

# Pacific Islands National Forest Inventory for REDD+



## BOOKLET 4: DATA ANALYSIS

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Pacific Islands National Forest Inventory for REDD+

Booklet 1: Guidance for Policy makers

Booklet 2: Guidance for Planners and Managers

Booklet 3: Field Operations

Booklet 4: Data Analysis

# Pacific Islands National Forest Inventory for REDD+

## Data Analysis

Supported by:

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# Table of Contents

Pacific Islands National Forest Inventory for REDD+ .....	3
Acknowledgements.....	4
List of Figures .....	7
List of Tables.....	7
List of Photos .....	7
Foreword.....	10
Purpose and Scope .....	12
Skills Required .....	13
Processing of Field Samples.....	16
Plant Accessions.....	17
Litter .....	18
Wood Density .....	19
Soil Analysis .....	21
Processing of Field Measurements .....	23
Quality Assurance/Quality Control of field and laboratory data.....	23
Quantifying Forest Biomass and Carbon.....	24
Forest carbon pools .....	24
Biomass Equations .....	26
Developing individual tree allometric models.....	27
Biomass of the bole .....	27
Biomass of the stump.....	28
Biomass of the buttress.....	29

Biomass of the leaves and branches.....	29
Above ground carbon .....	30
Below ground carbon .....	31
Dead wood.....	32
Standing dead trees .....	32
Downed dead wood.....	35
Litter.....	38
Soil carbon .....	42
Carbon Dioxide Equivalent.....	45
Quantifying Emission Factors.....	46
Considerations for emission factor creation .....	48
Carbon and carbon dioxide equivalents.....	49
Calculating Uncertainty .....	51
References .....	56

# List of Figures

Figure 1: Diagram of water displacement method for measuring wood core volume. The core is forced underwater with a needle. Pp. 20

# List of Tables

Table 1. Illustrates ways of calculating Emission Factors. Pp. 48

Table 2. Different units of an Emission Factor. Pp. 49

# List of Photos

Cover photo: NFI training 2014, Makira, Solomon Islands. Photo by Senilolia H. Tuiwawa.

# List of Abbreviations

AD: Activity Data

AGB: Above Ground Biomass

BGB: Below Ground Biomass

CI: Confidence Interval

EE: Emission Estimates

EF: Emission Factor

FAO: Food and Agriculture Organization of the United Nations

GHG: Greenhouse Gas Emission

GIS: Geographic Information System

GWP: Global Warming Potential

IPCC: International Panel of Climate Change

NFI: National Forest Inventory

PICs: Pacific Island Countries

QA/QC: Quality Assurance/Quality Control

REDD+: Reducing Emissions from Deforestation and Forest Degradation in developing countries; and the role of conservation, sustainable management of forest and enhancement of forest carbon stocks in developing countries.

SPC: Secretariat of the Pacific Community

SQL: Structured Query Language

## **Measurements**

cm: centimeters

cm<sup>3</sup>: cubic centimeter

CO<sub>2</sub>e: carbon dioxide equivalents

dbh: diameter at breast height, 1.3m above ground, over bark

g: grams

ha: hectares

kg: kilogram

m<sup>3</sup>: cubic meter

t: tonnes

VOL: volume

WD: wood density

# Foreword

Booklet 4 details the analysis of national forest inventory data of the field measurement component (booklet 3) of the National Forest Inventory designed to meet the reporting guideline for REDD+ participants. It provides guidance for biometricians, database designers and data analyst responsible for assessing national forest inventory field datasets. The data analysis is critically important for accuracy, transparency and credibility purposes required by forest management and the IPCC. This booklet details the procedures of analyzing field samples, field measurements and describes in depth the steps involved in calculating carbon, emission factors and uncertainty. Reporting requirements are provided in booklet 2.

Booklet 4 is part of a series of four booklets to provide the appropriate guidance to policy makers, managers, technical and field personnel on the proper conduct of a national forest inventory, from planning to implementation. The booklet series will ensure a common understanding that would help facilitate the regional sharing and mobilization of relevant expertise to support the conduct of national forest inventories in pacific island countries. The aim is to foster a consistent approach to the planning and conducting of NFI within the pacific communities, noting that the specific details may vary from country to country.

# Background

Booklet 4 is the last of a four booklet series designed for REDD+ member countries engaging in National Forest Inventory (NFI) activities. It covers the principles and guidelines of analyzing a sound NFI dataset that has been collected in accordance with the principles and methodological approaches outlined in Booklets 1, 2 and 3. Whilst it can be a considered reference for any interested party, the target audiences are the Forestry officers who directly report to the managers, policy and decision makers in the various Forestry Departments and or related sectors in the PICs. These personnel include foresters, field technicians as well as forestry trainees.

While the primary intention of this document is to build and enhance capacity in the forestry and related sectors, it is also aimed to serve as a guiding basis for designing the data analysis phase of a pilot NFI. Booklet 4 provides the basic outline for field reporting, data entry and analysis of field datasets using specific software packages (databases and spreadsheets). More importantly, the booklet documents the course of action to consider when reporting at the national level and to the international community.

## Purpose and Scope

Having the appropriate data analysis and reporting procedures are essential to the transparency and credibility of an NFI.

These include the proper and successful computation and management of field datasets and the reporting to managers on the groundwork activities. As capacity improves and systems become more automated, field foresters can build their capacity to view, review and audit data to ensure quality and reliability.

This booklet provides the basic structure and analysis procedures for processing basic inventory data designed to measure forest carbon stocks and inventory volume. More information about the field procedures used is found in Booklet 3.

# Skills Required

Three skills are required, not necessarily in the same person.

- Forest statistician/mensuration (biometrician) – to define the procedures and mathematical formulae at the planning stages. Requires degree qualifications, probably post graduate, at least at the start;
- Data base designer and maintainer – to design and construct the database and any associated implementation of the functions. Subsequently to maintain the system. Requires IT qualifications;
- Data analyst/database administrator – to receive data from the field, supervise its input to the system, carry out error checking and correction, to implement the carbon and volume analysis and to carry out any ad hoc queries from users. Can be trained on job, but must have good interaction skills particularly with field crew and be intolerant of poor measurement practice.

The forest biometrician must understand the overarching objectives of the NFI, be involved in the initial planning stages and must have a clear understanding of the parameters used. The database designer must not only program and implement the system at the start but is also required to maintain and enhance the database system. It is very important for the data analyst / database administrator to have a hands-on understanding of field operations and the procedures used, as well as the overarching inventory objectives. They must have a

clear understanding of the forest parameters used and be able to interpret site location and field work notes to identify specific anomalies. The analyst does not necessarily have to be part of the routine field operations but should have access to the field officers that did carry out the field activities to verify the integrity of the data. Strong skills in electronic file management, 'versioning', execution of quality assurance (QA) / quality control (QC) protocols, and use and interpretation of spreadsheets and relational databases are required.

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*Three skill sets are required;  
biometrician, data base designer and  
data analyst/database administrator*

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While it is necessary that a fully-fledged NFI would have clear links between data capture (a handheld computer or datasheet) and a completed database, there are always issues that arise with technological advancements, changes in models used, modifications in software operations, and changes in reporting requirements for international or national-level concerns. As such, staff needs to be versed in solving data-related problems in a manner that ensures accuracy and data integrity.

Databases are a useful tool for processing, managing and securely storing large field datasets such as those collected with a NFI.

Databases are efficient tools as they:

- allow for easy linking of data from different tables;
- allow for straight-forward and stepwise manipulation of data to obtain results that can be readily modified;
- are customizable, save in macros, and execute automatically;
- can store large amounts of data and are updateable with pre-planning query function to meet standard reporting.

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*Databases are an efficient tool for analyzing, storing and managing large NFI datasets*

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Databases require a steeper learning curve than a typical spreadsheet. A database can be structured for standard enquiries and calculations. A spreadsheet is more useful for ad-hoc analysis.

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*Spreadsheets and databases are resourceful tools for NFI data analysis but have different strengths and uses*

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# Processing of Field Samples

Depending upon the methodologies used, some physical samples from the field may be required to conduct further analysis in the laboratory. As part of the quality assurance / quality control (QA/QC) plan, the procedure of sample custody and processing in potentially three different areas (field, laboratory and database) will need to be tested and well developed. Typically these involve the following types of samples:

- **Plant accessions:** Unknown plant species that could not be identified in the field, or other accessions that are sent to a centralized herbarium or other source for proper storage and identification;
- **Litter:** Bags collected of fine leaf litter to be weighed and dried then processed for carbon content;
- **Wood density samples:** Wood cores taken from the field;
- **Soil samples:** Fixed volume core samples (recommended only for the mangroves) that require accurate dry weight and potentially carbon/nutrient content;
- **Photo point data:** Fixed camera angles and GPS locations of plot centers.

## Plant Accessions

It is inevitable that field operators may come across plant species that they cannot identify. While the NFI design should select objectives that are within reasonable grasp of the country's capacity to perform, there must be a mechanism for collecting unknown plant samples and ensuring there is integrity in the field data being collected, so that in the post-collection phase, that species can be attributed to the appropriate line of data.

Several methods can be used to capture the unknown information. A digital camera with high zoom can be used to capture the functional components of the plant, and assign a unique identification number that can be traced back to the datasheets (or data capture devices). The electronic data can then be sent to a centralized herbarium for identification and (ideally) the field operator can enter in the appropriate species name.

Herbarium samples may require collecting, This may be required for unknown samples, or for a subsample of species as part of the identification checking or simply adding to the herbarium collection. This process will involve data tracking to the site, subplot, and measured individual from which the sample was taken. Samples will need to be prepared in the field and shipped to the central facility. In addition, the quality checks for species identification must be cross-referenced with the original data for comparison in the audit.

## Litter

While leaf litter may not be a large contributor to forest ecosystem carbon pools, national circumstances may require the collection of leaf litter in the upland and mangrove forest plots. Typically these require clipping fine materials (live and dead) into bags to be weighed and dried.

Leaf litter sampling can generate a large amount of material that is difficult to dry, is bulky, and susceptible to mold and fungal growth. Plant and leaf litter should be dried to constant weight and attributed to the sample or plot number. In the laboratory, these are dried and weighed with subsamples of the leaf material then taken for carbon analysis. Sample numbers must be linked directly with the plot and subplot number and carried through the drying, weighing throughout the laboratory phase.

## Wood Density

The determination of wood density of tree species is necessary to determine the carbon pool estimates for the country and region.

Wood core samples can be extracted using an increment borer to extract a narrow, long sample to the center of the tree (or as close as will not damage the tree). These samples are removed in the field and can be kept in a “drinking straw”. Numbered samples must remain integral with the database, and carried through to the lab.

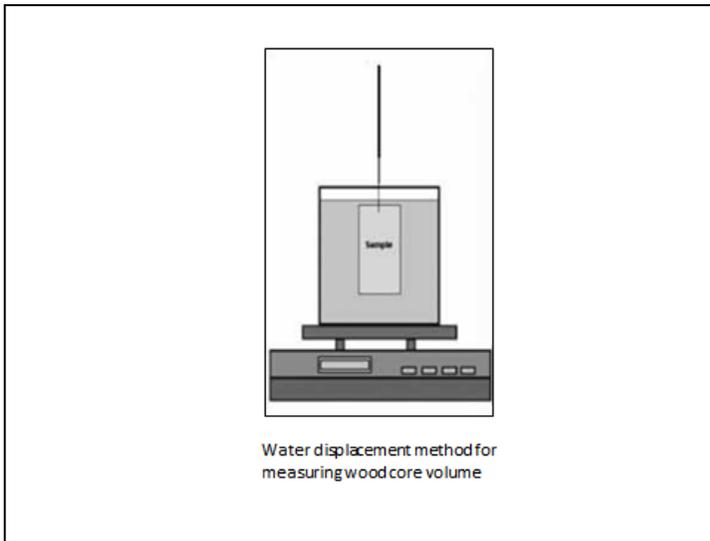
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*Wood density varies with tree species, growth conditions and parts of the tree*

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Samples are prepared for green volume measurement by soaking the full core in water for about 30 minutes (Figure 1). Volume can be estimated using the water displacement method by weighing the difference of completely and carefully submerging the wood piece in water, where 1 g = 1 cm<sup>3</sup> of volume for water. The sample is then dried and weighed. Wood density (WD) is calculated as:

$$WD = \frac{\text{dry wt of sample (g)}}{\text{displaced water (cm}^3\text{)}}$$



*Figure 1: Diagram of water displacement method for measuring wood core volume. The core is forced underwater with a needle. The core should not touch the edges of the container. When the sample is sunk underwater, the level of water raises, and, for the balance everything is as if one had added the amount of water equivalent to the volume of the sample. Therefore the reading on the digital balance is equal to the volume of the core (with the equivalence  $1\text{ g} = 1\text{ cm}^3$ ). Source: Chave, J. 2002-2006.*

Carbon analysis on dry wood samples can be done using a carbon analyzer with a high-temperature induction furnace in a laboratory. Alternatively, biomass calculation and the use of appropriate formulae can be used to calculate carbon values.

Values from samples must be tied to the individual trees measured in the database. The data steward must maintain the chain of custody

and labeling/audit procedures to ensure data streams well documented and accountable.

## Soil Analysis

In Booklet 3 there are guidelines for extracting mangrove forest soils and measuring depths. Since samples are fixed volume samples, it is important to obtain accurate measures of soil bulk density. Bulk density provides the units required to convert a soil sample to total grams (or tonnes) of carbon per unit land area (ha).

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### *Bulk density is a measure of soil carbon pool*

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Collection of fixed-volume samples can be difficult in the field. The samples should be carefully placed in tight-fitting soil cans with a unique identifier. It is critical that this identifier be transcribed properly to the data collection device in the field so that in post-field processing, the data integrity remains strong with that specific sample.

Soil samples should be dried as quickly as convenient to a constant weight, but with temperatures that do not exceed 60 °C to avoid any carbon losses. Samples are weighed and then packaged in air-tight plastic bags for laboratory analysis. Numbering systems are critical at this point as it is very easy to mix up samples and apply incorrect numbers to the soil profile. Careful auditing of this procedure is an important part of the process that also adds cost and staffing.

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*Maintaining integrity of sample numbers in the field, lab and database is important*

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# Processing of Field Measurements

## Quality Assurance/Quality Control of field and laboratory data

A primary mechanism is the QA/QC between field operators and the conveyance to datasheets and databases. Prior to any data analysis, the field data quality must be reviewed by field operators and the database administrator, checked for completeness and errors then entered into the database. Errors need to be corrected before analysis. The data flow must be seamless to the data analyst, and any other laboratory, audit or external samples be consolidated appropriately and in a timely fashion in the central database.

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*For transparency, data must be quality checked and passed from field to laboratory for analysis though documented*

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Hence, a large part of the process is to ensure the data analysis and the process of QA/QC is well organized and tested so that there is a high degree of integrity in the field data being collected.

# Quantifying Forest Biomass and Carbon

## Forest carbon pools

For carbon inventories, stocks and stock changes of the five forest carbon pools and their total need to be reported:

1. Above ground biomass;
2. Below ground biomass;
3. Dead wood;
4. Litter;
5. Soil

Total carbon stock in the five carbon pools (C)

$$C = C_{AB} + C_{BB} + C_{DW} + C_{LI} + C_{SO}$$

Changes in the five forest carbon pools ( $\Delta C$ )

$$\Delta C = \Delta C_{AB} + \Delta C_{BB} + \Delta C_{DW} + \Delta C_{LI} + \Delta C_{SO}$$

[AB: Above ground biomass; BB: Below ground biomass; DW: Dead wood; Li: Litter; SO: Soil]

The overview of the process to estimate carbon stocks and stock change for a country from an NFI is:

1. Define from literature, (or collect sample data (usually by felling trees) to develop), volume and biomass equations and/or coefficients for the individual tree that are appropriate for the country conditions;
2. Calculate stem volume, biomass and carbon for individual trees, summing to give plot and cluster statistics for above ground biomass. Calculate carbon in each of the other pools, including total carbon stock, and hence calculate per hectare values for each plot cluster;
3. Calculate per hectare strata values and confidence limits;
4. Calculate country total values and confidence intervals at the 95% probability level, given the areas of each stratum. (A 90% confidence interval maybe used when 95% requires a large number of samples and is too expensive);
5. When the NFI is repeated at a second time, calculate carbon stock change from the difference between the two inventories.

## Biomass Equations

There are many referenced sources available for quantifying forest biomass. Biomass is often proportional to volume and basal area at the stand level, and diameter and height at the individual tree level. It is also related to abiotic factors such as water, nutrients and energy of individual plants and stands.

Biomass equations usually express dry biomass as function of tree dimension or stand level variables such as basal area. The equations in the literature are often developed with data collected from narrow geographic ranges. It may be necessary for a country to develop its own biomass functions, in which case destructive sampling is carried out by felling a small number of trees, directly measuring volumes and weights in order to regress biomass as a function of tree parameters such as dbh, height and wood density.

A recommended equation from the literature in the first instance to predict above ground biomass for pantropical tree species (Chave et al. 2014) is;

$$AGB_{est} = (0.0673 \times WD \times D^2H)^{0.976}$$

$$\sigma = 0.357, AIC = 3130, df=4002$$

Where:

$AGB_{est}$  = above ground biomass of an individual tree (g)

WD = wood density ( $g/cm^3$ )

D = dbh (cm)

H = height (m)

## Developing individual tree allometric models

In order to develop a country specific individual tree allometric model to predict biomass, a sample of trees would have been felled and destructively measured. To calculate the tree dry biomass from destructive sampling, the following field data are required: tree species, height and dbh; data on the felled tree of its volume and wood density or its dry weight, for relevant tree components of bole, stump, buttress, leaves and branches (Haywood, 2015).

### Biomass of the bole

Measure the bole for diameter at known intervals along its length.

Calculate the total volume of the bole by summing the volume of all of the sections. The volume of each section is calculated using the equation for the volume of a conic frustrum.

$$VOL = \sum \frac{1}{3} \times \pi \times L \times \left( \left( \frac{D_T}{2} \right)^2 \times (D_T \times D_B) \times \left( \frac{D_B}{2} \right)^2 \right) \times 10^{-6}$$

Where:

VOL = volume (m<sup>3</sup>)

L = length (cm)

D<sub>T</sub> = top diameter of section (cm)

D<sub>B</sub> = bottom diameter of section (cm)

b) Use the tree's wood density (calculated or found in literature) and the volume to calculate the biomass:

$$DW_{\text{bole}} = WD \times \text{VOL} \times 1000$$

Where:

$DW_{\text{bole}}$  = biomass of the bole (kg)

WD = bole wood density (g/cm<sup>3</sup>)

VOL = volume (m<sup>3</sup>)

### **Biomass of the stump**

To calculate the volume of the stump, identify the shape the stump most closely resembles, frustrum, cube, or cylinder, use the appropriate volume equation, and multiply the volume by wood density.

$$DW_{\text{stump, v}} = \text{VOL} \times WD \times 1000$$

Where:

$DW_{\text{stump, v}}$  = biomass of the stump (kg)

VOL = volume (m<sup>3</sup>)

WD = wood density (g/cm<sup>3</sup>)

## Biomass of the buttress

$$DW_{\text{buttress}} = \sum WW_i \times \text{DFR}$$

Where:

$DW_{\text{buttress}}$  = dry weight biomass of the buttress (kg)

$WW_i$  = wet weight of the  $i_{\text{th}}$  piece of the buttress (kg)

DFR = dry-to-wet ratio, determined by taking the fresh and oven-dried weight of at least three subsamples, finding the ratio, and averaging across all samples

## Biomass of the leaves and branches

Biomass of the leaves and branches is measured and calculated in separate groups: for leaves and branches <10cm in diameter; for branches 10-20 cm in diameter; and for branches >20 cm in diameter. The formula below can be used for each group.

$$DW_{\text{branch}} = \sum WW_i \times \text{DFR}$$

Where:

$DW_{\text{branch}}$  = dry weight biomass of leaves and branches (kg)

$WW_i$  = wet weight (kg) of pieces of the leaves and/or branches

DFR = dry-to-wet ratio, determined by taking the fresh and oven-dried weight of at least three subsamples, finding the ratio, and averaging across all samples

## Above ground carbon

In calculating above ground carbon, the field measurements for each plot are required: individual tree dbh and heights, plot area and slope, the allometric equations to apply to each sampled tree, and any additional parameter to complement the allometric equations such as wood density.

The steps for calculating the above ground carbon pool in a stratum are as follows:

1. For each tree in the plot, calculate above ground dry biomass using the selected allometric equation.
2. Multiply the tree biomass by the correct scaling factor based on the size of the plot or sub-plot in which the tree was measured.
3. Convert biomass in kilograms to biomass in tons. The units of biomass used in allometric equations are often kg dry biomass.
4. Sum the biomass per hectare of all trees in each plot. If adjustment for slope is to be made during data analysis, ensure the horizontal area and the slope scaling factors have been calculated for each plot or subplot. (If adjustment for slope is made during the fieldwork, this step is not necessary).

5. Convert biomass to carbon:

$$C_p = DM \times CF$$

Where:

$C_p$  = carbon stock in plot (t C/ha)

$DM$  = dry biomass in plot (t dry matter/ha)

$CF$  = carbon fraction (t C/t dry matter)

For tree vegetation, use the Carbon Fraction 0.47 or species-specific values from the literature (per IPCC 2006 GL, V4, Ch4, Table 4.3)

6. Calculate the mean and confidence interval AG and BG carbon pools for the stratum.

## Below ground carbon

Because measuring root mass to calculate below ground biomass is difficult, time consuming and very expensive, the calculation is invariably performed using a root/shoot ratio or an equation based on the above ground biomass. Root-to-shoot ratios are generally based on above ground biomass for an entire plot, rather than an individual tree.

$BGB = 0.235 \times AGB$ , if  $AGB > 62.5$  tonnes C/ha

$BGB = 0.205 \times AGB$ , if  $AGB \leq 62.5$  tonnes C/ha

Where:

BGB = below ground biomass

AGB = above ground biomass

(Source: Mokany et al., 2006)

## Dead wood

### Standing dead trees

To calculate the carbon of standing dead trees, the information required includes the field measurements, scaling factors for all the field plots, the relevant allometric equations, wood density of 'sound' dead wood classes, and an estimation of the percentage of tree biomass in leaves. (Note: If species/location specific data is not known the following default values of leaf biomass may be used: 3% of above ground biomass for hardwood/broadleaf species, 6% of above ground biomass for softwood/conifer species)

1. To calculate the biomass of standing dead tree classes 1 and 2, the calculation steps are:

- 1) Trees that fall within the Class 1 category,
  - The biomass of tree is estimated using the same allometric equation as for live trees. (Note: If the allometric equation

requires wood density, use the density for the 'sound' dead wood class).

- The biomass of the leaves is then subtracted;
- To then estimate the biomass of each tree on a per hectare basis, multiply the dead tree biomass by the correct scaling factor based on the size and slope of the plot.

2) Trees that fall within the Class 2 category,

- Where it is unclear what proportion of the original biomass is lost, it is advisable to adopt the conservative approach to estimate the biomass only of the bole of the tree. The approach comprises calculating the volume of the bole and converting the volume of dry biomass using the wood density estimate:

A. Calculate the volume of the bole:

If the top diameter of the bole has been measured, the volume is calculated using diameter and bole length measurements and the estimates of the top diameter. Volume is then estimated as the volume of a truncated cone. If the top diameter of the bole ( $d_2$ ) has not been measured the value can be treated as zero.

$$VOL = \sum \frac{1}{3} \times \pi \times L \times \left( \left( \frac{D_T}{2} \right)^2 \times (D_T \times D_B) + \left( \frac{D_B}{2} \right)^2 \right) \times 10^{-6}$$

Where:

VOL = volume (m<sup>3</sup>)

L = length (cm)

D<sub>T</sub> = top diameter of section (cm)

D<sub>B</sub> = bottom diameter of section (cm)

B. Volume is converted to dry biomass using the sound wood density estimate:

$$DB = VOL \times WD \times 0.001$$

Where:

DB = dry biomass (kg)

VOL = volume (cm<sup>3</sup>)

WD = wood density, from samples (g/cm<sup>3</sup>)

As the wood must be sound to support the still-standing tree, the sound wood density from the downed dead wood measurements shall be used.

2. Convert biomass in kilograms to biomass in tons. The units of biomass used in allometric equations are often kg dry biomass, in which case conversion to tons requires multiplying by 0.001.
3. To estimate the biomass of each standing dead tree on a per hectare basis multiply the dead tree biomass by the correct scaling factor for the plot area.
4. Sum the biomass per hectare of all standing dead trees in each plot
5. Convert estimates of biomass to carbon using a carbon fraction ratio of 0.47.
6. Calculate the mean and confidence interval for the stratum.

$$C_p = DM_{plot} \times CF$$

Where:

$C_p$  = carbon stock in plot (t C/ha)

$DM_{plot}$  = dry biomass in plot (t dry matter/ha)

CF = carbon fraction. For dead trees, use 0.47 t C/t

### Downed dead wood

For downed dead wood, lying on the ground, the following information is needed for the analysis: field data from the line intercepts for each plot, the wood densities of sound, intermediate and rotten dead wood classes (these can be calculated from literature or from field sampling).

For large pieces of wood ( $\geq 10$ cm diameter) measured on a 12m line transect, the calculation steps are as follows:

1. For each sampling point, the volume of downed dead wood per unit area is estimated using the equation (Warren and Olsen 1964) as modified by Van Wagner (1968) separately for each density class.

$$VOL_{LWD} = \pi^2 \times \left[ \frac{(d_1^2 + d_2^2 \dots d_n^2)}{8L} \right]$$

Where:

$VOL_{LWD}$  = Volume of downed dead wood per hectare in density class in plot ( $m^3$ /ha)

$d_1 \dots d_n$  = Diameter of piece n of dead wood along the transect in plot (cm)

L = Length of the transect in the plot (m)

2. Calculate biomass of downed dead wood in each density class and total within each plot:

$$BML_{LWD} = \sum_{\text{density classes}}^3 Vol_{\text{plot, class}} \times Dens_{\text{class}}$$

Where:

$BML_{LWD}$  = Biomass of downed dead wood per unit in plot (t dry matter /ha)

$Vol_{\text{plot, classes}}$  = Volume of downed dead wood in density class in plot (m<sup>3</sup>/ha)

$Dens_{\text{class}}$  = Mean density of dead wood in density class (sound, intermediate and, rotten) (t dry matter/m<sup>3</sup>)

3. Calculate carbon stocks of lying dead wood for each plot by converting from biomass to carbon:

$$CS_{LWD} = BM_{LWD} \times CF_{LWD}$$

Where:

$CS_{LWD}$  = Carbon stock of downed dead wood in plot (t C/ha)

$BM_{LWD}$  = Biomass of downed dead wood in plot (t dry matter/ha)

$CF_{LWD}$  = Carbon fraction of dry matter in dead wood (t C/dry matter) (Default value 0.47 tC/t dry matter (per IPCC 2006GL, V4, Ch4, Table 4.3))

4. Repeat steps for all sampled locations within a stratum
5. Calculate the mean downed dead wood and confidence interval for the stratum.

For small wood material ( $\geq 5$ -10 cm diameter) counted along 2 m transects in the field, the volume is measured ( $\text{m}^3/\text{ha}$ ):

$$V_{DW} = \frac{\pi^2((\text{Number of Pieces} \times \text{QMD}^2)}{8L}$$

Where:

$V_{DW}$ =volume of down wood ( $\text{m}^3/\text{ha}$ )

QMD=quadratic mean diameter, constant as 3.04

$L = 2\text{m}$

## Litter

For litter analysis, using the method described, all the clip plots collected at a sampling location (whether from a single plot or from a cluster of plots) are summed together and treated as one sample. The information required includes laboratory scale and drying oven.

To carry out the analysis, the following steps are:

1. Where the weights recorded in the field include the weight of the bag/sheet and/or subsample bag, calculate the wet weight of the sample and subsample as follows:

$$WW_{CP\ sample} = W_{bagt + material} - (W_{bag})$$

$$WW_{CP\ subsample} = (W_{subsample\ bag} + subsample\ material) - (W_{subsample\ bag})$$

Where:

$WW_{CP\ sample}$  = wet weight of clip plot sample (g)

$W_{bag}$  = weight of bag or sheet (g)

$WW_{CP\ subsample}$  = wet weight of clip plot subsample (g)

$W_{subsample\ bag}$  = weight of subsample bag (g)

2. Calculate dry-to-wet ratio:

a) In the laboratory, dry subsamples to a constant weight. Place samples in a drying oven at 70°C until sample reaches constant weight over multiple days.

b) Weigh the subsample to obtain its dry weight. This dry weight should not include the weight of the subsample bag.

Calculate dry-to-wet ratio of subsample:

$$DWR = \frac{DW_{CP \text{ subsample}}}{WW_{CP \text{ subsample}}}$$

Where:

DWR =Dry-to-wet ratio

DW<sub>CP subsample</sub> =dry weight of clip plot subsample (g)

WW<sub>CP subsample</sub> =wet weight of clip plot subsample (g)

3. Estimate total wet weight of sampled material per sampling location by summing the wet weights of each clip plot sample

4. Using the dry-to-wet ratio, estimate the total dry weight of material for each sampling location

$$DW_{CP\text{material}} = DWR \times WW_{CP\text{material}}$$

Where:

$DW_{CP\text{material}}$  =dry weight of clip plot material (g)

DWR =Dry-to-wet ratio

$WW_{CP\text{material}}$  =wet weight of clip plot material (g)

5. Calculate total area sampled within each plot:

$$TA_{clip\text{ plots}} = A_{CP\text{ frame}} \times \text{number of CP per sample}$$

Where:

$TA_{clip\text{ plots}}$  =total area of clip plots ( $m^2$ )

$A_{CP\text{ frame}}$  =Area of clip plot frame ( $m^2$ )

Number of CP per sample = number of clip plots per sample

6. Calculate scaling factor

$$SF = \frac{10,000 \text{ m}^2}{CP_{\text{total area, pp}}}$$

Where:

SF =Scaling factor

$CP_{\text{total area, pp}}$  =Total area of clip plots per plot ( $\text{m}^2$ )

7. Multiply the scaling factor by the total dry mass sampled at one sampling location to obtain dry biomass per hectare.

8. Convert dry biomass to total carbon per hectare using carbon fraction and 0.001 to convert from kg to tonnes.

$$Cp = DM \times CF \times 0.001$$

Where:

$Cp$  = carbon stock per hectare in the plot

$DM$  = dry biomass in plot

$CF$  = carbon fraction. The IPCC default value is 0.47.

9. Repeat the steps for all sample locations within a stratum.

10. Calculate the mean and uncertainty estimate for all plots for each stratum, and for the total forest.

## Soil carbon

In calculating the carbon stock for soil carbon pool, the following information is required to complete the analysis i.e. field data to estimate soil carbon content and bulk density, as well as the laboratory analysis of carbon concentration of soil samples.

For terrestrial forests, the soil depths to 30cm contains majority of carbon and are most susceptible to land use change. In the mangrove forest, measure to bedrock or 3m. It is expected that the NFI will only measure soil carbon in the mangrove forest.

Using a high-temperature induction furnace, fixed mass soil samples are processed for total carbon, and expressed as a percentage of the sample. Soil bulk density is calculated for each soil fraction and the soil depth interval (number of centimeters the sample represents) is recorded for each fraction. Carbon content for the soil fraction is computed as follows:

$$\text{Soil bulk density } \left( \frac{g}{cm^3} \right) = \frac{\text{Oven dry sample mass } (g)}{\text{Sample Volume } (cm^3)}$$

$$C_{soils} (Mg/ha) = \text{bulk density } (g/cm^3) \times \text{soil depth interval } (cm) \\ \times \text{percent carbon concentration } [C]$$

Total soil carbon the sum of all fractions for the subplot.

Bulk density ring or soil corer of known diameter and length to calculate volume using the formula below:

$$\text{Soil bulk density } \left(\frac{\text{g}}{\text{m}^3}\right) = \frac{\text{Oven - dry sample mass (g)}}{\text{Sample volume (m}^3\text{)}}$$

With respect to the organic carbon concentration, there are two methods recommended. The dry combustion method, in which LECO CHN-2000 combusts carbon at 850°C using only 0.1 mg of soil, and wet combustion that uses the Walkley method where not all the carbon is burnt.

Calculation is carried out as follows:

1. Calculate the bulk density of the mineral soil core:  
Dry bulk density soil samples in drying oven at 105°C for a minimum of 48 hours.
2. Using the carbon concentration data obtained from the laboratory, the amount of carbon per unit area is given by:

$$BD = \frac{DM}{VOL_{core} - \left(\frac{M_{coarse\ frag}}{Dens_{rock\ frag}}\right)}$$

Where:

BD =bulk density (g/cm<sup>3</sup>)

DM =dry mass (g/cm<sup>3</sup>)

VOL<sub>core</sub> =mineral soil core volume (cm<sup>3</sup>)

M<sub>coarse frag</sub> =mass of coarse fragments (g)

Dens<sub>rock frag</sub> =density of rock fragments (g/cm<sup>3</sup>)

3. Calculate mean soil carbon stock for each plot.
4. Repeat steps for all plots within stratum.
5. Calculate mean and uncertainty estimate for all plots within carbon pool within each stratum.

$$C = BD_{\text{soil}} \times \text{Depth}_{\text{soil}} \times C \times 100$$

Where:

C = carbon (t/ha)

$BD_{\text{soil}}$  = soil bulk density (g/cm<sup>3</sup>)

$\text{Depth}_{\text{soil}}$  = soil depth

In this equation C must be expressed as a decimal fraction e.g. 2.2% carbon is expressed as 0.022 in the equation

## Carbon Dioxide Equivalent

To convert Carbon into Carbon Dioxide equivalent use the conversion factor of  $44/12$  (3.6667).

# Quantifying Emission Factors

If a country has a NFI that has been repeated at least once, then carbon stock change is best calculated from the difference between the estimates derived directly from the NFIs at the different times. A direct measurement of changes is most commonly adopted as it applies to permanent sample plots. The inventory and re-measurements of permanent sample plots in an NFI is regarded as a Tier 3 method, this is the preferred method.

An Emission Factor (EF) is a coefficient that quantifies the emissions or removals in areas undergoing human-induced changes ( $\text{tCO}_2\text{e/ha}$ ). In other words, it is an estimate of the change in carbon pools impacted by the land use change, where the forests are being degraded (Heider, 2014).

If EFs are to be calculated, they are quantified through changes in carbon stocks in the pools considered by the IPCC. A direct measurement of changes is most commonly adopted as it applies to permanent sample plots (Tier 2 and 3). Thus in measuring and reporting carbon emissions and removals related to forestry, it is critical to know the equation below:

*Activity data (AD) X Emission Factor (EF) = Emissions Estimate (EE)*

*Activity data: Area change data from satellite remote sensing*

*Emission Factor: Forest carbon stock change data from a national forest inventory*

*Emissions Estimate: Inventory of greenhouse gas emissions from the forest sector*

Activity data is obtained from remote sensing to determine the change in land use for a given area. For example, a section of forest may have been converted to an agricultural pasture. Hence the activity data is the cumulative land area converted. Emission factors are then used to quantify the change in carbon stocks between the different land use types on a per hectare basis. Hence, the emissions estimate from the change in land area of forest to agricultural lands is calculated by multiplying the land area (ha) by the emission factor (tCO<sub>2</sub>e/ ha) of that change to yield the size (tCO<sub>2</sub>e) of the GHG source (or sink).

## Considerations for emission factor creation

When total carbon stock data is used to create emission factors, the wood product pool will be incorporated into the emission factors, with the carbon stored in long-term wood products subtracted from the carbon emissions.

*Table 1. Illustrates ways of calculating Emission Factors*

	Stock-Change	Gain-Loss
Definition	Difference in C stocks in a particular pool in pre- and post forest cover change	Net balance of additions to and removals from a carbon pool
Data requirements	Data needed on forest carbon stocks in key pools and fate of carbon after conversion	Annual data needed on C losses associated with tree harvest (e.g. felled tree and collateral damage in gap and from skid trails), and gains such as annual rates of forest growth post-harvest
Applications	Most appropriate for avoided deforestation and afforestation/reforestation	Most appropriate for forest degradation caused by tree harvest and enhancement of carbon stocks in existing forests

Table 2. Different units of an Emission Factor

Units of an Emission Factor	
A) tCO <sub>2e</sub> /ha?	Activities resulting from land cover change (e.g. deforestation)
B) tCO <sub>2e</sub> /ha/yr?	Emissions/removals that occur over time in one location (e.g. tree planting)
C) tCO <sub>2e</sub> /m <sup>3</sup> ?	Activities where emissions can be associated with volume (e.g. logging)

## Carbon and carbon dioxide equivalents

Carbon and carbon dioxide equivalents (CO<sub>2e</sub>) are standardized measures of describing the amount of greenhouse gases in the atmosphere. Carbon dioxide equivalent emission is the amount of CO<sub>2</sub> emission that would cause the same time-integrated radiative forcing, over a given time horizon, as an emitted amount of a long-lived GHG or a mixture of Greenhouse Gas Emissions (GHGs).

The CO<sub>2</sub>e emissions are obtained by multiplying the emission factor of a GHG by its Global Warming Potential (GWP) for the given time horizon (e.g. 50 years). For a mix of GHGs, it is obtained by summing the CO<sub>2</sub>e emissions of each gas. Carbon dioxide equivalent is a standard and useful metric for comparing emissions of different GHGs but does not imply the same climate change responses. CO<sub>2</sub>e are the units that are used to identify the amount of heat trapped by a GHG, in equivalent terms of carbon dioxide. Forest carbon measures are converted to CO<sub>2</sub>e to quantify their source or sink of carbon dioxide through forest cover change or growth, respectively.

# Calculating Uncertainty

Uncertainty is a statistical measure of the degree of precision to which an estimate is known. For example, the total standing volume of a forest block 100 ha in area may be estimated as  $24,000 \pm 2,300$  m<sup>3</sup> at the 95% probability level. This is different from accuracy – an estimate may have a bias, for example if a somewhat short field crew member had been carelessly measuring dbh at 1.1 m rather than 1.3m.

Generally, the precision of an inventory is increased with more intensive sampling. Improving accuracy is more likely to occur through the development of country-specific information and good field measurement practice (Haywood, 2015).

Important terms to know are:

- Statistical population - The entire underlying set of individuals from which samples are drawn. e.g. all the trees in state forest
- Statistical sample - A set of objects from which measurements are taken. We want the sample to be an unbiased representative subset of a population

- Sample Mean 
$$\bar{x} = \frac{\sum x_i}{n}$$

- Sample Variance 
$$s^2 = \frac{\sum (x_i - \bar{x})^2}{n-1}$$

- Sample Standard Deviation 
$$s = \sqrt{\frac{\sum (x_i - \bar{x})^2}{n-1}}$$

- Standard error of the mean

- With replacement or infinite population 
$$s_{\bar{x}} = \sqrt{\frac{s^2}{n}}$$

- Without replacement from a finite population 
$$s_{\bar{x}} = \sqrt{\frac{s^2}{n} \left( \frac{N-n}{N} \right)}$$

- Coefficient of Variation

$$CV = \frac{S}{\bar{x}}$$

- Confidence limits for the mean

$$\bar{x} \pm t_{\alpha} S_{\bar{x}}$$

Where t is obtained from the t distribution (tables or Excel)

Confidence limits of the mean define an interval that we expect will enclose the true mean. The likelihood that this is true is determined by  $\alpha$ . If we set  $\alpha$  at 5% (hence specifying 95% confidence intervals), then the region enclosed by the confidence intervals will capture the true mean 95 times out of 100.

Thus in calculating uncertainty in each pool, the mean, standard deviation and standard error need to be estimated across all the plots within each strata.

Carbon stock is usually reported with a 95% confidence interval. Alternatively, when the sample units are very variable and the 95% confidence interval is too wide and to reduce it would be too costly to achieve, a 90% probability level may be used.

There are two methods to estimate total uncertainty with Tier 1 and Tier 2.

The first approach is the Tier 1 “Simple Propagation of Errors” method. It is most appropriate under the following conditions:

- the uncertainties are relatively small, the standard deviation divided by the mean value being less than 0.3;
- the uncertainties have Gaussian (normal) distributions;
- the uncertainties have no significant covariance.

To calculate uncertainty, the following method should be followed:

- calculate % uncertainty in each pool
- quantify total uncertainty across all pools using IPCC Tier 1 “Simple Propagation of Errors” method

$$U_{total} = \frac{\sqrt{(U_1 \times x_1)^2 + (U_2 \times x_2)^2 + \dots + (U_n \times x_n)^2}}{|x_1 + x_2 + \dots + x_n|}$$

Where:

$U_{total}$  = total uncertainty;

$U_n$  = uncertainty associated with each pool, in percent;

$x_n$  = average (mean) of each pool

For Tier 2 the “Method of a Monte Carlo simulation” maybe used. When the conditions listed above are not met, it is necessary to use a numerical statistical technique, such as Monte Carlo analysis to estimate uncertainty. Such a method should be used under the following conditions:

- uncertainties are large,
- their distribution is non-Gaussian,
- the algorithms are complex functions

Correlations occur between some of the activity data sets, emission factors, or both.

Monte Carlo analysis method iteratively evaluates a deterministic model using sets of random numbers as inputs. The analysis uses a computer model to repeatedly perform relevant calculations, numerous times, each time randomly substituting model parameters with a user-defined range of values for any factor with uncertainty, creating a stochastic model. Because a distribution is rarely normal and correlations almost always exist between various measured carbon pools and between estimates at different times, it is preferable to use this method for propagation of uncertainty, if possible. It generates a total uncertainty distribution consistent with the input uncertainty distributions of the model parameters, emission factors, and activity data, thereby improving estimates of uncertainty, resulting in a Tier 2 method.

# References

1. Batjes, N. 2000. Soil vulnerability to diffuse pollution in Central and Eastern Europe SOVEUR Project (Version 1.0). Food and Agricultural Organization and International Soil Reference and Information Centre.
2. Cairns, M., Brown, S., Helmer, E. and Baumgardner, G. 1997. Root biomass allocation in the world's upland forests. *Oecologia* 111 (1): 1-11.
3. Cannell, M. 1984. 'Woody biomass of forest stands', *Forest Ecology and Management*, Vol. 8, pp.299-312.
4. Chave, J. 2002-2006. Measuring Wood density for Tropical Forest Trees: A Field Manual. Sixth Framework Programme. Pan-Amazonia Project. pp. 6.
5. Chave, J. 2014. Chap 6. Floristic shifts versus critical transitions in Amazonian forest systems. In *Forests and Global Change: part of Ecological Reviews*, Cambridge University Press, Isbn: 9781107614802.
6. Chave, J., Andalo, C., Brown, S., Cairns, M. , Chambers, J. , Eamus, D., Fölster, H., Fromard, F., Higuchi, N., Kira, T., Lescure, J., Nelson, B., Ogawa, H., Puig, H., Riéra, B., Yamakura, T. 2005. Tree allometry and improved estimation of carbon stocks and balance in tropical forests. *Oecologia* 145: 87-99.

7. Chave, J., Coomes, D., Jansen, S., Lewis, S., Swenson, N., Zanne, A. 2009. Towards a worldwide wood economics spectrum. *Ecology Letters* 12(4): 351-366.  
<http://dx.doi.org/10.1111/j.1461-0248.2009.01285.x>
8. Chave, J., Rejou-Mechain, M., Burquez, A., Chidumayo, E., Colgan, M., Delitti, W., Duque, A., Eid, T., Fearnside, M., Goodman, R., Henry, M., Martinez-Yrizar, A., Mugasha, A., Muller-Landau, H., Mencuccini, M., Nelson, B., Ngomanda, A., Nogueira, E., Ortiz-Malavassi, E., Pelissier, R., Ploton, P., Ryan, C., Saldarriaga, J. and Vieilledent, G. 2014. Improved allometric models to estimate the above ground biomass of tropical trees. *Global Change Biology* 20 (10): 3177-3190.
9. Haywood, A. 2015. Presentation: NFI Data Analysis Workshop, Nadi, Fiji, 17-19 May.
10. Heider, C. 2014. Presentation: NFI Workshop, Makira, Solomon Islands, 1-16 November.
11. IPCC, 2006. Volume 1: *General Guidance and Reporting*. Kherfan, S. and Radunsky, K. (Eds). Intergovernmental Panel on Climate Change (IPCC), IPCC/IGES, Hayama, Japan.
12. IPCC, 2006. Volume 4: *Guideline for National Greenhouse Gas Inventories-Agriculture, Forestry and Other Land Use*. Eggleston, S., Buendia, L., Ngara, T. and Tanabe, K. (Eds.). Intergovernmental Panel on Climate Change (IPCC), IPCC/IGES, Hayama, Japan.

13. Kauffman, J. and Donato, D. 2012. Protocols for the measurement, monitoring and reporting of structure, biomass and carbon stocks in mangrove forests. Working Paper 86. CIFOR, Bogor, Indonesia.
14. Magnussen, S. and Reed, D. 2004. Modelling for estimation and monitoring. FAO-IUFRO, 2004.
15. Mokany, K., Raison, R. and Prokushkin, A. 2006. Critical analysis of root: shoot ratios in terrestrial biomes. *Global Change Biology* 12: 84-96.
16. UNFAO. 2014. Accessed from <http://www.fao.org/home/en/>