Forest-PLUS has developed two protocols (2.2 Session II: Plot design protocol and

2.3 Session III: Forest carbon plot inventory and measurement protocol), three sampling methodologies (2.1.4 Forest Carbon Measurement) and a set of simple but robust tools supporting community forest carbon measurement. The two protocols specify: 1) the steps for laying out a plot and 2) the method for measuring tree parameters and litter used in estimating forest carbon. The three sampling methodologies support robust measurement of carbon stocks. Four tools or apps for recording plot inventory data are installed on an android device and collectively are called the mForest App (2.4 Session IV: mForest App).

Module 3: Application and Field Practicum

Module 3 provides guided hands-on field training in laying out a plot and using the mForest App. Training of Trainers includes the ability of trainees to implement the skills learned. Trainees will be graded on these skills as part of Module 3. Feedback from trainees will also be incorporated in developing the training material used for field testing in February 2016.

Training Schedule

Time	Session
	Day 1
09:00 - 09:15	Registration
09:15 - 09:30	Introductions
09:30 - 09:50	Overview of the training course
09:50 - 10:10	Training Expectations
10:10 - 10:30	Pre-training Survey
10:30 - 11:00	Tea break
11:30 - 11:45	Group photo
11:45 - 13:00	Module I Session I
13:00 - 14:00	Lunch Break
14:00 - 15:30	Module I Session II
15:30 - 16:00	Tea break
16:00 - 17:30	Module I Session III
	Day 2
09:00 - 09:30	Recap from Day 1
09:30 - 11:00	Module II Session I
11:00 - 11:30	Tea break
11:30 - 13:00	Module II Session II
13:00 - 14:00	Lunch Break
14:00 - 15:30	Module II Session III
15:30 - 16:00	Tea break
16:00 - 17:30	Module II Session IV
	Day 3
09:00 - 09:30	Recap from Day 2
09:30 - 10:00	Travel to field site
10:00 - 12:00	Module III Session I
12:00 - 13:00	Module III Session II
13:00 - 14:00	Lunch Break
14:00 - 15:30	Module III Session III
15:30 - 16:00	Travel back from field site
16:00 - 16:30	Tea break
16:30 - 17:40	Module III Session IV
17:40 - 18:00	Post-training Survey
18:00 - 18:30	Vote of Thanks and Certificate Ceremony

Module 1

Community Training Concepts

The module will cover the following:

- REDD+ and REDD+ Safeguards
- Fundamental understanding of carbon as a community forest resource
- Community benefits: access, tenure rights, benefit sharing
- Effective communication with communities
- Understanding and fostering communities as partners

1.0 MODULE 1: COMMUNITY TRAINING CONCEPTS

Duration

1 Full day (7-8 hours)

Module Summary

Module 1 presents core principles and tenets of working with communities, in particular those who take part in areas managed jointly with a forest department. Best practices are highlighted for community engagement in measuring forest carbon and co-managing forest areas. Trainees will learn the fundamental principles of (REDD+), REDD+ safeguards and community benefits. This includes access and tenure rights, benefit sharing, and Free Prior and Informed Consent (FPIC). This module also reinforces the concept that carbon is simply another forest resource from which local people can and do benefit.

Overall Module Learning Objectives

- REDD+ and REDD+ Safeguards;
- Community benefits: access, tenure rights, benefit sharing;
- Fundamental understanding of carbon as a community forest resource;
- Effective communication with communities; and
- Understanding and fostering communities as partners.

Training Format

- Lecture with PowerPoint;
- Exercises; and
- Discussion.

Topics

- Empowering Communities to Participate in Community-Based Forest Carbon Inventory;
- Primer on REDD+ and REDD-Readiness;
- Co-benefits of REDD+;
- Participatory Measurement, Reporting, and Verification (PMRV);
- Safeguards for REDD+ Initiatives;
- Fundamentals of Training Delivery;
- Needs Assessment Before a Training;
- Entering a Community;
- Community Resource Mapping Exercise;
- Carbon as a Community Resource;
- Ecosystem Services Concepts;
- Payments for Ecosystem Services (PES) Concepts;
- The Potential for Income from REDD+;
- Ownership of Carbon & Distribution of Carbon Benefits in JFM; and
- Discussion: Challenges and Opportunities for Community-Based Carbon Management.

Table 1-1: List of Learning Objectives for Each Lecture/Exercise for Module 1

Lecture/Exercise	Learning Objectives
I: Principles for Successful Engagement in Communities	• Fundamental understanding of the role of the trainers of community forest carbon measurement. • Essential background on REDD+, climate change, and climate change mitigation efforts in order to become specialists on the topics and inform communities why this work is being performed.

Lecture/Exercise	Learning Objectives
	• Awareness of the co-benefits of REDD+ and the safeguards in place to ensure their implementation. • Fundamental understanding of PMRV.
II: Training in a Community Context	• Fundamentals of delivering training in communities in India where REDD+ may eventually be implemented. • Sensitivity regarding working in rural areas with people of different cultural backgrounds than the trainer. • Equipping participants with tools and knowledge to implement an effective training program for adults in rural areas. • Knowledge of different forms of needs assessments. • Strategies for entering a community in a respectful manner.
III: Carbon as a Community Resource	• Essential background on ecosystem services concepts for establishing the mindset of conserving ecosystem function. • Fundamental understanding of the ecosystem service related to carbon sequestration by forest, the main driver of REDD+. • Fundamental understanding of payment for ecosystem services programs. • An understanding of how funds from a REDD+ program might be distributed. • Awareness of potential barriers related to land tenure and benefit distribution that could limit the implementation of REDD+.

1.1 SESSION I: PRINCIPLES FOR SUCCESSFUL ENGAGEMENT IN COMMUNITIES

Session I will cover the following topics:

1. Climate Change and Forestry
2. Essential Background on REDD+
3. REDD+ Readiness
4. Co-benefits of REDD+: Beyond Climate
5. What if REDD+ Does Not Happen? "No Regrets REDD+"
6. Safeguards for REDD+ Initiatives
7. The Importance of Participatory Measurement, Reporting & Verification in REDD+ (PMRV)
8. Empowering Communities to Participate in Community-Based Forest Carbon Inventory
9. Why Should We Involve Communities in Forest Carbon Inventories?
10. The Challenges of Working with Communities

In this session, essential background for climate change, forestry, and REDD+ is presented, as well as some of the uncertainties and contingencies surrounding REDD+. The reasons for engaging communities in forest carbon measurement are covered, as well as some of the unique challenges and solutions to that approach.

1.1.1 CLIMATE CHANGE AND FORESTRY

Climate change is arguably the toughest environmental challenge of the 21st century. One of the biggest contributors to climate change is carbon dioxide, of which the human race has produced increasing amounts since the industrial age. Trees decrease the concentration of carbon dioxide in the atmosphere by absorbing it from the air and converting it into oxygen, which they release, and carbon, which they store. Forests absorb 2.6 billion tonnes of carbon dioxide each year, about one-third of the carbon dioxide released from the burning of fossil fuels. Because of this natural process, healthy forests are a natural system to combat climate change. However, this great storage system also means that when forests are cut down, the impact is big. According to the fifth assessment report from the Intergovernmental Panel on Climate Change (IPCC), the land use sector (including agriculture, forestry, and land use change) currently accounts for 24% of global greenhouse gas (GHG) emissions. The GHG removal capacity of forests is decreased as forests are lost. Forests have **three major roles in climate change**:

1. They currently contribute to **global carbon emissions** when cleared, overused, or degraded (when managed sustainably);
2. They **produce wood fuels as a benign alternative to fossil fuels**; and
3. They have the potential to **absorb carbon emissions**.

Since forests and climate change are inherently linked, when kept healthy, forests play a key role in the national climate change strategy. However, loss of forests' ability to mitigate the effects of climate change will mean losing many important ecosystem benefits. Impacts on the well-being of forests likely to be caused by climate change will therefore have a dramatic effect. India is a mega-biodiversity country. It is essential that we recognize the value of this benefit by avoiding deforestation, restoring damaged forests, and maintaining healthy ecosystems. Managing forests to help them retain and increase their carbon storage potential can maximize their ability to mitigate climate change.

With nearly 173,000 villages classified as forest villages, there is a large dependence of communities on forest resources in India. The country has a large afforestation program of over 1.32 mha/annum, and more area is likely to be afforested under programs such as the "Green India Mission" and "Compensatory Afforestation Fund Management and Planning Authority"(CAMPA). Thus it is necessary to assess the likely impacts of projected climate change on existing forests and afforested areas, and develop and implement adaptation strategies to enhance the resilience of forests to climate change.

1.1.2 ESSENTIAL BACKGROUND ON REDD+

It is important to gain some context about the global initiatives to address climate change. About 24% of global emissions come from Agriculture, Forestry and Land Use Change (AFOLU). About 10% of global emissions come from land use change and forestry (Smith et. al. 2014). For this reason, stopping the conversion and degradation of forests and woodlands is critical to combating climate change.

REDD+ is an alternative to traditional approaches to stop deforestation in the tropics. REDD+ stands for: **R**educing **E**missions from **D**eforestation and forest **D**egradation. The "Plus (+)" was added to include conservation of stocks of forest carbon, enhancement of stocks of forest carbon, and sustainable management of existing forests (United Nations Framework Convention on Climate Change [UNFCCC], 2011).

A key idea behind REDD+ is to place a value on standing forests—not just those that are cleared for agricultural uses or wood products. By valuing the role that forest ecosystems play in the capture and sequestration of carbon, intact forests may compete economically with alternate land uses that result in their destruction.

Through REDD+, developing countries may receive a financial compensation of performance-based payment for any reduction of CO_2 emissions that come from a decrease in the deforestation and degradation of forests.

The primary goal of REDD+ is reduction of GHG emissions, consistent with the goal of the UNFCCC to achieve "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system" (1992).

One aim of community-based training and engagement is to realize a global vision to address climate change—at the most local level.

1.1.3 REDD+ READINESS

REDD+ is one of the few areas with a high level of global consensus in the international agreements and processes in which India participates. After 10 years of REDD+ development, many analysts expect that the climate change mitigation agreement from Conference of the Parties (COP) 21 in Paris will result in concerted action to implement and fund REDD+.

Optimistic that a full REDD+ program will be approved in the near future, India is one of many countries that are participating in so-called "REDD readiness" capacity building. REDD+ readiness is the process of determining and filling the gaps among existing social, technical, and institutional capacities and those that may be required for participation in an eventual REDD+ mechanism. Some of these activities include:

- Planning and outreach to stakeholders;
- Expanding technical capacity for mapping, measuring, monitoring, and verifying carbon stocks; and
- Developing sub-national REDD+ demonstration projects.

India is involved in all of the above.

1.1.4 CO-BENEFITS OF REDD+: BEYOND CLIMATE

REDD+ is expected to bring much more than emissions reductions; a properly designed mechanism is expected to contribute to multiple benefits. Depending on the location and type of REDD+ activity, these co-benefits potentially include:

- Poverty alleviation;
- Indigenous rights;
- Improved community livelihoods;
- Technology transfer;
- Sustainable use of forest resources; and
- Biodiversity conservation (Murphy, 2011).

1.1.5 WHAT IF REDD+ DOES NOT HAPPEN? "NO REGRETS REDD+"

Because there is no guarantee that REDD+ will be approved and funded, it would be wise for the Government of India (GOI) to pursue a "No regrets REDD+" agenda. Much of REDD+ readiness is excellent forest policy, even if reducing carbon emissions is a low priority. By pursuing REDD+, India will experience the following benefits:

- Promote conservation by removing "perverse" subsidies to forest destruction and degradation;
- Improvement of forest governance and reduction of corruption;
- Clarification of land tenure;
- Expansion of data on forests; and
- Expansion of capacity for sustainable forestry (Evans, 2012).

1.1.6 SAFEGUARDS FOR REDD+ INITIATIVES

The Cancun Agreements from COP 16 included a set of seven safeguards to be promoted and supported when undertaking REDD+ activities. Known as **the Cancun Safeguards**, these safeguards are intended to minimize, mitigate, and manage social and environmental risks and impacts and enhance the benefits of REDD+ to all, with special emphasis on the poor, women, and indigenous groups (UNFCCC, 2011; Murphy, 2011).

The Cancun Safeguards contain important concepts that inform the actions of practitioners who implement REDD+ activities. Although extremely valuable, the actual Cancun Safeguards are written in formal language targeted at policymakers. Over the past few years, other standards for REDD+ initiatives – with the very same goals in mind - have been developed with language more suited to practitioners. One of these standards is the REDD+ Social & Environmental Standards (REDD+ SES), developed by the NGOs CARE and the Climate, Community & Biodiversity Alliance.

Like the Cancun Safeguards, REDD+ SES enable stakeholders to design and implement REDD+ programs at any level that respect the rights of indigenous peoples and local communities and create significant social and environmental benefits while reducing risks.

The core principles of REDD+ SES are:

1. Rights to lands, territories, and resources are recognized and respected by the REDD+ program.
2. The benefits of the REDD+ program are shared equitably among all relevant rights holders and stakeholders.
3. The REDD+ program improves long-term livelihood security and well-being of Indigenous Peoples and local communities with special attention to the most vulnerable people.
4. The REDD+ program contributes to broader sustainable development, respect, and protection of human rights and good governance objectives.
5. The REDD+ program maintains and enhances biodiversity and ecosystem services.
6. All relevant rights holders and stakeholders participate fully and effectively.
7. All rights holders and stakeholders have timely access to appropriate and accurate information to enable informed decision making and good governance of the REDD+ program.
8. The REDD+ program complies with applicable local and national laws and international treaties, conventions and other instruments (CARE and Climate, Community & Biodiversity Alliance [CCBA], 2011).

1.1.7 THE IMPORTANCE OF PARTICIPATORY MEASUREMENT, REPORTING & VERIFICATION IN REDD+ (PMRV)

An important principle in REDD+ is "payment for performance." The vision for REDD+ is that the countries able to reduce deforestation and forest degradation, expand sustainable forest management and enhance carbon stocks, should receive appropriate compensation. How is this accomplished?

In order to determine payments, carbon stocks are subject to:

- **M** for Measurement;

- **R** for Reporting; and
- **V** for Verification.

To ensure that emissions reductions are not just real but also additional and permanent, forest carbon stocks must be measured (Angelsen et al., 2008). This data that is collected must be reported on a periodic basis in a transparent and consistent manner that conforms to the reporting requirements. Furthermore, a stringent verification process that follows established standards should be carried out by an independent, extra-national organization.

This curriculum advocates a participatory measurement, reporting, and verification (PMRV) approach that involves local people in the measurement, reporting, and verification of forest carbon stocks that are needed to assess the impact and co-benefits of REDD+. The goal is to increase local participation so REDD+ co-benefits will increase (Hawthorne & Boissière, 2014). An additional benefit of PMRV involves the ability to utilize the collected data to inform local management decisions (Danielsen et al., 2009).

1.1.8 EMPOWERING COMMUNITIES TO PARTICIPATE IN COMMUNITY-BASED FOREST CARBON INVENTORY

The GOI has actively participated in discussions about the role of forests in addressing the global problem of climate change. India's National Plan of Action on Climate Change (NAPCC) includes a National Mission for a Green India (GIM) that would "enhance carbon sinks in sustainably managed forests and other ecosystems." Meanwhile, the MoEFCC 2014 National Working Plan Code defines standards for forest management that include "conservation of forests and reducing forest degradation, maintenance and enhancement of ecosystem services, […] increasing the growing stock and carbon sequestration potential, [and] **people's involvement in planning and management of forests,** fulfilling socio-economic and livelihood needs."

These socio-economic and livelihood needs are indeed significant. Nearly 300 million Indians rely on forests for their livelihoods, including around 87 million tribal people (Government of India, 2013). The forests of India are of critical importance to the country in myriad ways as:

- An important part of Indian culture and identity;
- A source of ecosystem services that support human life; and
- A storehouse for incredible biodiversity.

At the 2009 United Nations Climate Change Conference of the Parties (COP 15), climate talks in Copenhagen, the UNFCCC agreed to mobilize a **Green Climate Fund** in the amount of US$100 billion per year by 2020 to address the needs of developing countries to mitigate and adapt to climate change. India is participating in this "compensated conservation" approach and is making preparations to utilize these funds to maintaining and increase carbon stocks in forests.

Training in community-based carbon measurement serves as a specific bridge for forest conservation. On one side of the bridge are the global vision to address climate change and the GOI's plan to implement that vision. On the other side of the bridge are the communities that depend on forests and all of the wealth of ecosystem services and forest products that they provide. We use community in this document to mean a group of interacting people with a common location, interests, ethno-cultural or religious affinity, and language.

Potentially, the Green Climate Fund and other global climate mechanisms will make benefits available down to the community level. With local empowerment, these communities will:

- Gain the capacity to measure the amount of carbon stored in their forests;
- Increase their capacity for community-based sustainable forest and natural resource management;
- Prepare to access funds and other benefits in exchange for conserving and increasing carbon stocks in forests;
- Understand how global climate mechanisms such as REDD+ will affect communities;
- Understand community rights under global climate mechanisms; and

- Understand the importance of ecosystem services provided by forests, including carbon sequestration.

1.1.9 WHY SHOULD WE INVOLVE COMMUNITIES IN FOREST CARBON INVENTORIES?

There are at least three sound reasons to involve communities in forest carbon inventories:

1. Research worldwide and experience in India supports the contention that forest governance with significant local input is more effective. Higher levels of local monitoring and enforcement of locally made forest use rules leads to improved forest restoration and regeneration and reduction of forest degradation. In addition, strong rule-making autonomy at the local level (and not rules imposed solely by government) is the key predictor of both better forests and yield of goods and services to support livelihoods of local people. As such, co-management committees in communities that have local rule-making, local monitoring, and local enforcement are seen to be more likely to succeed in their efforts directed toward better forests and improved livelihoods.
2. Involvement by communities reduces the cost of managing a forest carbon project. If less money is spent on bringing in experts from outside of the community—or even the country—more resources can go directly to the community.
3. Direct involvement in the measurement and conservation of forest on which they depend for their livelihoods will increase 1) a community's rights and access to carbon benefits; 2) awareness of the importance of wise and sustainable management of ecosystem services, such as the relationship with fuel wood and charcoal availability; and 3) the level of buy-in by the community to low carbon forest management initiatives.

1.1.10 THE CHALLENGES OF WORKING WITH COMMUNITIES

Trainers often encounter a cultural context in rural communities that is very different from their own. Their first language or customs may be different. Although each individual is intelligent, capable, and in possession of his or her own strengths, it is likely that nobody possesses a trainer's level of expertise in this field.

The fact that trainers are experts in their field does not mean they are automatically an expert in teaching another person about their field of expertise. People who facilitate participatory processes should use special communication skills in their work. These skills can be improved with practice. To address these needs, we provide in this course strategies for the effective delivery of training material in a rural community setting and explore communication techniques used by professional facilitators and apply them to community forest-carbon measurement.

1.2 SESSION II: TRAINING IN A COMMUNITY CONTEXT

Session II will cover the following topics:

1. Fundamentals of Training Delivery
2. Good Practices for Trainers
3. Basics of Training
4. Needs Assessment before a Training
5. Entering a Community

1.2.1 FUNDAMENTALS OF TRAINING DELIVERY

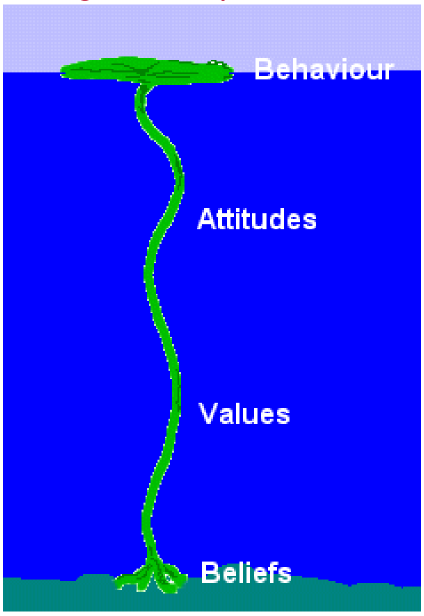
This Session provides some basic tips for trainers in how to deliver material to communities or Trainers of Trainers. In this session we explore the fundamentals of delivering training in communities. We explore good practices for trainers, basics of training with emphasis on adult learners, performing needs assessments before trainings, and strategies for entering a community.

1.2.2 GOOD PRACTICES FOR TRAINERS

Understanding Differences

The *lily pad model,* as illustrated Figure 2-1, is an excellent way to understand the differences in behaviors, beliefs, values, attitudes that we will see when working with people who are different from us.

Figure 2-1: Lily Pad Model



The leaf floating on the surface of the water is the behavior that we see from people—how people conduct themselves, how they react to a situation, etc. From above, you do not see what is below the surface—the attitudes, values and beliefs. The underwater high stalk of the lily pad represents the attitudes—assumed or learned perspectives—that a person has towards the world. Attitudes, which are not easily changed, may change after one is exposed to new information or experiences. The underwater low stalk represents values. Values are deeply held views about what is desirable, right, or important. Finally, the roots of the lily pad in the lakebed are the most deeply held beliefs. These beliefs are assumptions that people develop about themselves, about others in the world, and about how they expect things to be. These are ideas taken for granted (Cheek, 2007).

Promoting a Learning Attitude

Success in your training experience will be more likely if you engage the community and value their contributions to the process. You can promote a learning attitude by promoting the following values:

1. Value diversity (incomes, gender, age, ethnicity, age, etc.);
2. Provide a welcoming, safe, and comfortable environment for all;
3. Listen and learn from others;
4. Accept differences and value the opinions of all people;
5. Recognize and value the experiences of others; and
6. Value traditional and local knowledge.

The Value of Transparency

Another value that is important for a successful training experience is transparency. You can promote transparency by working to develop the following:

1. Honesty and openness to different ideas and perspectives;
2. Trust building; and
3. Compromise and consensus among your group members through effective communication.

Working in an Ethical Manner

Ethics are norms for conduct regarding behavior that is acceptable or unacceptable. As professionals, you carry a higher level of responsibility than members of the general public. Therefore, we must always follow the highest ethical standards, including:

1. Being open and honest;
2. Obtaining informed consent;
3. Prioritizing local values, concerns, and needs;
4. Not raising false expectations; and
5. Not exposing people to danger.

Involvement of Women

Generally speaking, state policies have had a significant impact on women's rights to forest resources due to changes in forest management, loss of forest resources, and changes in livelihoods. Because women depend on forest resources for their families' livelihood and their social status, they have become more economically, socially, and politically marginalized as their traditional rights to the forest have diminished. For these reasons, we should work hard to actively involve women in our work.

Effective Communication

Trainers can employ a wide range of strategies in order to communicate effectively with participants. Using active listening, the trainer:

1. Listens to participants and reflects back what participants say or ask;
2. Helps the participants to feel that they are heard;
3. Encourages participants to speak and contribute and makes them feel heard; and
4. Uses active learning questions that are open-ended, supportive, clarifying, re-stating, summarizing, and validating.

Using effective verbal language, the trainer must:

1. Speak in a language easily spoken by everyone, or use qualified translators;
2. Speak clearly and at an appropriate volume;
3. Stand/sit where everyone can see and hear; and
4. Verify that participants understand what is being said.

1.2.3 BASICS OF TRAINING

General recommendations regarding training events for adults are as follows:

1. Training events should be short, ideally about 90 minutes.
2. It is critical to involve all important stakeholders.
3. Building local capacity and training trainers are important goals.
4. The program should move from general to specific, simple to complex, and easy to difficult.
5. The material should correspond to the trainees' abilities.
6. The tone and environment of a training should be supportive, positive, and encouraging.

Education vs. training. Education is broad and general; training is shorter and more specific and has *concise* objectives.

Considerations about adult learning:

1. Adults feel comfortable controlling their own learning.
2. Adults need to see the relevance of the training.
3. Motivation for adults is internal.
4. Trainings should relate to the real-life working experience of adults.
5. Adults generally appreciate active engagement in learning experiences.
6. Earlier experiences provide an excellent resource for learning.
7. Training that provides satisfaction promotes effective learning.

8. Adults generally appreciate experiential learning.
9. Adults like to compare their achievements with a standard.
10. The attention span of an adult is about 1.5 hours.

Working and thinking as a group. A number of strategies can be employed in order to promote effective communication between the trainer and the group. Strategies include:

1. Using a recorder, who:
   a. Captures ideas in the "group memory";
   b. Notes the group's key words and phrases;
   c. Remains neutral and does not participate;
   d. Asks the group to slow down or clarify, if needed; and
   e. Assists the trainer to keep track of information.
2. Keeping track of the group memory because it:
   a. Provides the group with a visual record;
   b. Can be used as minutes;
   c. Helps the group to focus;
   d. Legitimizes participants' ideas;
   e. Depersonalizes ideas;
   f. Provides a non-human target for criticism;
   g. Prevents repetition; and
   h. Is low cost and simple to implement.
3. Making decisions as a group:
   a. Brainstorm and build on the group's ideas;
   b. Prioritize the most important ideas together; and
   c. Arrive at conclusions that have consensus (Barkai, undated).

Understand community dynamics. True engagement of a community is challenging but worth the effort and essential to increasing the benefits of REDD+. First, a definition of community: A community is a group of interacting people with common location, interests, ethno-cultural or religious affinity, and language.

Common assumptions are that communities are:

1. Harmonious;
2. Homogenous;
3. Inclusive; and
4. Willing to participate.

PMRV could:

1. Result in hostile reactions from different communities;
2. Be easily dominated by the most powerful; and
3. Be difficult to manage in certain communities.

The trainer's role is to understand these complexities in communities and work with them. The trainer must know who is who, why participants do or do not participate, and what must be done to ensure equal opportunities and support for all who participate.

1.2.4 NEEDS ASSESSMENT BEFORE A TRAINING

Why Conduct a Training Needs Assessment?

A Training Needs Assessment (TNA) offers guidance for a productive training event. A TNA can provide the trainer with:

1. An assessment of the knowledge base among the community members;
2. Baseline data for planning content and scope of training;
3. Information about the economic, political, social, and cultural environment; and
4. The human and physical resources that are available.

Approaches to Training Needs Assessment

Common approaches to TNAs include interviews, questionnaires, observations, and skills/knowledge tests. Each approach has advantages and disadvantages.

1. Interviews
   a. *Pros:* Provide in-depth information and can be performed in groups.
   b. *Cons:* Is labor-intensive and can favor outspoken people.
2. Questionnaires
   c. *Pros:* Information can be collected from a large group.
   d. *Cons:* Free expression is limited and can be misleading where literacy is limited.
3. Observations
   e. *Pros:* Skills, attitudes, and behaviors can be observed directly.
   f. *Cons:* Can be time-consuming and labor-intensive.
4. Skills/Knowledge Tests
   g. *Pros:* Provide in-depth information and can be performed in groups.
   h. *Cons:* Free expression is limited and can be a misleading where literacy is limited.

1.2.5 ENTERING A COMMUNITY

Building a strong relationship with communities is key for establishing a successful participatory process. Time must be invested to ensure that the communities are prepared to participate, have a strong understanding of the process, and can see how the training is relevant to their lives. The steps to entering a community are:

1. Establish contacts in the community:
   a. Make initial contact with community leaders who can introduce you to the wider community;
   b. Build rapport between the outsiders and insiders; and
   c. Share as much information as possible in a transparent manner and allow for questions to ensure buy-in by community.
2. Become familiar with the community surroundings:
   a. Take transect walks or drives with local people;
   b. Participate in daily activities in the community;
   c. Listen to and engage in conversations in public spaces; and
   d. Stay overnight if possible to learn about local history and customs.
3. Identify community support structures:
   a. It is useful to work through existing community support structures; and
   b. Seek ways to make community support more inclusive for marginalized people.
4. Manage community relations:
   a. Communities will participate in processes if they are clear about purposes and outcomes;
   b. Clarify objectives and benefits to avoid creating false expectations;
   c. Become informed about past projects that did not improve the local situation as promised; and
   d. Clarify what the training can and cannot offer.
5. Use the findings from the training and participation in community forest carbon measurement:
   a. Encourage the community to envision how involvement in this training and in community forest carbon measurement will improve their community in the long run.

1.3 SESSION III: CARBON AS A COMMUNITY RESOURCE

Session III will cover the following topics:

1. Introduction
2. Ecosystem Services Concepts
3. Payments for Ecosystem Services (PES) Programs
4. The Potential for Income from REDD+
5. Ownership of Carbon and Distribution of Carbon Benefits
6. Discussion: Challenges and Opportunities for Community Based Carbon Management

1.3.1 INTRODUCTION

In this session, we explore the role of carbon as a community resource. An important role for you as a trainer is to help communities to understand the implications of a community's involvement in a forest carbon initiative involving REDD+. To this end, one must understand the full range of ecosystem services provided by forests and how, in a REDD+ initiative, a community is working to leverage the particular service of carbon sequestration (i.e., removing carbon dioxide from the atmosphere and storing it in forest ecosystems).

We further illustrate how payment for environmental services (PES) schemes work. In PES programs, forest—and sometimes other—resource owners and related stakeholders are compensated for conserving the resource that provisions the environmental service directly to the community and/or the wider world. In our case, we will focus on the payment for carbon stored in forests.

Because a community might potentially receive a payment in a REDD+ initiative, we will discuss the implications of this on a community. In this context, we will discuss use rights, land tenure considerations, and benefit distribution.

1.3.2 ECOSYSTEM SERVICES CONCEPTS

Historically, the greatest sources of economic value from forests have been their liquidation via intensive extraction of timber and other forest products, not to mention the clearing of forests for conversion to agriculture and other non-forest uses. In general, lesser value has been placed on healthy, functioning forest ecosystems.

To a large degree, forests provide benefits – ones essential to human survival – that are taken for granted. The typical forest landowner around the world that conserves forests is essentially providing a trove of benefits – in an altruistic manner, without receiving benefit in return - to the surrounding community, not to mention humankind worldwide. This situation has arisen because historically, the global economic system has focused primarily on the structural elements of forests and ignored their function. However, the structural and functional elements of ecosystems are interdependent. The structural elements of a forest ecosystem – individuals and communities of plants and animals – act together to make a 'whole' that is greater than the sum of its parts. These emergent properties of ecosystems are called ecosystem functions, including activities such as atmospheric gas regulation (e.g. oxygen and carbon dioxide), climate regulation, nutrient cycling, photosynthesis and the water cycle. These emergent properties of forest ecosystems manifest themselves as beneficial to humans in these more concrete ways:

1. Supplies of clean ground and surface water for human use, including a more regular supply during the dry season;
2. Waste treatment;
3. Regulation of air quality;
4. Regulation of extreme temperatures and humidity levels;
5. Maintenance of local soil nutrients;
6. Provision of stable environmental conditions amiable to biodiversity, important non-timber forest products and habitat for game animals;
7. Buffering from the effects of high-intensity weather events (e.g., cyclones, flood-causing rainfall);
8. Spiritual, educational, aesthetic and religious values; and
9. A renewable source of food, fuel, and fiber.

For our work, it is important to understand the difference between the following types of biotic resources:

1. **Renewable resources**: the elements of ecosystem structure that provide the raw materials valued by humans for use in economic processes.
2. **Ecosystem services**: the ecosystem functions (as outlined above) that are generated by the interacting elements of ecosystem structure and are of value to humans.

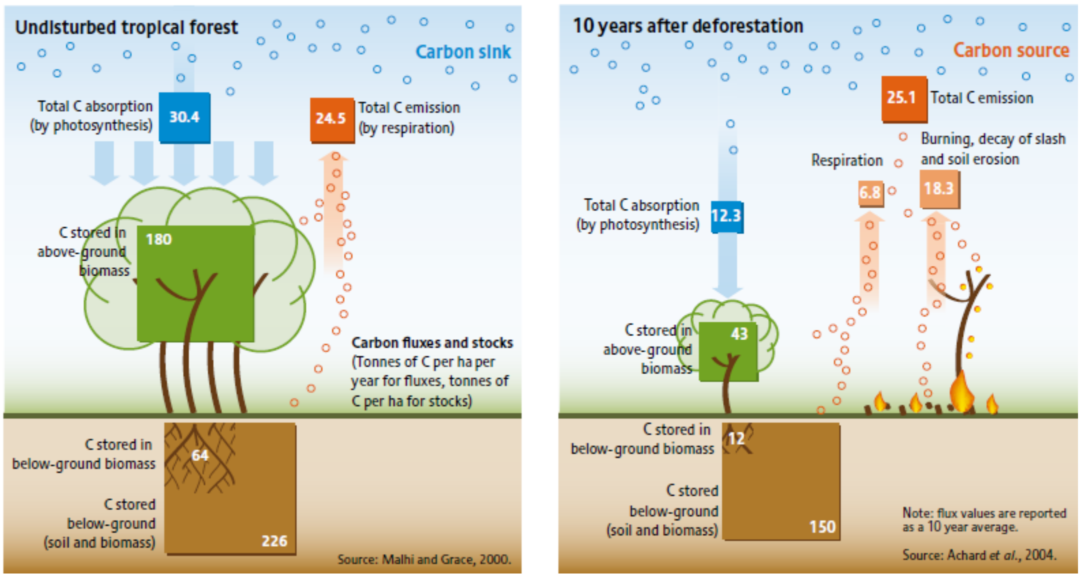
In REDD+ programs, forests can still be utilized for their renewable forest resources (e.g., fuelwood, timber, non-timber forest products [NTFPs], etc.), but the exploitation must be done at a sustainable level (i.e., with net growth exceeding extraction). We discuss this aspect further, and explain how measurement and carbon inventory can be used as a tool to maximize the information needs to sustainably harvest some forest areas for fuelwood and charcoal production for community benefits.

More closely tied to the aims of REDD+, the forest serves as a provider of services to sequester and store carbon, including removing it from the atmosphere under certain management approaches. A priority of REDD+ programs is to maximize the forest's potential to provide ecosystem services. By reversing deforestation and forest degradation, the result is a net increase in the provision of ecosystem services. While all ecosystem services are important, the dominant one in REDD+ is the GHG regulation function: the absorption of atmospheric carbon dioxide and storing carbon in biomass and soils. This can be done by promoting an increase in forest cover and quality, which in turn increases the gas regulation potential of the forest ecosystem.

Undisturbed and regenerating forests can act as carbon sinks (i.e., storage places) that remove a net amount of carbon dioxide from the atmosphere and sequester it in biomass and soils, thus mitigating climate change. Deforested areas and degraded forest act as carbon sources that add carbon dioxide to the atmosphere, thus contributing to climate change.

It is also important to note that ecosystem services are extremely difficult to substitute. It would be impossible for humans to find an alternative way to supply all of the ecosystem services provided by forests. Imagine the difficulty and cost of developing a technology that could not only sequester carbon but also control flooding and erosion and provide purified water and habitat for countless animals and plants. These are services that are a prerequisite to human survival. Because these ecosystem services are so valuable, a large part of the work in communities will involve educating people to understand the distinction between ecosystem structure and function, and between renewable resources and ecosystem services. These concepts should form the basis of a holistic resource planning process in communities that involves sustainable resource exploitation while maintaining key ecosystem services.

Figure 2-2: Illustration of Intact Forests as Carbon Sinks and Destroyed Forests as Carbon Sources



(Bates 2013)

1.3.3 PAYMENTS FOR ECOSYSTEM SERVICES (PES) PROGRAMS

REDD+ is an example of a payment for environmental services program, or PES. In PES, a mechanism is established to enable parties—individuals, companies, organizations, or governments—wanting a particular ecosystem service to enter into a contract with resource owners, paying for the provision of the particular ecosystem service.

In REDD+, funding is projected to come from the global community of nations seeking to harness the power of forests to mitigate climate change on a global level. Those funds are "payments for results." An increase in the amount of healthy forests that grow and sequester carbon results in a payment per ton of carbon sequestered.

REDD+ is one of many schemes that aims to place a monetary value on the carbon sequestration service that forests perform. Other schemes include payments for conservation of biodiversity and watershed protection for provision of clean water.

1.3.4 THE POTENTIAL FOR INCOME FROM REDD+

Because funds for REDD+ may eventually arrive in the community in which you will work, this early juncture is a good time to begin the conversation about the implications of an infusion of external capital.

It is important to speak in realistic terms and not raise expectations. While a REDD+ program is certainly probable, it is by no means guaranteed, and it may take several years to realize. Additionally, it takes time for a project to get off the ground. After measuring the carbon baseline, initiatives must be put in place to improve the quality and quantity of forest ecosystems. Then, these forest ecosystems need time to sequester carbon. Conserving the forests that lock up carbon in trees on a large scale is a long-term initiative!

Even if funds do arrive in a community, there is no guarantee what form they will take. Although a payment for carbon sequestration might arrive as a cash payment, it might arrive in the form of investment that seeks to:

1. Increase capacity for territorial planning and management;
2. Develop the forest-based supply chain;
3. Improve legal and political frameworks;
4. Monitor and evaluate activities and policies; and
5. Provide technical support for low-emissions development, e.g., in NTFPs, sustainable agriculture, agroforestry systems, fire management, ecotourism, etc. (Line, 2015).

At this point, keeping expectations realistic about benefits from REDD+ arriving in the communities is the most prudent approach.

1.3.5 OWNERSHIP OF CARBON AND DISTRIBUTION OF CARBON BENEFITS

The issue of distribution of benefits from REDD+ to communities is a complex one. Here we will merely touch on the potential challenges of guaranteeing an equitable distribution of benefits from REDD+. Community leaders should be informed about these potential challenges so that they can begin preparing themselves for future engagement on the topic.

The idea behind Community-Based Forest Management (CBFM) is to create space for community participation, emphasizing the sharing of control, responsibilities, and decision-making authority over forest between the government and local user groups. Since the late 1980s, CBFM has been successful in numerous ways, including the active involvement of previously excluded stakeholders, increased forest productivity and regeneration, improved provision of valuable ecosystem services, greater biodiversity of plant and animal species, and greater availability of NTFPs. CBFM has also generated significant employment, including in isolated rural areas.

Despite these gains, numerous contravening issues remain in CBFM. Studies have revealed that most economic benefits go to the most influential community members. In some areas, orthodox timber production practices exist rather than a pro-poor and livelihood-oriented forest management system. In contrast, recall the REDD+ safeguard outlined previously: "The benefits of the REDD+ program are shared equitably among all relevant rights holders and stakeholders." This current state of inequitable distribution of economic benefits must be remedied in order to move forward with REDD+.

Also, well-defined land tenure and active participation of the stakeholders are of utmost importance. In a REDD+ program, all forest area that will claim carbon benefits must have clearly defined property rights that have been accepted by the local communities, verified by the local institutions and legally recognized by the government.

1.3.6 DISCUSSION: CHALLENGES AND OPPORTUNITIES FOR COMMUNITY BASED CARBON MANAGEMENT

Discussion Topics

1. Do programs exist in India to deliver benefits of REDD+ using existing programs and governance structures?
2. Can widespread monitoring and verification by communities be realized? Why or why not?
3. Can benefits be shared equitably in communities? Why or why not?
4. How can women play a significant role?
5. What is the "reality" of JFM in the communities in which you have worked?

Module 2

Forest Carbon Measurement

The module will cover the following:

- Forest Carbon accounting
- Forest Carbon plot design
- Forest carbon plot inventory and measurement
- mForest, a mobile application for carbon measurement

2.0 MODULE 2: FOREST CARBON MEASUREMENT FOR REDD+

Duration

1 full day (8 hours)

Module Summary

Module 2 covers the fundamentals of forest carbon mensuration and accounting with an emphasis on making the material accessible and useful for Indian forests. It assumes use of certain Forest-PLUS tools and techniques to aid in land cover classification, sampling, and forest inventory. The material emphasizes plot layout and field measurement, but gives an introduction to the methods required for sampling using a stratified random sample and to the remote sensing techniques used for stratification and monitoring stock changes. If there is interest in understanding the theory underpinning these heuristics, readers are referred to Lohr (2010) for sampling; Avery and Burkhart (1994) for forest measurements; and to Pierson, Brown, and Birdsey (2007) for a good general treatment of the measurement of carbon sequestration in forests.

Module 2 starts with an introduction to the terms carbon pools and fundamentals of forest carbon accounting from a carbon stocking perspective. It includes the basics of forest carbon accounting (plots, tree inventory and measurements, allometric equations, and converting biomass or volume to carbon values). In-depth training will be given regarding plot layout design and forest carbon measurements. Trainees will also be shown a demo of the mForest App, receive training in using the mForest App, and practice inputting data to the device.

Training Format

- Lecture with PowerPoint;
- Discussion; and
- Practicum with the mForest App.

Topics

- Forest carbon accounting – basics;
- Forest-PLUS plot design protocol;
- Forest-PLUS forest carbon plot inventory and measurement protocol; and
- mForest App.

Overall Module Learning Objectives

- Fundamental information on forest carbon accounting;
- Detailed knowledge and training in the Forest-PLUS plot design protocol;
- Detailed knowledge and training in the Forest-PLUS forest carbon plot inventory and measurement protocol; and
- Detailed knowledge and training in using the mForest App.

Table 2-1: List of Module 2 Lecture/Exercise and Reading Material for Each Session Subject

Module 2: Session	Lecture/Exercise	Supplemental Reading Material
I: Forest Carbon Accounting	• Pools of forest carbon • Forest carbon accounting fundamentals • Three sampling methods	• Intergovernmental Panel on Climate Change. (2003). Good practice guidance for land use, land-use change and forestry. Institute for Global Environment Strategies, Kanagawa, Japan. • Intergovernmental Panel on Climate Change. (2006). 2006 IPCC guidelines for national greenhouse gas

Module 2: Session	Lecture/Exercise	Supplemental Reading Material
		inventories. Institute for Global Environment Strategies, Kanagawa, Japan. • Picard, N., Saint-André, L., & Henry, M. (2012). Manual for building tree volume and biomass allometric equations: from field measurement to prediction. • Pearson, T., Walker, S., & Brown, S. (2005). Sourcebook for land use, land-use change and forestry projects. • Lohr, S. L. (2010). Sampling: design and analysis (2nd ed.). Boston, MA: Brooks/Cole. • Pearson, T., Brown, S., and Birdsey, R. (2007). Measurement guidelines for the sequestration of forest carbon. USDA Forest Service 39 Northern. Retrieved from http://www.nrs.fs.fed.us/pubs/gtr/gtr_nrs18.pdf. • Avery, T.E., and H.E. Burkhart (eds.). 1994. Forest Measurements, 4th edition. McGraw-Hill, New York.
II: Plot Design	• Plot design protocol for Tier 3 forest carbon data	• Training Manual
III: Plot Measurement and Inventory	• Forest carbon plot inventory and measurement protocol for Tier 3 forest carbon data	• Training Manual
IV: mForest App	• Description of the mForest App tools • Integration of mForest App data collection to the Forest-PLUS DMS • Using the mForest App	• Training Manual

2.1 SESSION I: FUNDAMENTALS

Session I will cover the following topics:

1. Introduction
2. REDD+ terms
3. Forest Carbon Pools
4. Forest Carbon Measurement
5. Forest Carbon Monitoring
6. Setting a Historical Baseline
7. Reporting Emissions
8. Session I Training Exercises

2.1.1 INTRODUCTION

Forest carbon accounting is the recording and reporting of changes in forest carbon stocks. Carbon accounting requires rigor and scientific principles such as consistency, completeness, accuracy, and validity. Forest carbon stocks are most commonly reported in metric tons of carbon per hectare with the notation tC^{-ha}.

2.1.2 REDD+ TERMS

Activity Data

Activity data for REDD+ activities refers to the area change data, expressed in hectares per year. It should also include trends for deforestation, degradation, and forestation. It is used to generate inventories of GHG emissions and removals and can be used in combination with emissions/removal factors to calculate historic emissions estimates for REDD+.

Emission Factors

GHG emissions and/or removals per unit area, for example tons of carbon dioxide (CO_2) emitted per hectare of deforestation. These can be derived from the carbon stock measurements from plot inventory data for each stratum.

Tiers and Types of Carbon Data

When possible, ground measurements are used to estimate stocks of carbon in forest strata and forest types. In IPCC terminology this would be referenced as Tier 3 data. However, when Tier 3 data are not available, Tier 2 data, such as the national forest inventory data from Forest Survey of India (FSI) stratified by forest cover type using the FSI forest cover layers can be used. In the case where large areas are being measured and monitored and neither Tier 3 nor Tier 2 data exist, IPCC default Tier 1 data from the published tables in IPCC (2003) or IPCC (2006) can be used.

2.1.3 FOREST CARBON POOLS

Forest carbon is stored in living biomass, dead organic matter and soil. From these three forest components, five pools of forest carbon are identified as:

1. Living Biomass:
   a. Above-ground biomass (AGB); and
   b. Below-ground biomass (BGB).
2. Dead Organic Matter:
   a. Litter; and
   b. Deadwood.
3. Soil:
   a. Soil Organic Carbon (SOC).

Living Biomass

Above-Ground Biomass (AGB)

Definition: "All living biomass above the soil including stem, stump, branches, bark, seeds, and foliage." (IPCC 2003); "All biomass of living vegetation, both woody and herbaceous, above the soil including stems, stumps, branches, bark, seeds, and foliage." (IPCC, 2006)

Above-ground biomass (AGB) is calculated using plot level tree inventory data and may include shrub data, though the carbon stock of shrubs is generally a small fraction of the AGB in forest ecosystems. Tree dendrometric measurements are used in allometric equations that compute AGB. A fraction of tree biomass is carbon. The UNFCCC IPCC default value for the carbon fraction for trees is 0.47. Shrub counts and general class are used with carbon estimates either from scientific literature or derived from destructive sampling.

Example of carbon stock for a tree: a tree that is estimated at 300 kilograms or .3 tons is estimated to be 141 kg of carbon or 0.141 tons of carbon. A forest inventory plot that is .05 ha in size that had 15 trees that all weigh 300 kg each totaling 4,500 kg or 4.5 tons would have a carbon stock value of 42.30 tC^{-ha}.

$$CS_p = ((AGB_{kg}/1000) * Cf) * (1\ ha/P_{m2})$$

Where,

CS_p	Carbon stock for a single plot: noted in tons of carbon per hectare, tC^{-ha}
AGB	Above-Ground Biomass: on a per tree basis, the value is noted in kilograms calculated using tree dendrometric measurements and allometric equations. The sum of AGB for all trees inside the plot in metric tons (converting kilograms to metric tons)
Cf	Carbon Fraction of Biomass, 0.47
P	Plot: unit area in terms of square meters or converted to hectares

Example:

CS_p =	AGB_t *	Cf *	(1 ha / P_{ha})
42.3	4.5	0.47	20

Term	Value	Note
CS_p	Computed	Carbon Stock for the plot (tC^{-ha})
AGB_{kg}	4,500	Sum of all tree biomass in plot
AGB_t	4.5	Divide AGB_{kg} by 1000
Cf	0.47	Carbon Fraction of biomass (IPCC default)
P_l (dimension in m)	25	Length
P_w (dimension in m)	20	Width
P_{m2} (area in m^2)	500	Multiply length x width
P_{ha} (area in ha)	0.05	Divide Area in m^2 by 10000

Shrubs

Shrubs are considered in the living biomass pool but distinguished from trees in that over the course of their life they never grow to meet the minimum height threshold to be included in the tree pool.

The size of the shrub pool has been estimated using 1) point-intercept and line-intercept methods along transects, 2) visual cover estimates in fixed area units, 3) diameter measurements in fixed-area sampling plots (Hoover, 2008). The third method will give the most precise estimate if implemented with sufficient sampling effort. Shrub diameters can be measured in a subset or the full plot of a fixed-area plot, and extrapolated to the strata using methods provided here for above-ground biomass. Allometric equations are necessary, however, to convert diameters to biomass or carbon estimates.

Shrubs typically have multiple forks in their stems, and may have a large proportion of biomass locked up in their branches instead of their stems. As such, separate allometric equations should be developed to estimate their stocks at a Tier 3 level. For the most part, these equations have not yet been developed in India. The IPCC does provide Tier 1 estimates for classes of shrub land (IPCC, 2006).

Below-Ground Biomass (BGB)

***Definition*:** "All living biomass of live roots. Fine roots of less than (suggested) 2mm diameter are sometimes excluded because these often cannot be distinguished empirically from soil organic matter or litter." (IPCC, 2003 and 2006)

Below-ground biomass can be calculated through destructive sampling methods. However, the IPPC Guidelines for National Greenhouse Gas Inventories Chapter 4 Agriculture, Forestry and Other Land Use (2006) and the IPCC Good Practice Guidance for Land Use, Land-Use Change and Forestry (2003) provide default root to shoot ratios that estimate BGB from the AGB value.

Figure 2-3 and Figure 2-4 below show Table 3A.1.8 from the IPCC Good Practice Guidance for Land Use, Land-Use Change and Forestry (2003) and Table 4.4 from the IPPC Guidelines for National Greenhouse Gas Inventories Chapter 4 Agriculture, Forestry and Other Land Use (2006), which give the default root:shoot ratios for geographic domains, ecological zones and vegetation types. The tables provide an upper and lower range as well as mean value.

Figure 2-3: Root:Shoot Ratios

TABLE 3A.1.8

AVERAGE BELOWGROUND TO ABOVEGROUND BIOMASS RATIO (ROOT-SHOOT RATIO, R) IN NATURAL REGENERATION BY BROAD CATEGORY (tonnes dry matter/tonne dry matter)

(To be used for R in Equation 3.2.5)

	Vegetation type	Aboveground biomass (t/ha)	Mean	SD	lower range	upper range	References
Tropical/sub-tropical forest	Secondary tropical/sub-tropical forest	<125	0.42	0.22	0.14	0.83	5, 7, 13, 25, 28, 31, 48, 71
	Primary tropical/sub-tropical moist forest	NS	0.24	0.03	0.22	0.33	33, 57, 63, 67, 69
	Tropical/sub-tropical dry forest	NS	0.27	0.01	0.27	0.28	65
Conifer forest/ plantation	Conifer forest/plantation	<50	0.46	0.21	0.21	1.06	2, 8, 43, 44, 54, 61, 75
	Conifer forest/plantation	50-150	0.32	0.08	0.24	0.50	6, 36, 54, 55, 58, 61
	Conifer forest/plantation	>150	0.23	0.09	0.12	0.49	1, 6, 20, 40, 53, 61, 67, 77, 79
Temperate broadleaf forest/ plantation	Oak forest	>70	0.35	0.25	0.20	1.16	15, 60, 64, 67
	Eucalypt plantation	<50	0.45	0.15	0.29	0.81	9, 51, 59
	Eucalypt plantation	50-150	0.35	0.23	0.15	0.81	4, 9, 59, 66, 76
	Eucalypt forest/plantation	>150	0.20	0.08	0.10	0.33	4, 9, 16, 66
	Other broadleaf forest	<75	0.43	0.24	0.12	0.93	30, 45, 46, 62
	Other broadleaf forest	75-150	0.26	0.10	0.13	0.52	30, 36, 45, 46, 62, 77, 78, 81
	Other broadleaf forest	>150	0.24	0.05	0.17	0.30	3, 26, 30, 37, 67, 78, 81
Grassland	Steppe/tundra/prairie grassland	NS	3.95	2.97	1.92	10.51	50, 56, 70, 72
	Temperate/sub-tropical/ tropical grassland	NS	1.58	1.02	0.59	3.11	22, 23, 32, 52
	Semi-arid grassland	NS	2.80	1.33	1.43	4.92	17-19, 34
Other	Woodland/savanna	NS	0.48	0.19	0.26	1.01	10-12, 21, 27, 49, 65, 73, 74
	Shrubland	NS	2.83	2.04	0.34	6.49	14, 29, 35, 38, 41, 42, 47, 67
	Tidal marsh	NS	1.04	0.21	0.74	1.23	24, 39, 68, 80

NS = Not specified

(IPCC, 2003)

Figure 2-4: Root:Shoot Ratios

TABLE 4.4
RATIO OF BELOW-GROUND BIOMASS TO ABOVE-GROUND BIOMASS (R)

Domain	Ecological zone	Above-ground biomass	R [tonne root d.m. (tonne shoot d.m.)$^{-1}$]	References
Tropical	Tropical rainforest		0.37	Fittkau and Klinge, 1973
	Tropical moist deciduous forest	above-ground biomass <125 tonnes ha^{-1}	0.20 (0.09 - 0.25)	Mokany *et al.*, 2006
		above-ground biomass >125 tonnes ha^{-1}	0.24 (0.22 - 0.33)	Mokany *et al.*, 2006
	Tropical dry forest	above-ground biomass <20 tonnes ha^{-1}	0.56 (0.28 - 0.68)	Mokany *et al.*, 2006
		above-ground biomass >20 tonnes ha^{-1}	0.28 (0.27 - 0.28)	Mokany *et al.*, 2006
	Tropical shrubland		0.40	Poupon, 1980
	Tropical mountain systems		0.27 (0.27 - 0.28)	Singh *et al.*, 1994
Subtropical	Subtropical humid forest	above-ground biomass <125 tonnes ha^{-1}	0.20 (0.09 - 0.25)	Mokany *et al.*, 2006
		above-ground biomass >125 tonnes ha^{-1}	0.24 (0.22 - 0.33)	Mokany *et al.*, 2006
	Subtropical dry forest	above-ground biomass <20 tonnes ha^{-1}	0.56 (0.28 - 0.68)	Mokany *et al.*, 2006
		above-ground biomass >20 tonnes ha^{-1}	0.28 (0.27 - 0.28)	Mokany *et al.*, 2006
	Subtropical steppe		0.32 (0.26 - 0.71)	Mokany *et al.*, 2006
	Subtropical mountain systems		no estimate available	
Temperate	Temperate oceanic forest, Temperate continental forest, Temperate mountain systems	conifers above-ground biomass < 50 tonnes ha^{-1}	0.40 (0.21 - 1.06)	Mokany *et al.*, 2006
		conifers above-ground biomass 50-150 tonnes ha^{-1}	0.29 (0.24 - 0.50)	Mokany *et al.*, 2006
		conifers above-ground biomass > 150 tonnes ha^{-1}	0.20 (0.12 - 0.49)	Mokany *et al.*, 2006
		Quercus spp. above-ground biomass >70 tonnes ha^{-1}	0.30 (0.20 - 1.16)	Mokany *et al.*, 2006
		Eucalyptus spp. above-ground biomass < 50 tonnes ha^{-1}	0.44 (0.29 - 0.81)	Mokany *et al.*, 2006
		Eucalyptus spp. above-ground biomass 50-150 tonnes ha^{-1}	0.28 (0.15 - 0.81)	Mokany *et al.*, 2006
		Eucalyptus spp. above-ground biomass > 150 tonnes ha^{-1}	0.20 (0.10 - 0.33)	Mokany *et al.*, 2006
		other broadleaf above-ground biomass < 75 tonnes ha^{-1}	0.46 (0.12 - 0.93)	Mokany *et al.*, 2006
		other broadleaf above-ground biomass 75-150 tonnes ha^{-1}	0.23 (0.13 - 0.37)	Mokany *et al.*, 2006
		other broadleaf above-ground biomass >150 tonnes ha^{-1}	0.24 (0.17 - 0.44)	Mokany *et al.*, 2006
Boreal	Boreal coniferous forest, Boreal tundra woodland, Boreal mountain systems	above-ground biomass <75 tonnes ha^{-1}	0.39 (0.23 - 0.96)	Li *et al.*, 2003; Mokany *et al.*, 2006
		above-ground biomass >75 tonnes ha^{-1}	0.24 (0.15 - 0.37)	Li *et al.*, 2003; Mokany *et al.*, 2006

(IPCC, 2006)

Dead Organic Matter

Litter

Definition: "Includes all non-living biomass with a diameter less than a minimum diameter chosen by the country (for example 10 cm), lying dead, in various states of decomposition above the mineral or organic soil. This includes litter, fumic, and humic layers. Live fine roots (of less than the suggested diameter limit for belowground biomass) are included in litter where they cannot be distinguished from it empirically." (IPCC, 2003); "Includes all non-living biomass with a size greater than the limit for soil organic matter (suggested 2mm) and less than the minimum diameter chosen for deadwood (e.g., 10cm), lying dead, in various states of decomposition above or within the mineral or organic soil. This includes the litter layer as usually defined in soil." (IPCC, 2006).

The IPCC Good Practice Guidance for Land Use, Land-Use Change and Forestry (2003) includes a table of default carbon stock values for litter by climate and forest type—see Figure 2-5 on page 26.

Litter carbon stocks can also be measured and calculated with field data. Litter from a known unit area is weighed in the field. This is called fresh-weight (or wet weight). A sub-sample is collected and also weighed in the field. The sub-sample is then dried to an oven-dry state and weighed. The dried litter is termed litter dry matter. "Dry matter refers to biomass that has been dried to an oven-dry state, often at 70ºC" (IPCC, 2003). The sub-sample dry-weight to fresh-weight is a dry-wet ratio. The ratio is used to compute the dry matter mass of the total litter sample from the field. The dry matter mass is converted to a carbon value using a carbon fraction value. The IPCC default carbon fraction value for litter dry matter is 0.37 (IPCC, 2003). The litter carbon stock in tC^{-ha} is calculated by computing the sample C mass in terms of tons and multiplying this times the sum of 1 hectare divided by the unit area of the litter sample.

Example: A litter frame that is 0.5 m^2 has an amount of fresh-weight litter equal to 5 kg. A sub-sample of this weighs 1.3 kg. The dry matter weight of the sub-sample equals 0.4 kg. The dry-wet ratio therefore is 0.4:1.3 or 0.31 to 1. Therefore, the dry matter weight of the total sample is 1.54 kg and in terms of metric tons equals 0.001538 t. The area of the litter frame in terms of hectares is equal to 0.00005 ha. Therefore the litter carbon stock for this one sample is 11.38 tC^{-ha}.

$$CS_{litter} = (DW_{litter} * Cf_{litter}) * (1 \text{ ha} / P_{litter})$$

$$DW_{litter} = FW_{litter} * DW_{ratio}$$

$$DW_{ratio} = DW_{sub} / FW_{sub}$$

Where,

CS_{litter} Carbon stock for a litter sample: noted in tons of carbon per hectare, tC^{-ha}

DW_{litter} Mass in kilograms of the sample frame oven-dried, litter dry matter

Cf_{litter} Carbon Fraction of Biomass, 0.37

P_{litter} Plot: unit area in terms of square meters

FW_{litter} Mass in kilograms of the sample frame fresh (wet) litter

DW_{ratio} Ratio of dry matter mass to fresh litter mass

DW_{sub} Mass in kilograms of the sub-sample of the total frame fresh (wet) litter that has been oven-dried; litter dry matter

FW_{sub} Mass in kilograms of a sub-sample of the total frame fresh (wet) litter

Example

DW_{ratio} =	DW_{sub} /	FW_{sub}	
0.31	0.4	1.3	
DW_{litter} =	FW_{litter} *	DW_{ratio}	
1.54	5	0.31	
CS_{litter} =	DW_{litter} *	Cf_{litter} *	(1 ha/P_{litter})
11.38	0.001538	0.37	20000

4. Term	5. Value	6. Note
CS_{litter}	Computed	Carbon Stock for the plot (tC^{-ha})
DW_{litter}	Computed	Fresh weight litter times dry-wet ration
Cf_{litter}	0.37	
P_{litter}	0.5	
FWlitter	Measured	Fresh weight or mass of litter collected in the plot sample area
DW_{ratio}	Computed	The ration of the sub-sample dried litter mass to the sub-sample wet mass
DW_{sub}	Measured	The weight of a sub-sample of the total sample oven-dried
FW_{sub}	Measured	The fresh- or wet-weight of a sub-sample of the total

"An alternative approach for systems where the litter layer is well-defined and deep (more than 5 cm), is to develop a local regression equation that relates depth of the litter to the mass per unit area. This can be done by sampling the litter in the frames as mentioned above and at the same time measuring the depth of the litter. At least 10–15 such data points should be collected, ensuring that the full range of the expected litter depth is sampled." (IPCC, 2003).

Figure 2-5: Table of Default Litter Carbon Stocks

TABLE 3.2.1
UPDATED DEFAULTS FOR LITTER CARBON STOCKS (TONNES C HA^{-1}) AND TRANSITION PERIOD (YEARS)
(Net annual accumulation of litter carbon is based mostly on data for managed forest and default period of 20 years)

Climate	Forest Type							
	Broadleaf Deciduous	Needleleaf Evergreen	Broadleaf Deciduous	Needleleaf Evergreen	Broadleaf Deciduous	Needleleaf Evergreen	Broadleaf Deciduous	Needleleaf Evergreen
	Litter carbon stock of mature forests (tonnes C ha^{-1})		Length of transition period (years)		Net annual accumulation of litter C over length of transition period [bc] (tonnes C ha^{-1} yr^{-1})		Net annual accumulation of litter C, based on 20 year default (tonnes C ha^{-1} yr^{-1})	
Boreal, dry	25 (10-58)	31 (6-86)	50	80	0.5	0.4	1.2	1.6
Boreal, moist	39 (11-117)	55 (7-123)	50	80	0.8	0.7	2.0	2.8
Cold Temperate, dry	28 (23-33)[a]	27 (17-42)[a]	50	80	0.6	0.4	1.4	1.4
Cold temperate, moist	16 (5-31)[a]	26 (10-48)[a]	50	50	0.3	0.5	0.8	1.3
Warm Temperate, dry	28.2 (23.4-33.0)[a]	20.3 (17.3-21.1)[a]	75	75	0.4	0.3	1.4	1.0
Warm temperate, moist	13 (2-31)[a]	22 (6-42)[a]	50	30	0.3	0.7	0.6	1.1
Subtropical	2.8 (2-3)	4.1	20	20	0.1	0.2	0.1	0.2
Tropical	2.1 (1-3)	5.2	20	20	0.1	0.3	0.1	0.3

Source: Siltanen *et al.*, 1997; and Smith and Heath, 2002; Tremblay *et al.*, 2002; and Vogt *et al.*,1996, converted from mass to carbon by multiplying by conversion factor of 0.37 (Smith and Heath, 2002).

Note: Ages follow Smith and Heath (2002).

[a] Values in parentheses marked by superscript "a" are the 5[th] and 95[th] percentiles from simulations of inventory plots, while those without superscript "a" indicate the entire range.

[b] These columns indicates the annual increase in litter carbon when starting from bare ground in land converted forest land.

[c] Note that the accumulation rates are for carbon being absorbed from the atmosphere. However, depending on the methodology, these may be transfers from other pools.

(IPCC, 2003)

Deadwood

Definition: "Includes all non-living woody biomass not contained in the litter, either standing, lying on the ground, or in the soil. Deadwood includes wood lying on the surface, dead roots, and stumps larger than or equal to 10 cm in diameter or any other diameter used by the country." (IPCC, 2003 and 2006)

Pages 4.104 – 4.105 in the IPCC Good Practice Guidance for Land Use, Land-Use Change and Forestry (2003) describe two methods for calculating deadwood carbon stocks.

Soil Organic Carbon

Definition: "Includes organic carbon in mineral and organic soils (including peat) to a specified depth chosen by the country and applied consistently through the time series. Live fine roots (of less than the suggested diameter limit for belowground biomass) are included with soil organic matter where they cannot be distinguished from it empirically." (IPCC, 2003 and 2006)

Pages 4.105 – 4:106 in the IPCC Good Practice Guidance for Land Use, Land-Use Change and Forestry (2003) describe two methods for calculating SOC carbon stocks.

2.1.4 FOREST CARBON MEASUREMENT

There are fundamental steps in forest carbon measurement using a stratified random sample:

1) Stratification;
2) Inventory plot allocation;
3) Carbon stock estimation; and
4) Calculation of uncertainty.

In addition, for REDD+,

5) Monitoring for changes in stocks is required to account for fluxes to and from the atmosphere; and
6) Establishing a baseline against which to measure carbon stocks is mandatory.

This training material provides a brief introduction to these steps, but assumes that learners will be using the Forest-PLUS Forest Data Management System (fDMS) or other similar tool to aid in the technical work necessary. If such a tool isn't available a forest biometrician should be consulted.

Land Cover Classification and Stratification of the Forest Landscape

The size and location of the various land covers that occur must be delineated. Knowledge of project land cover types is required for stratification. Use of Global Positioning System (GPS) or Geographic Information System (GIS) analyses to define strata boundaries is necessary. Strata can be defined according to land cover (forest vs. non-forest), forest type (natural vs. plantation), tree species, age class, climate zones (wet, dry, or moist), and soil types, among others. Strata should be reported in hectares.

This curriculum explains how to estimate carbon stocks using a stratified random sample. A stratified random design provides a more efficient approach to provide an estimate of a given precision than a systematic sample or a simple random sample. A stratified random sample allows for defensible augmentation of the sample if a higher precision is desired than the initial target of the sample design. See Van Laar and Akca (2007) for a general treatment of forest sampling, and Chapter 3 of Lohr (2010) for an explanation of the relative advantages of stratified random sampling. The Forest-PLUS DMS also allows and facilitates the use of a systematic grid-based sample as the FSI uses.

Sampling Methods for Calculating Forest Carbon Stocks

Land Cover Classification and stratification

Monitoring strata and changes in strata over time constitute activity data. At a minimum, accurate area and boundaries for forest land and non-forest land should be recorded. Changes in forest land that result in deforested land, degraded forest land, and reforested land must also be recorded.

Plot Inventory Allocation

The plot inventory provides information on raw plot data. This includes plot metadata (e.g., plot dimension, plot type, plot area, and geographic conditions, among others) and tree level mensuration data (e.g., species, diameter at breast height [DBH], total tree height, tree crown dimension, and wood density).

Carbon Stock Estimation

General allometric equations are used for quantifying biomass at the plot and strata (parcel) levels. Tier 3 allometric equations are to be selected wherever possible. Tier 2 and Tier 1 equations are to be used in that order only if Tier 3 equations are not available. Calculation of carbon content in litter and deadwood and soil organic carbon is preferably calculated using a Tier-3 methodology. In the absence of Tier-3 data, Tier-2 or Tier-1, in that order, may be used.

Tree allometry establishes quantitative relations between some key characteristic dimensions of trees, like DBH or height, and other properties, like biomass or volume. Where a statistical relationship, established on the basis of detailed measurements on a small sample of typical trees, is true for other individuals, allometry allows for estimations on the basis of a single or a few tree measurements. Allometric equations can be used to compute biomass or volume of trees based on measurement like DBH and height. Volumetric equations together with wood density can compute biomass. Carbon stock measurements (as noted above) can be calculated from biomass.

Carbon stocks values are computed for all plots as tons of carbon per hectare (tC^{-ha}). Mean values of tC^{-ha} are computed for all plots associated with a strata (parcel) and total carbon is computed for all strata using the mean value of tC^{-ha} and the total area of the stratum.

Land Cover Classification and Stratification

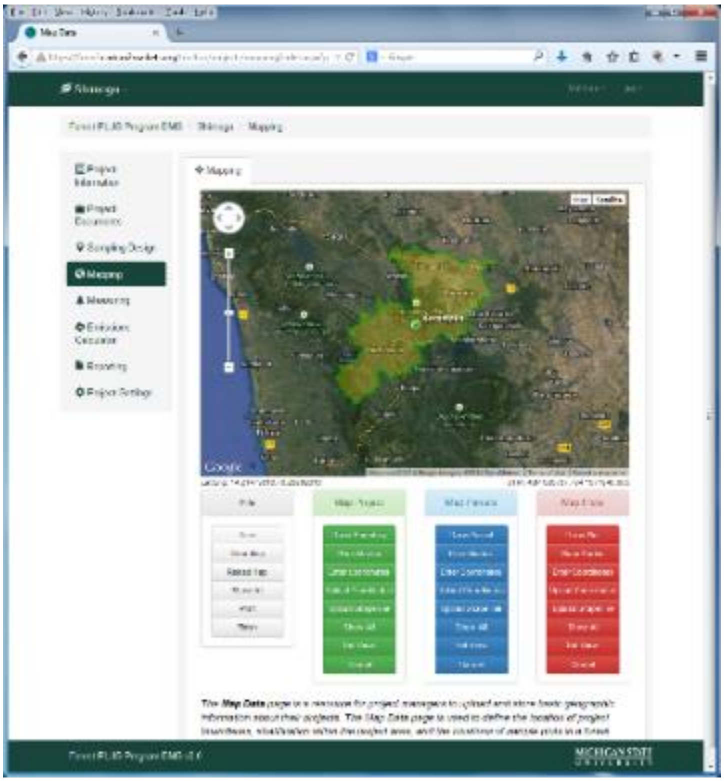
Defining a Boundary

A project boundary is required for analyzing land cover changes and for computing a baseline. The boundary may be at any scale, including sub-national project and jurisdictional levels up to the national level.

Project boundaries should be delineated using GPS and GIS or remote sensing software. Field-based delineated boundaries, boundaries derived from cartographic sources (e.g., topographic and cadastral maps), and official legal entity boundaries are acceptable. National standards for map coordinate systems, projections, and geographic (datum) transformations should be adhered to for consistency and accuracy. Project boundary files should be stored as GIS data sets.

The mapping toolkit in the Forest-PLUS DMS supports the creation, visualization, management, and reporting for a project boundary. The mapping toolkit includes an online, web-based mapping system for creating and storing a project boundary using reference maps and satellite imagery on-screen or uploading geographic polygon data (entering vertices coordinates, uploading a comma-separated values [CSV] delimited file of coordinates, or uploading an ArcMap [ESRI] Shapefile). The project boundary polygon and vertices and the computed area (in hectares) of the project boundary are stored in the Forest-PLUS DMS relational database. A map showing the project boundary with reference maps and satellite data can be output from the Forest-PLUS DMS.

Figure 2-6: DMS Mapping Toolkit



Project Stratification

Unless the landscape within the project boundary is completely homogenous (e.g., dense tropical evergreen forest), the landscape should be stratified. The process for stratification should include the use of remote sensing satellite data, together with direct observation of landscape characteristics. Secondary data sources, such as forest cover or land cover maps may be used if these are derived from remote sensing satellite data. Stratification of the landscape should aim to first delineate forest cover areas from non-forest cover areas. Further stratification of the forest cover areas may be required if there is more than one forest type present in the landscape.

Acceptable methods for remote sensing stratification with optical remote sensing data include supervised and unsupervised classification that rely solely on spectral information, hybrid approaches that combine spectral data with object classification, and hybrid approaches that use spectral data and/or object detection algorithms with ancillary data such as digital elevation model – topographic (DEM) data and soil data.

The Forest-PLUS remote sensing models support preliminary data processing and analysis of optical remote sensing data (Landsat, Advanced Spaceborne Thermal Emission and Reflection Radiometer [ASTER] Visible Near Infra-Red [VNIR], Advanced Wide Field Sensor [AWiFS], and Linear Imaging Self-Scanning [LISS]-III). The models are built using Earth Resource Development Assessment System (ERDAS) Imagine Spatial Modeler and the algorithms are used for processing raw satellite data to intermediary data products useful for stratification.

Inventory Plot Allocation

To use resources efficiently, stratified random sample plots are allocated to minimize the standard error in all strata taken together. This allows for the same degree of certainty about the estimated carbon stocking with relatively low resource investment.

A pre-sample is necessary to calculate the required number of plots. With that data, the full number of plots in the sample can be calculated based on the desired precision and the resources available for sampling.

Plot and Data Collection as a Pre-Sample

This method identifies the steps to determine a sample plot design for the collection of a pre-sample of forest inventory data. The pre-sample is used to estimate carbon stock variance and mean for each forest strata, which are used to develop a robust sample design that meet specific error and confidence levels for calculating carbon stocks.

1. Stratify the project area to land cover classes of forest and non-forest strata; further stratify the forest areas to sub-classes if possible or necessary.
2. Map and calculate the area in hectares for each strata.
3. Upload the strata geospatial data to the Forest-PLUS DMS through the mapping tool.
4. Using the sampling design plot mapping tool of the Forest-PLUS DMS, randomly place a minimum of 10 – 30 plots for each strata listed. (Alternatively, use ESRI ArcMap to create a randomly placed set of points within each strata.)
5. If strata are across multiple polygons, be sure that each polygon has a minimum of one plot point.
6. Output the plot coordinates.
7. Navigate to each coordinate and establish the plot center point.
8. Demark the plot area (follow the Forest-PLUS plot design protocol).
9. Collect tree inventory data at the plot using the Forest-PLUS mForest Apps or record data on a hardcopy of the Forest-PLUS plot data record sheet (follow the tree inventory and measurement protocol).
10. Navigate to the next plot and repeat steps 8 and 9.
11. Repeat until all plots have been reached and data collected.
12. Upload data to the Forest-PLUS DMS.
13. Using the Forest-PLUS DMS Carbon Uncertainty report from the Carbon Calculations tab in the Measuring Tool, identify strata where there is high variance (standard deviation). Strata with large standard deviation values may need to be reclassified into more than one stratum.
14. In the case that some strata require additional reclassifying, repeat steps 2 through 12 for each new strata class.

Note on plot locations: forest carbon tree inventory plots should adhere to the following:

- No plot area should be closer than 50 m from a road or forest edge; preferably 100 m away for road or forest edge.
- No plot area should include more than one strata.
- No plot area should include or be located too near certain geographic features such as cliffs, ravines, and/or large rivers. Minimum 50 m away.
- No plot area should be located on dangerously steep slopes (~ greater than 30^{o}).

Plots that fall under one or more criteria above should be discarded from the data collection plan. Alternative plots can be used either by:

1. Oversampling the number required by 10–20 % in Step 4; or
2. In cases where a plot area would be satisfactory by moving the point a maximum of 100 m in any direction, do so and record the GPS point or record the distance and direction using measuring tape or rangefinder and a compass.

Figure 2-7: Plot Allocation in the DMS

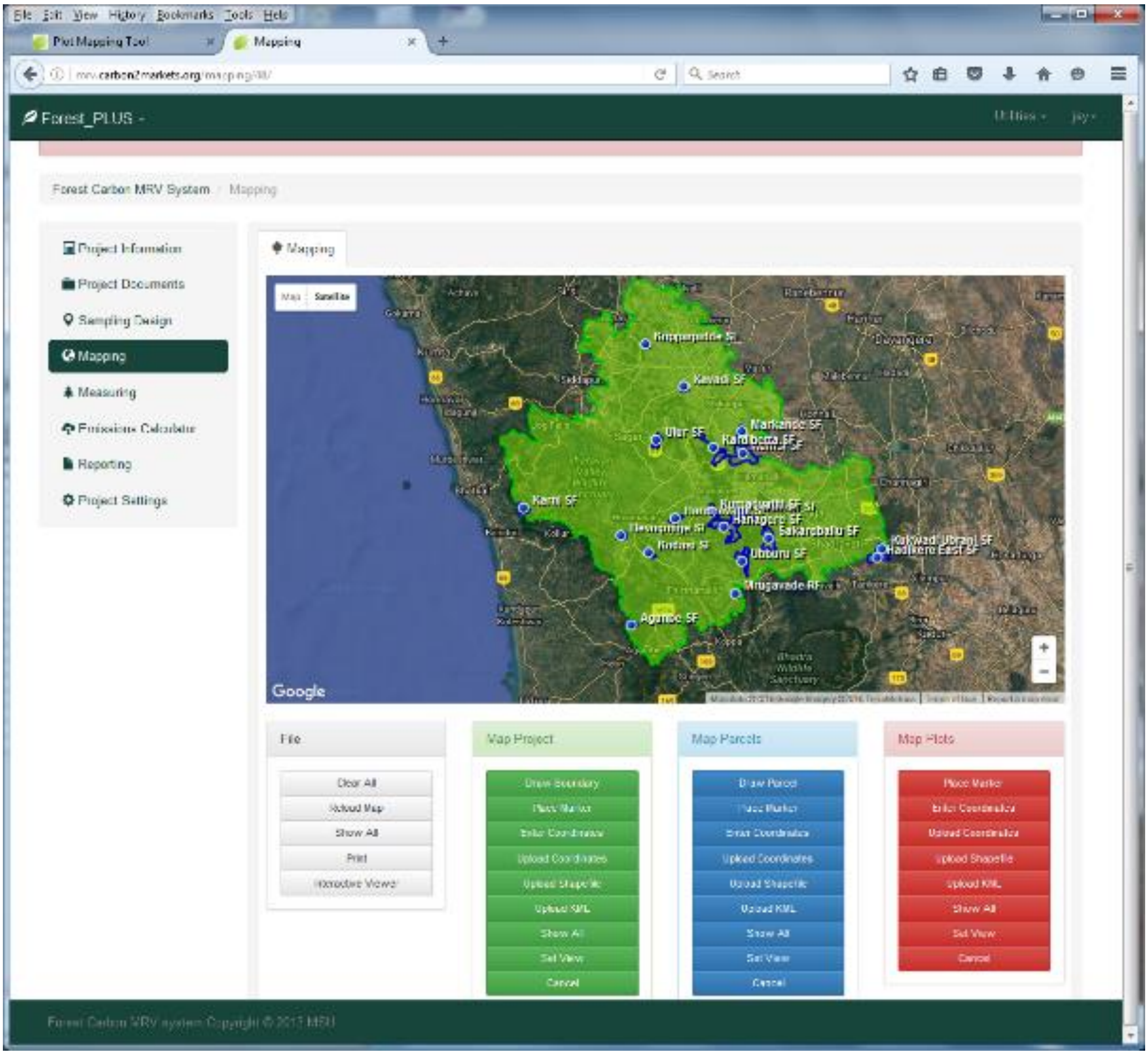


Figure 2-8: Strata Uploaded to the Forest-PLUS DMS Mapping Tool (Step 3)

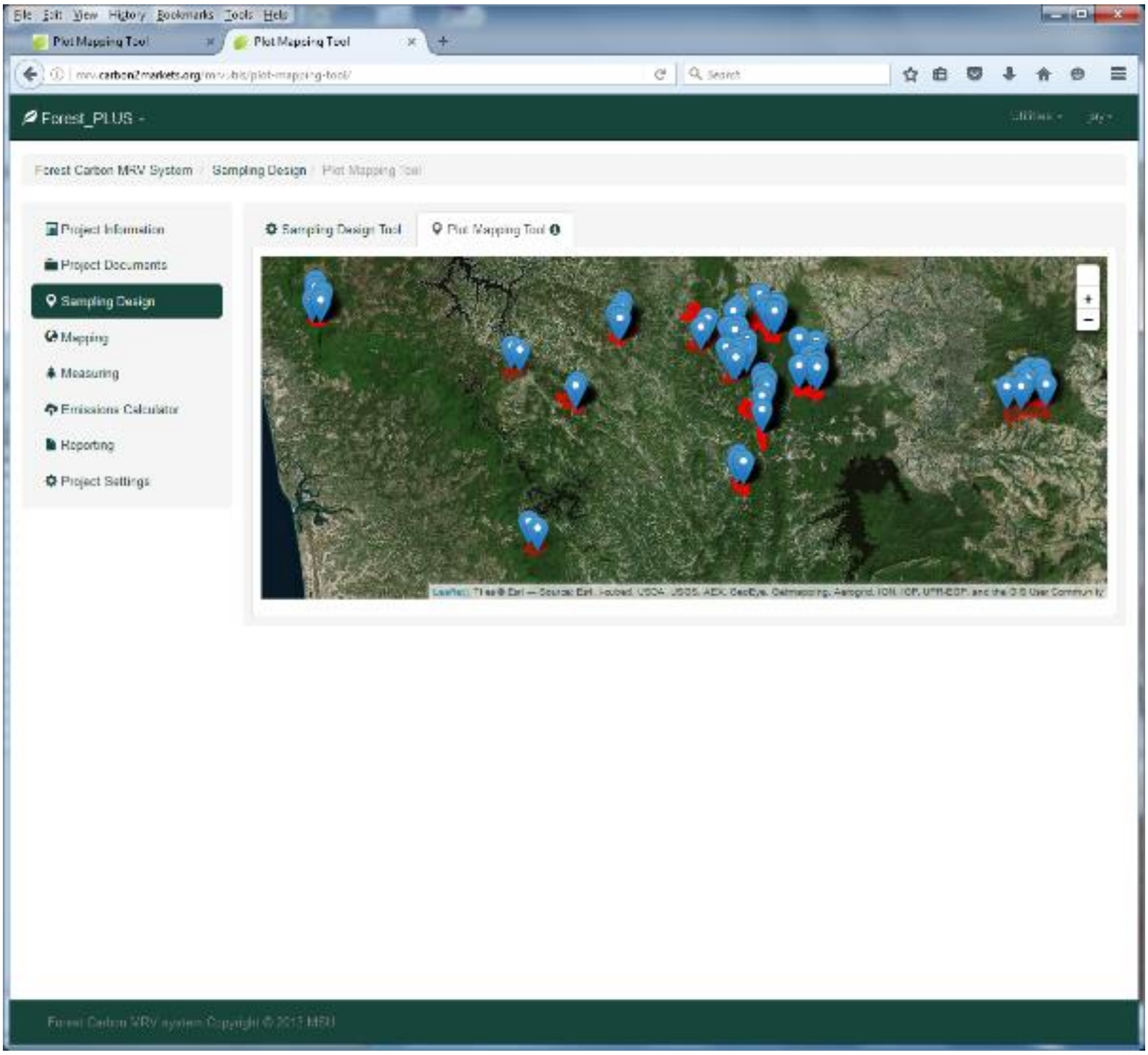


Figure 2-9: Sample Plots Randomly Located in Strata Using the Forest-PLUS DMS Sample Design Tool (Step 4).

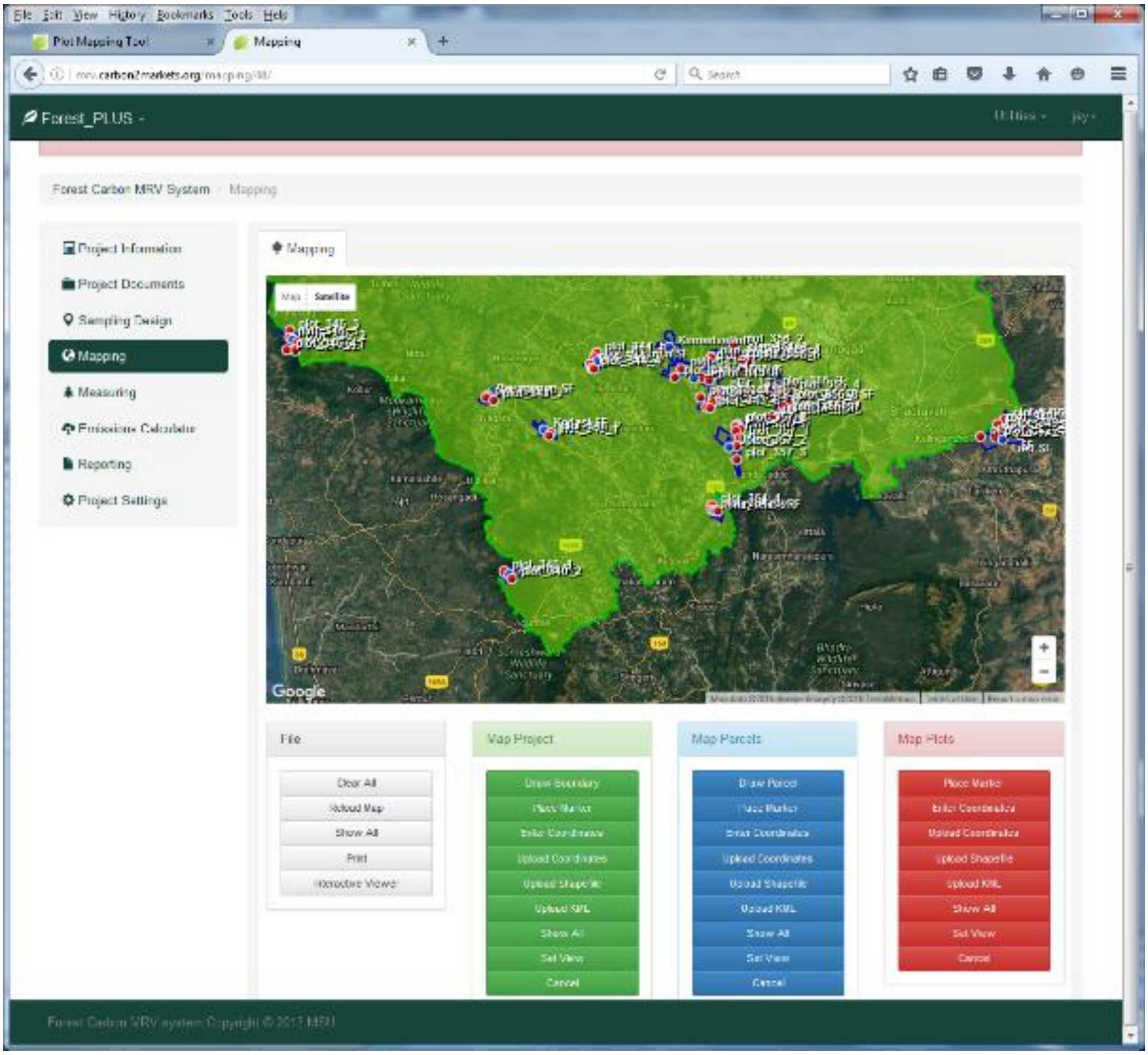


Figure 2-10: Sample Plots Located on Map in Forest-PLUS DMS

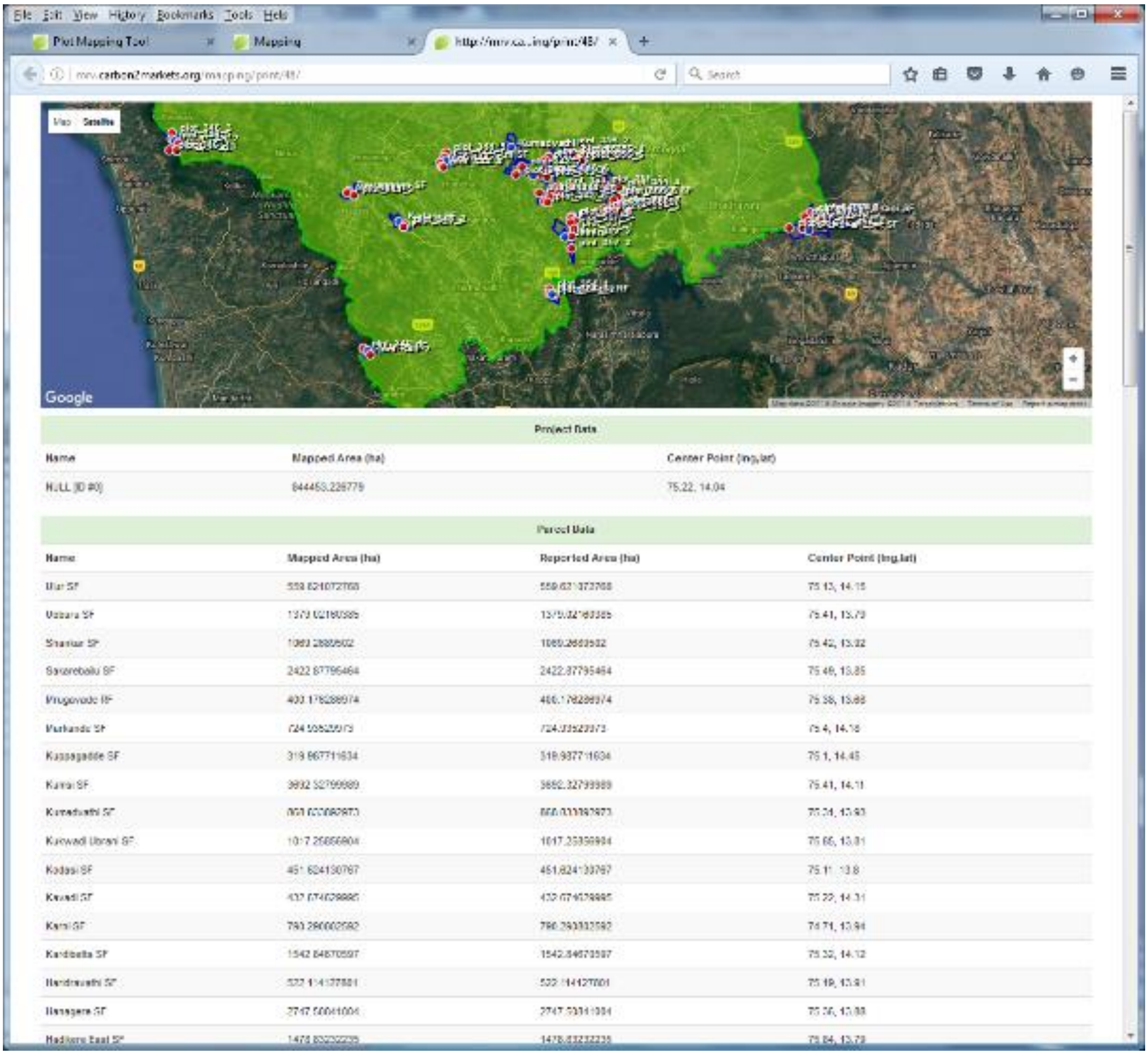
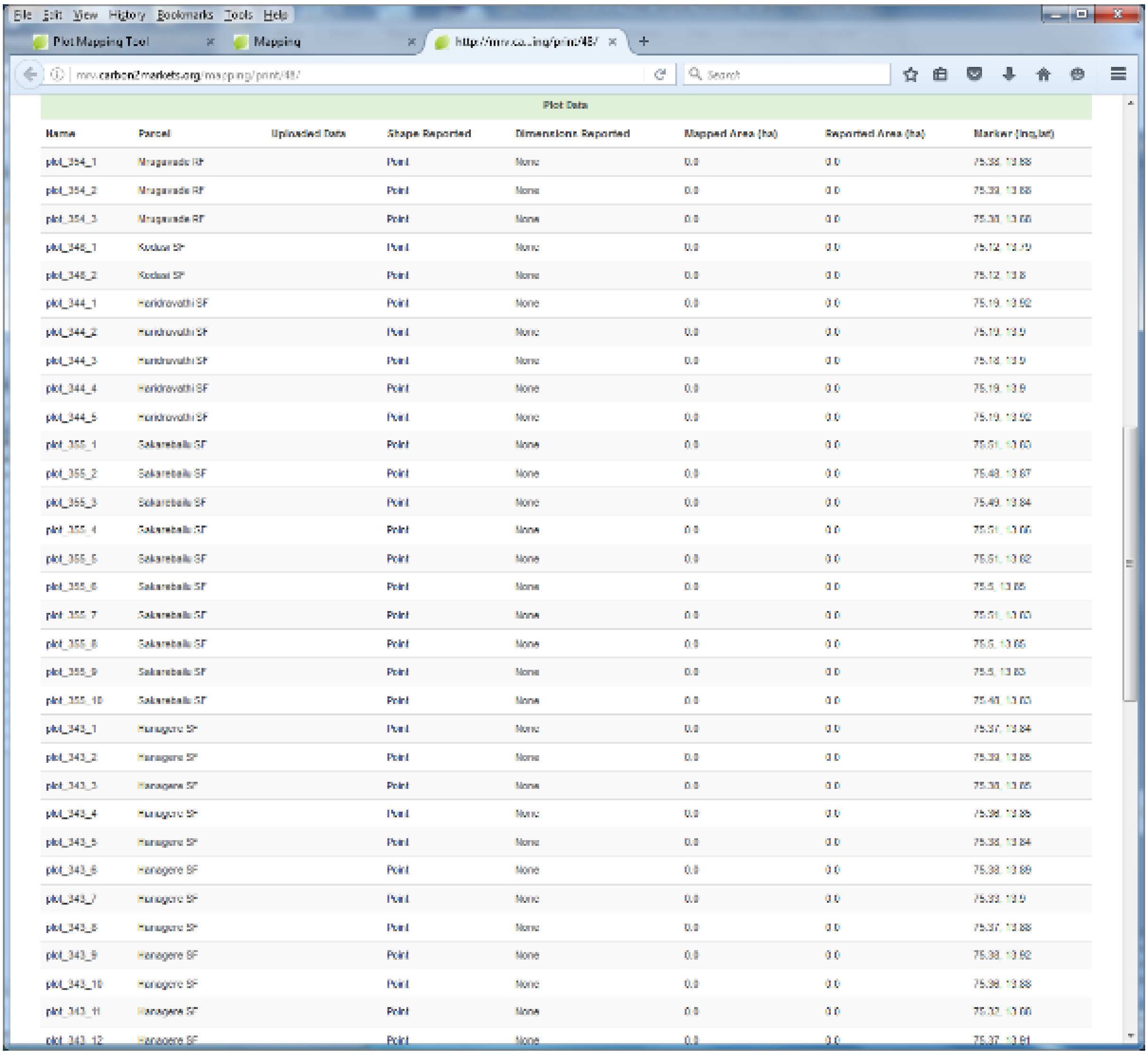


Figure 2-11: Forest-PLUS DMS Output of Strata (Area and Centroid Point in Geographic Lat/Long Decimal Degrees)



Plot Data

Name	Parcel	Uploaded Data	Shape Reported	Dimensions Reported	Mapped Area (ha)	Reported Area (ha)	Marker (lng,lat)
plot_354_1	Mragavade RF		Point	None	0.0	0.0	75.38, 13.88
plot_354_2	Mragavade RF		Point	None	0.0	0.0	75.39, 13.88
plot_354_3	Mragavade RF		Point	None	0.0	0.0	75.38, 13.86
plot_348_1	Kodsai SF		Point	None	0.0	0.0	75.12, 13.79
plot_348_2	Kodsai SF		Point	None	0.0	0.0	75.12, 13.8
plot_344_1	Haridravathi SF		Point	None	0.0	0.0	75.19, 13.92
plot_344_2	Haridravathi SF		Point	None	0.0	0.0	75.19, 13.9
plot_344_3	Haridravathi SF		Point	None	0.0	0.0	75.18, 13.9
plot_344_4	Haridravathi SF		Point	None	0.0	0.0	75.19, 13.9
plot_344_5	Haridravathi SF		Point	None	0.0	0.0	75.19, 13.92
plot_355_1	Sakarebailu SF		Point	None	0.0	0.0	75.51, 13.63
plot_355_2	Sakarebailu SF		Point	None	0.0	0.0	75.48, 13.67
plot_355_3	Sakarebailu SF		Point	None	0.0	0.0	75.49, 13.64
plot_355_4	Sakarebailu SF		Point	None	0.0	0.0	75.51, 13.66
plot_355_5	Sakarebailu SF		Point	None	0.0	0.0	75.51, 13.62
plot_355_6	Sakarebailu SF		Point	None	0.0	0.0	75.5, 13.65
plot_355_7	Sakarebailu SF		Point	None	0.0	0.0	75.51, 13.63
plot_355_8	Sakarebailu SF		Point	None	0.0	0.0	75.5, 13.65
plot_355_9	Sakarebailu SF		Point	None	0.0	0.0	75.5, 13.63
plot_355_10	Sakarebailu SF		Point	None	0.0	0.0	75.48, 13.63
plot_343_1	Hanagere SF		Point	None	0.0	0.0	75.37, 13.84
plot_343_2	Hanagere SF		Point	None	0.0	0.0	75.39, 13.85
plot_343_3	Hanagere SF		Point	None	0.0	0.0	75.38, 13.85
plot_343_4	Hanagere SF		Point	None	0.0	0.0	75.38, 13.85
plot_343_5	Hanagere SF		Point	None	0.0	0.0	75.38, 13.84
plot_343_6	Hanagere SF		Point	None	0.0	0.0	75.38, 13.89
plot_343_7	Hanagere SF		Point	None	0.0	0.0	75.33, 13.9
plot_343_8	Hanagere SF		Point	None	0.0	0.0	75.37, 13.88
plot_343_9	Hanagere SF		Point	None	0.0	0.0	75.38, 13.92
plot_343_10	Hanagere SF		Point	None	0.0	0.0	75.38, 13.88
plot_343_11	Hanagere SF		Point	None	0.0	0.0	75.32, 13.86
plot_343_12	Hanagere SF		Point	None	0.0	0.0	75.37, 13.91

Carbon Stock Estimation

Carbon stocks can be determined using the Forest-PLUS DMS. Here the theory is briefly covered to orient the user.

General Method for Calculation of Above Ground Biomass (AGB)

Step 1: Calculate mercantile volume using volume equations (m^3).

$V = a + bD^2H$

Where,

V = Mercantile volume (m^3)

D = DBH (cm or m)

H = Height (cm or m)

Step 2: Calculate the mass of the AGB biomass in tons

$G_{AGB} = V * BEF * WD$

Where,

G_{AGB} = Biomass at above ground biomass in tons of dry matter (t)

V = Mercantile volume (m^3)

BEF = Biomass Expansion factor

WD = Wood density

Calculation of Below Ground Biomass (BGB)

The mean carbon stock in belowground biomass per unit area is estimated based on field measurements of aboveground parameters in sample plots. Root to shoot ratios are coupled with the aboveground biomass estimate to calculate belowground from aboveground biomass.

Step 3: Calculate the mass of BGB (roots) using the RF

$G_{BGB} = G_{AGB} * RF$

Where,

G_{BGB} = Biomass at below ground biomass in tons of dry matter (t)

G_{AGB} = Biomass at above ground biomass in tons of dry matter (t)

RF = Root to shoot ratio

Calculation of Total Biomass

Step 4: Calculate the total biomass (G_{Total})

$G_{TOTAL} = G_{AGB} + G_{BGB}$

Where,

G_{TOTAL} = Total biomass of the tree in tdm

G_{BGB} = Biomass at below ground biomass in tons of dry matter (t)

G_{AGB} = Biomass at above ground biomass in tons of dry matter (t)

Calculation of Carbon Content

Step 5: Calculation of carbon content from biomass in a forest involves calculation of carbon in a tree followed by carbon content of a plot and finally the carbon content per ha of land.

(a) Carbon Content in a Tree

$C_i = G_i * 0.5$

Where,

C_i = Carbon content in a tree (tC)

G_i = Biomass of the tree in tdm

(b) Caron Content of a Plot

$C_{Plot} = \sum(C_{i1} + C_{i2} + \cdots)$

(c) Carbon Content on one hectare basis

Total carbon content/ha, i.e.

$C_{Ha} = (C_{Plot} * 1ha/\text{area of plot in ha}) + SOC^* + C_{DW} + C_L$

Where,

SOC = Soil Organic Carbon (tC^{-ha})

C_L= Carbon Content in Litter (tC^{-ha})

C_{DW} = Carbon Content in Dead Wood (tC^{-ha})

*SOC is to be calculated based on the lab analysis.

(d) Carbon Content in total project area

Total carbon content, i.e., $\mathbf{C_{Total}} = \mathbf{C_{Ha}} * $ **Total** project area (ha)

Calculation of Net Anthropogenic CO2 Sequestration

Step 6:

ER = C_{TOTAL} * 44/12

Where,

ER = Net anthropogenic sequestration or CO_2 sequestered in tCO_2

C_{TOTAL} = Total carbon content in the project area (tC)

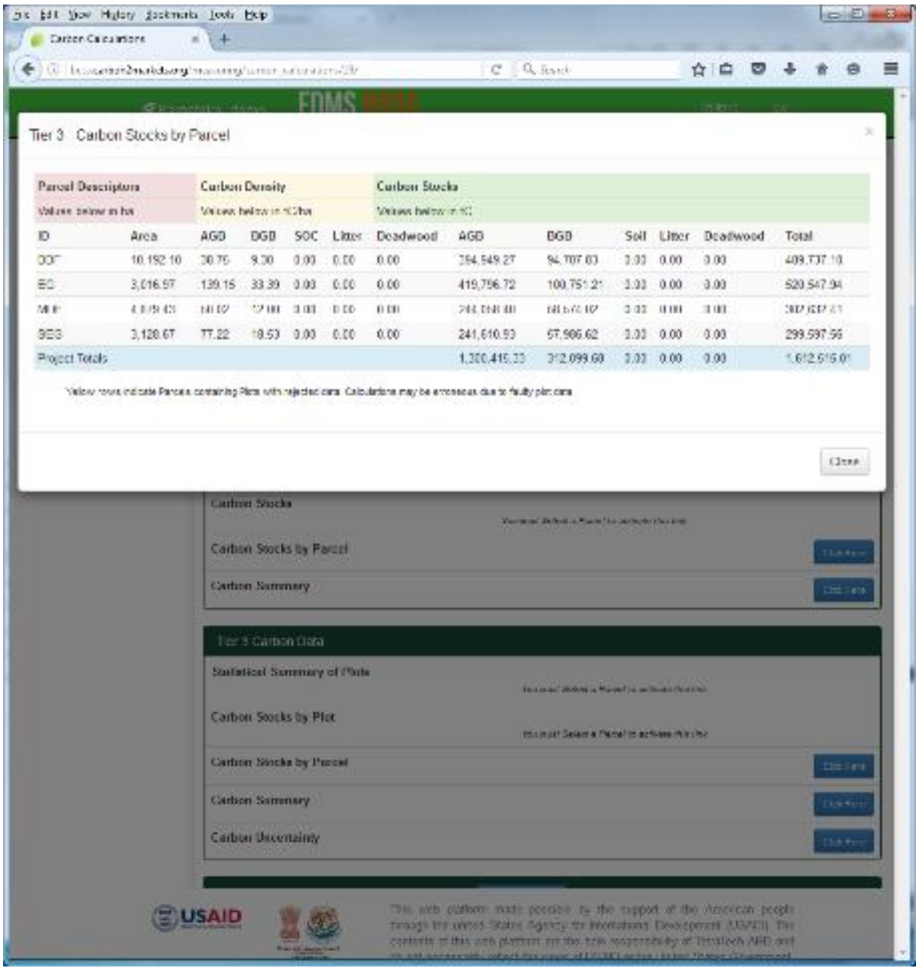
The selection of which pools to measure and monitor is likely to depend on several factors, including expected rate of change, magnitude and direction of the change, availability and accuracy of methods to quantify change, and cost to measure. Provisions could include that all pools that are expected to decrease as a result of project activities must be measured and monitored, or that all pools that are expected to increase need not be measured and monitored. In practical terms, the latter provision could be the case if monitoring costs are high relative to the expected increase in carbon stocks—which might be the case, for example, with understory herbaceous vegetation in an afforestation/reforestation project.

Emission Factors (EF)

Emission factors (EF) may include factors for all five pools of carbon. EFs can be Tier 1, Tier 2, or Tier 3. Tier 3 EF are derived from plot level field data for each strata. In the absence of Tier 3 data, nationally reported Tier 2 EF data can be used. In the absence of both Tier 3 and Tier 2 data, IPCC reported Tier 1 data can be used. Emission factors are reported in tons of carbon per hectare (tC^{-ha}).

The Forest-PLUS DMS: The measuring toolkit of the DMS is used to manage plot level forest inventory data and compute plot-level and strata-level biomass and carbon. The database managing the measuring toolkit has a relational linkage to the mapping database, where strata and plot geographic data are managed. Plot inventory data include tree measurements such as diameter-at-breast height (dbh) and total tree height as well as species identification. The measuring toolkit contains a catalog of allometric equations use to compute biomass and carbon stock at the plot level. Mean value carbon stocks are then computed for all strata from all plots within a stratum, which are Emission Factors.

Figure 2-12: Carbon Stock Calculations in the DMS



Plot and Data Collection for Determining Emission Factors (Carbon Stocks) with the fDMS

This method identifies the steps to determine a robust sample plot number for each stratum that meets specific error and confidence levels for calculating emission factors and carbon stocks. The methods used the pre-sample data as input to the following mathematical model:

Figure 2-13: Sample Size Formula for a Stratified Random Sample

$$n_h = n \cdot \frac{N_h \cdot s_h}{\sum N_h \cdot s_h}$$

$$n = \frac{\left(\sum N_h \cdot s_h\right)^2}{\left(\left(\sum N_h\right) \cdot \frac{E}{t}\right)^2 + \left(\sum N_h \cdot s_h^2\right)}$$

n = number of sample plots in total project area
n_h = number of sample plots in stratum h
E = allowable error (level of error - weighted mean tC/ha)
t = sample statistic from the t-distribution (90%, 95%, or 99% confidence level)
N_h = number of sampling units in the population
s_h = number of sampling units in stratum h

(Avery and Burkhart, 1994)

1. Using the Forest-PLUS DMS sampling design tool, calculate the number of plots required that meet the specified confidence and error level (step of the tool) given the pre-sample mean and standard deviation carbon values for each strata.

2. Run the tool several times, changing the confidence and error levels and the plot size to determine the optimal number of plots given there are tradeoffs in accuracy as well as costs associated with a large number of small plots versus fewer large plots.
3. Using the sampling design plot mapping tool of the Forest-PLUS DMS, randomly place the required number of plots minus the pre-sample for each strata listed. (Alternatively, use ESRI ArcMap to create a randomly placed set of points within each strata.)
4. If strata are across multiple polygons, be sure that each polygon has a minimum of one plot point.
5. Output the plot coordinates.
6. Navigate to each coordinate and establish plot corner point 1 – SW corner.
7. Demark the plot area (Follow the Forest-PLUS plot design protocol).
8. Collect tree inventory data at the plot using the Forest-PLUS mForest App or record data on a hardcopy of the Forest-PLUS plot data record sheet. (Follow the tree inventory and measurement protocol.)
9. Navigate to the next plot and repeat steps 7 and 8.
10. Repeat until all plots have been reached and data collected.
11. Upload data to the Forest-PLUS DMS.
12. Using the Forest-PLUS DMS Carbon Stocks by Plot report from the Carbon Calculations tab in the Measuring Tool, note the mean value in Total tC^{-ha} for carbon density. This is the emission factor for the strata selected prior to viewing the report.

Note on plot locations: forest carbon tree inventory plots should adhere to the following:

- No plot area should be closer than 50 m from a road or forest edge, preferably 100 m away from road or forest edge;
- No plot area should include more than one strata;
- No plot area should include or be located too near certain geographic features such as cliffs, ravines, and/or large rivers, minimum 50 m away; and
- No plot area should be located on dangerously steep slopes (~ greater than 30^{o}).

Plots that fall under one or more criteria above should be discarded from the data collection plan. Alternative plots can be used either by:

1. Oversampling the number required by 10–20% in Step 4; or
2. In cases where a plot area would be satisfactory by moving the point a maximum of 100 m in any direction, then do so and record the GPS point or record the distance and direction using measuring tape or rangefinder and a compass.

Figure 2-14: Forest-PLUS DMS Sample Plot Design Tool: Define Desired Confidence Level and Error Level for Model (Step 1).

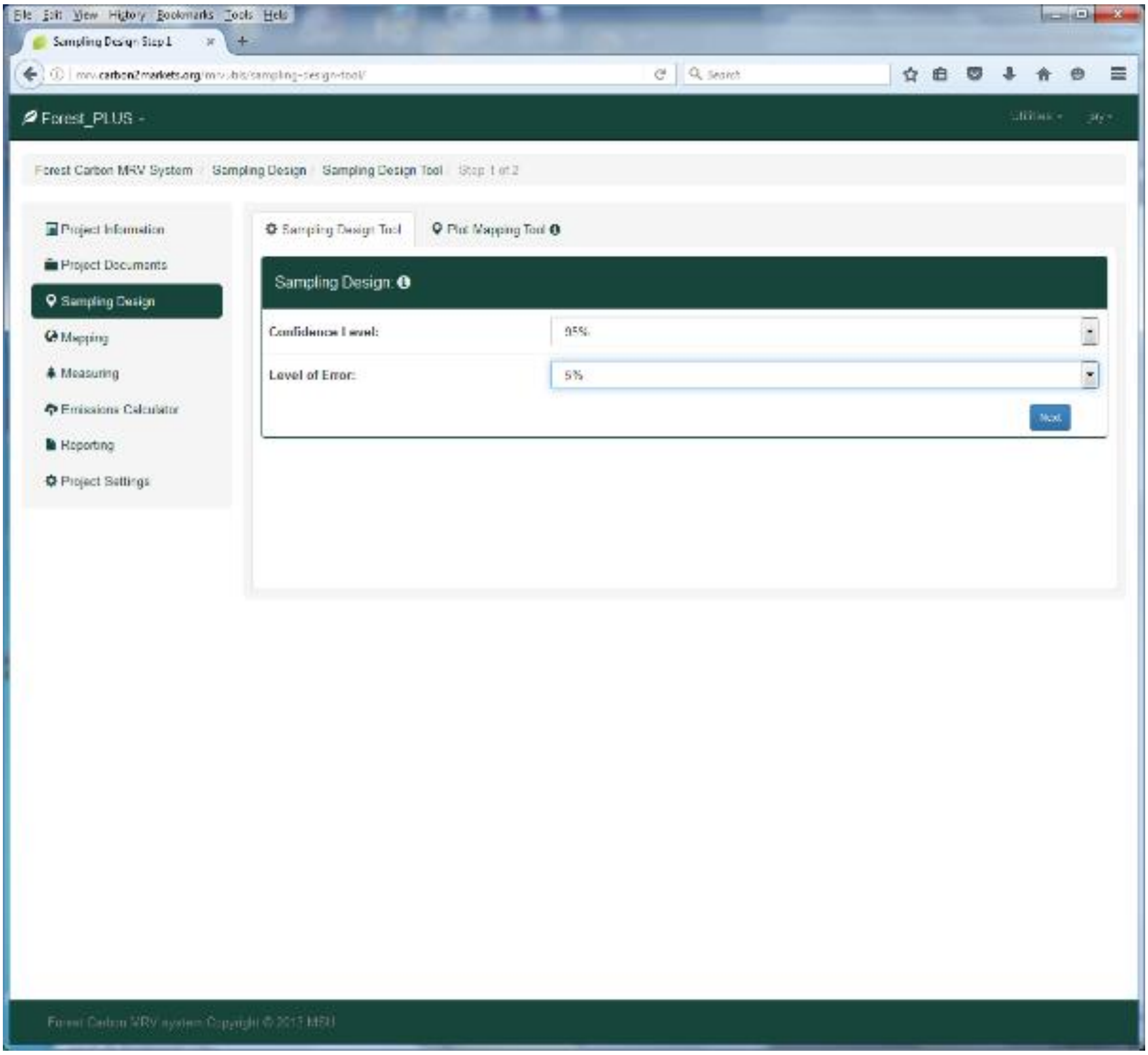


Figure 2-15: Forest-PLUS DMS Sample Plot Design Tool: Using the Pre-Sample Data Results Computing the Mean and Standard Variation of Carbon in Each Strata, Add the Plot Size in Hectares and Run the Model (Step 1)

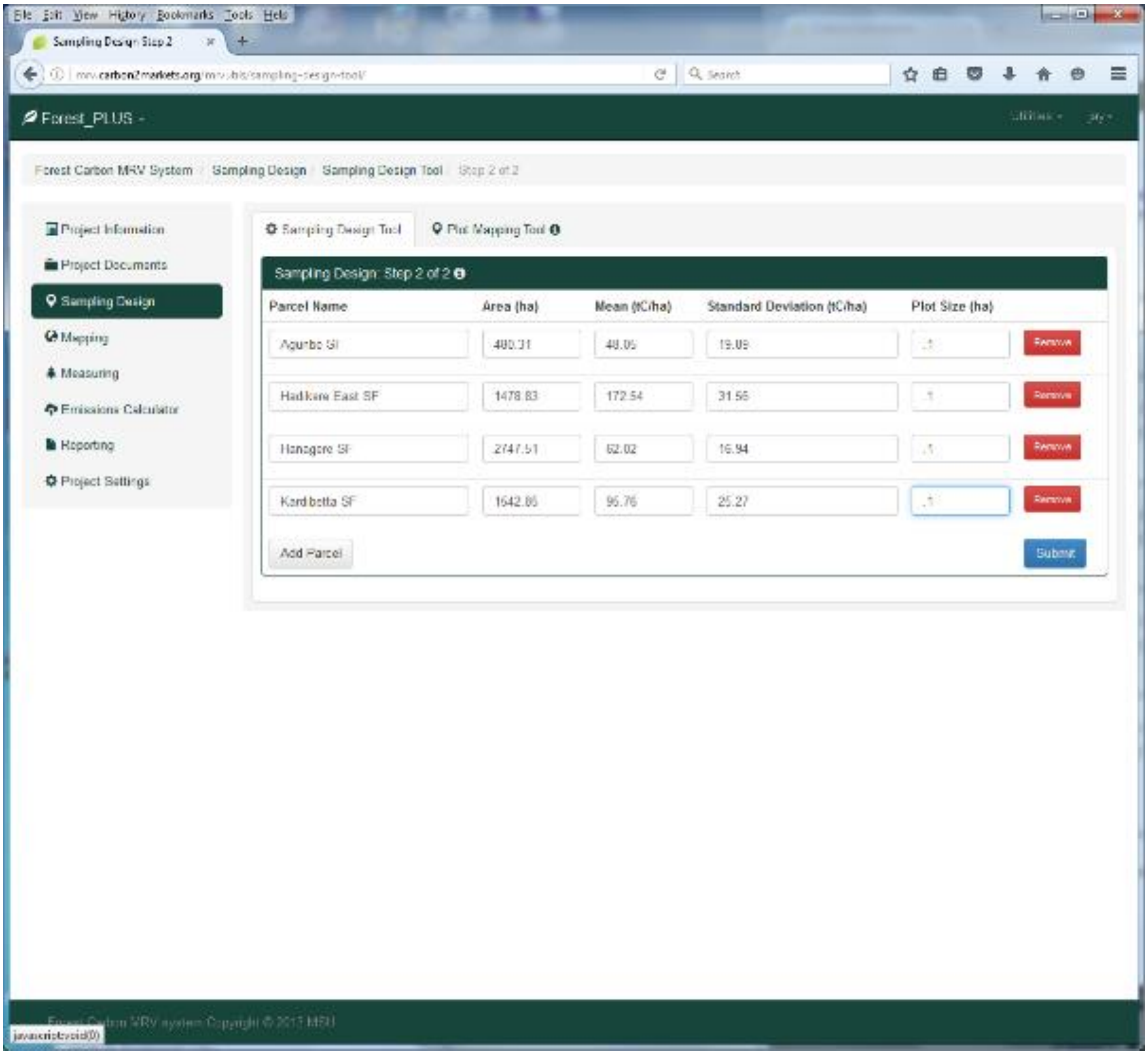
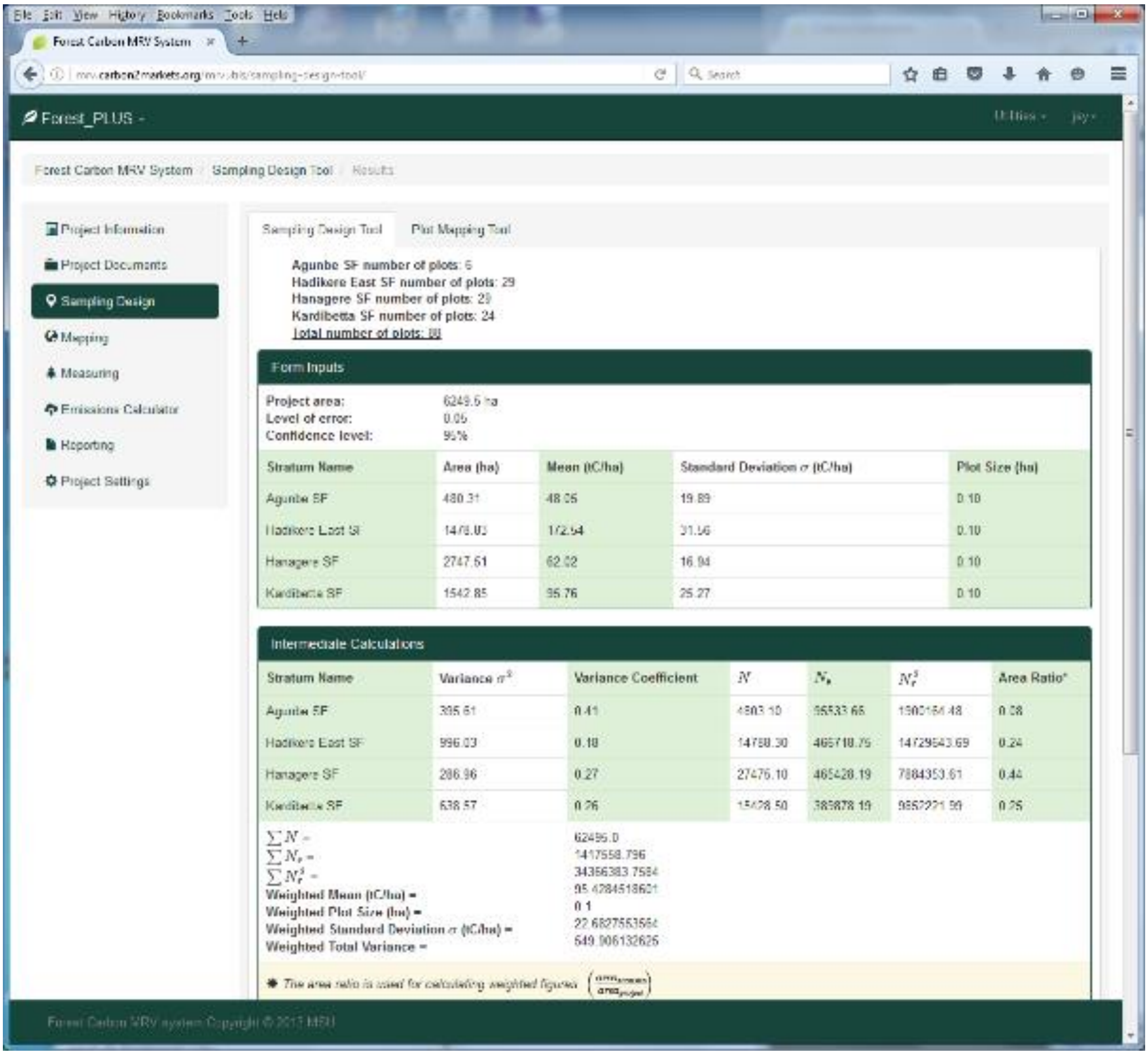


Figure 2-16: Forest-PLUS DMS Sample Plot Design Tool: Results from the Model Show the Number of Plots Required to Meet the Confidence and Error Levels Based on the Pre-Sample Mean and Variance of Carbon in Each Strata (Step 2)



2.1.5 MONITORING CARBON STOCK CHANGES

Plot and Data Collection for Monitoring Carbon Stock Changes

This method identifies the steps to monitor forest carbon stock by re-measuring a subset of the total plots used to calculate the emission factors and carbon stocks in strata. Monitoring the carbon stocks and stock changes over time provides the means for evaluating forest management practices aimed at low-carbon emissions.

Method

1. Identify from local expert knowledge and, if possible, from analyses of satellite data, strata within the surrounding the project area that are changing over time in terms of biomass. These are land-use, land-cover changes and constitute activity data. Changes may include conversion from one land cover to another (e.g., forest to agriculture or grassland to forest). Changes also may include increase or decrease in biomass within a single land cover (e.g., degradation of forest that still remain a forest or regeneration of a degraded forest).

2. In the identified strata where biomass is changing, establish a sample design plan for repeat measurement of plots. The sample design plan will include temporal and spatial aspects:
    a. Temporal plan: Repeat measurement every 1–2 years.
    b. Spatial plan: Re-sampling intensity of 50% or more of the original plots.
3. In known strata that are not changing rapidly, establish a sample design plan for repeat measurement of plots. The sample design plan will also include temporal and spatial aspects, but at less frequent temporal periods and fewer plots than are required for strata that are impacted by land cover changes:
    c. Temporal plan: Repeat measurement every 3–5 years.
    d. Spatial plan: Re-sampling intensity of 15–20% of the original plots.
4. Selection of the sub-sample of original plots for each plan should be done randomly. A random number generator can be used. The number of plots will be determined by the total number of original sample plots in the strata.
5. Once the sub-sample of plots are identified, navigate to each coordinate and establish plot center point.
6. Demark the plot area. (Follow the Forest-PLUS plot design protocol.)
7. Collect tree inventory data at the plot using the Forest-PLUS mForest App or record data on a hardcopy of the Forest-PLUS plot data record sheet. (Follow the tree inventory and measurement protocol.)
8. Navigate to the next plot and repeat steps 6 and 7.
9. Repeat until all plots have been reached and data collected.
10. Upload data to the Forest-PLUS DMS.
11. Using the Forest-PLUS DMS Carbon Stocks by Plot report from the Carbon Calculations tab in the Measuring Tool, note the mean value in Total tC^{-ha} for carbon density.
12. Plots where land cover conversion has occurred can be reported using the emission factor times the area in hectares that was converted. This may be a sink or source for carbon emissions.

Plots where carbon stocks have changed but the land cover type was not converted can report the difference in carbon stock from time period 1 and time period 2, the repeat measurement. This may be a degradation (emission source) or enhancement (emission sink) of carbon stocks.

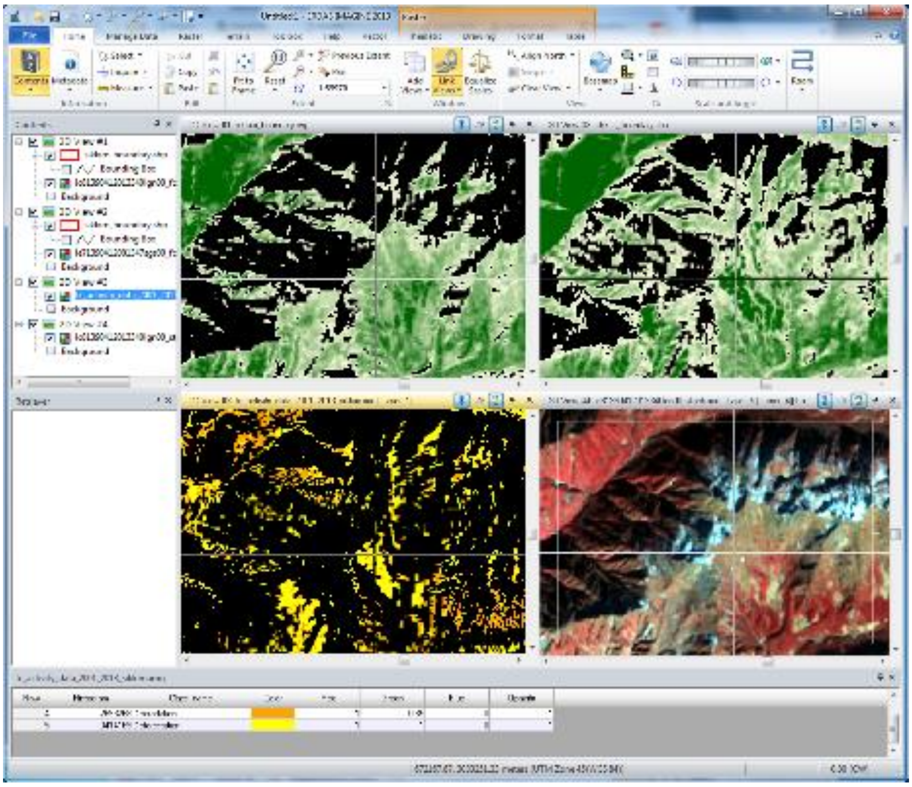
Activity Data (AD)

Activity data includes (1) areas of deforestation, (2) areas of forest degradation, and (3) intensity of forest degradation. Activity data is mapped from the analyses of multi-temporal land cover (strata) data that are derived from remote sensing data. Geographic overlay of land cover data (strata) result in a matrix of areas of change between time periods from one land cover type to another or one strata to another. The area change by strata is the extent of change. The rate of change is calculated by dividing the area extent by the time period in years represented by the two time periods.

Degradation is measured using a continuous-fields or vegetation fractional cover (fC) analyses with multi-temporal satellite data. See the published Forest-PLUS document on Remote Sensing Models. This analysis is completed for all forest strata that remain forest from one time period to another. The change analyses between two fC data products computes reductions in biomass over time.

The Forest-PLUS Remote Sensing (RS) Models: The published remote sensing models support preliminary data processing and analysis of optical remote sensing data (Landsat, ASTER VNIR, AWiFS, and LISS-III). The models are built using ERDAS Imagine Spatial Modeler and the algorithms are used for processing raw satellite data to intermediary data products for stratification and for multi-temporal analyses to compute activity data and forest degradation over

Figure 2-17: Activity Data in ERDAS



Monitoring Activity Data

Monitoring AD is essential for overall forest carbon project monitoring and reporting. Multi-temporal remote sensing data is used in specific temporal steps. An annual increment is used to monitor deforestation. Three-to-five year increments are used to measure and monitor degradation. Monitoring deforestation and degradation using satellite remote sensing should also be coupled with ground data and with climatological and fire incidence and location data.

Monitoring Includes:

- Annual analyses of remote sensing data to map deforestation using the forest fractional cover method:
  - Deforestation = $fC_{yr1} - fC_{yr2}$, where $fC_{yr1} = fC_{veg}$ and $fC_{yr2} = fC_{soil}$ or a threshold change for $fC_{veg} > fC_x$ and $fC_{soil} < fC_y$; where fC_x is a fractional value that is greater than fC_y
- Three-to-five-year analyses of remote sensing data to map degradation using the forest fractional cover method:
  - Degradation = $fC_{yr1} - fC_{yrx}$, where $fC_{yr1} = fC_{veg} > fC_{yrx}$ by a specific threshold value
- Field monitoring:
  - Natural events, e.g.:
    - Drought;
    - Pest, disease; and
    - Fire.
  - Anthropogenic events (project interventions), e.g.:
    - Illegal grazing;
    - Illegal tree harvesting;
    - Illegal agricultural expansion;
    - Legal conversion of forest land; and
    - Legal harvesting.
- Additional ancillary data:
  - Climate and weather data; and

– Fire hot-spot data (e.g., MODIS Fire Product).

2.1.6 SETTING A HISTORICAL BASELINE

Defining the Historical Period of Analyses

The historical period of analyses requires a minimum of two time periods. Analysis of data that includes more than two time periods may show a variable trend in deforestation and forest degradation both in terms of rate and extent over the period of analysis. The period of analyses must be determined in a logical manner that meets the needs for why a baseline is being determined. Reporting and analyses requirements may be determined by national legislation, in determining national action plans or convention reporting, or may be necessitated by specific "market" protocols. It is not within the scope of this document to determine what should be the historical period of analyses.

Estimate Projected Baseline Emissions

The IPCC guidelines use an approach that computes emissions from the multiplication EF times AD, where EF are based on the biomass and carbon stock estimates, configured to account for the fraction that is burned and the fraction that is lost to decay over time. All five pools of carbon may be considered.

A Historical Baseline (B_h) is established through the use of retrospective remote sensing of land cover. A Business-as-Usual Baseline (B_t) is projected for the rate and extent of deforestation and for the rate and intensity of degradation. The forward-looking B_t is the ex-ante projection based on a simple projection of the B_h trend.

AD trends show the area and rate of deforestation and also the area and intensity of forest degradation. Emissions baselines for B_h and B_t are computed using AD and EF. The baselines explain both emissions from deforestation and emissions from forest degradation. The sum total is the ex-ante baseline.

The Forest-PLUS DMS: The emissions calculator toolkit of the DMS supports the estimate of ex ante baseline emissions for deforestation and forest degradation. Activity Data and Emission Factors are input to a modeling framework which computes stock-changes of emissions for a specific period of time.

2.1.7 REPORTING EMISSIONS

Monitoring activity data provides the necessary data to calculate emissions reductions from project interventions. The monitoring and reporting of emissions is compared against the B_t projection. Emissions are calculated as AD times EF.

The Forest-PLUS DMS: The emissions calculator toolkit of the DMS supports the reporting of emission monitoring for deforestation and forest degradation. Activity Data and Emission Factors are input to a web-interfaced database to compute the monitored stock-changes of emissions for specific monitoring time periods and compared against the Business-As-Usual baseline projections of emissions.

2.2 SESSION II: PLOT DESIGN PROTOCOL

Session II will cover the following topics
Plot design protocol for tier 3 forest carbon data
1. General description of the protocol
2. Required tools
3. Plots on sloping ground

2.2.1 GENERAL DESCRIPTION OF THE PROTOCOL

The plot design protocol is a specific set of procedures or steps for identifying and demarcating the area where tree inventory and tree measurements will be collected and recorded. These steps should be followed in order.

The plot design protocol does not include the sample design. Sample design concerns the number of plots as well as the placement of these plots in the landscape. The Forest-PLUS DMS includes a tool to support sample design.

The steps described below are for demarcating a standard National Working Plan Code (2014) plot with dimension 31.62x31.62m with nested plots at 5x5m, 3x3m, and a 1x1m plot in North-East and South-West direction at a distance of 30m from the center of the main plot (MoEFCC, 2014). Two 1x1m nested plots need to be laid inside the main plot at North-East and South-West corner of it. The area of the largest plot is equal to 0.1 ha with nested plots equally 0.0025 ha, 0.0009 ha, and 0.0001 ha. (See Figure 2-18, Figure 2-19, and Figure 2-20).

Figure 2-18: Nested, Rectangular Plot Design (for Non-Hilly Area)

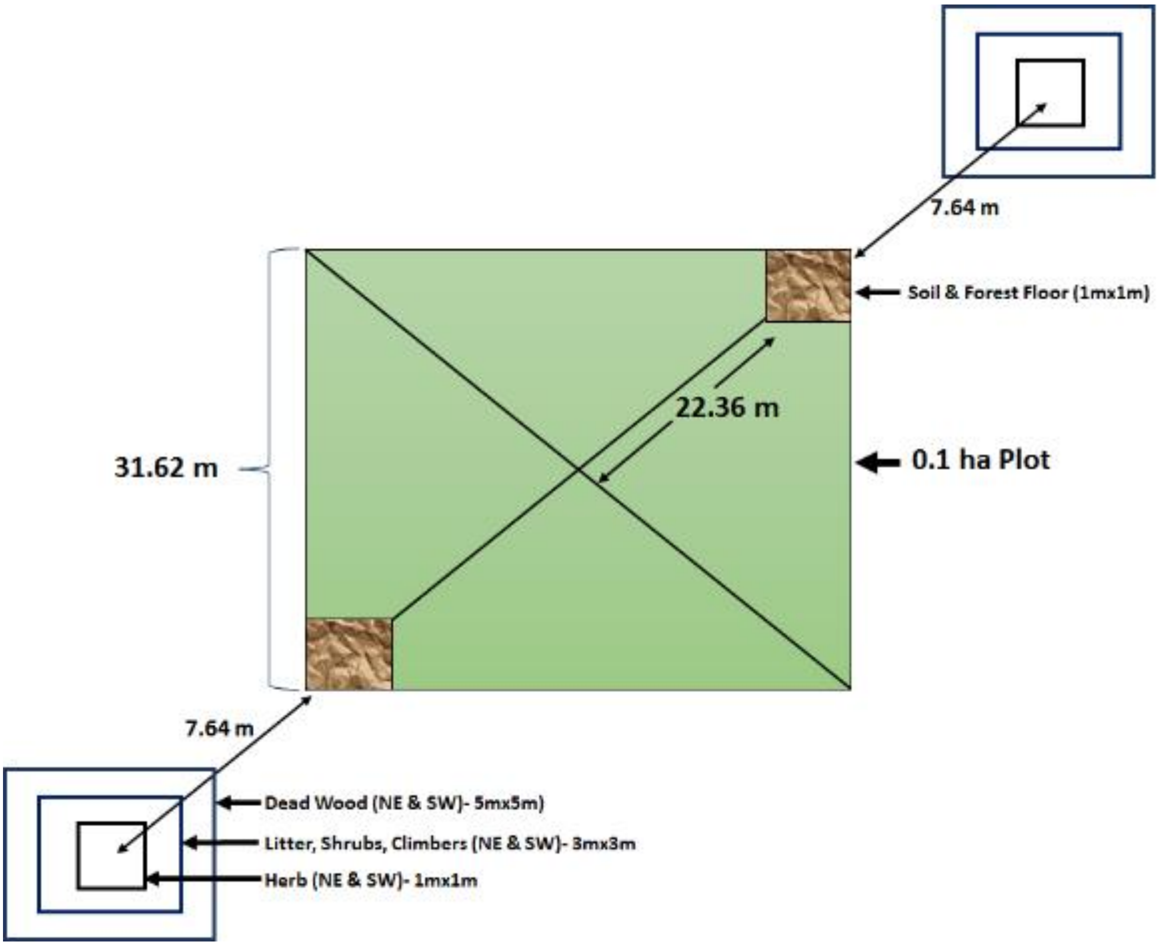


Figure 2-19: Nested, Rectangular Plot Design (for Hilly Areas)

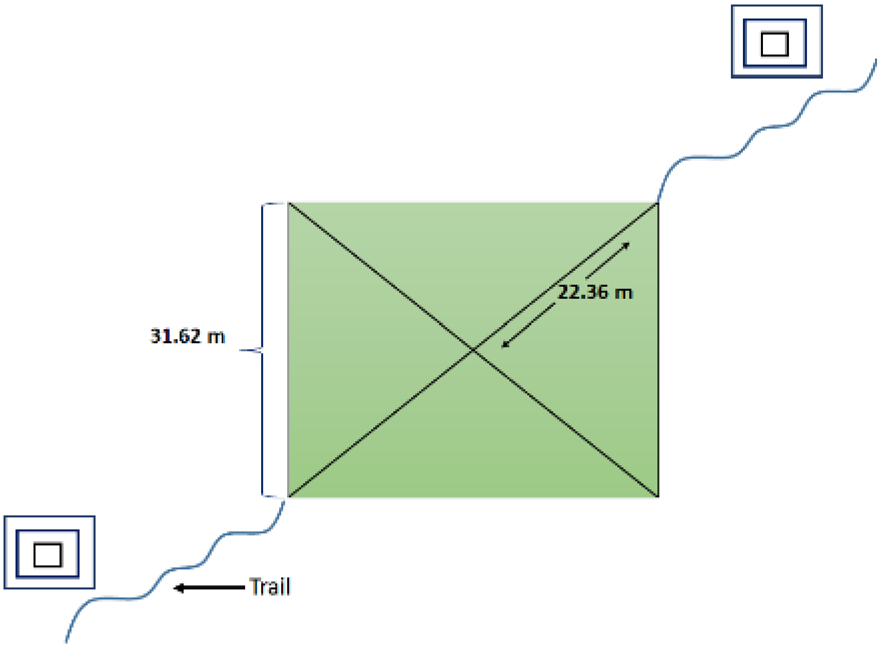
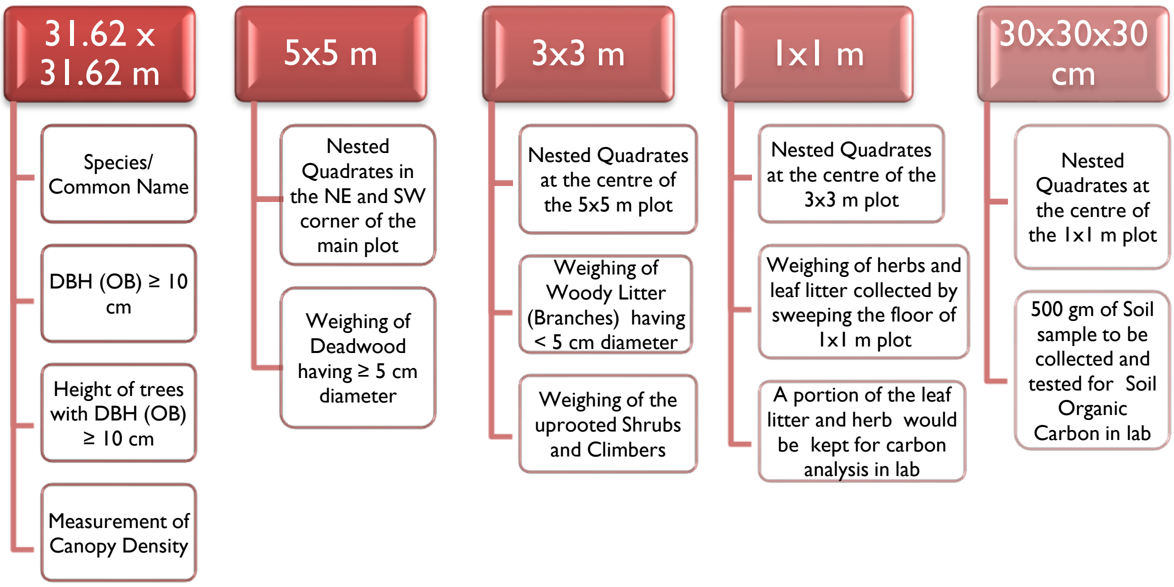


Figure 2-20: Plot Enumeration for Assessment of Forest Vegetation



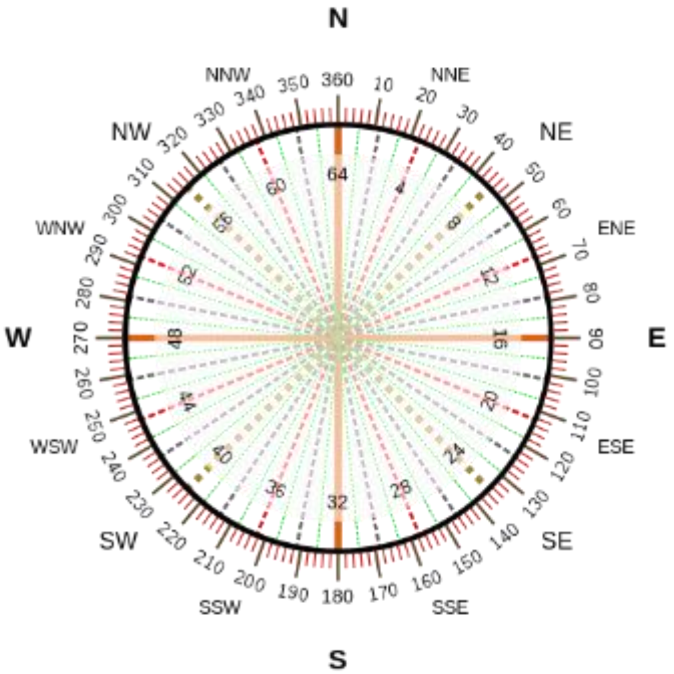
2.2.2 TOOLS REQUIRED

To delineate a plot area, the following tools are needed:

1. 30-to-50-meter measuring device: the measuring device could be a measuring tape or a rope of known length and with meter marking;
2. GPS device;
3. Compass;
4. Flagging tape or cloth;
5. mForest App (GPS-navigation); and
6. Field-scale measuring to the grams.

Compass readings are in 360 degrees, a complete circle. The notation for degrees is the degree symbol ° (for example, 360°). North is at 0 ° (or 360°), East at 90°, South at 180°, and West at 270° (see Figure 2-21).

Figure 2-21: Compass



At 7.64 m NE and SW from the NE and SW corners of the main plot of 0.1 ha, nested quadrats of size 5x5m, 3x3m, and 1x1m, should be laid out in the selected grid for the estimation of carbon stock, subject to availability of resources and funds. In the 5x5m plot, all the deadwood above 5 cm diameter is collected, weighed, and recorded. In 3x3m plot, all the woody litter (that is, all branches below 5 cm diameter) is collected, weighed, and recorded. All shrubs and climbers in the 3x3m plots are up-rooted, weighed, and recorded. For trees, allocation of carbon in root, stem, branch, twigs, and leaves may be obtained separately. In the 1x1m plot, all the herbs/grasses including leaf litter are collected, weighed, and recorded. Dry biomass is converted into carbon stock. For collecting data on humus and soil carbon, the forest floor of the 1x1m plot at the NE and SW corner of the main plot area is swept and materials thus collected are weighed and a portion are kept for the carbon analysis. After that a pit of 30x30x30cm would be dug at the center of these 1x1m plots and a composite sample of soil weighing 200gm would be kept for organic carbon analysis.

If a survey is cost-prohibitive, FSI has collected this data across India and their survey data can be used.

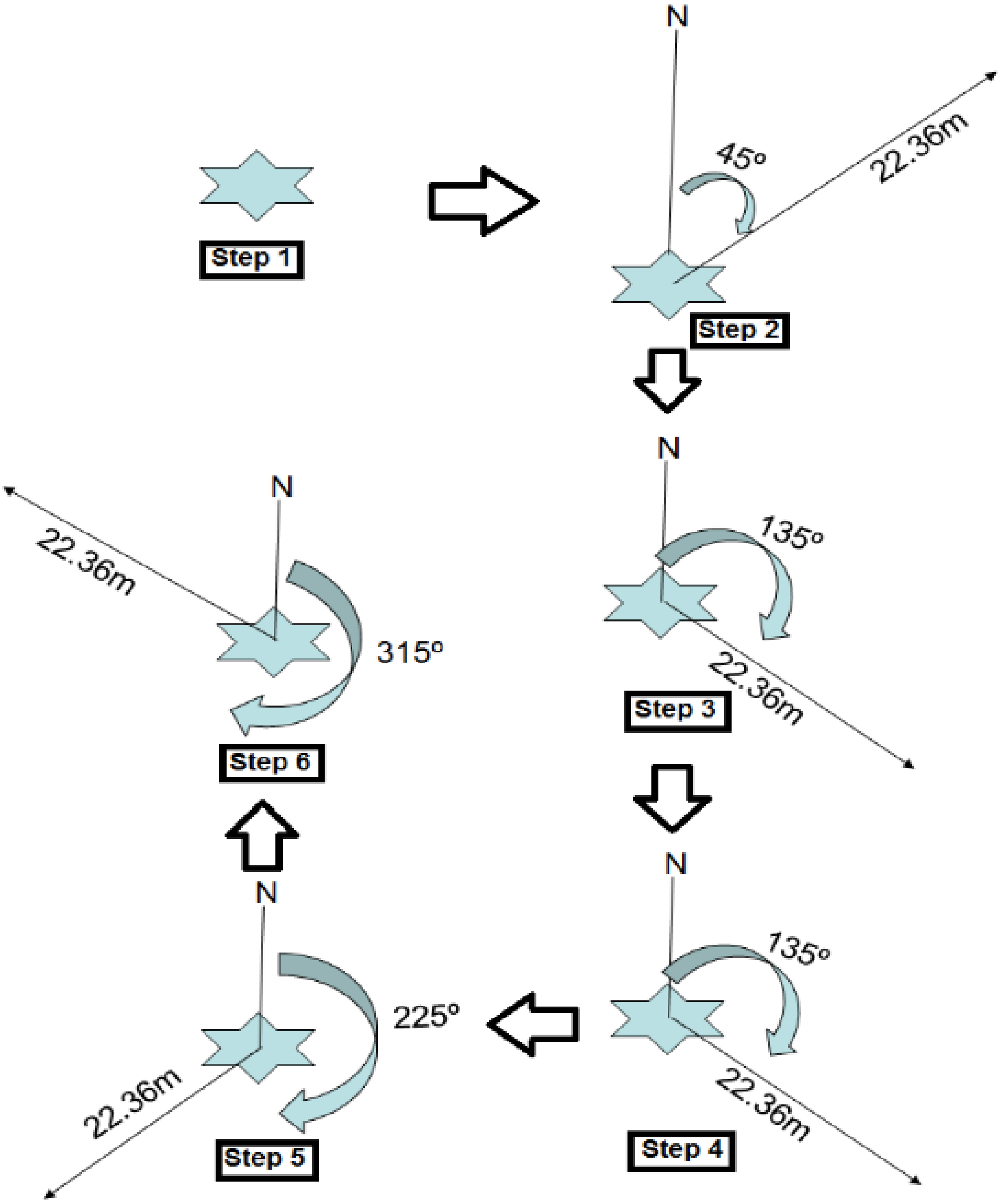
Protocol Steps – 31.62m plot (Figure 2-22)

1. Navigate to the plot point using the GPS/compass/mForest App.
2. Mark this point as center.
3. Standing at the center, keeping north as 0˚, measure 22.36m at an angle of 45˚ with the help of compass and 50m tape. Mark it as NE corner.
4. Return back to the center point.
5. Measure 22.36m at an angle of 135˚ with the help of compass and 50m tape. Mark it as SE corner.
6. Return back to the center point.
7. Measure 22.36 m at an angle of 225˚ with the help of compass and 50m tape. Mark it as SW corner.
8. Return back to the center point.
9. Measure 22.36m at an angle of 315˚ with the help of compass and 50m tape. Mark it as NW corner.
10. Each side of the square should be 31.62m.

Flagging tape along the boundary is needed in only very dense vegetation condition to aide in knowing which trees are in the plot and which trees are outside of the plot boundary. Trees inside are to be enumerated while trees outside are not.

Plot corner points can be marked with a stick or stake or a piece of flagging tape/cloth. It should be clear where the corners for each plot are located. Flagging tape or cloth that is used between corner points are required to determine the trees that are "in" versus "out" of plot areas. "In" trees will be inventoried. "Out" trees will not be inventoried.

Figure 2-22: Steps for Plotting 0.1 Ha Main Plot



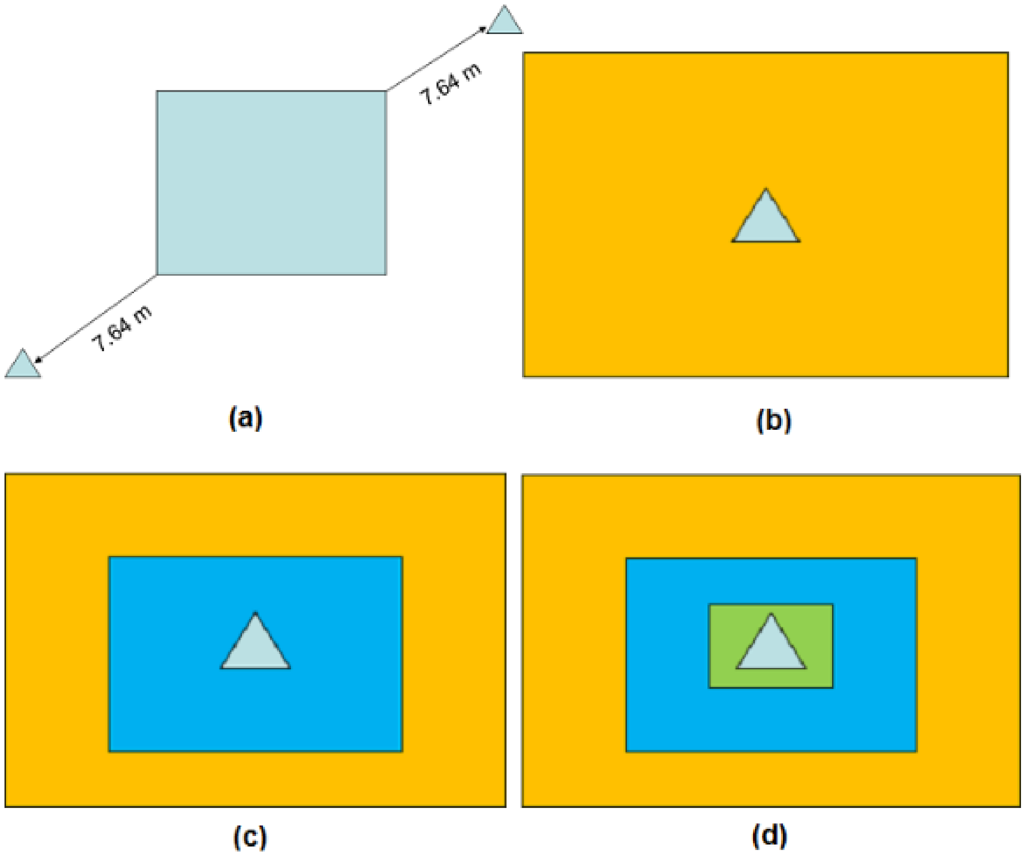
Protocol Steps for Nested Plot – 5x5m, 3x3m and 1x1m (Figure 2-23)

1. Measure 7.64m from the NE (45°) and SW (225°) corner (a).
2. Keep the sub plot point at the center and create a 5x5m sub plot (b).
3. Keep the sub plot point at the center and create a 3x3m sub plot (c).
4. Keep the sub plot point at the center and create a 1x1m sub plot (d).
5. Lay 1x1m plot at the NE and SW corner of the main plot (0.1ha plot).

All corner angles should be 90 ° right angles.

Plot corner points can be marked with a stick or stake or a piece of flagging tape/cloth. It should be clear where the corners for each plot are located. Flagging tape or cloth that is used between corner points are required to determine the trees that are "in" versus "out" of plot areas.

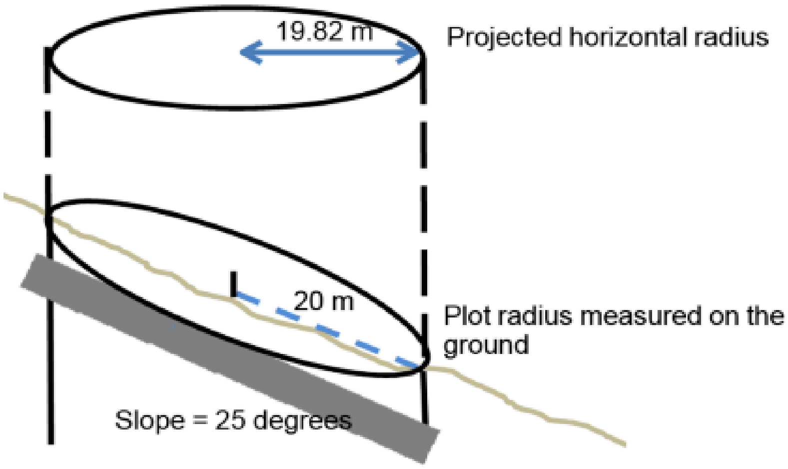
Figure 2-23: Steps for Plotting 0.1ha Main Plot



2.2.3 PLOTS ON SLOPING GROUND

If the plot is located on sloping land a slope correction factor must be applied to the layout of the plot. The distance between two points, measured along one slope (d1) is always longer than an equivalent horizontal distance (h1). On slope terrain, the horizontal distance must be multiplied by a factor that corresponds to the inclination in order to obtain a corrected distance (see Figure 2-24).

Figure 2-24: Slope angle and slope correction



Use the clinometer to measure slope (Point A to Point B). In using the clinometer to measure slope, ***the angle must be parallel to the average slope of the ground between the two distances***.

How to Use a Clinometer:

A clinometer is an instrument for measuring angles of slope (or tilt), elevation, or depression of an object with respect to gravity. Clinometers measure both inclines (positive slopes, as seen by an observer looking upwards) and declines (negative slopes, as seen by an observer looking downward) using three different units of measure: degrees, percent, and topo (See Figure 2-25).

- Stand at the center of the plot.
- Hold the clinometer to your eye.
- Ensure there is no obstruction.
- While holding clinometer to your eye, line up the crosshair and "0" reading in clinometer with the reference point.
- Read the scale with percentage sign to know the of slope percentage.
- It is also used to measure the height of the tree.

Figure 2-25: Clinometer and How to Hold and Site a Slope

As an alternative to a Suunto clinometer, which may not be available, a simple tool can be made with a protractor, string, straw, and a small weight like a nut or washer. See Figure 2-26 (next page).

Table 2-2 (next page) gives the slope correction factor and corrected distance. For horizontal distances not included in the table, the corrected distance can be calculated by multiplying the slope correction factor of the known slope by the horizontal distance.

Figure 2-26: Basic Clinometer Tool

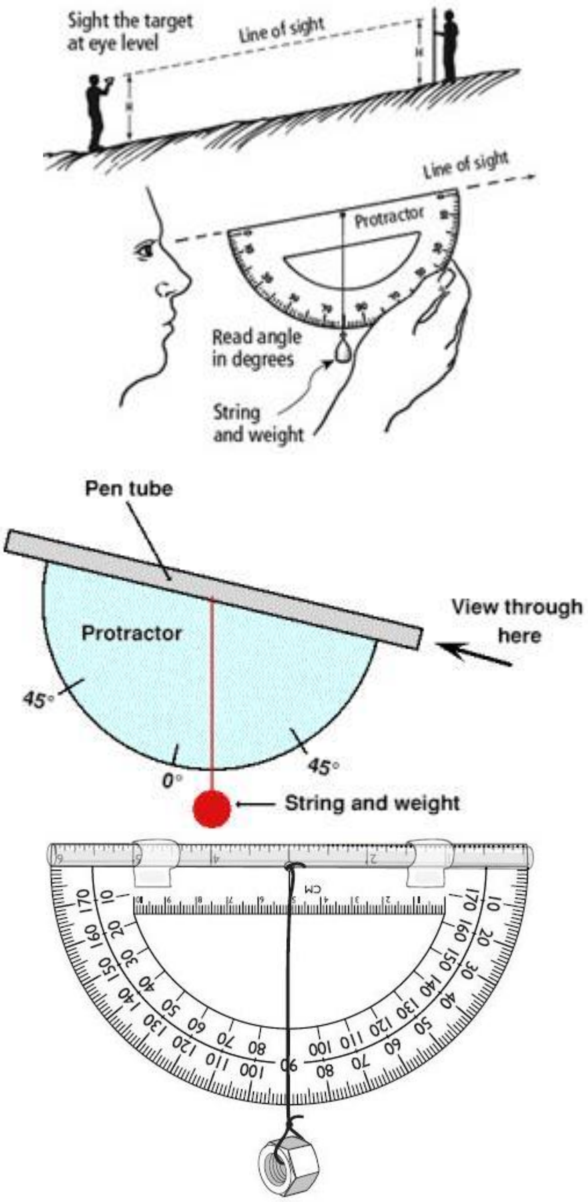


Table 2-2: Slope Correction Factors for Various Distances

Slope	Degree	Factor	Horizontal Distances										Slope
%	°	fs	5	10	15	20	25	30	40	50	125	245	%
15	9	1.0112	5.1	10.10	15.2	20.2	25.3	30.3	40.4	50.6	126.4	247.7	15
20	11	1.0198	5.1	10.20	15.3	20.4	25.5	30.6	40.8	51.0	127.5	249.9	20
25	14	1.0308	5.2	10.30	15.5	20.6	25.8	30.9	41.2	51.5	128.8	252.5	25
30	17	1.0440	5.2	10.40	15.7	20.9	26.1	31.3	41.8	52.2	130.5	255.8	30
35	19	1.0595	5.3	10.60	15.9	21.2	26.5	31.8	42.4	53.0	132.4	259.6	35
40	22	1.0770	5.4	10.80	16.2	21.5	26.9	32.3	43.1	53.9	134.6	263.9	40
45	24	1.0966	5.5	11.00	16.4	21.9	27.4	32.9	43.9	54.8	137.1	268.7	45
50	27	1.1180	5.6	11.20	16.8	22.4	28.0	33.5	44.7	55.9	139.8	273.9	50
60	31	1.166	5.8	11.7	17.5	23.3	29	35	46.6	58	145.8	285.7	60
70	35	1.221	6.1	12.2	18.3	24.4	31	36.6	48.8	61	152.6	299.1	70
80	39	1.281	6.4	12.8	19.2	25.6	32	38.4	51.2	64	160.1	313.8	80
90	42	1.345	6.7	13.5	20.2	26.9	34	40.4	53.8	67	168.2	329.6	90
100	45	1.414	7.1	14.1	21.2	28.3	35	42.4	56.6	71	176.8	346.5	100
110	48	1.487	7.4	14.9	22.3	29.7	37	44.6	59.5	74	185.8	364.2	110
120	50	1.562	7.8	15.6	23.4	31.2	39	46.9	62.5	78	195.3	382.7	120

Table 2-3: Slope Correction Factors for Distance of 5m and 31.62m

Slope	Degree	Factor	Horizontal Distance (m)		Slope
%	°	fs	5	31.62	%
15	9	1.0112	5.06	31.97	15
20	11	1.0198	5.10	32.25	20
25	14	1.0308	5.15	32.59	25
30	17	1.0440	5.22	33.01	30
35	19	1.0595	5.30	33.50	35
40	22	1.0770	5.39	34.05	40
45	24	1.0966	5.48	34.67	45
50	27	1.1180	5.59	35.35	50
60	31	1.1660	5.83	36.87	60
70	35	1.2210	6.11	38.61	70
80	39	1.2810	6.41	40.51	80
90	42	1.3450	6.73	42.53	90
100	45	1.4140	7.07	44.71	100
110	48	1.4870	7.44	47.02	110
120	50	1.5620	7.81	49.39	120

In cases where the plot is located on sloping terrain, the orientation of a rectangular plot should have one side parallel to the slope. This means that directional from one point to another may not necessarily be north, east, south, and west. These directions, however, should be recorded in the data sheet. In such cases, the information in the steps above are somewhat modified as needed.

2.3 SESSION III: FOREST CARBON PLOT INVENTORY AND MEASUREMENT PROTOCOL

Session II will cover the following topics:

Forest carbon plot inventory and measurement protocol for tier 3 forest carbon data:

1. Introduction
2. Definitions
3. Required Tools
4. Stem DBH Measurements
5. Protocol Steps

2.3.1 INTRODUCTION

The forest carbon plot inventory and measurement protocol is a specific set of procedures or steps for collecting data used in estimating forest carbon stock or emissions factors. Trees and shrubs will be enumerated for above-ground biomass. Litter will be enumerated only if a field scale is available. The protocol steps should be followed in order.

2.3.2 DEFINITIONS

DBH: Diameter at Breast Height is a dendrometric measurement of a tree trunk (also known as stem or bowl) at 1.3 meters above the ground.

Tree: A woody perennial with a single main stem, or in the case of coppice with several stems, having a more or less definitive crown. Includes bamboos, palms, and other woody plants meeting the above criteria (IPCC, 2006).

Shrub: Woody perennial plants, generally more than 0.5 meters and less than 5 meters in height at maturity and without definite crown. Height limits for trees and shrubs should be interpreted with flexibility, particularly the minimum tree and maximum shrub height, which may vary between 5 and 7 meters (IPCC, 2006).

Litter: Includes all non-living biomass with a diameter less than a minimum diameter chosen by the country (for example 10 cm), lying dead, in various states of decomposition above the mineral or organic soil. This includes litter, fumic, and humic layers. Live fine roots (of less than the suggested diameter limit for belowground biomass) are included in litter where they cannot be distinguished from it empirically (IPCC, 2003).

2.3.3 REQUIRED TOOLS

The tools required for plot inventory and measurement include:

1. DBH or circumference tape;
2. Chalk or other marking tool;
3. mForest App (species list and DBH recording); and
4. Field scale and collection bag (optional) if measuring litter.

If using a standard metric measuring tape, the DBH measurement will be a conversion from circumference (girth) to diameter. Table 2-4 gives the circumference and diameter equivalents for the range of diameter values in increments of 1/10th cm from 5.0 to 20.0 cm. The conversion is:

$C = \pi \ x \ D$ Eq. 1

Where

C = circumference in cm

π = 3.14

D = diameter in cm

Table 2-4: Circumference – Diameter Conversion Chart

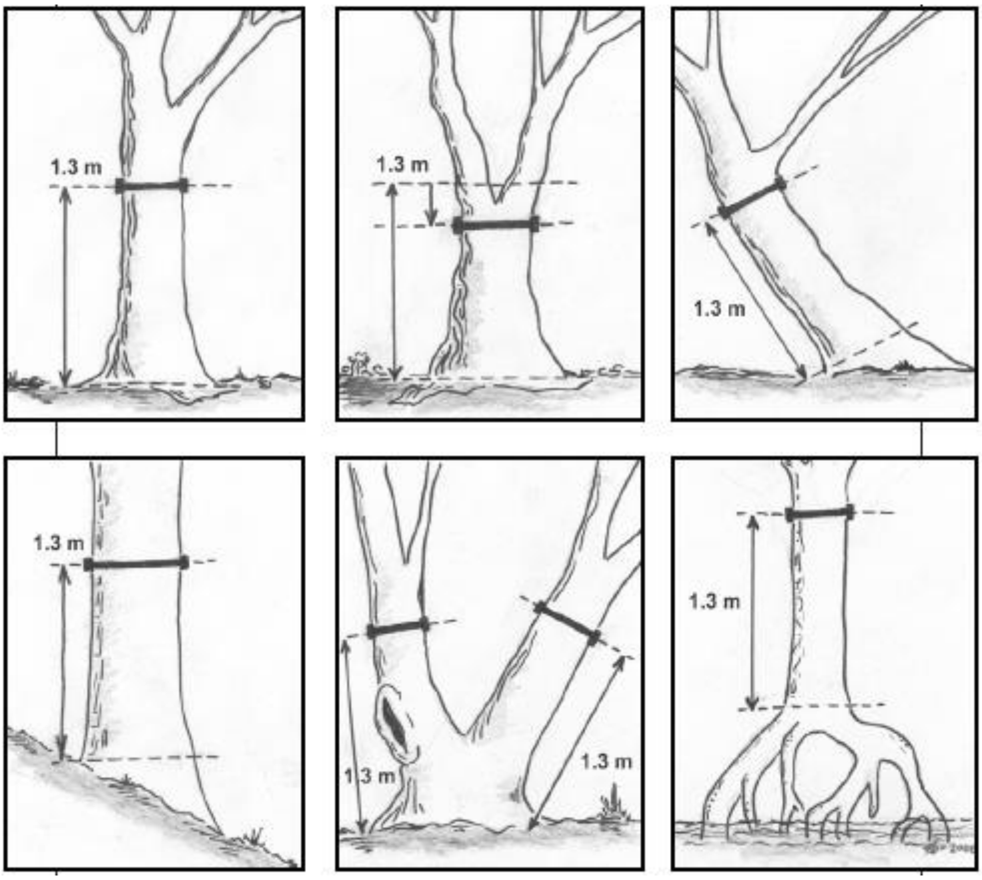
Conversion chart for DBH measurements from circumference (girth) to diameter
Units of .1 cm from 5.0 to 20.0 cm diameter

Girth (cm)	Diameter (cm)	Girth (cm)	Diameter (cm)	Girth (cm)	Diameter (cm)
15.7	5.0	31.7	10.1	47.4	15.1
16.0	5.1	32.0	10.2	47.8	15.2
16.3	5.2	32.4	10.3	48.1	15.3
16.7	5.3	32.7	10.4	48.4	15.4
17.0	5.4	33.0	10.5	48.7	15.5
17.3	5.5	33.3	10.6	49.0	15.6
17.6	5.6	33.6	10.7	49.3	15.7
17.9	5.7	33.9	10.8	49.6	15.8
18.2	5.8	34.2	10.9	50.0	15.9
18.5	5.9	34.6	11.0	50.3	16.0
18.8	6.0	34.9	11.1	50.6	16.1
19.2	6.1	35.2	11.2	50.9	16.2
19.5	6.2	35.5	11.3	51.2	16.3
19.8	6.3	35.8	11.4	51.5	16.4
20.1	6.4	36.1	11.5	51.8	16.5
20.4	6.5	36.4	11.6	52.2	16.6
20.7	6.6	36.8	11.7	52.5	16.7
21.0	6.7	37.1	11.8	52.8	16.8
21.4	6.8	37.4	11.9	53.1	16.9
21.7	6.9	37.7	12.0	53.4	17.0
22.0	7.0	38.0	12.1	53.7	17.1
22.3	7.1	38.3	12.2	54.0	17.2
22.6	7.2	38.6	12.3	54.3	17.3
22.9	7.3	39.0	12.4	54.7	17.4
23.2	7.4	39.3	12.5	55.0	17.5
23.6	7.5	39.6	12.6	55.3	17.6
23.9	7.6	39.9	12.7	55.6	17.7
24.2	7.7	40.2	12.8	55.9	17.8
24.5	7.8	40.5	12.9	56.2	17.9
24.8	7.9	40.8	13.0	56.5	18.0
25.1	8.0	41.2	13.1	56.9	18.1
25.4	8.1	41.5	13.2	57.2	18.2
25.8	8.2	41.8	13.3	57.5	18.3
26.1	8.3	42.1	13.4	57.8	18.4
26.4	8.4	42.4	13.5	58.1	18.5
26.7	8.5	42.7	13.6	58.4	18.6
27.0	8.6	43.0	13.7	58.7	18.7
27.3	8.7	43.4	13.8	59.1	18.8
27.6	8.8	43.7	13.9	59.4	18.9
28.0	8.9	44.0	14.0	59.7	19.0
28.3	9.0	44.3	14.1	60.0	19.1
28.6	9.1	44.6	14.2	60.3	19.2
28.9	9.2	44.9	14.3	60.6	19.3
29.2	9.3	45.2	14.4	60.9	19.4
29.5	9.4	45.6	14.5	61.3	19.5
29.8	9.5	45.9	14.6	61.6	19.6
30.2	9.6	46.2	14.7	61.9	19.7
30.5	9.7	46.5	14.8	62.2	19.8
30.8	9.8	46.8	14.9	62.5	19.9
31.1	9.9	47.1	15.0	62.8	20.0
31.4	10.0				

2.3.4 STEM DBH MEASUREMENTS

DBH tapes are calibrated to directly measure diameter on one side (circumference/π) and often have standard length (equals the circumference) on the other side of the tape. It is important that all field crew know which values to record and the correct zero point on the tape. The DBH tape must be used properly to ensure consistency of measurement. Field crew should measure where 1.3m is on their body or use a 1.3m long staff to identify the correct height to measure the diameter of every tree. If the tree is on a slope, always measure on the uphill side. If the tree is leaning, the DBH tape must be wrapped to be perpendicular to the main axis of the trunk (not parallel to the ground). If the tree is forked below 1.3 m, measure the two trunks as separate trees. If the tree forks above 1.3m, measure DBH of the main stem (unless there is an unusual bulge right at 1.3m). If the tree forks close to the 1.3m height, measure DBH of the mail stem just below the fork. Figure 2-27 shows the stem DBH measurements for straight ("normal") trees as well as non-normal trees and conditions.

Figure 2-27: DBH Measurement Locations for Irregular and Normally Shaped Trees



(Pearson et al., 2005)

2.3.5 PROTOCOL STEPS

31.62 Meter Plot

Starting in the SW corner (Point 1) data are to be collected for all trees that are greater than or equal to 10cm DBH (girth = 31.4cm) within the 31.62x31.62m demarcated plot.

Data collected will include the tree species and the DBH measurement accurate to the first decimal place, the tenth place of a cm.

1. Start in the SW corner and identify the closest tree to Point 1 that is 10 cm DBH or more.
2. Identify and record the species.
3. Measure and record the DBH and height of the tree.
4. Mark the tree to indicate that the tree data have been recorded.
5. Moving in a North direction, identify the next tree that is 10 cm DBH or more and repeat steps 2, 3, and 4.
6. Continue identifying and recording tree data until you reach the plot boundary demarcating Points 2 and 3.

7. Turn East and move in a South direction identifying and recording tree data until you reach the plot boundary demarcating Points 1 and 4.
8. Turn East and move in a North direction identifying and recording tree data until you reach the plot boundary demarcating Points 2 and 3. (See Figure 2-28, next page.)
9. Complete the data collection for the large plot and be sure no trees were missed and no trees were recorded twice.

Protocol Steps: 1st Nested Plot – 5m plot

Starting in the SW corner (Point 1) data are to be collected include all the deadwood above 5 cm diameter measurement accurate to the first decimal place, the tenth of a cm. It will include deadwood counts by classification size.

1. All deadwood above 5cm diameter (girth = 15.7cm), needs to be weighed. Mark the deadwood to indicate that the tree data have been recorded.
2. For bigger deadwood, weight can to be taken for each piece individually, or together whenever possible.
3. Total deadwood weight should be calculated by summing the weight of all measured pieces

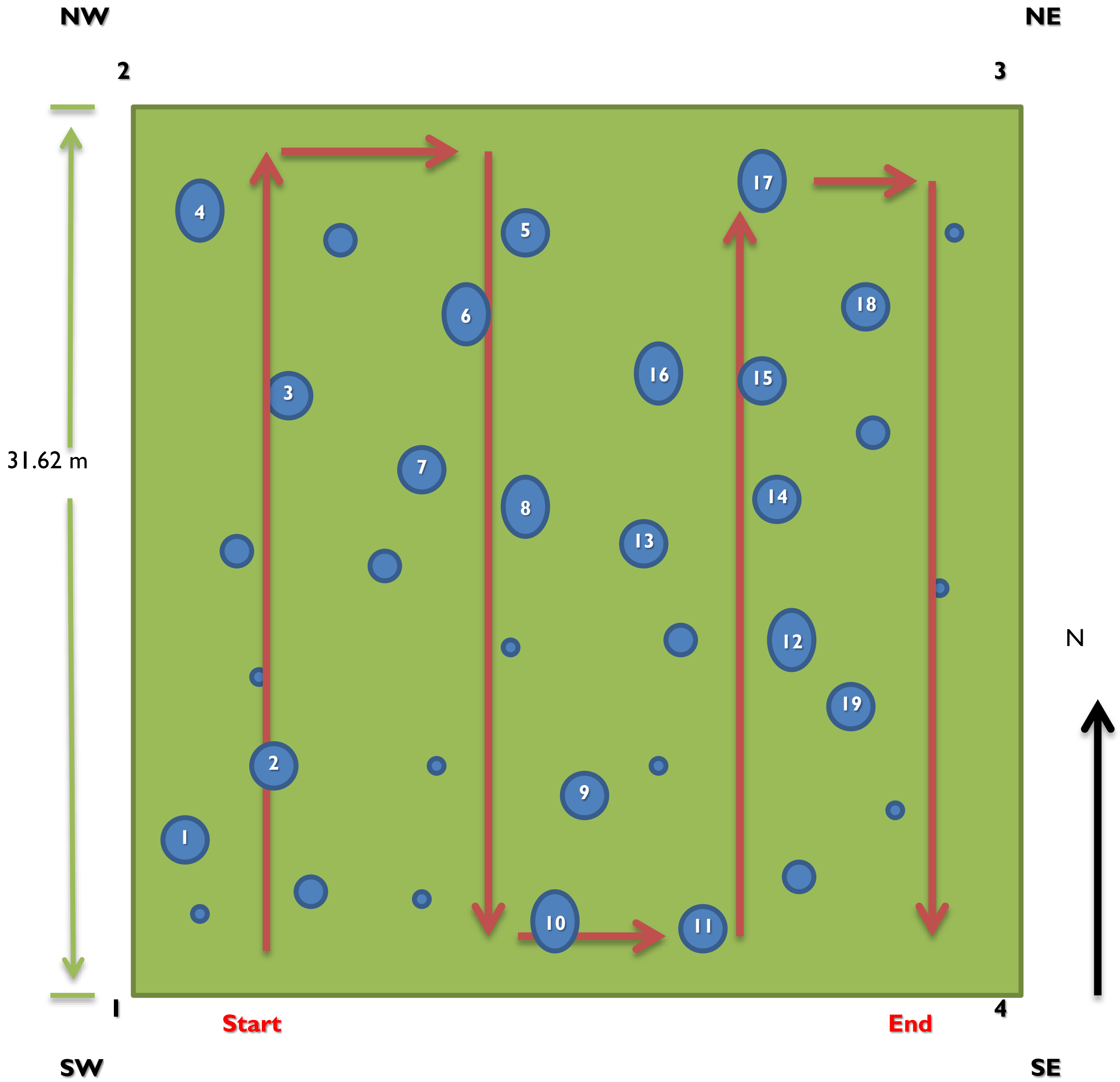
Protocol Steps: 2nd Nested Plot – 3m plot

Starting in the SW corner (Point 1), weight needs to be measured and recorded for all woody litter that is less than 5 cm DBH (girth = 15.7cm), and shrubs and climbers within the 3x3m demarcated plot. Take weight accurate to the first decimal place and record properly. Uproot all shrubs and climbers, and measure their wet weight in the field. A sample of about 500gm wet from the 3x3m plot should be weighed in the field and be taken from the field to the lab to measure oven dry weight.

Protocol Steps: the Two Nested 1m plot (optional)

Uproot all grass/herbs within the 1x1m plots to measure weight. A sample of about 500gm wet from the 3x3m plot should be weighed in the field and be taken from the field to the lab to measure oven dry weight.

Figure 2-28: Tree Measurement Route through a 31.62m Plot



Tools for Plot Layout and Measurement

There are several tools available for scientific plot laying and estimation of carbon stock in the plot. A few of the recent and widely applicable devices used for the above are:

1. GPS;
2. Manual Compass;
3. Clinometer;
4. Densiometer;
5. Measuring Tape/Steel Tape/Diameter Tape;
6. Ravi Altimeter; and
7. Hypsometer.

Garmin GPS

A GPS is used to locate the geo-coordinates of the plots, altitude, and aspect.

How to use a Garmin etrex 10 GPS:

- Switch on GPS.
- Press PAGE button to reach the fifth screen with the Title MAIN MENU.

- Use arrow to reach SETUP MENU.
- Press ENTER.
- Use arrow to scroll to NAVIGATION and press ENTER.

To store a position of the waypoint: Switch ON the instrument by pressing the red button on the instrument > Wait the till the position appears in the second screen > Press Mark Button > Change the label and symbol if required > Press Enter Button (DONE).

To create a way point: Go to Main Menu Page > Waypoint > New > Enter the position, number, label > Done.

To Navigate: Press GOTO Button > Select Waypoint from the list > Press Enter Button > It Displays the Compass with Bearing and Distance.

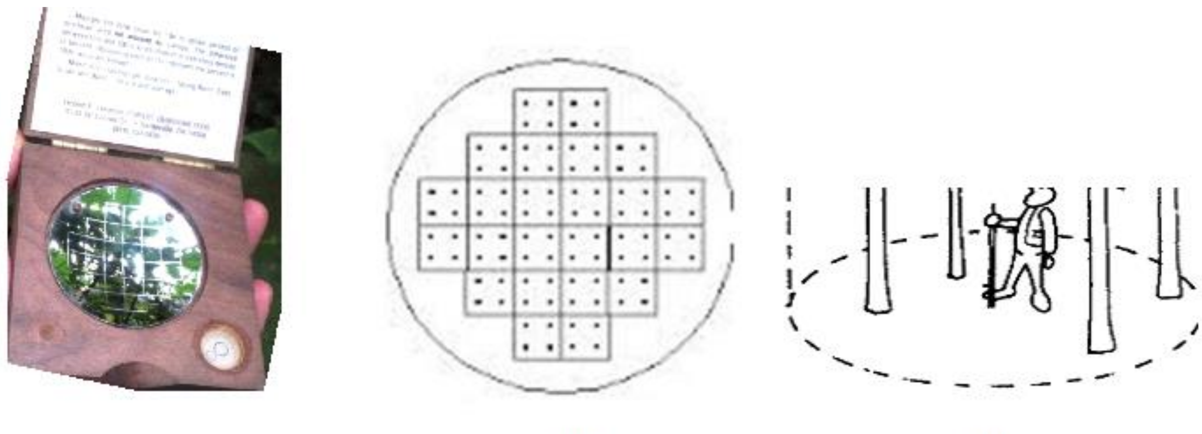
Densiometer

Densiometers are used to estimate the canopy density. The densiometer has a mirror on which 24 squares are marked as shown in Figure 2-29. Each square is mentally divided into 4 parts called "dots." The densiometer is used by holding it at breast height so that the observer's head is reflected from the edge of the mirror just outside the graticule. The curved mirror reflects the canopy above, and canopy closure can be estimated by calculating the number of squares (or quarters of squares) that the image of the canopy covers.

How to Use a Densiometer:

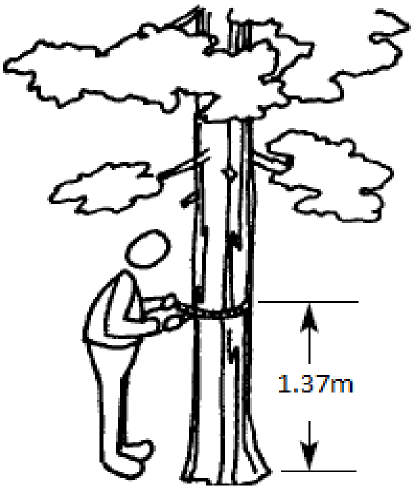
- Place the densiometer at elbow height.
- First try to bring the air bubble in the spirit level at the center.
- Count the dots in the mirrored grid covered by image of the canopy.
- Each square completely occupied by tree canopy is counted as 4 "dots." Similarly, a half-filled square is counted as 2 "dots;" a three-quarters-filled as 3 "dots;" and a one-quarter-filled as 1 "dot."
- The reading should be taken in four directions.
- These are then totaled and averaged to get the canopy density.

Figure 2-29: (a) Densiometer, (b) Canopy Estimation Process, (c) its Handling Technique



(a) (b) (c)

Measuring Tape/Steel Tape/Diameter Tape



Diameter tape is a common measuring tool in forestry. Its design allows for a measure of great length, to be easily carried in a pocket or toolkit, and permits one to measure around curves or corners.

How to Use a Diameter Tape:

- Measure diameter/girth of the tree.
- Wrap the tape around the bole of tree without twists or bends at 1.37cm.
- Handle the tape tightly and record the diameter/girth.
- Keep the tape perpendicular to the tree bole.

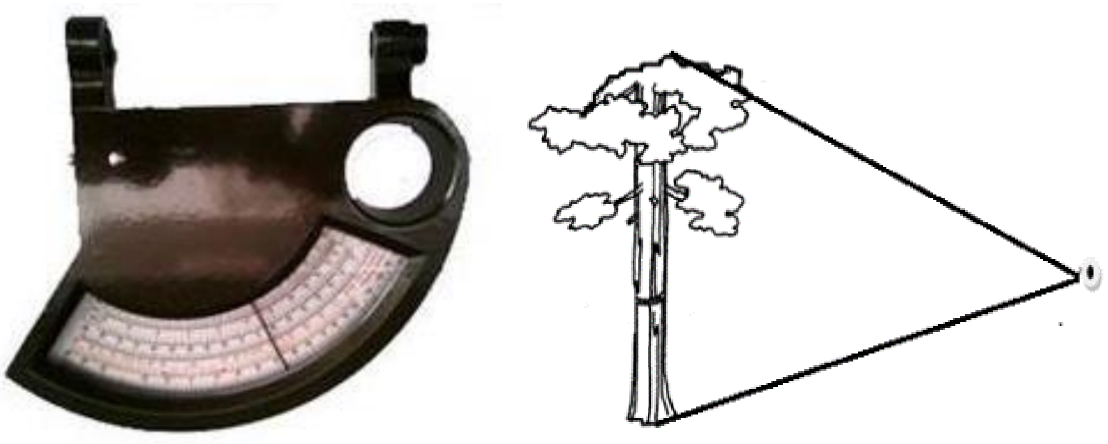
Ravi Altimeter

The Ravi altimeter has five scales: two for the heights graduated to distances, one for the degrees, one for the slope correction, and one for the slope percent. Tree height determination requires altimeter readings of both tree top and base levels. The values will be added if they have the opposite sign and subtracted from one another if they have the same sign (Figure 2-30).

How to Use a Ravi Altimeter:

- Estimate height of the tree.
- Measure the distance of 20/30m from base of the tree in the direction that top and bottom are visible.
- Hold the altimeter in one hand.
- Sight the top and end of the tree with eye.
- Press the lock button of the altimeter.
- See the scale and note down the reading.

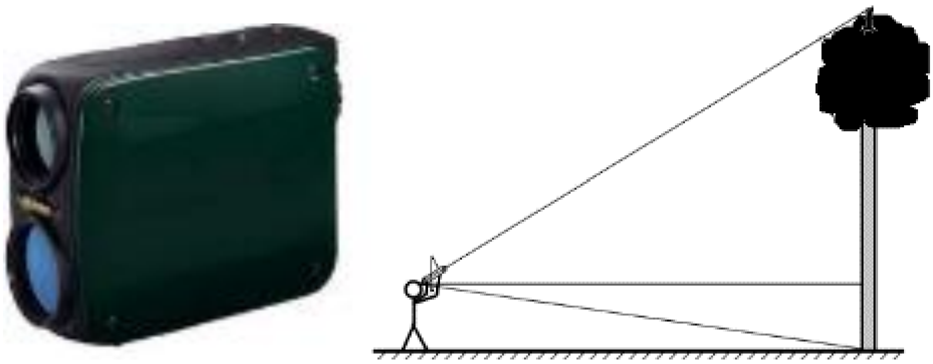
Figure 2-30: Ravi Altimeter and its Handling Technique



Hypsometer

A simple scale hypsometer allows the height of a building or tree to be measured by sighting across a ruler to the base and top of the object being measured when the distance from the object to the observer is known (Figure 2-30). Modern hypsometers use the combination of a laser rangefinder and a clinometer to measure distances to the top and bottom of objects, and the angle between the lines from the observer to each to calculate height (Figure 2-31).

Figure 2-31: Hypsometer and its Handling Technique



2.4 SESSION IV: MFOREST APP

Session IV will cover the following topics:

1. Description of the mForest App tools
2. Integration of mForest App data collection to the Forest-PLUS DMS
3. Summary of the Forest Data Management System (DMS)
4. Module 2 – Sessions IV Training Exercise

2.4.1 DESCRIPTION OF THE MFOREST APP TOOLS

The mForest App is a suite of tools launched from any android device. Android is a mobile operating system (OS) and is common with smartphones and tablet computers. Three tools comprise the mForest App: the GPS location and data recording tool, the plot photo tool, and the plot mensuration tool. These tools support the forest carbon data collection at the plot level by communities and front line foresters.

GPS Location and Data Recording Tool

The mForest App geographic tool is used in one of two ways: 1) to navigate to a plot corner point location or 2) to capture a plot corner point GPS location or geographic boundary for stratification or project boundary delineation.

Plot Photo Tool

The mForest App photo capture tool follows a protocol to capture digital images of a forest carbon plot. These images are tagged with information that relates it to the plot ID and identifies directional information.

Plot Mensuration Tool

The mForest App plot mensuration tool supports the data collection following the "tree inventory and measurement protocol for Tier 3 forest carbon data." Tree DBH measurement data is recorded and stored on the Android device. Each tree recorded is given a tree-ID and is associated with the plot ID. Tree species information is also stored for each tree measured. Information for other pools of carbon in the plot may also be stored on the device.

2.4.2 INTEGRATION OF MFOREST APP DATA COLLECTION TO THE FOREST-PLUS DMS

Forest-PLUS has developed two data systems that support forest carbon inventory, quantification, and reporting. The first system manages plot level forest inventory data and computes carbon stocks. These reported carbon stocks for particular forest strata are referred to as Emissions Factors. The second system computes fluxes of carbon and non-carbon greenhouse gases from changes to land cover over time. The land cover dynamics are referred to as Activity Data.

For the purpose of this document, we refer to the first system as the Forest Carbon Inventory System and the second as the Activity Data Emissions System. Both systems are bundled in the Forest-PLUS Data Management System, as a web-based platform. Combined these two systems support a number of measuring and reporting requirements for REDD+ activities.

The mForest App is an extension of the Forest-PLUS DMS. It integrates with the on-line platform through web services. The mForest App tools integrate with the Forest Carbon Inventory System. Figure 2-32 and Figure 2-33 on the next page show 1) the general workflow and integration between the mForest App and the Forest-PLUS DMS and 2) the schema integrating the database elements of the Forest-PLUS DMS and the mForest App.

Figure 2-32: mForest App and Forest-PLUS DMS Integrated System

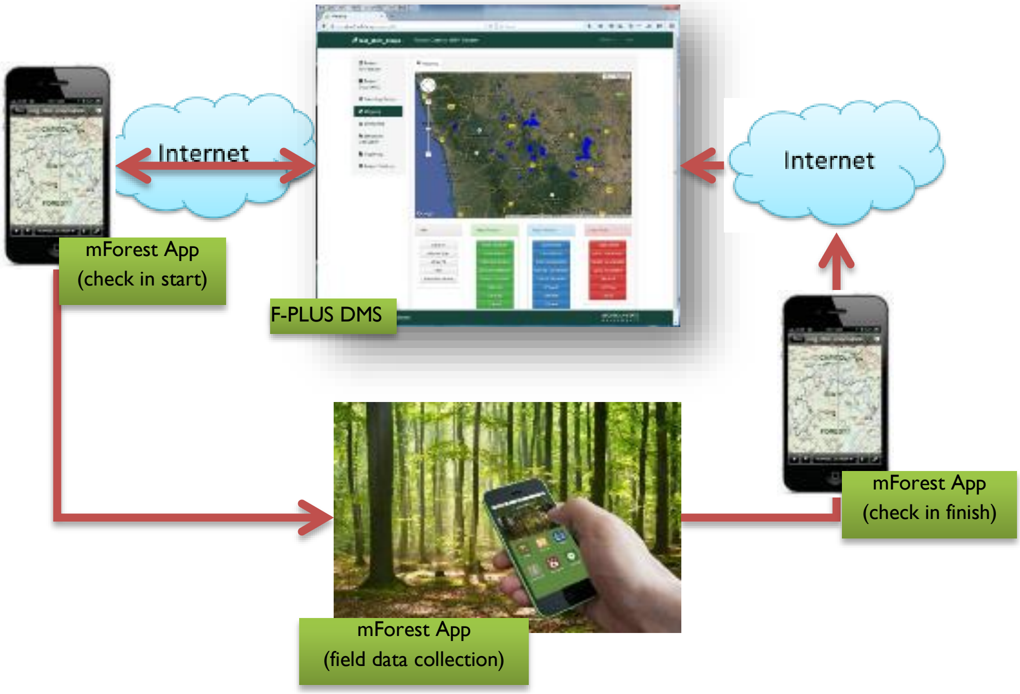
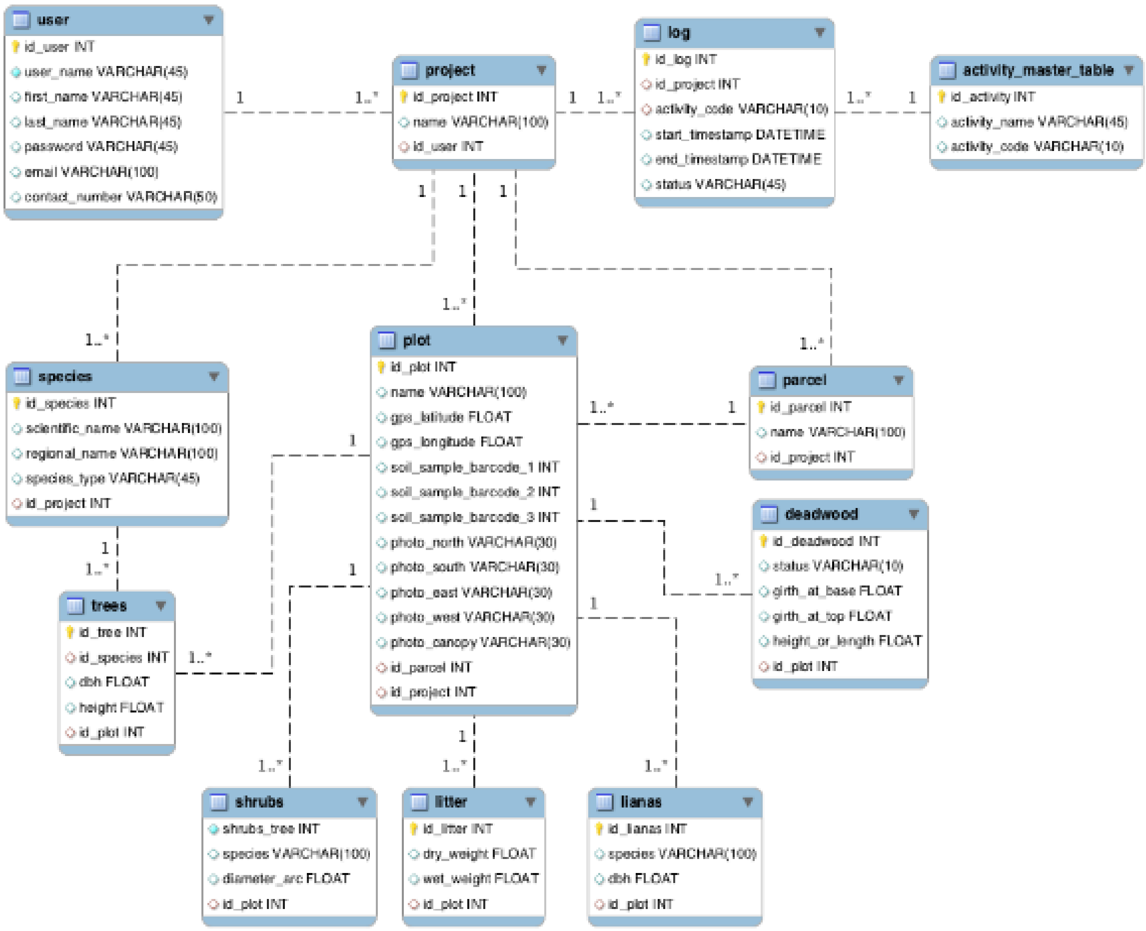


Figure 2-33: Forest-PLUS and mForest App Database Elements for Integration and Extension



The integration between the mForest App and the Forest-PLUS DMS occurs prior to and after field data collection. Prior to navigating to the plot for photo and tree mensuration data collection, there is a "check out" procedure. The mForest App device connects with the Forest-PLUS DMS through web service and downloads plot location data, plot and strata information and regional species lists. Field crews then collect data at the plots. For the "check in" procedure, the mForest App device again connects with the Forest-PLUS DMS through web service and uploads photos and plot inventory data as well as any new plot points or geographic polygon data.

Using the mForest App

The general protocol for using the mForest App is:

1. mForest App device check out: acquires data from Forest-PLUS DMS.
2. Field crew navigates to plot location for data collection:
    a. Field crew accepts plot GPS location or relocates and records new plot center point in the case where the plot location from the DMS is not acceptable (e.g., slope too steep, located to close to a stream or road, etc.).
    b. Photo capture tool protocol: images of the plot captured at four cardinal directions and angle (slope) of the photo recorded; images tagged with plot ID and photo direction.
    c. Forest mensuration data recorded: each tree > 10cm DBH within the plot → species id, DBH (height, etc.). Soil collection bar code recorded, litter and deadwood data recorded.
3. mForest App device check in: uploads data to the Forest-PLUS DMS.

There are two use scenarios for the mForest App. The first is the case where strata (parcel) and plot data have been generated and organized in the Forest-PLUS DMS. The second is the case where no plot data and/or strata (parcel) are organized in the Forest-PLUS DMS. The two use scenarios are outlined as:

1. Scenario 1: Project has parcel and plot IDs and locations:
    a. mForest App checks in → login → select project → download parcel and plot geographic data → download parcel and plot database information (parcel ID, parcel name, parcel area; plot ID, plot name, plot dimensions, plot shape, plot area, plot-to-parcel relationship → download tree species list → log off.
    b. mForest App field collection:
        1. Navigate to Plot 1 location. If Plot 1 location is OK, check "yes"; if not, check "no" and go to new point and record lat/long.
        2. Use forms to collect inventory data (DBH, height, species, etc.).
        3. Use picture app to collect four plot photos that are named to associate with plot and cardinal direction.
    c. mForest App checks in → login → upload collected data:
        1. New GPS points for "corrected" plot location.
        2. Form data of measurements.
        3. Photos.
2. Scenario 2: Project doesn't have parcel and plot IDs and locations – only project name:
    a. mForest App checks in → login → select project → "no parcel/plot" information to download.
    b. mForest App field collection:
        1. Navigate to Plot 1 location record lat/long.
        2. Use forms to collect inventory data (DBH, height, species, etc.) and field identified strata.
        3. Use picture app to collect four plot photos that are names to associate with plot and cardinal direction.
    c. mForest App checks in → login → upload collected data:
        1. GPS point for plot location.
        2. Form data of measurements (include field-identified strata).
        3. Photos.

GPS Location and Data Recording Tool

This app utilizes the GPS location and navigation system of Android platform cell phones. The app stores a list of plot names (IDs) and coordinate locations (lat/long or UTM). Field crews use the app to navigate to a plot center point. If the plot location meets certain criteria (e.g., is not inaccessible or doesn't include a road or river, or is too close to a cliff or at the edge of a forest), it is accepted. If it is rejected, the field crew navigates to the next plot location. When an accepted plot is located, the tool uses directional information (NESW) and distance from center point (m) to assist in laying out a plot: plot corners for rectangular plot and determining trees that are "in" or "out" with a specific radius for a circular plot.

The app downloads a set of plots (names and coordinate information) through a "check out" routine (with connectivity to the DMS). The app can also download ancillary thematic maps to assist in navigation. These maps may include transportation network, river network, DEM or topography, land use/cover, and political boundaries, among others. The app clusters plots into groups to inform "smart" navigation for field crews.

Plot Photo Tool

This app utilizes digital imaging capabilities as well as directional information in Android platform cell phones. The app directs a user to take four field photographs of the plot. These are stored on the device and uploaded to the MRV system. A protocol directs the field crew to take one picture at each cardinal direction (NESW). Each photo is be tagged with an ID that specifies direction, location, and plot name (ID). Additional information may be tagged to individual photos or to sets of photos. The user has an option to take additional field photos beyond the four cardinal direction photos.

Plot Mensuration Tool

This is a form app for plot level tree inventory data collection. The app includes a list of tree species and form fields for at least DBH (cm) and total tree height measurements (m), wood density, and tree crown measurements (drip line to drip line in two dimension at 90°). Plot metadata is included through a "check out" routine (with connectivity to the DMS) with users having additional fields for adding data and information. These fields include: plot name (ID), parcel name (ID), project name (ID), crew, plot shape (pull-down with selection of "circular" or "rectangular"), plot dimensions (1 radius = circular or length x width = rectangular), slope condition, and comments. Date, start time, and end time are automatically logged.

Data collected and logged are stored on the device until there is internet connection to upload the data to the DMS. This app also includes a quality assurance/quality control check on DBH and height measurements recorded by "flagging" measurements that exceed a logic rule (for example, a tree DHB that is four times greater than the mean DBH of all trees) within a simple report.

2.4.3 SUMMARY OF THE FOREST DATA MANAGEMENT SYSTEM (FDMS)

The Forest Data Management System is an enterprise solution supporting improved forest management in India. The fDMS will receive and analyze decentralized data using various tools and mobile apps being developed by Forest-PLUS. A key module of the fDMS is the Inventory Data Management System (IDMS), which measures carbon stocks and land emission fluxes. The IDMS combines field data with the analysis of remote sensed data to report forest carbon estimates.

The DMS is composed of two integrated platforms that support forest carbon inventory, quantification, and reporting. The first system manages plot-level forest inventory data and forest stratification, and computes carbon stocks. These reported carbon stocks for particular forest strata are referred to as Emissions Factors. The second system computes fluxes of carbon and non-carbon GHG from changes to land cover, such as deforestation and forest degradation. The land cover dynamics are referred to as Activity Data. The DMS uses AD derived from the Forest-PLUS developed remote sensing Forest Carbon Models and Protocols. The DMS supports a number of measuring and reporting requirements for National and Jurisdictional Forest Carbon efforts (National Communication [NATCOM], Jurisdictional and Nested REDD+ [JNR], etc.).

The forest carbon inventory platform of the DMS includes a suite of tools designed to organize and manage data required for estimating forest carbon stocks. The core components of the system are:

- Project information management toolkit;
- Plot sample design toolkit;
- Geographic data management toolkit; and
- Forest carbon measuring toolkit (including a plot inventory manager, allometric equation library, forest carbon [EF] reporting).

The Activity Data Emissions System is used to develop reference emissions baselines and emissions reductions based on project interventions. The system supports ex ante reporting often required for project development and it supports project monitoring and ex post reporting. Core components of the system are:

- System defined (Tier 1) or user defined (Tier 2 or Tier 3) land cover emission factors;
- IPCC Agriculture, Forestry, and Other Land Use (AFOLU) GHG Stock-Change quantification of emissions;
- Reference emissions level calculation and reporting;
- Project emissions/removals level calculation and reporting; and
- Emissions reductions calculations and reporting.

The DMS is also extended to the field through the mForest App for use by frontline foresters and in working with community-based forest carbon management projects.

2.4.4 MODULE 2 – SESSIONS IV TRAINING EXERCISE

1. Hands-on work with the mForest App device.

Module 3

Application and Field Practicum

The module will cover the following:

- Fundamental skill in laying out a plot using the Forest-PLUS plot design protocol—Field Practicum
- Fundamental skill in collecting data using the mForest App—Field Practicum
- Review Training Manual

3.0 MODULE 3: APPLICATION AND FIELD PRACTICUM

Duration

1 full day (7–8 hours)

Module Summary:

Module 3 is designed for trainees to gain hands-on practical experience in laying out a plot for data collection and in using the mForest App. Trainees will first be guided through the processes for laying out a plot and using the mForest App in the field by the trainers. Next they will work in small teams to lay out their own plots and collect data with some guidance provided. Finally, they will complete the exercise unguided and will be scored by the trainers.

Trainees will be asked to provide feedback and input for revision of the training material.

Overall Module Learning Objectives

- Fundamental skill in laying out a plot using the Forest-PLUS plot design protocol; and
- Fundamental skill in collecting data using the mForest App.

Training Format

- Field Practicum;
- Field Testing; and
- Discussion.

Topics

- Plot Layout;
- mForest App; and
- Review and input to training material.

Table 3-1: Module 3 Lecture/Exercise and Reading Material for Each Session Subject

Module 3: Session	Lecture/Exercise	Supplemental Reading Material
I: Field Practicum 1	• Directed plot layout and data collection (all trainees together)	Training Manual – Protocols
II: Field Practicum 2	• Small team assisted plot layout and data collection	Training Manual – Protocols
III: Field Practicum 3	• Tested and graded small team plot layout and data collection	Training Manual – Protocols
IV: Review Training Manual	• Review and feedback on the training manual	Training Manual

Table 3-2: List of Learning Objectives for Each Lecture/Exercise for Module 3

Lecture/Exercise	Learning Objectives
Directed plot layout and data collection (all trainees together)	• Hands-on training in laying out a plot and collecting tree inventory data using the mForest App tools. • Opportunity for clarification and discussion in the field
Small team assisted plot layout and data collection	• Hands-on training in laying out a plot and collecting tree inventory data using the mForest app tools in field crew teams. • Opportunity for clarification and discussion in the field
Tested and graded small team plot layout and data collection	• Testing of Master Trainer's abilities to execute the Plot Design Protocol and the Tree Inventory and Measurement Protocol
Review and feedback on the training manual	• Co-development of the training material

Module 3 Lecture/Exercise Outlines

Session I–IV will cover the following topics:
1. Directed plot layout and data collection (all trainees together)
2. Small team assisted plot layout and data collection
3. Tested and graded small team plot layout
4. Review and feedback on the training manual

Directed plot layout and data collection (all trainees together):

1. Required tools:
   a. Practice using tools.
2. Plot layout;
3. Tree measurement and data recording; and
4. Discussion as needed.

Small team assisted plot layout and data collection:

1. Crew assignments;
2. Plot layout;
3. Tree measurement and data recording; and
4. Corrections and assistance as needed.

Tested and graded small team plot layout and data collection:

1. Explanation of grading;
2. Crew assignments;
3. Plot layout;
4. Tree measurement and data recording; and
5. Grading feedback.

Review and feedback on the training manual:

1. Break-out groups | Assignments;
2. Review; and
3. Suggested revisions:
   a. Additions.
   b. Omissions.
   c. Corrections.

Module 3 Lecture/Exercise Notes

Sessions I, II, and III for Module 3 will be in the field. The site will be forested and large enough to accommodate multiple 30m^2 sample plots. Equipment for these sessions will include:

- mForest App;
- GPS;
- DBH tape;
- Flagging tape;
- Chalk;
- 30m tape;
- Litter bag;
- Field scale with accuracy to the gram; and
- Write-in-rain notebook.

3.1 SESSION I: GUIDED FIELD TRAINING I (LARGE GROUP)

The trainees as a group will be guided through an example of 1) establishing a 30m² plot area and 2) collecting inventory data. The protocol steps, as described above, will be followed for each task. Trainees will be encouraged to ask questions and seek clarification on any of the protocol steps.

3.2 SESSION II: GUIDED FIELD TRAINING II (SMALL TEAMS)

The trainees will be organized into two-to-three small groups. Each group will be required to 1) establish a 30m² plot area and 2) collect inventory data. Trainers will be assigned with each group to provide constructive guidance on both tasks. Trainees will be encouraged to ask questions and seek clarification on any of the protocol steps.

3.3 SESSION III: GRADED FIELD PRACTICUM

The trainees will be re-organized into two to three small groups of different pairings than those of Session II. Each group will be required to 1) establish a 30m² plot area and 2) collect inventory data. No guidance from trainers will be allowed. Individuals will be required to participate in a minimum of four different tasks. These tasks include:

- GPS location of the plot corner Point 1;
- Flagging or marking corner points;
- Running plot boundaries with measuring device;
- Sighting corner points with compass;
- Flagging or marking plot boundaries;
- Marking sub-plot corner points;
- Taking tree DBH measurements;
- Recording tree DBH measurement;
- Identifying tree species;
- Collecting litter; and
- Weighing and recording fresh-weigh litter.

Each group will be graded and each individual team member will be graded on a rating scale of 1 to 4. The rating scale is:

- 1 = Fail with no skill proficiency;
- 2 = Fail with only some skill proficiency;
- 3 = Pass with most skills proficient; and
- 4 = Pass with all skills proficient.

3.4 SESSION IV: TRAINING MANUAL REVIEW

The trainees will convene in small groups to review the material in this training manual with particular focus on the "Guidance on Training Communities" section. Trainees will be expected to suggest important revisions and modifications to improve the training manual. Trainee expertise of the landscapes (state) they work in and of the communities involved in CFM and JFM activities are important. Adding input to the training material is important for creating a successful and sustainable approach to community forest carbon measurement.

Trainee comments and suggested will be reviewed and discussed as a group.

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5.0 EXERCISES IN DIFFERENT MODULES

Module 1 – Sessions I and II Training Exercises

1. Principles of Training: Collaborative Learning and Training
2. Focus – Gap Analyses

Module 2 – Sessions I Training Exercises

1. Pools of Carbon
2. Carbon Cycle Diagram
3. Calculate carbon given specific parameters

Module 2 – Sessions IV Training Exercise

1. Hands-on work with the mForest App device

APPENDIX 1. POOLS OF CARBON

- Working in small teams of three-to-five participants, write down on a piece of paper the pools of forest carbon.
- Go around one group at a time and write down answers on flipchart paper.
- Discuss the IPCC and the five pools or measurable carbon in forests.

Carbon Cycle Diagram

a) Working in small teams of three-to-five participants, hand out flipchart paper and ask the teams to diagram cycling of carbon through the environment.
b) Ask each team to have a volunteer come up and describe their teams diagram to the participants.
c) Discuss:
    - Large (global) carbon cycle: atmosphere, biosphere and hydrosphere.
    - Forest stand and tree level carbon cycle: photosynthesis, breakdown of detritus, etc.

Calculate Carbon Given Specific Parameters

Ask each participant to calculate the value of tC^{-ha} give the following parameters. Participants can use the information in the training material.

- Plot size = 30m x 30m
- Tree Inventory
    - 6 trees = 400 kg each
    - 10 trees = 210 kg each
    - 17 trees = 95 kg each

Answer = 6115 kg = (6115 kg /0.47) = 2874.5 kgC / 1000 = 2.874 tC

2.874 tC/plot x 1/(.09) = 31.93 tC^{-ha}

APPENDIX 2. MAKING AND USING A SIMPLE CLINOMETER

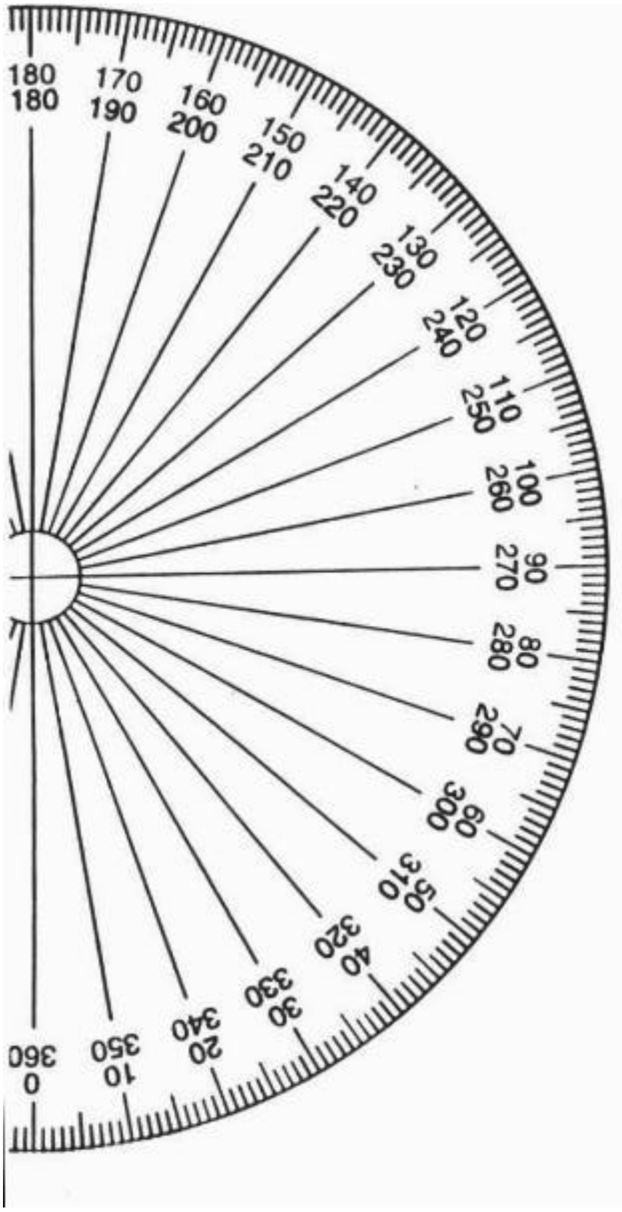
Materials Needed

- Print out of a protractor, laminated and trimmed;
- See attached page;
- 8–12” string;
- Scissors;
- Straw;
- Tape;
- Glue;
- Washer or other weight;
- Piece of cardboard;
- Hammer; and
- Nail.

Procedure

1. Cut out the copy of the laminated protractor.
2. Punch a small hole with a nail through cross-hair section of the protractor center.
3. Glue or tape the straw to the edge so that it is flush with the 0° and 180° line at the bottom of the protractor. Make sure you can see all the way through the straw.
4. Thread the string through the hole.
5. Tie a knot in the string so that it will not slip through the hole. Make sure the rest of the string is freely hanging on the side with the protractor.
6. Tie the other end of the string to a washer or other weight.

******* Print This Page On Heavyweight Paper and Laminate *******



How to Use a Clinometer to Determine a Slope Angle

Materials Needed

- Clinometer;
- Notebook or piece of paper and writing utensil to record measurements;
- Tape measure or meter stick; and
- Partner.

Procedure

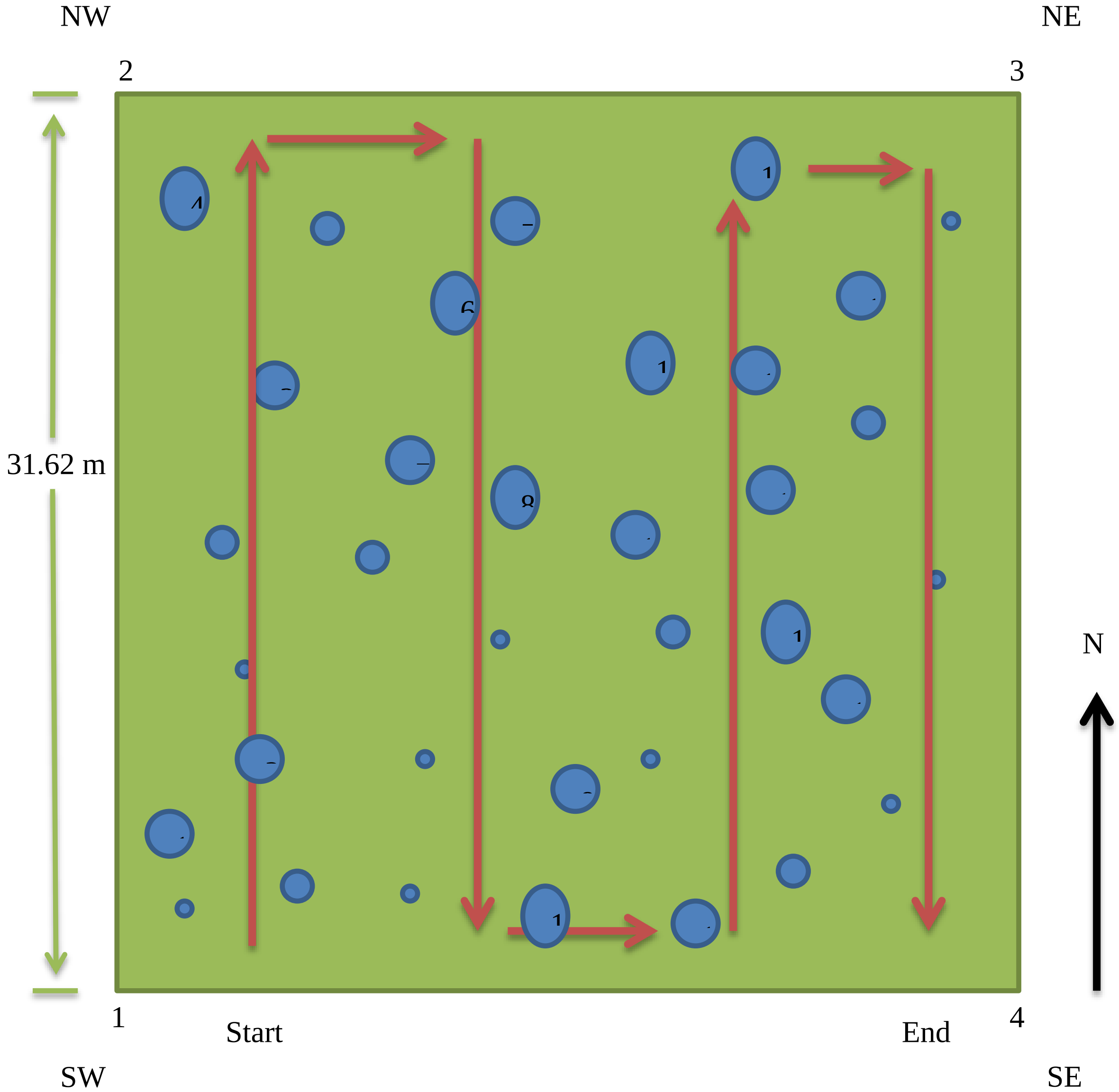
1. Stand on the down slope from your partner about 30 meters from each other.
2. Hold the clinometer in your right or left hand and look through straw to your partner's eyes (or to the position of your partner's body that is at the same height as your eyes).
3. Record the angle measure from 90° where the string crosses the lines on the protractor (read only the outer values of the protractor). This is the slope angle in degrees. (Example: if your string crosses 70° the difference from 90° is 20°. Therefore the slope is 20°)

Material to be printed out, laminated, and used in the field

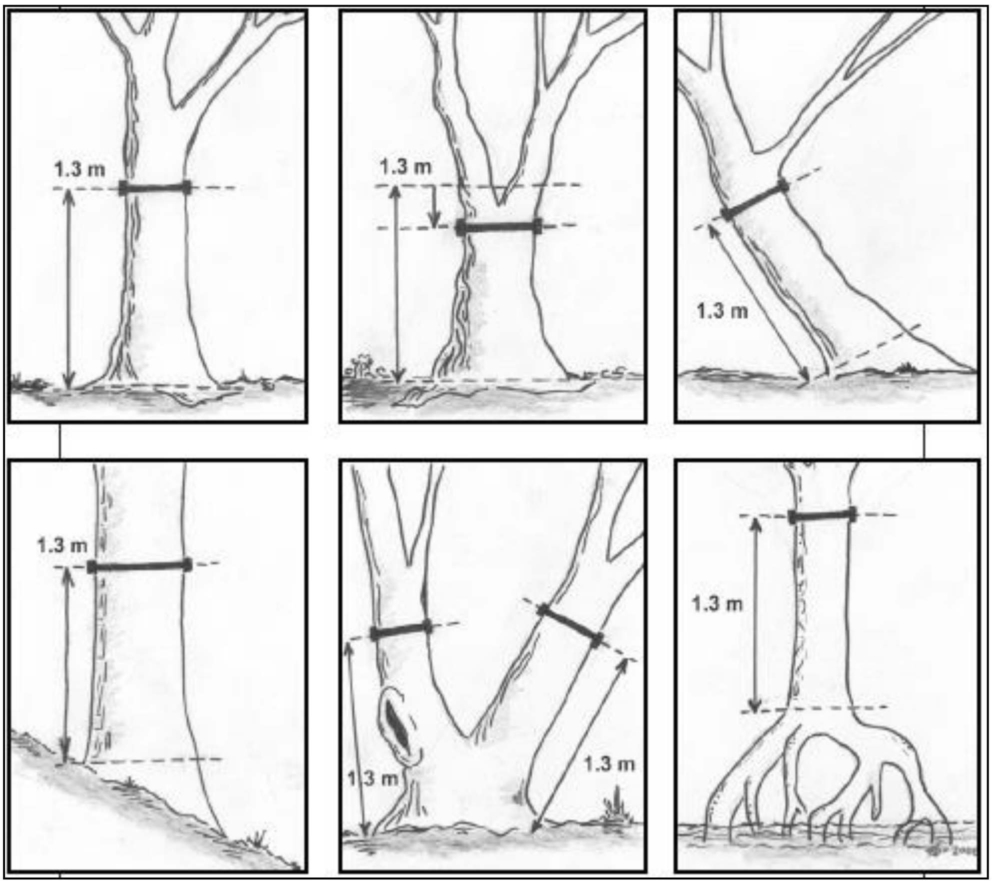
The following pages from the training material are to be printed, laminated and used to support the field data collection by community members and facilitators from the forestry departments.

1. Plot design and set up steps;
2. Data collection steps;
3. Creating a 90^{o} plot corner angle using the 3 – 4 – 5 technique;
4. Slope correction conversions;
5. Using a clinometer;
6. DBH Measurements on Irregular Trees; and
7. Field chart for Carbon estimates (by region and select species).

Plot Data Collection (1)



DBH Measurements on Irregular Trees (1)



DBH tapes are calibrated to directly measure diameter on one side (circumference / π) and often have standard length (equals the circumference) on the other side of the tape. It is important that all field crew know which values to record and from the correct zero point on the tape. The DBH tape must be used properly to ensure consistency of measurement. Field crew should measure where 1.3m is on their body or use a 1.3m long staff to identify the correct height to measure the diameter of every tree. If the tree is on a slope, always measure on the uphill side. If the tree is leaning, the DBH tape must be wrapped to be perpendicular to the main axis of the trunk (not parallel to the ground). If the tree is forked below 1.3m, measure the two trunks as separate trees. If the tree forks above 1.3m, measure DBH of the main stem (unless there is an unusual bulge right at 1.3m). If the tree forks close to the 1.3m height, measure DBH of the mail stem just below the fork. This figure shows the stem DBH measurements for straight ("normal") trees as well as non-normal trees and conditions.

APPENDIX 3. DBH MEASUREMENTS ON IRREGULAR TREES

Circumference or girth can also be measured and converted to DBH with the following chart.

Conversion chart for DBH Measurements From circumference to diameter Units of .1 cm from 5.0 to 20.0 cm diameter									
Circ (cm)	Dia (cm)	Circ (cm)	Dia (cm)	Circ (cm)	Dia (cm)	Circ (cm)	Dia (cm)	Circ (cm)	Dia (cm)
15.7	5.0	27.3	8.7	39.0	12.4	50.6	16.1	62.2	19.8
16.0	5.1	27.6	8.8	39.3	12.5	50.9	16.2	62.5	19.9
16.3	5.2	28.0	8.9	39.6	12.6	51.2	16.3	62.8	20.0
16.7	5.3	28.3	9.0	39.9	12.7	51.5	16.4		
17.0	5.4	28.6	9.1	40.2	12.8	51.8	16.5		
17.3	5.5	28.9	9.2	40.5	12.9	52.2	16.6		
17.6	5.6	29.2	9.3	40.8	13.0	52.5	16.7		
17.9	5.7	29.5	9.4	41.2	13.1	52.8	16.8		
18.2	5.8	29.8	9.5	41.5	13.2	53.1	16.9		
18.5	5.9	30.2	9.6	41.8	13.3	53.4	17.0		
18.8	6.0	30.5	9.7	42.1	13.4	53.7	17.1		
19.2	6.1	30.8	9.8	42.4	13.5	54.0	17.2		
19.5	6.2	31.1	9.9	42.7	13.6	54.3	17.3		
19.8	6.3	31.4	10.0	43.0	13.7	54.7	17.4		
20.1	6.4	31.7	10.1	43.4	13.8	55.0	17.5		
20.4	6.5	32.0	10.2	43.7	13.9	55.3	17.6		
20.7	6.6	32.4	10.3	44.0	14.0	55.6	17.7		
21.0	6.7	32.7	10.4	44.3	14.1	55.9	17.8		
21.4	6.8	33.0	10.5	44.6	14.2	56.2	17.9		
21.7	6.9	33.3	10.6	44.9	14.3	56.5	18.0		
22.0	7.0	33.6	10.7	45.2	14.4	56.9	18.1		
22.3	7.1	33.9	10.8	45.6	14.5	57.2	18.2		
22.6	7.2	34.2	10.9	45.9	14.6	57.5	18.3		
22.9	7.3	34.6	11.0	46.2	14.7	57.8	18.4		
23.2	7.4	34.9	11.1	46.5	14.8	58.1	18.5		
23.6	7.5	35.2	11.2	46.8	14.9	58.4	18.6		
23.9	7.6	35.5	11.3	47.1	15.0	58.7	18.7		
24.2	7.7	35.8	11.4	47.4	15.1	59.1	18.8		
24.5	7.8	36.1	11.5	47.8	15.2	59.4	18.9		
24.8	7.9	36.4	11.6	48.1	15.3	59.7	19.0		
25.1	8.0	36.8	11.7	48.4	15.4	60.0	19.1		
25.4	8.1	37.1	11.8	48.7	15.5	60.3	19.2		
25.8	8.2	37.4	11.9	49.0	15.6	60.6	19.3		
26.1	8.3	37.7	12.0	49.3	15.7	60.9	19.4		
26.4	8.4	38.0	12.1	49.6	15.8	61.3	19.5		
26.7	8.5	38.3	12.2	50.0	15.9	61.6	19.6		
27.0	8.6	38.6	12.3	50.3	16.0	61.9	19.7		

APPENDIX 4. FIELD CHART FOR CARBON ESTIMATES (SIKKIM)

Region: Eastern Himalayas		State: Sikkim					
Species: *Rhododendron arboreum*							
Wood Density (10^3 kg/m^3)		0.49					
Volume Equation		V=(0.06007 - 0.21874 * SQRT(D) + 3.63428 * D^2)					
BE1	R 112.6006*(D/100)^2+135.5182*(D/100)-2.3433						
BE2	R 11.2386*(D/100)^2+3.0581*(D/100)+0.1432						
BE3	R 0.1194*(D/100)^2-0.0907*(D/100)+0.9907						
BE4	R 0.0018*(D/100)^2 + 0.0516*(D/100) + 0.0361						

Diameter Class		**Number Trees - tC**					
DBH (cm)	***Circ (cm)***	***1***	***5***	***10***	***15***	***20***	***50***
5.0	15.7	0.02	0.11	0.21	0.32	0.43	1.07
10.0	31.4	0.09	0.45	0.90	1.34	1.79	4.48
15.0	47.1	0.20	0.99	1.98	2.97	3.96	9.91
20.0	62.8	0.35	1.74	3.49	5.23	6.98	17.44
25.0	78.5	0.54	2.71	5.42	8.13	10.84	27.09
30.0	94.2	0.78	3.88	7.77	11.65	15.54	38.84

Region: Eastern Himalayas		State: Sikkim					
Species: *Quercus species*							
Wood Density (10^3 kg/m^3)		0.75					
Volume Equation		V=(5.09470 + 0.00563/D^2)*D^2					
BE1	R 69.2347*(D/100)^2+135.6707*(D/100)-1.4147						
BE2	R 0.8100*(D/100)^2+8.7234 * (D/100) + 0.1811						
BE3	R 0.1810*(D/100)^2 - 0.4654*(D/100) + 1.6797						
BE4	R 0.0024*(D/100)^2 + 0.0991*(D/100) + 0.0344						

Diameter Class		**Number Trees - tC**					
DBH (cm)	***Circ (cm)***	***1***	***5***	***10***	***15***	***20***	***50***
5.0	15.7	0.05	0.23	0.46	0.69	0.91	2.28
10.0	31.4	0.19	0.93	1.86	2.79	3.72	9.31
15.0	47.1	0.41	2.07	4.14	6.22	8.29	20.72
20.0	62.8	0.73	3.66	7.33	10.99	14.65	36.63
25.0	78.5	1.14	5.70	11.41	17.11	22.82	57.04
30.0	94.2	1.64	8.20	16.39	24.59	32.78	81.95

BE1 = Biomass equation for estimating small wood of trees with DBH > or = 10 cm
BE2 = Biomass equation for estimating foliage of trees with DBH > or = 10 cm
BE3 = Biomass equation for estimating small wood of trees with DBH < 10 cm
BE4 = Biomass equation for estimating foliage of trees with DBH < 10 cm
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APPENDIX 5. FIELD CHART FOR CARBON ESTIMATES (HIMACHAL PRADESH)

Region: Western Hmalayas			State: Himachal Pradesh				
Species: *Abies densa*							
Wood Density (10^3 kg/m^3)			0.38				
Volume Equation		V=(-0.084305+3.060072*D)^2					
BE1	None						
BE2	None						
BE3	None						
BE4	None						

Diameter Class		Number Trees - tC					
DBH (cm)	***Circ (cm)***	***1***	***5***	***10***	***15***	***20***	***50***
5.0	15.7	0.04	0.21	0.41	0.62	0.83	2.07
10.0	31.4	0.17	0.83	1.66	2.49	3.33	8.32
15.0	47.1	0.37	1.87	3.75	5.62	7.50	18.75
20.0	62.8	0.67	3.34	6.67	10.01	13.34	33.36
25.0	78.5	1.04	5.21	10.43	15.64	20.86	52.15
30.0	94.2	1.50	7.51	15.02	22.54	30.05	75.12

Region: Western Hmalayas			State: Himachal Pradesh				
Species: *Quercas dilatata*							
Wood Density (10^3 kg/m^3)			0.78				
Volume Equation		V=(0.0988/D^2 -1.5547/D + 10.1631)*D^2					
BE1	None						
BE2	None						
BE3	None						
BE4	None						

Diameter Class		Number Trees - tC					
DBH (cm)	***Circ (cm)***	***1***	***5***	***10***	***15***	***20***	***50***
5.0	15.7	0.09	0.45	0.90	1.35	1.81	4.52
10.0	31.4	0.37	1.83	3.67	5.50	7.34	18.35
15.0	47.1	0.83	4.15	8.30	12.45	16.60	41.49
20.0	62.8	1.48	7.39	14.79	22.18	29.58	73.95
25.0	78.5	2.31	11.57	23.14	34.72	46.29	115.72
30.0	94.2	3.34	16.68	33.36	50.04	66.72	166.81

BE1 = Biomass equation for estimating small wood of trees with DBH > or = 10 cm
BE2 = Biomass equation for estimating foliage of trees with DBH > or = 10 cm
BE3 = Biomass equation for estimating small wood of trees with DBH < 10 cm
BE4 = Biomass equation for estimating foliage of trees with DBH < 10 cm
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APPENDIX 6. FIELD CHART FOR CARBON ESTIMATES (KARNATAKA)

Region: Western Ghats			State: Karnataka				
Species: *Lagerstoemia lanceolata*							
Wood Density (10^3 kg/m^3)			0.55				
Volume Equation		V=(0.23839-2.48071*(D/100)+10.14106*(D/100)^2)					
BE1	R -123.7223*(D/100)^2+290.7752*(D/100)-13.5650						
BE2	R-2.7947*(D/100)^2+7.1714*(D/100)-0.3286						
BE3	R 0.2400*(D/100)^2-0.1514*(D/100)+0.7339						
BE4	R 0.0041*(D/100)^2 - 0.0095*(D/100) + 0.0495						

Diameter Class		**Number Trees - tC**					
DBH (cm)	***Circ (cm)***	***1***	***5***	***10***	***15***	***20***	***50***
5.0	15.7	0.06	0.31	0.63	0.94	1.26	3.14
10.0	31.4	0.26	1.31	2.63	3.94	5.25	13.13
15.0	47.1	0.59	2.97	5.93	8.90	11.87	29.67
20.0	62.8	1.05	5.27	10.55	15.82	21.10	52.75
25.0	78.5	1.65	8.24	16.47	24.71	32.94	82.36
30.0	94.2	2.37	11.85	23.70	35.55	47.41	118.51

Region: Western Ghats			State: Karnataka				
Species: *Xylia xylocarpus*							
Wood Density (10^3 kg/m^3)			0.75				
Volume Equation		V=(0.01631+2.20921*D)^2					
BE1	R 568.7019*(D/100)^2-55.8345*(D/100)+21.923						
BE2	R 41.5004*(D/100)^2 -8.6750 * (D/100) + 1.3020						
BE3	R 0.2545*(D/100)^2 + 0.2466*(D/100) + 0.0771						
BE4	R 0.0093*(D/100)^2 - 0.287*(D/100) + 0.0676						

Diameter Class		**Number Trees - tC**					
DBH (cm)	***Circ (cm)***	***1***	***5***	***10***	***15***	***20***	***50***
5.0	15.7	0.04	0.22	0.43	0.65	0.86	2.16
10.0	31.4	0.18	0.92	1.83	2.75	3.66	9.15
15.0	47.1	0.40	2.00	4.00	6.00	8.01	20.01
20.0	62.8	0.70	3.52	7.05	10.57	14.10	35.25
25.0	78.5	1.10	5.49	10.97	16.46	21.94	54.86
30.0	94.2	1.58	7.88	15.77	23.65	31.54	78.84

BE1 = Biomass equation for estimating small wood of trees with DBH > or = 10 cm
BE2 = Biomass equation for estimating foliage of trees with DBH > or = 10 cm
BE3 = Biomass equation for estimating small wood of trees with DBH < 10 cm
BE4 = Biomass equation for estimating foliage of trees with DBH < 10 cm
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APPENDIX 7. FIELD CHART FOR CARBON ESTIMATES (MADHYA PRADESH)

Region: North Deccan	State: Madyha Pradesh
Species: *Tectona grandis*	
Wood Density (10^3 kg/m^3)	0.70
Volume Equation	V=(-0.106720 + 2.562418 * D)^2
BE1	R 724.8313*(D/100)^1.8139
BE2	R-5.7898*(D/100)^2 + 16.1859 * (D/100) -0.8153
BE3	R 0.1710*D^2 - 0.5602*D + 1.3209
BE4	R 0.0080*D^2 + 0.0186*D + 0.0245

Diameter Class		Number Trees - tC					
DBH (cm)	***Circ (cm)***	***1***	***5***	***10***	***15***	***20***	***50***
5.0	15.7	0.05	0.27	0.55	0.82	1.09	2.73
10.0	31.4	0.22	1.10	2.20	3.30	4.40	10.99
15.0	47.1	0.49	2.47	4.95	7.42	9.90	24.75
20.0	62.8	0.88	4.40	8.80	13.20	17.60	44.00
25.0	78.5	1.37	6.87	13.75	20.62	27.49	68.73
30.0	94.2	1.98	9.89	19.79	29.68	39.58	98.94

Region: East Deccan	State: Madyha Pradesh
Species: *Shorea robusta*	
Wood Density (10^3 kg/m^3)	0.72
Volume Equation	V=(0.00389/D^2-0.27516/D+6.90733)*D^2
BE1	R 96.1525*(D/100)^2+141.9383*(D/100)-7.6058
BE2	R-17.2383*(D/100)^2 + 4.2380 * (D/100) -0.1970
BE3	R -0.0561*D^2 + 1.3533*D - 0.6625
BE4	R 0.0001*D^3 - 0.0085*D^2 + 0.1150*D - 0.0198

Diameter Class		Number Trees - tC					
DBH (cm)	***Circ (cm)***	***1***	***5***	***10***	***15***	***20***	***50***
5.0	15.7	0.06	0.30	0.60	0.91	1.21	3.02
10.0	31.4	0.24	1.18	2.37	3.55	4.73	11.83
15.0	47.1	0.53	2.66	5.32	7.99	10.65	26.62
20.0	62.8	0.95	4.73	9.45	14.18	18.91	47.27
25.0	78.5	1.48	7.38	14.75	22.13	29.51	73.77
30.0	94.2	2.12	10.61	21.23	31.84	42.45	106.13

BE1 = Biomass equation for estimating small wood of trees with DBH > or = 10 cm
BE2 = Biomass equation for estimating foliage of trees with DBH > or = 10 cm
BE3 = Biomass equation for estimating small wood of trees with DBH < 10 cm
BE4 = Biomass equation for estimating foliage of trees with DBH < 10 cm
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