

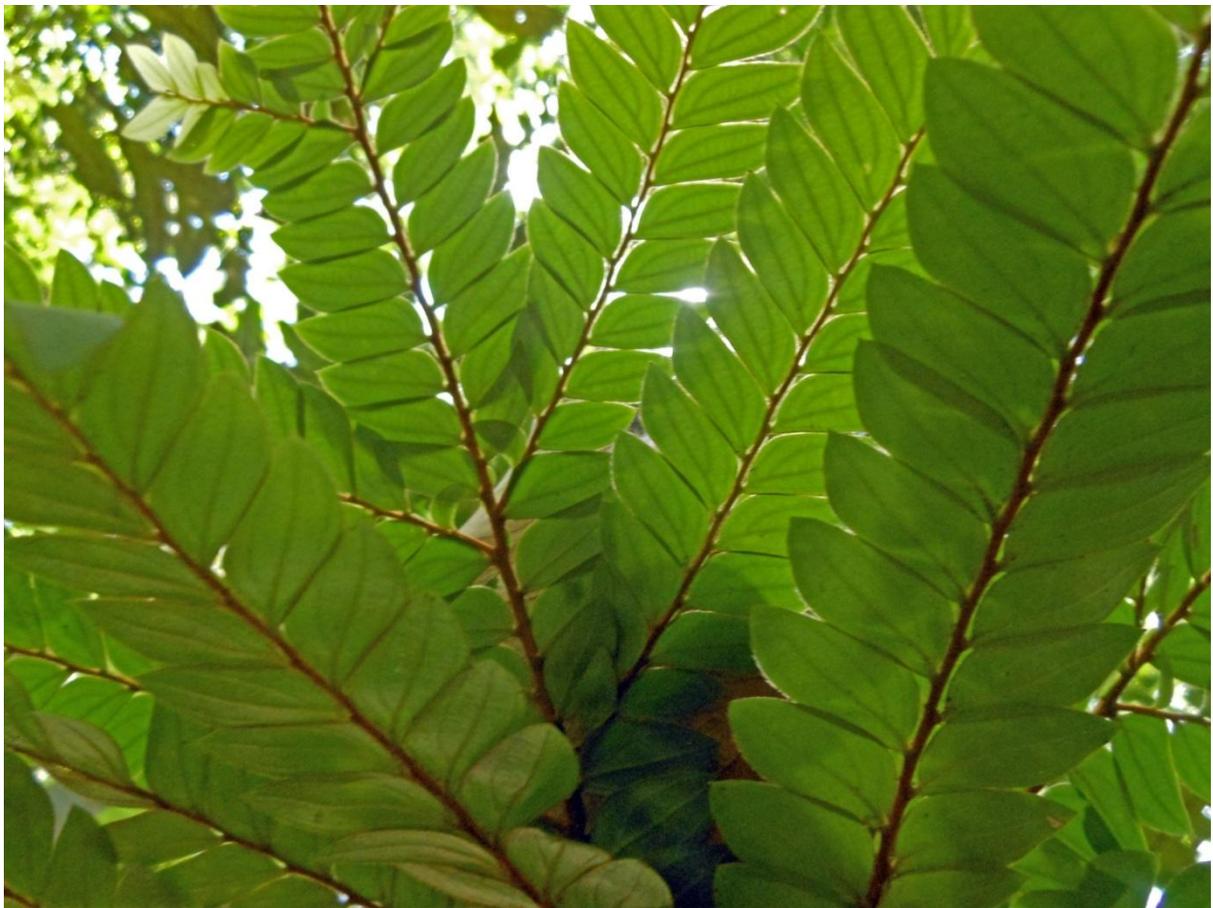


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**LEAF TECHNICAL GUIDANCE SERIES FOR THE  
DEVELOPMENT OF A NATIONAL OR SUBNATIONAL  
FOREST CARBON  
MONITORING SYSTEM FOR REDD+**

**Module STR-NFI: Forest Carbon  
Stratification Using NFI Data**



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**Module STR-NFI: Forest Carbon Stratification Using NFI Data**

**Winrock International**

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## ICONS WITHIN THE DOCUMENT

The icons below are found throughout the document and indicate areas that the reader should pay special interests to:

Icon	What does it signify?
	A key decision that must be made
	A key technical step that must be accomplished before moving forward
	The need for personnel with specified skill set
	An example
	A key term described in the framework
	A reference to relevant resource

## 1. SCOPE

This module provides guidance on the stratification process for the development of accurate and statistically rigorous estimates of forest carbon stocks based on available National Forest Inventory (NFI) data. Not all forests have the same composition, structure and carbon stocks; therefore forest carbon stratification divides the forest area into groups (strata) with similar carbon stocks . Stratification increases the precision of carbon stock estimates as it diminishes the sampling effort necessary, while maintaining the same level of confidence, because of smaller variation in carbon stocks in each stratum than in the whole area.

The purpose of stratification for situations where national forest inventory already exist is to optimally divide forest areas between areas with carbon stock similarity.

## 2. APPLICABILITY

This module is applicable for dividing the forest area into strata with similar carbon stocks based on the national forest inventory data. This module is developed based on the Pearson et al, 2013.<sup>1</sup> Experience with NFI and spatial analysis are essential skills for applying this module.

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<sup>1</sup> Pearson T, F Casarim and S Brown. 2013. Guidelines for stratification for REDD+ using a national inventory. Report submitted to LEAF Head Office and available online at <http://www.leafasia.org/library/guidelines-stratification-redd-using-national-inventory>

### 3. PRODUCTS

This module provides the methods and procedures to create spatially explicit forest carbon strata map, where each stratum is defined as forests with similar carbon stock based on the national (or potentially sub-national) inventory data.

### 4. REQUIRED INPUTS

Key prerequisites should be satisfied to be able to apply this module:

- National or sub-national forest inventory data
- Forest type map using IPCC forest categories



Forest type maps using IPCC forest categories are defined spatially from the FAO Global Ecological Zones (GEZ) dataset available at <http://www.fao.org/geonetwork/srv/en/main.home> (search Global Ecological Zones).

- National or sub-national forest map



Guidance on available satellite images and different RS techniques for creating land cover and forest change maps can be found in the GOFCC-GOLD Sourcebook - COP 18 version 1 (<http://www.gofccgold.wur.nl/redd/>).

### 5. METHODS AND PROCEDURES

The steps for developing a forest carbon stratification map based on a national forest inventory are designed to go from simple to complex analysis within a hierarchical decision tree (Figure 1). Analysis 1 uses the IPCC forest categories, Analysis 2 uses the national forest type categories and Analysis 3 uses expert opinion to stratify the forest carbon stocks based on the national forest inventory data. Analysis 4 finalizes the forest carbon stratification map. This approach allows countries to consider the most economical approach to stratification before introducing additional layers of complexity (Figure1).



## Figure 1: Hierarchical approach for developing a forest carbon stratification map based on a national forest inventory

To illustrate the stratification with NFI data procedure, a hypothetical example is presented to walk the reader through the steps for each of the analyses for creating a forest carbon stratification map for a country “X”. In this example IPCC and national forest type category maps along with NFI data exist for the country.

### Analysis 1: Using IPCC forest category

The following steps are used to stratify the national forest based on IPCC forest categories:

**STEP 1:** Extract the IPCC forest categories using the FAO GEZ dataset for the national forest area. The locations of the national forest inventory plots should be overlaid with the IPCC categories for the national forest area.

**STEP 2:** Estimate the mean of the measured carbon stock (usually measured in tons of carbon per hectare) and 95% confidence interval of all inventory plots within each of the IPCC forest categories.

**STEP 3:** Conduct a precision test for each of the IPCC forest categories. The precision test examines the 95% confidence interval and the mean carbon stock for each forest type category. The precision test for an IPCC forest category is met when the half width of the 90% confidence interval is less than 20% of the mean carbon stock for this forest type.

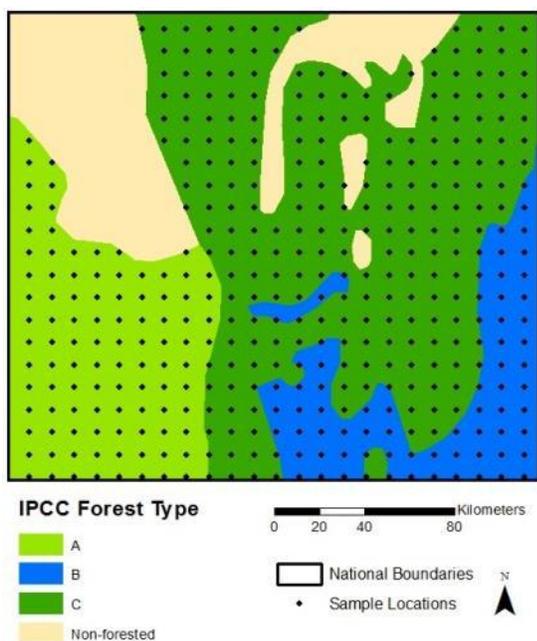


Technical guidance for estimating the mean carbon stock based on the NFI data and the 95% confidence interval is provided in a module addressing data analysis and uncertainty calculations.

**STEP 4:** Extract the national IPCC forest categories for which the precision test was not met. These categories will be stratified further in Analysis 2.



In the hypothetical example country “X”, the national forest is covered by three different IPCC forest categories: **A**, **B**, and **C** as well as non-forested areas and NFI plots collected systematically at every intersection of a 10km x 10km grid as shown in Figure 2.



**Figure 2: Forest cover map of country "X" according to IPCC forest classes.**

By using the National Forest Inventory data, carbon stocks for each IPCC forest category along with the uncertainty are estimated (Table 1).

**Table 1: Carbon stocks (t C/ha) of different forest types in country "X" based on IPCC classes.**

	A	B	C
Mean (t C ha <sup>-1</sup> )	264.8	95.4	165.1
90%CI	30.4	15.8	48.3
CI as % of mean	11%	17%	29%
N	78	85	96

The IPCC category **A** and **B** meet the test (precision test) of the half width of the confidence interval being less than 20% of the mean at the 90% confidence level with 11% and 17%, respectively, indicating that the carbon stocks for these forest types are sufficiently homogeneous. However, the half width of the confidence interval at 90% confidence interval for IPCC category C is 29%, indicating that carbon stocks are heterogeneous for this forest type.

The IPCC category **C** does not meet the precision test and therefore is further stratified with the national forest type map in Analysis 2.

## Analysis 2: Using national/ sub-national forest type map

The following steps are used to stratify forest type categories using a national/sub-national forest type map:

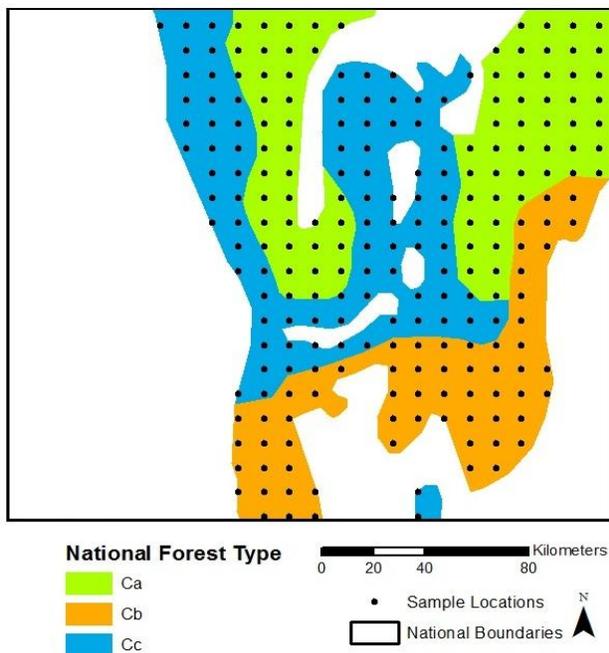
**STEP 1:** Overlay the IPCC categories for which the precision test failed with a national forest map (if one exists, if not see next section) and determine the mean of measured carbon stocks and 90% confidence interval of all plots by each forest class within the national forest map.

**STEP 2:** Conduct the precision test. Where the half width of the 90% confidence interval is less than 20% of the mean for each national forest type stratum then the precision is sufficient and no further stratification is necessary.

**STEP 3:** Extract the national forest categories for which the precision test was not met. These categories will be stratified further in Analysis 3.



In the hypothetical example, the IPCC forest category **C** is composed of three national forest types: **Ca**, **Cb**, and **Cc** (Figure 3).



**Figure 3: Division of forest type C based on country "X"'s National forest map.**

The 96 sample points within IPCC forest category **C** are now split into 3 national forest types: **Ca**, **Cb**, **Cc**. By analyzing the data and estimating the carbon stocks of each of the national forest types, it was identified that within forest types **Ca** and **Cc** carbon stocks are homogeneous (Table 2). However, the forest type **Cb** still showed highly variable carbon stocks (i.e. half width of the 90% confidence interval is greater than 20% of the mean), and therefore requiring further stratification using expert opinion in Analysis 3.

**Table 2: Carbon stocks (t C/ha) of different forest types in country "X" based on National forest map.**

	<b>Ca</b>	<b>Cb</b>	<b>Cc</b>
Mean (t C ha <sup>-1</sup> )	195.2	129.7	170.3
90%CI	17.4	33.4	5.1
% uncertainty	9%	26%	3%
N	31	33	32

### Analysis 3: Using expert opinion

The following steps are used to stratify forest types based on expert opinion:

**STEP 1:** Consult national and if necessary international experts to determine an appropriate stratification for all national forest categories that have not met the previous precision test. The following represents potential means of stratification:

- Accessibility (e.g. buffer around roads to have more and less accessible strata – likely to have more and less existing degradation)
- Management (e.g. where significant in area, plantations can and should be separated from natural forest)
- Splitting or lumping existing national forest map classes based on local knowledge of forest type and structure

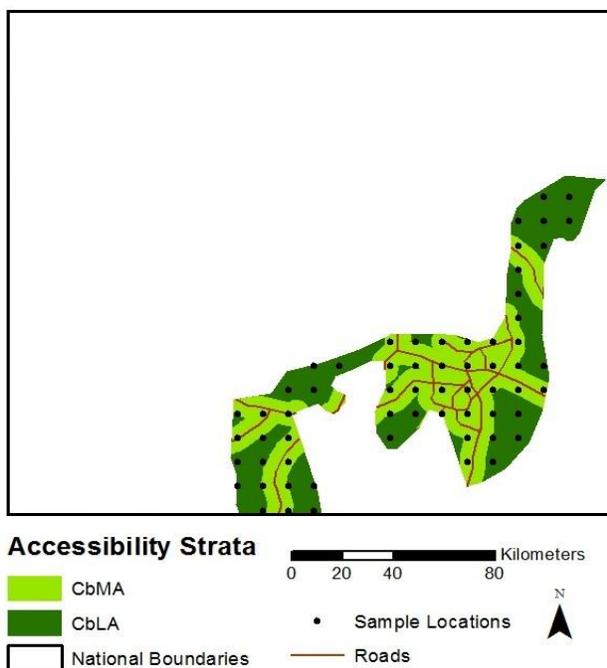
**STEP 2:** Estimate the mean and 90% confidence interval of all plots for each of the expert-derived strata.

**STEP 3:** Continue reassessing until all expert-derived strata meet the precision test (the half width of the confidence interval being less than 20% of the mean at the 90% confidence level).

**STEP 4:** Collect additional plot data for specific areas and scenarios where precision cannot be met using NFI data.



In the hypothetical example, local experts and officials know that communities located in the area encompassed by forest type **Cb** gathered fuelwood for cooking and heating. Therefore a decision to further divide **Cb** based on the human accessibility to the forest was made. Participatory Rural Appraisals (PRAs) were conducted and indicated that a person would travel 5 km into the forest for collecting fuelwood. Thus, a buffer of 5km was created along either side of all roads in forest type **Cb** (Figure 4).



**Figure 4: 5km buffers along either side of all roads in Cb: (i) CbMA corresponds to more accessible areas, and (ii) CbLA corresponds to less accessible areas outside of the buffers.**

After subdividing forest type **Cb**, data analysis showed homogeneous distribution of forest carbon stocks in either the More and the Less Accessible areas (MA and LA respectively) (Table 3).

**Table 3: Carbon stocks (t C/ha) of More and Less accessible areas (MA and LA respectively) of forest type Cb in country "X"**

	CbMA	CbLA
Mean (t C ha <sup>-1</sup> )	115.9	152.7
90%CI	16.7	24.3
% uncertainty	14%	16%
N	19	14

#### Analysis 4: Finalizing forest carbon stratification map

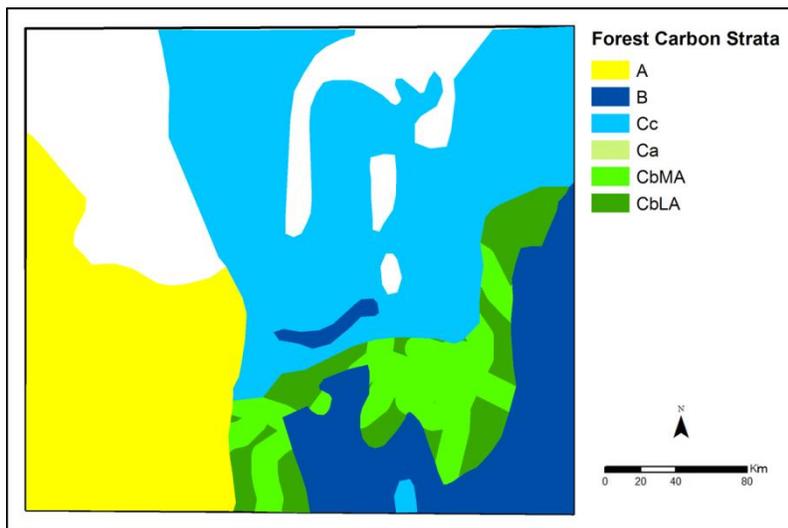
It is possible that in some cases the stratification could result in multiple forest carbon strata with effectively identical carbon stocks leading to superfluous strata. Therefore, to optimize the ultimate efficiency of carbon stratification while maintaining the precision of the carbon stocks with each stratum, the following steps are used to finalize the forest carbon stratification map:

**STEP 1:** Conduct an analysis of variance (ANOVA) to compare the individual carbon stock numbers from within each stratum. The test examines the variance of carbon stocks between the carbon strata. The ratio of variance between the strata to the variance within a stratum is given by the value of the F

statistic. A post hoc test (e.g. Tukey’s Test) should be conducted to determine strata for which no significant difference exists.

**STEP 2:** The p statistic for the ANOVA across the full forest inventory dataset should be significant ( $p < 0.05$ ) given the work already undertaken to determine separation between strata. However, where the post hoc test illustrates no difference between specific strata ( $p > 0.05$ ) combine the strata.

The analysis of variance for the hypothetical example did not find carbon strata with similar carbon stocks, therefore the final forest carbon map for country “X” would encompass a total of 6 strata: strata **A** and **B** (based on the IPCC forest categories), strata **Ca** and **Cc** (based on the national forest type) and strata **CbMA** and **CbLA** (based on the expert opinion for accessibility to the forest) (Figure 5).



**Figure 5: Final forest carbon stratification map for country “X”.**

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