# Lao PDR’s Forest Reference Emission Level and Forest Reference Level for REDD+ Results Payment under the UNFCCC

**January 2018**

**Department of Forestry**

**Ministry of Agriculture and Forestry, Lao PDR**

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## Acronyms

| | |
|---|---|
| AE | Allometric Equation |
| AGB | Above Ground Biomass |
| B | Bamboo |
| BGB | Below Ground Biomass |
| CF | Coniferous Forest |
| DBH | Diameter at Breast Height |
| DD | Dry Dipterocarp Forest |
| DOF | Department of Forestry |
| DW | Dead Wood |
| EG | Evergreen Forest |
| E/R factors | Emission and Removal Factor |
| FIPD | Forestry Inventory and Planning Division |
| FREL | Forest Reference Emission Level |
| FRL | Forest Reference Level |
| FTM | Forest Type Map |
| GHG | Greenhouse Gas |
| GIS | Geographic Information System |
| IPCC | Intergovernmental Panel on Climate Change |
| Lao PDR | Lao People's Democratic Republic |
| MAF | Ministry of Agriculture and Forestry |
| MCB | Mixed Coniferous Broadleaved Forest |
| MD | Mixed Deciduous Forest |
| NFI | National forest Inventory |
| NFMS | National Forest Monitoring System |
| P | Plantation |
| REDD+ | Reducing Emissions from Deforestation and forest Degradation plus the conservation of forest carbon stocks, sustainable management of forests and enhancement of forest carbon stocks |
| FREL/FRL | Forest Reference Emission level/Forest Reference Level |
| RV | Regenerating Vegetation |
| StD | Standard Deviation |
| StE | Standard errors |
| UC | Upland Crop |
| UNFCCC | United Nations Framework Convention on Climate Change |

## Acknowledgement

The Department of Forestry and the Government of Lao PDR would like to acknowledge the technical support and collaboration on REDD+ received from the various development partners. The development and submission of Lao PDR's Forest Reference Emission Level (FREL) and Forest Reference Level (FRL) for REDD+ has been supported by Japan International Cooperation Agency.

# 1. FOREST DEFINITION

According to the Land Law (2003) and Forestry Law (2007), forest and forest resources in Lao PDR occur in lands that are designated by the Government as forest lands and in areas outside forest lands, and includes both stocked and temporarily un-stocked forests.

Lao PDR has a national definition of forests, for which a summary is shown in the following Table 1. This same definition is used in the construction of the proposed Forest Reference Emission Level/ Forest Reference Level (FREL/FRL).

**Table 1: Forest definition of Lao PDR**

| Parameter | Value |
|---|---|
| **DBH** | Minimum of 10cm |
| **Crown Density** | Minimum of 20% |
| **Area** | Minimum of 0.5 ha |

The decision for this forest definition over a more conventional one, which includes a height threshold is to allow for better results in the identification of land cover classes through remote sensing. By applying this definition with a minimum average stand DBH of 10cm, land covered with small diameter trees which would have been classified as forest under a height threshold definition, can be excluded. The other reason for selecting this forest definition is to do with trees in rice paddy landscapes in the flatland areas. In order to avoid misinterpretation of these paddy lands as forests particularly through remote sensing, as such lands often have canopy cover of over 10%, the 20% crown density threshold has been adopted.

This same forest definition was used also in the past two National Communications on Climate Change, submitted to the UNFCCC. Nationally, decisions have already been taken to also employ the same definition into the future in compiling the national GHG inventory starting with the Third National Communication which the Government plans to submit to the UNFCCC in early 2019.[1]

[1] This definition is different from what Lao PDR used for the reporting to the FAO Forest Resources Assessment (FRA) 2015. In FAO-FRA 2015, Lao PDR defines “forest” as: minimum height of trees of 5.0 m; minimum forest canopy cover of 10%; and minimum area of 0.5ha.

# 2. LAND AND FOREST CLASSIFICATION AND STRATIFICATION SYSTEMS

## 2.1. Land and forest classification system

The land and forest classification system of the country applies two levels of classification, namely, Level 1 consisting of seven classes including "Current Forest" and "Potential Forest" among others, and Level 2 which further classifies "Current forest" class under Level 1 into six natural and plantation forest classes. The land classification system is illustrated in Table 2 below, and a full description of the definition of each Level 2 class is available at the Department of Forestry (DOF)'s website[2].

Around 2010, when Lao PDR initiated the development of its national Forest Type Maps (FTMs: wall-to-wall maps of the entire territory) to support REDD+, the government and the stakeholders, first, reviewed the land/forest classification system to be applied for the mapping exercise.

**Table 2: National level land and forest classification system of Lao PDR with IPCC definition on land use categories**

| IPCC Definition | National level classification system | | |
|---|---|---|---|
| | Level 1 | Level 2 | |
| Forest Land | Current Forest | Evergreen Forest | EG |
| | | Mixed Deciduous Forest | MD |
| | | Dry Dipterocarp Forest | DD |
| | | Coniferous Forest | CF |
| | | Mixed Coniferous and Broadleaved Forest | MCB |
| | | Forest Plantation | P |
| | Potential Forest | Bamboo | B |
| | | Regenerating Vegetation | RV |
| Grassland | Other Vegetated Areas | Savannah | SA |
| | | Scrub | SR |
| | | Grassland | G |
| Cropland | Cropland | Upland Crop | UC |
| | | Rice Paddy | RP |
| | | Other Agriculture | OA |
| | | Agriculture Plantation | AP |
| Settlement | Settlement | Urban Areas | U |
| Other land | Other Land | Barren Land and Rock | BR |
| | | Other Land | O |
| Wetland | Above-ground Water Source | River (Water) | W |
| | | Wetland (Swamp) | SW |

An important point was to ensure the classification system was in harmony with the land-use category definition of the IPCC in order to maintain consistency between the REDD+ FREL/FRL and MRV and the National Greenhouse Gas (GHG) Inventory. Another was to determine how to categorize the temporarily un-stocked forests in the classification system (i.e. "regenerating vegetation: RV"). This reflects the unique situation of forests and forest use in the country, and in particular, the prevalence of shifting cultivation, and presence of vast areas of forest fallow. This

[2] http://dof.maf.gov.la/en/home/

land-use is seen throughout the country where a significant area is covered under forest fallow stages of shifting cultivation, regenerating through natural vegetative succession, going in and out (currently only in limited cases) of temporarily un-stocked states. Restoration of RV into the forest state has been a high priority agenda of the Government as stated in the 8th National Socio-Economic Development Plan.

**Box 1: Lands under shifting cultivation**

Of the above land/forest classes, UC (upland crops) and RV (forest fallow) classes are for the most part considered to be stages of the shifting cultivation cycle, and these lands can re-grow and recover into stocked forest (mostly to Mixed Deciduous Forest (MD)) through natural vegetative succession. Through intensive discussions within the DOF and with stakeholders on whether to classify these under the IPCC land use category of "Forest Land" or "Cropland", it was concluded that, in line with the IPCC definition, to classify RV as Forest Land as they are "…vegetation that currently fall below, but are expected to exceed, the threshold of forest land category." (IPCC, 2003) and classify UC as "Cropland" as they are used, even temporarily, for cropping at the time of mapping.

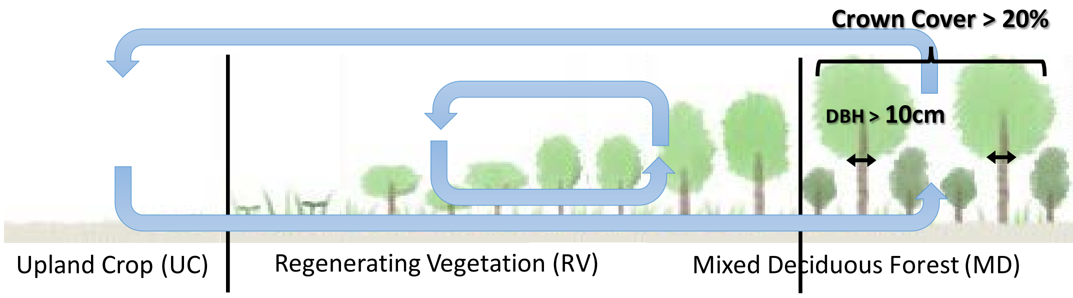


Figure 1: Slash-and-burn cycle and land/forest classes

Lao PDR recognizes that by applying such method of classification, a piece of land not undergoing land use change, but, only temporary land cover change (i.e. short-term changes) would be subject to designation as undergoing a change event. However, Lao PDR choses to apply this method for the REDD+ FRL/FREL and MRV. The strong rationale for this decision is the Government's commitment to its agenda of stabilizing the shifting cultivation landscape and increasing forest cover to 70%. The estimation of change resulting from method of classification is consistently and symmetrically conducted for emissions and removals. For example, when a shifting cultivation landscape undergoes change from RV (forest fallow) to UC (upland crop) this short-term loss is recorded; on the other hand, when the UC is left for fallow and regenerates into RV, this removal is also recorded; meaning that estimation of emissions is offset by estimation of removals, so far as the rotational agricultural practice continues.

## 2.2. Stratification

For the purpose of the REDD+ MRV, the national land and forest classification explained in Section 2.1 are condensed into five strata. Such simplified stratification will help reduce uncertainty of emissions and removals while balancing the accuracy of sampling and the cost/efforts required. The forest stratification used for the construction of the FREL/FRL includes the following five types of forest land and non-forest land as shown in Table 3:

- Evergreen Forest (EG) has distinctly high carbon stocks (200.0tC), thus, separated as an independent stratum – Stratum 1 (expanse: 2,605,557ha, 11.3% of the total land area).

- Mix Deciduous Forest (MD), Conifer Forest (CF) and Mixed Coniferous and Broadleaved Forest (MCB) will form one stratum on the basis of similarity in carbon stocks per hectare (87.7tC, 92.6tC, 114.7tc). – Stratum 2 (expanse: 9,437,688ha, 40.9% of the total land area).
- Dry Dipterocarp Forest (DD) will form one stratum due to the difference in carbon stock from other forest classes (43.2tC), and also due to the fact that they are mostly distributed in the low-lands and prone to conversion to other land use – Stratum 3 (expanse: 1,188,198ha, 5.2% of the total land area).
- Plantation (P), Bamboo (B) and Regenerating Vegetation (RV) will form one stratum on the basis of similarity in average carbon stock (37.2tC, 24.4tC, 17.4tC) – Stratum 4 (expanse: 6,300,445ha, 27.3% of the total land area).
- The remaining 12 non-forest classes will form one stratum – Stratum 5 (expanse: 3,522,370ha, 15.3% of the total land area).

**Table 3: Stratified land/forest classification system and the five land/forest strata**

| Land/forest classes | | | Area (ha) | % of total area | Strata |
|---|---|---|---|---|---|
| Level 1 | Level 2 | | | | |
| Current Forest | Evergreen Forest | EG | 2,605,557 | 11.3% | 1 |
| | Mixed Deciduous Forest | MD | 9,437,688 | 40.9% | 2 |
| | Coniferous Forest | CF | | | |
| | Mixed Coniferous and Broadleaved Forest | MCB | | | |
| | Dry Dipterocarp Forest | DD | 1,188,198 | 5.2% | 3 |
| | Forest Plantation | P | 6,300,445 | 27.3% | 4 |
| Potential Forest | Bamboo | B | | | |
| | Regenerating Vegetation | RV | | | |
| Other Vegetated Areas | Savannah | SA | 3,522,370 | 15.3% | 5 |
| | Scrub | SR | | | |
| | Grassland | G | | | |
| Cropland | Upland Crop | UC | | | |
| | Rice Paddy | RP | | | |
| | Other Agriculture | OA | | | |
| | Agriculture Plantation | AP | | | |
| Settlement | Urban Areas | U | | | |
| Other Land | Barren Land and Rock | BR | | | |
| | Other Land | O | | | |
| Above-ground Water Source | Wetland (Swamp) | SW | | | |
| | River (Water) | W | | | |
| Total | | | 23,054,258 | 100% | |

# 3. ELEMENTS FOR FREL/FRL

## 3.1. Activities

The REDD+ activities applied under the FREL/FRL of Lao PDR are as follows;

**Table 4: REDD+ activities included in the FREL/FRL**

| Activities | Included? | Justification / Explanation |
|---|---|---|
| Emissions from deforestation | Yes | A deforestation event is a change of a forest land stratum to a non-forest land stratum.<br>This can be caused by activities such as conversion of forests to agricultural land, infrastructure, urbanization, etc.<br>The total emissions from deforestation account for approximately 34% of all forest-related emissions in the reference period (2005-2015). |
| Emissions from forest degradation | Yes | A degradation event is a change within forest land strata from a higher biomass stratum to lower biomass stratum, and also through measurement of tree stumps as a proxy indicator of logging activities (see Section4.2.3).<br>This can be caused by activities such as selective logging. The event of a conversion of natural forest to forest plantation is also by definition, a degradation event[3]. The short-term changes between certain stages of rotational agriculture may also be recorded as a degradation event. Such degradation events occur most often in Evergreen forests (Stratum 1) and Mixed Deciduous forests (Stratum 2) being degraded into RV (Stratum 4).<br>The total emissions from forest degradation account for approximately 66% of all forest-related emissions in the reference period (2005-2015). |
| Removals from forest enhancement (Restoration) | Yes | A restoration event is a change within forest land stratum from a lower biomass stratum to a higher biomass stratum (in IPCC terms, “forest land remaining forest land”).<br>This is often a result of regrowth of the RV (Stratum 4) to other natural forest classes. |
| Removals from forest enhancement (Reforestation) | Yes | A reforestation event is a change of non-forest stratum (Stratum 5) to forest land strata (Strata 1-4).<br>This is often a result of a non-forest land (Stratum 5) being converted into the Plantation class, or regenerating into the RV (both Stratum 4). |
| Emissions and Removals from conservation of carbon stock | No | There is no national definition for this REDD+ activity[4]. |
| Emissions and Removals from | No | There is no national definition for this REDD+ activity. |

[3] Lao PDR acknowledges that as per UNFCCC Decision 1/CP.16, Appendix 1, Section 2(e), conversion of natural forests into forest plantations should not be considered as a REDD+ activity. However, there is a high interest in the forestry sector to promote sustainable plantation development. Lao PDR intends to consult this issue with the UNFCCC, and reflect the conclusions in the MRV. Note that the MRV will use geographically explicit data to allow identification of such areas.

[4] In the future, Lao PDR may include restoration from improved RV management and forests remaining in the same category with increased carbon stock in this category – but for now, this is not possible due to lack of datasets. For the same reason, emissions from degradation occurring in forests remaining in the same category is also not

| | | |
|---|---|---|
| sustainable management of forests | | However, there is a comprehensive accounting for GHG emissions and removals from forests so GHG emissions and removals that could potentially be included in this activity are included in the other REDD+ activities. |

In Lao PDR's carbon accounting, all the emissions from deforestation and forest degradation are regarded as anthropogenic, for the reason that, forests in the country are home to many different mountain ethnic groups in and interacting with the forests in their daily lives; and large-scale natural disasters in forest areas or forest diseases are not common. In addition there is no suitable technology yet to clearly distinguish anthropogenic and non-anthropogenic emissions.

### 3.2. Carbon Pools

The following table shows the carbon pools considered in the FREL/FRL.

**Table 5: Carbon pools accounted for in the FREL/FRL**

| Carbon Pools | Selected? | Justification / Explanation |
|---|---|---|
| Above Ground Biomass (AGB) | Yes | AGB consists the majority of the forest biomass in Lao PDR, thus, considered as a significant carbon pool. |
| Below Ground Biomass (BGB) | Yes | On average, BGB constitutes 37.6% of the AGB per ha. Thus, BGB is considered as a significant carbon pool.<br>Due to the lack of country-specific data, the IPCC default values were used for the estimation. |
| Dead Wood (DW) | No | The 2nd NFI involved measurement of DW. The results showed that emissions from DW through deforestation account only 1.6% of the sum of the AGB, BGB and DW, therefore, considered insignificant (See "Annex 2: Emission/Removal Factors Report" for more details).<br>Lao PDR currently lacks complete data to account DW in the FREL/FRL, and considers to improve this in the measurement of the next NFI.<br>Exclusion of DW is considered to be conservative. |
| Litter | No | The past NFIs have not involved measurement of litter.<br>Exclusion of litter is considered to be conservative. |
| Soil | No | There is no reliable country specific data for soil organic carbon.<br>Exclusion of soil organic carbon is considered to be conservative. |

### 3.3. Gases

The following table shows the GHG considered in the FREL/FRL.

**Table 6: Gases accounted for in the FREL/FRL**

| Greenhouse gases | Selected? | Justification / Explanation |
|---|---|---|
| **$CO_2$** | Yes | The FREL/FRL account for $CO_2$ emissions and removals. |
| **Non-CO2 (CH4 and N2O)** | No | Shifting cultivation is an important disturbance event nationally, where nearly 170,000ha/year of forest lands are assumed to be affected by |

accounted, except for the emission from selective logging estimated through measurement of tree stumps as a proxy indicator.

| | | |
|---|---|---|
| | | slash and burn practices. CH4 and N2O are the gases emitted from biomass burning.<br>The estimates of emissions from non-CO2 gases caused by shifting cultivation account for 3.5% of all forest-related CO2 emissions in the reference period (2005-2015).<br>However, by the nature of shifting cultivation which is defined as not being permanent, the area of shifting cultivation can only be finally determined through a retrospective confirmation of plots not continuing to be cultivated, which would take place during the next mapping cycle. Therefore, it is difficult to confidently estimate emissions of non-CO2 gases from shifting cultivation for the current period (See "Annex 1: Activity Data Report" for more details).<br>There is no country-specific biomass combustion factor which can be applied for slash and burn activities.<br>Forest fires, which are mostly uncontrolled spreading of fire from slash and burn activities, are another source of emissions of CH4 and N2O. Lao PDR currently does not have a national system to accurately monitor forest fires and its affected areas, and it is also a challenge to distinguish whether the fires are anthropogenic or naturally caused.<br>For the above reasons, non-CO2 gases (CH4 and N2O) are excluded from the FREL/FRL. Exclusion of CH4 and N2O is considered to be conservative.<br>However, Lao PDR considers accounting of non-CO2 gases (CH4 and N2O) as one area for technical improvement into the future. |

### 3.4. Scale

The scale of Lao PDR's FREL/FRL is national.

Lao PDR developed the FTMs for years 2000, 2005, 2010 and 2015, of which the FTMs for 2005, 2010 and 2015 are used for deriving the Activity Data (AD) for the current FREL/FRL. Lao PDR also conducted the 2nd National Forest Inventory (NFI) during 2015-2017, which provides biomass stock data for the forest classes measured, and used for estimating the Emissions/Removal Factors. These two national level data are considered sufficient to develop the FREL/FRL for the national scale.

### 3.5. Reference period

The reference period of the FREL/FRL is 10 years, with 2005 as the start-date and 2015 as the end-date[5].

The reason for the selection of 2015 as the end-date is because the latest available FTM used for the development of the AD is for the year 2015, and there is no alternative data available. On the other hand, the reason for the selection of 2005 as the start-date is due to the availability of reliable dataset

[5] In fact, the FTM 2005 used the satellite imagery taken in 2004-2005 dry season, and the FTM 2015 used that of 2014-2015 dry season which result in the 10 years period of the FREL/FRL. The future MRV is also thought to follow the same theory, meaning that satellite imagery of year (X) to (X+1) dry season will be regarded as the FTM of year X+1.

which covers the entire national territory. Some background in arriving at this decision is presented below:

1) FTMs have been developed at a frequency of 5 years for a number of reasons: a) based on considerations in the early stages of REDD+ readiness, the Government initiated the development of FTMs in 2010; b) Government's intention is to carry out NFIs every 5 years, and a corresponding interval for FTMs was considered appropriate to cross-reference; c) as large part of Lao PDR's landscape is shifting cultivation, a 5-year interval was deemed as the maximum interval to capture resulting land/forest use changes. As a result, FTMs for years 2000, 2005, 2010 and 2015 are the official national-level maps only available as for now.
2) By using the FTM 2010 as the benchmark map, the FTM 2000, 2005 and 2015 were developed through change detection method. As shown in the table below, there is a concern on the adequacy of using the FTM 2000 due to the significant difference in the resolution of satellite imagery used. There is a relatively high possibility of uncertainty due to the accumulated errors originating from change detection (overlaying 2010 – 2005 imagery to develop the FTM 2005, and then 2005-2000 imagery to develop the FTM 2000).
3) As the FREL/FRL for the FCFP-CF Emissions Reduction Program intends to select 2005-2015 for its reference period, selecting the same reference period for the national FREL/FRL will help to maintain consistency between the two.

**Table 7: Resolution of the satellite imagery used for the FTM development**

| Year | 2000 | 2005 | 2010 and 2015 |
|---|---|---|---|
| Satellite Image | Landsat 5 | SPOT4/5 MS | RapidEye |
| Resolution | 30m | 10m | 5m |

# 4. CONSTRUCTION OF THE FREL/FRL

## 4.1. Method of construction

### 4.1.1. National circumstances and adjustments

According to Decision 12/CP.17 II. Paragraph 9, countries can submit information and rationale on the development of FREL/FRLs, including details of national circumstances and if adjusted include details on how the national circumstances were considered.

Notwithstanding, Lao PDR does not wish to adjust its FREL/FRL.

### 4.1.2. General methodologies

Considering the available nationally-derived data, Lao PDR applies the stock-difference method[6] in calculating the average annual historical emissions over the Reference Period, except for the emissions from selective logging (see Section 4.2.3).

The annual average of carbon stock change is calculated with the following formula:

**EQUATION 2.5**
**CARBON STOCK CHANGE IN A GIVEN POOL AS AN ANNUAL AVERAGE DIFFERENCE BETWEEN ESTIMATES AT TWO POINTS IN TIME (STOCK-DIFFERENCE METHOD)**

$$\Delta C = \frac{(C_{t_2} - C_{t_1})}{(t_2 - t_1)}$$

(2006 IPCC Guideline, Volume 4, Chapter 2)

Where
$\Delta C$ = annual carbon stock change in the pool, (tC/yr)
Ct1 = carbon stock in the pool at time t1 (tC)
Ct2 = carbon stock in the pool at time t2 (tC)

Reflecting the dynamic nature of land-use change in Lao PDR, and also to adequately monitor the future impacts of REDD+ implementation, Lao PDR considers it more appropriate to present historical emissions and removals separately per each source and sink activity. Accordingly, the four sources and sinks (i.e. emissions from deforestation and degradation, and removals from restoration and reforestation) are estimated by calculating the changes in biomass caused by the shift from one land/forest strata to another, following the equation given in the IPCC Guideline 2006:

**EQUATION 2.16**
**INITIAL CHANGE IN BIOMASS CARBON STOCKS ON LAND CONVERTED TO ANOTHER LAND CATEGORY**

$$\Delta C_{CONVERSION} = \sum_i \{(B_{AFTER_i} - B_{BEFORE_i}) \bullet \Delta A_{TO\_OTHERS_i}\} \bullet CF$$

(2006 IPCC Guidelines, Volume 4, Chapter 2)

[6] Noting that, as Lao PDR, so far, has only one set of forest biomass data which is from the 2nd NFI data (and others from IPCC, neighbouring countries, etc.), the calculation only uses ‘t1’ value. A true stock-difference method will become applicable only after the 3rd NFI is conducted. The reason for not using the 1st NFI data is explained in the “Annex 2: Emission/Removal Factors Report” attached to the submission.

Where:
$\Delta C_{CONVERSION}$ = initial change in biomass carbon stocks on land converted to another land category, tonnes C
$B_{AFTERi}$ = biomass stocks on land type i after the conversion, tonnes d.m. ha-1
$B_{BEFOREi}$ = biomass stocks on land type i before the conversion, tonnes d.m. ha-1
$\Delta A_{TO\_OTHERSi}$ = area of land use i converted to another land-use category, ha
CF = carbon fraction of dry matter, tonnes C (tonnes d.m.)-1
i = type of land use converted to another land-use category

The formula for estimation of Emission and Removal factors (E/R factors) for each combination of change among the five forest/land strata is as follows:

$EF\ or\ RF_{ij}\ (tCO2e/ha) = (C_i - C_j) \times 44/12$

Where:
*EF or RFij* is Emission Factor or Removal Factor when the change incurred from forest/land strata *i* to forest/land strata *j*.
*Ci* and *Cj* is carbon stock per ha of forest/land strata *i* and *j* corresponding to the changes;
If $C_i > C_j$, such change is considered emissions;
If $C_i < C_j$, such change is considered removals.

### 4.2. Historical data used for the construction of the FREL/FRL

#### 4.2.1. Activity Data[7]

In Lao PDR, the FTMs were developed for the national level for years 2005, 2010 and 2015[8]. Importantly, FTMs are developed applying the 'Level 2' of land/forest classification system, and then further stratified into the five land/forest strata. The satellite imagery used for creating FTM 2005, 2010 and 2015 are summarized in Table 8 below. The mapping scale was decided to be 1/100,000, and the minimum mapping unit of 0.5ha was consistently used for developing the FTMs.

**Table 8: Details of the satellite imagery used for the development of Forest Type Maps**

| Name | SPOT4 / 5 MS | RapidEye | RapidEye |
|---|---|---|---|
| Year | 2005 | 2010 | 2015 |
| Observation term | From Oct. 2004 to Apr. 2006 | From Nov. 2010 to Mar. 2011 for FTM 2010 | From Nov. 2014 to Feb. 2015 for FTM 2015 |
| Number of scenes | 114 | 146 | 94 |
| Resolution | 10m | 5m | 5m |
| Bands | Band1: Green | Band1: Blue | Band1: Blue |

[7] The detailed process of the development of AD is described in "Annex 1: Activity Data Report" attached to the submission.

[8] As Lao PDR selected 2005-2015 as the reference period, the FTM 2000 is not used for the FREL/FRL, thus not explained here.

| | | | |
|---|---|---|---|
| | Band2: Red<br>Band3: NIR<br>Band4: SWIR | Band2: Green<br>Band3: Red<br>Band4: Rededge<br>Band5: NIR | Band2: Green<br>Band3: Red<br>Band4: Rededge<br>Band5: NIR |

The general process for the development of FTM 2005, 2010 and 2015 is described in Figure 2. In order to secure time-series consistency among the maps of different years, and also taking into account costs and map quality, first, FTM 2010 was developed as the benchmark map. Next, the satellite imagery of year 2010 was compared with the satellite imagery of years 2005 and 2015 respectively to extract the changes over the two respective periods (i.e. change detection). Then, the changed areas were overlaid with the FTM 2010 to develop FTM 2005 and 2015.

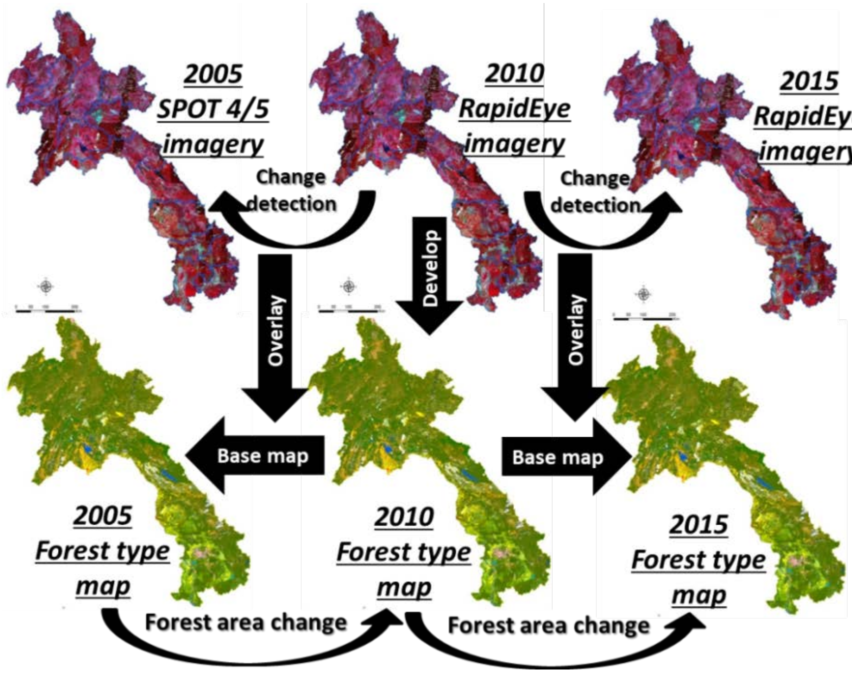


**Figure 2: Outline workflow of developing the Forest Type Maps**

From the draft FTMs developed, initial Forest Change Maps for the period of 2005-2010 and 2010-2015 were generated to conduct initial analysis of forest change and identify illogical changes. Through this diagnostic check, all of these areas were double-checked and corrected.

Then, the initial FTMs with Level 2 classification were stratified into five strata as the areas for each year shown in Table 9, and overlaid to create a second Forest Cover Change Maps and Forest Cover Change Matrices to estimate the AD. The final AD based on the stratification for the period 2005-2010 and 2010-2015 are shown in Table 10 and Table 11 below.

**Table 9: Area by five land/forest strata**

Unit: ha, percentage

| | 2015 | % | 2010 | % | 2005 | % |
|---|---|---|---|---|---|---|
| **Stratum 1** | 2,605,557 | 11.3% | 2,613,226 | 11.3% | 2,618,169 | 11.4% |
| **Stratum 2** | 9,437,688 | 40.9% | 9,721,635 | 42.2% | 9,961,368 | 43.2% |
| **Stratum 3** | 1,188,198 | 5.2% | 1,215,712 | 5.3% | 1,272,006 | 5.5% |
| **Stratum 4** | 6,300,445 | 27.3% | 6,042,075 | 26.2% | 6,183,370 | 26.8% |
| **Stratum 5** | 3,522,370 | 15.3% | 3,461,610 | 15.0% | 3,019,344 | 13.1% |
| **Total** | 23,054,258 | 100% | 23,054,258 | 100% | 23,054,258 | 100% |

**Table 10: Activity data after stratification 2005 – 2010**

Unit: ha

| | | 2010 | | | | |
|---|---|---|---|---|---|---|
| | | Stratum 1 | Stratum 2 | Stratum 3 | Stratum 4 | Stratum 5 |
| 2005 | Stratum 1 | 2,612,407 | 1,827 | 0 | 1,076 | 2,859 |
| | Stratum 2 | 773 | 9,635,593 | 0 | 216,717 | 108,284 |
| | Stratum 3 | 0 | 32 | 1,214,850 | 23,270 | 33,855 |
| | Stratum 4 | 46 | 84,183 | 862 | 5,523,929 | 574,350 |
| | Stratum 5 | 0 | 0 | 0 | 277,082 | 2,742,262 |
| | | | | | Total | 23,054,258 |

Deforestation

Degradation

Restoration

Reforestation

No Change

**Table 11: Activity data after stratification 2010 – 2015**

Unit: ha

| | | 2015 | | | | |
|---|---|---|---|---|---|---|
| | | Stratum 1 | Stratum 2 | Stratum 3 | Stratum 4 | Stratum 5 |
| 2010 | Stratum 1 | 2,605,557 | 355 | 13 | 873 | 6,429 |
| | Stratum 2 | 0 | 9,330,042 | 313 | 279,672 | 111,608 |
| | Stratum 3 | 0 | 10 | 1,187,781 | 15,778 | 12,143 |
| | Stratum 4 | 0 | 107,280 | 91 | 5,744,502 | 190,201 |
| | Stratum 5 | 0 | 0 | 0 | 259,621 | 3,201,989 |
| | | | | | Total | 23,054,258 |

Deforestation

Degradation

Restoration

Reforestation

No Change

### 4.2.2. Emission and Removal Factors[9]

The Emission and Removal factors (E/R factors) are developed for each type of land/forest cover change, stratified into five land/forest strata, and by taking the difference in carbon stock of each land/forest strata.

The sources of E/R factors consists of a combination of national dataset, and other data from Vietnam and IPCC defaults which are regarded as the best available options. The source of data are as follows;

**Five forest classes subject to the 2nd NFI (EG, MD, DD, CF and MCB)**

For strata 1 (EG), 2 (MD, CF, MCV) and 3 (DD), measurement data from the 2nd NFI is used.
The 2nd NFI was conducted in the dry seasons of 2015-2016 and 2016-2017, and a total of 559 survey plots were distributed across these strata through systematic-random-sampling.

Country-specific allometric equations were developed and applied for the three major Level 2 forest classes (EG, MD and DD). For the other two forest classes (CF and MCB) the allometric equations developed in Vietnam were used.

The BGB is estimated using the root-shoot ratio derived from the IPCC Guideline 2006 Volume 4 Chapter 4 Table 4.4. (0.2 for AGB < 125, and 0.24 for AGB > 125).

Biomass is converted to carbon stock by using the carbon fraction (CF= 0.46 or 0.47 depending on the land/forest class) derived from the IPCC Guideline 2006, Volume 4, Chapter 4, Table 4.3.

**Regenerating Vegetation (RV)**

Carbon stock of RV is estimated based on the results from the "RV survey"[10]. As RV occurs most prominently in northern Laos, survey sites were distributed in three provinces in the northern region, one province in the central region and one province in the southern region. A total of 120 survey plots (40 survey clusters with three survey plots each) were distributed and the measurement of DBH for trees, and measurement of the biomass weight for the understories were conducted.

**Bamboo (B)**

The E/R factors of the Northern Central Coast region of Vietnam is used.

**Plantations (P)**

Carbon stocks were derived from default factors of the IPCC database.

**Other land/forest classes**

The carbon stocks of remaining land/forest classes are derived mostly from IPCC Guideline 2006.

As the FREL/FRL is calculated based on the changes among the five land/forest strata, the average carbon stock for the strata was calculated by using weighted values as follows:

---

[9] The detailed process of the development of E/R factors is described in "Annex 2: Emission/Removal Factors" attached to the submission.

[10] DOF, et al. (2017). Development of a Lao-specific Equation for the Estimation of Biomass of 'Regenerating Vegetation' and Determination of the Threshold Years for its Regeneration into Forest. <http://dof.maf.gov.la/en/home/>

$$Cstrata\ (tC/ha) = (C1*A1+ C2*A2+....+Cn*An)/(A1+A2+....+An)$$

Where:

*Cstrata* = average carbon stock (tC/ha) of strata calculated from carbon stock and area of land/forest class;

*Ci* = carbon stock of land/forest class (tC/ha);

*Ai* = area (ha) of land/forest class in 2015.

The following table shows the resulting carbon stock of the five strata.

**Table 12: Carbon stock of the five strata**

| Strata | tC/ha |
|---|---|
| **Stratum 1 (EG)** | 200.0 |
| **Stratum 2 (MD, CF, MCB)** | 88.1 |
| **Stratum 3 (DD)** | 43.2 |
| **Stratum 4 (P, B, RV)** | 17.9 |
| **Stratum 5 (NF)** | 4.9 |

By taking the difference in average carbon stock of each land/forest strata the E/R factors are derived as shown in the table below.

**Table 13: Emissions/Removals Factors for changes (tCO2e)**

| | Stratum 1 (EG) | Stratum 2 (MD, CF, MCB) | Stratum 3 (DD) | Stratum 4 (P, B, RV) | Stratum 5 (NF) |
|---|---|---|---|---|---|
| **Stratum 1 (EG)** | | -410.5 | -575.1 | -667.6 | -715.4 |
| **Stratum 2 (MD, CF, MCB)** | 410.5 | | -164.6 | -257.1 | -304.9 |
| **Stratum 3 (DD)** | 575.1 | 164.6 | | -92.6 | -140.3 |
| **Stratum 4 (P, B, RV)** | 667.6 | 257.1 | 92.6 | | -47.8 |
| **Stratum 5 (NF)** | 715.4 | 304.9 | 140.3 | 47.8 | |

### 4.2.3. Supplementary analysis of the impact of selective logging

Unsustainable selective logging, both legal and illegal, is considered as a major driver of forest degradation. Emissions from such selective logging in addition to degradation accounted for through the Forest Cover Change Matrix (Section 4.2.1), predominately associated with rotational agriculture, could make forest degradation a significant source of emission for Lao PDR. Moreover, considering the Government's strong commitment to tackle illegal logging, the FREL/FRL attempts to explore methods to quantify historical emissions caused by selective logging.

The remote sensing technology currently applied in Lao PDR's forestry sector does not allow reasonable assessment of the historical biomass loss caused by selective logging. Other information sources, such as the government statistics related to logging, UN-COMTRADE statistics on timber export and published literature were reviewed, however they were found to be insufficient to provide reasonable estimates.

On the other hand, the 2nd NFI recorded the diameter and height of tree stumps observed in the measurement plots. By using this data the FREL/FRL attempts to estimate the historical emissions caused by selective logging through the following steps:

In the 2nd NFI, tree stumps are measured in all plots when observed.

For stumps, five parameters were measured:

1. Height (H) - below 1.3m
2. Smallest Diameter ($D_1$) – the smallest diameter across the top of the stump
3. $D_2$ – the diameter at a 90° angle to $D_1$.
4. Locational information (Latitude / Longitude)
5. Instrument used for tree felling (e.g. machine, saw axe)

Procedure for biomass loss estimation:

1. Calculate average diameter D from D 1 and D 2 for each stump
2. Exclude stumps that were not felled by "machine" or "saw axe" (to exclude incidents of natural disturbances)
3. Estimate the DBH from the diameter at the base and height by using the following equation developed in Cambodia[11] :

$$DBH=D-(-C1 \ln (H+1.0)-C1 \ln (2.3))$$

Where:

D=Average Diameter of stump, H=Height of stump,

$\ln (|C1|)=d0+d1*D+d2*H+d3*D*H$

d0=1.68, d1=0.0146, d2=-0.82, d3=0.0068

5. Estimate the AGB by using the allometric equation used in the 2nd NFI
6. Convert the AGB loss by using an area ratio (t/ha)
7. Sum up the AGB loss by sub-plot (one survey plot consists of four sub-plots)
8. Estimate plot average AGB loss (t/ha) by dividing the sum of AGB loss above by four (including non- stump plot)
9. Estimate average AGB loss(t/ha) for each forest class by dividing the total number of plot of each forest class
10. Estimate BGB loss by using default conversion factor found in the IPCC 2006 Guideline
11. Convert biomass to CO2 with the same conversion factor for estimating the carbon stock
12. Estimate total loss tCO2e by multiplying above value by the area of FTM 2015 for each forest class.

[11] Ito et al., 2010. Estimate Diameter at Breast Height from Measurements of Illegally Logged Stumps in Cambodian Lowland Dry Evergreen Forest. JARQ 44(4),440

The above method allows an estimation of the biomass loss (and thereby, the emissions) from selective logging. However, it does not give information on when the trees were actually felled, which is essential for accounting the results in the FREL/FRL.

An equation which allows the estimation of years required for wood materials to decompose from the experimental study in Pasoh in the Malaysian Peninsula[12] was referenced. Figure 3 below shows the change of relative value of material weight under different temperatures (Table 14) and climate conditions (e.g. precipitation) which is considered to be reasonably similar to that of Lao PDR.

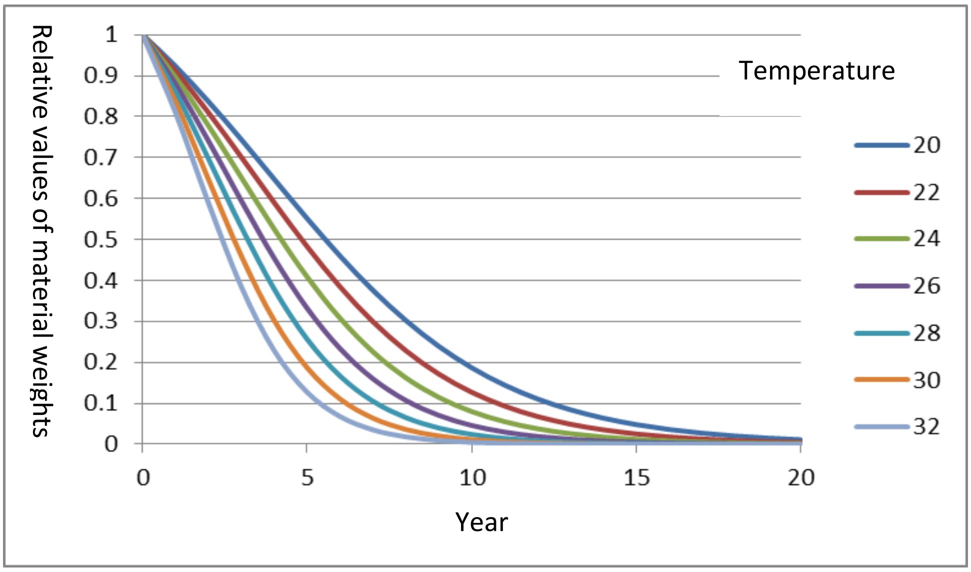


**Figure 3: Relative values of material weights over years**

**Table 14: Loss of material weights over years based on temperature**

| Temperature (°C) | 20 | 22 | **24** | **26** | 28 | 30 | 32 |
|---|---|---|---|---|---|---|---|
| 50% loss(year) | 5.6 | 4.8 | **4.2** | **3.7** | 3.2 | 2.8 | 2.4 |
| 95% loss(year) | 14.9 | 13.0 | **11.3** | **9.8** | 8.5 | 7.4 | 6.5 |

As in the following Table 15, the average temperature of Lao PDR is 26.9 °C. Assuming a cooler temperature of 24-26 °C in the forest, 3.7-4.2 years are required for 50% loss (decomposition) of a stump and 9.8 -11.3 years for 95% loss. Accordingly, it is considered reasonable to assume that the stumps observed and recorded in the 2nd NFI were felled within 12 years before its field survey (implemented in dry season of 2015-2016 and 2016-2017).

[12] Yoneda et al., 2016. Inter-annual variations of net ecosystem productivity of a primeval tropical forest basing on a biometric method with a long-term data in Pasoh, Peninsular Malaysia. TROPICS Vol. 25 (1) 1-12

**Table 15: Temperature and precipitation in Lao PDR (2014) [13] and Pasoh (study site)**

| | Temperature | Precipitation |
|---|---|---|
| | °C | mm/Y |
| Luang Prabang | 26.6 | 1469 |
| Vientiane capital | 27.0 | 1349 |
| Savannakhet | 26.5 | 1461 |
| Champasack | 27.3 | 2416 |
| *Average* | ***26.9*** | *1674* |
| Pasoh* | 25.5 | 1724.4 |

*Recorded in the forest

### 4.3. Calculation of the FREL/FRL

#### 4.3.1. Emission and removals calculated based on changes among land/forest strata

Based on the calculation method explained in Section 4.1, average annual historical emissions and removals based on the changes among land/forest strata over the reference period of 2005-2015 are described in the following table.

**Table 16: Historical Emissions and Removals – based on changes among land/forest strata**

| Source/Sink | Emissions(+)/ Removals(-) | | |
|---|---|---|---|
| | 2005-2010 (tCO2e) | 2010-2015 (tCO2e) | Annual average for 2005-2010 (tCO2e/year) |
| **Deforestation** | 67,242,736 | 49,414,340 | 11,665,708 |
| **Forest Degradation** | 59,341,473 | 74,152,505 | 13,349,398 |
| **Reforestation** | -13,235,181 | -12,401,104 | -2,563,628 |
| **Restoration** | -22,076,581 | -27,592,491 | -4,966,907 |
| **Total Emissions** | 126,584,209 | 123,566,845 | 25,015,105 |
| **Total Removals** | -35,311,762 | -39,993,595 | -7,530,536 |

#### 4.3.2. Emissions from selective logging (degradation)

As explained in Section 4.2.3, the 2nd NFI recorded the tree stumps of the trees felled by human activities. The biomass of the felled trees were estimated from the measured size of each tree stump, aggregated for each of the five forest class (i.e. EG, MD, DD, CF, CF) in order to estimate the average loss of carbon stock, and converted to tCO2e. Then, the results were multiplied with the area of each

[13] Lao Statistics Bureau (http://www.lsb.gov.la/en/Meteorology14.php)

forest class calculated from the FTM 2015, to estimate the assumed emissions from such logging events as shown in Table 17 below.

**Table 17: Estimated total emissions from selective logging**

| | Average loss (tCO2e/ha) | StD | Area from FTM 2015 (ha) | tCO2e/12 year |
|---|---|---|---|---|
| EG: Evergreen Forest | 17.8 | 39.3 | 2,605,557 | 46,353,989 |
| MD: Mixed Deciduous Forest | 4.8 | 11.3 | 9,205,036 | 44,531,308 |
| DD: Dry Dipterocarp | 14.3 | 18.3 | 1,188,198 | 16,995,658 |
| CF: Conifer Forest | 2.7 | 9.7 | 124,772 | 336,245 |
| MCB: Mixed Conifer and Broadleaved forest | 18.8 | 37.7 | 107,880 | 2,024,360 |
| Total | | | | **110,241,559** |
| Annual average (tCO2e) (Total divided by 12 years)* | | | | **9,186,797** |

### 4.3.3. Results of calculation

The FREL/FRL for Lao PDR is an aggregation of the historical emissions and removals calculated based on land/forest strata as explained in Section 4.3.1, and the emissions from selective logging as explained in Section 4.3.2.

However, if the latter is simply added to the former, the problem of double-counting of emissions occurs.

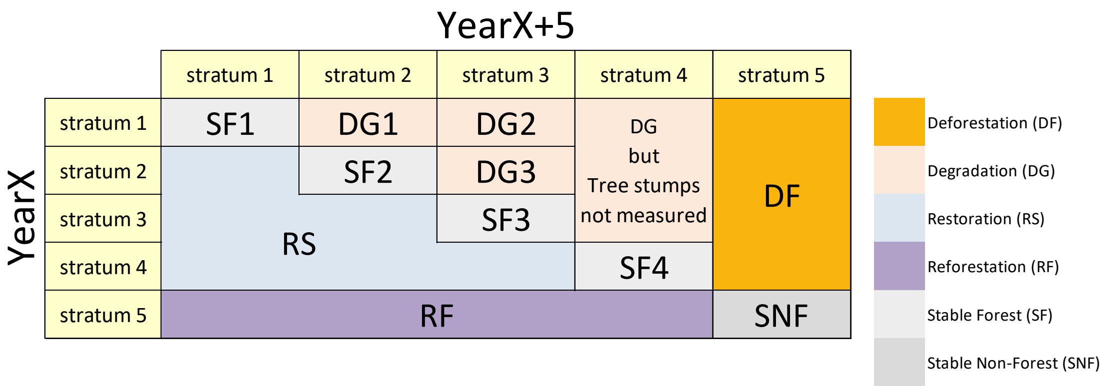


**Figure 4: Annotated change matrix among land/forest strata for addressing double-counting in degradation**

As in Figure 4, emissions from forest degradation estimated through the stratified FTMs are represented in DG1, DG2 and DG3 (note that tree stumps were not measured in Stratum 4). Forest degradation occurring within a single forest strata, are represented in SF1, SF2, SF3 (and SF4); these are not accounted for in the FREL/FRL (c.f. footnote 3 under Section 3.1).

In Strata 1, 2 and 3 (therefore, DG1, DG2, DG3, and SF1, SF2, SF3), tree stumps were measured during the 2nd NFI. Using these measurements, emissions from selective logging were estimated.

As a result, in DG1, DG2 and DG3, emissions from the Forest Cover Change Matrix and from selective logging are both represented, and parts of such emissions are assumed to be overlapping (i.e. double-counted). To avoid such double counting, either one of the forest degradation sources should be deducted from the estimation. Considering that the emissions from selective logging cannot be accurately associated with the Forest Cover Change Matrix[14], the option to deduct the emissions from the Forest Cover Change Matrix in DG1, DG2, and DG3, is selected. The following steps of estimations are applied (noting that figures have been rounded to the nearest whole number):

a. The emissions from forest degradation based on changes among land/forest strata (i.e. DG1 + DG2 + DG3 + DG) = 13,349,398 tCO2e/year.
b. The emissions from forest degradation based on changes among land/forest strata within the stratum (i.e. DG1 + DG2 + DG3) = 95,471 tCO2e/year.
c. The emissions from selective logging (included in SF1, SF2, SF3, DG1, DG2, DG3) = 9,186,797 tCO2e/year.

The total emissions from forest degradation is therefore 22,440,723 tCO2e/year
(13,349,398 (a) - 95,471 (b)) + 9,186,797 (c) = 22,440,723 tCO2e/year

As the result, the emissions and removals for the period 2005-2010 and 2010-2015 per sources and sinks, and its total over the entire reference period (2005-2015) is as summarized in Table 18 below.

**Table 18: Average Annual Historical Emissions and Removals over the Reference period**

| Source/Sink | Emissions(+)/ Removals(-) | | |
|---|---|---|---|
| | 2005-2010 (tCO2e) | 2010-2015 (tCO2e) | Annual average for 2005-2015 (tCO2e/year) |
| **Deforestation** | 67,242,736 | 49,414,340 | 11,665,708 |
| **Forest Degradation** | 104,525,310 | 119,881,923 | 22,440,723 |
| **Changes among land/forest strata** | 58,591,327 | 73,947,940 | 13,253,927 |
| **Selective logging** | 45,933,983 | 45,933,983 | 9,186,797 |
| **Reforestation** | -13,235,181 | -12,401,104 | -2,563,628 |
| **Restoration** | -22,076,581 | -27,592,491 | -4,966,907 |
| **Total Emissions** | 171,768,046 | 169,296,264 | 34,106,431 |
| **Total Removals** | -35,311,762 | -39,993,595 | -7,530,536 |

[14] The timing of the felling of the tree stump cannot be accurately determined, making the association with the Forest Cover Change Matrix a challenge.

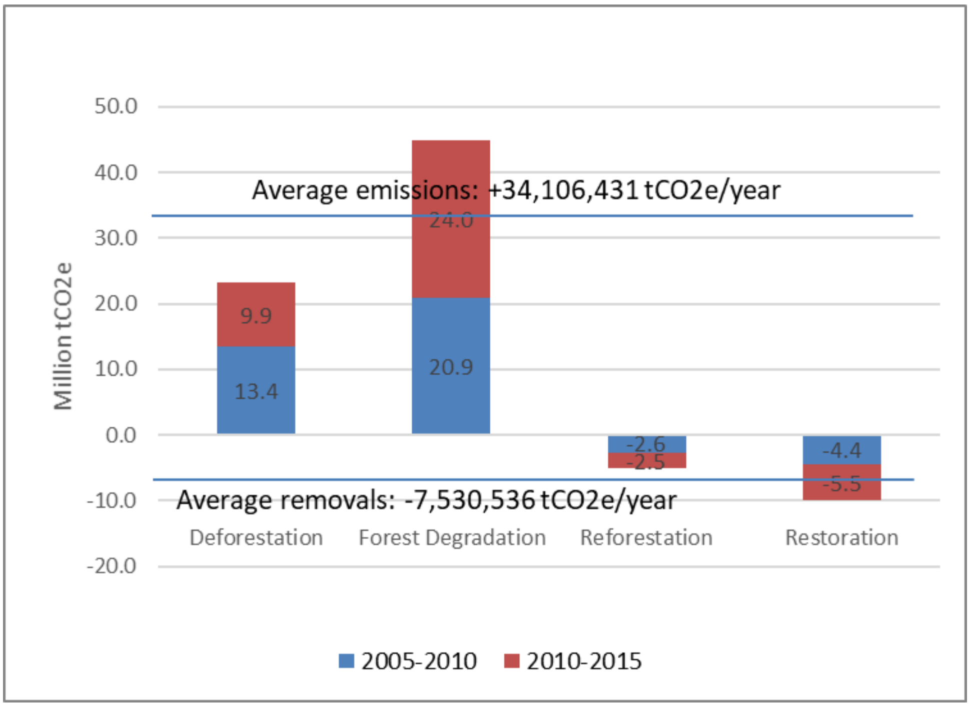


Figure 5: Historical emissions and removals in Lao PDR

In conclusion, the FREL/FRL for Lao PDR is 34,106,431 tCO2e/year for the emissions and 7,530,536 tCO2e/year for the removals as shown in Table 19.

**Table 19: Proposed reference emissions and removals for Lao PDR (2005-2015)**

| Emissions/Removals | tCO2e/year |
|---|---|
| Average historical emissions | +34,106,431 |
| Average historical removals | -7,530,536 |

### 4.3.4. Transparency and data necessary for the reconstruction of FREL/FRL

Lao PDR is in the process of developing its National Forest Monitoring System (NFMS) including the database system and web-based portal.

For the development of a database system which enables automated estimation of forest carbon stocks and its changes over time, this will be done through developing functions to:

1. Archive, calculate and output the AD
2. Archive, calculate and output the E/R factors
3. Calculate, evaluate and output the forest carbon stocks and its changes, and convert to tCO2e.

The advantage of such system is that it will unify all the existing official data used for the emissions and removals into one single database, reduce costs by means of automating, avoid the risks of human errors in the entire estimation process, and ensure transparency of the estimation methods and results. Moreover, overlaying such information with the administrative boundary data, forest category data, and other forestry-related data will allow the data users to analyse forests according to their interest.

| Data related to AD | Data type |
|---|---|
| FTM 2000, 2005, 2010, 2015 | Raster data |
| Forest cover change map 2000-2005, 2005-2010, 2010-2015 | Raster data<br>(partly vector data) |
| Satellite imagery used for the development of FTMs<br>Landsat (2000), SPOT4, 5 MS(2005), RapidEye (2010, 2015)<br>(both false colour and true colour) | Raster data |
| **Data related to E/R factors** | **Data type** |
| 1st NFI data | Tabular data |
| 2nd NFI data | Tabular data |
| **Other data** | **Data type** |
| Administrative area: national, province, district | Vector data |
| Forest category: Production Forest, Protection Forest, Conservation Forest | Vector data |
| **Reports** | **Data storage** |
| FREL/FRL Report to the UNFCCC including annexes | To be made available in UNFCCC website |
| 1st National Communication to the UNFCCC | Available in UNFCCC website |
| 2nd National Communication to the UNFCCC | |

The NFMS portal will enable access through internet [15] with differentiated access levels corresponding to the access permission level granted.

[15] At the time of this submission, the DOF is preparing the URL of the NFMS portal which shall complete in early 2018.

# 5. ISSUES FOR FUTURE FREL/FRL AND MRV

Lao PDR has identified the areas for future improvement on its FREL/FRL and MRV as follows:

**1) Areas for future improvements related to the Activity Data**

- Improvement of classification between RV and MD

Under FTMs with the Level 2 classification, distinguishing RV and MD is a challenge, especially when the land is under continuous phases of regeneration. The remote sensing team tried using ancillary data, such as the threshold year for RV to regenerate into MD. For the future forest mapping, Lao PDR will attempt to explore methods to fine-tune the classification in order to enable further analysis of land/forest cover change over time.

- Updating FTM 2015 map and FTMs

Distinguishing UC and OA is also a challenge, as they have very similar texture on satellite imagery. Therefore, in the current mapping method, continuous interpretation of a land as UC over the two time periods was determined as permanent agricultural land and the classification of the latter year was revised to OA class. In the future, Lao PDR may explore using options, such as the technologies to analyze 'big data', multi-temporal satellite dataset available, and GIS data from different sources (e.g. land concession data), which meet its needs.

- Further capacity building of the remote sensing, GIS and IT engineers

Under rapid innovation of remote sensing, GIS and IT technologies, demand for sufficient number of competent engineers/team is increasing. The skills and knowledge of the skilled senior engineers need to systematically be passed on to the younger generation, and there is also an emerging need for IT engineers who can manage and operate database systems which handle a large and diverse range of digital data.

**2) Areas for future improvements related to the Emission/Removal Factors**

- Carbon stock of RV

The carbon stock of RV was measured separately from the 2nd NFI and calculated from the average carbon stock of different years, therefore, there is a limitation in the representativeness of data which resulted in relatively high uncertainty. The measurement did not include DW. The future NFI could incorporate the measurement of carbon stock of RV, including DW, in its design.

- Continuous improvement of E/R factors

Default values from the IPCC Guidelines were used to estimate carbon stock for some of the land/forest classes where country-specific data do not exist. Also, allometric equations for minor forest classes applied ones from neighboring country (i.e. Vietnam). Having improved set of country-specific carbon stock data and allometric equation shall contribute to reducing the uncertainty of E/R factors.

**3) Others**

- Inclusion of non-CO2 gases emission from shifting cultivation and forest fire

Shifting cultivation is an important source of emission in Lao PDR. Although quantification of such emission was tested during the FREL/FRL construction process, due to the lack of reliable data (AD and E/R factors including specific combustion factor for shifting cultivation), non-CO2 gas emission from shifting cultivation and consequent uncontrolled spreading of fire are not accounted in the current FREL/FRL. Although exclusion of such non-CO2 gases (mostly CH4 and N2O) are considered as conservative, Lao PDR will consider this as one area for technical improvement in the future.

- Inclusion of dead wood (DW) as a carbon pool

The 2nd NFI measured DW for the five natural forest classes (i.e. EG, MD, CF, DD and MCB) which accounts for approximately 60% of the forest land (including RV), but not for the RV class. Therefore, the data on DW is considered incomplete, and partial inclusion of DW may result in inconsistent estimation and causing possibility of overestimation. Although exclusion of DW is considered as conservative, Lao PDR will consider this as one area for technical improvement in the future.

- Measurement of emissions from forest degradation by selective logging

As emissions from forest degradation by selective logging is difficult to measure in the current remote sensing capacity of Lao PDR, alternative approach (i.e. estimate the emissions from the tree stumps recorded in the 2nd NFI) was applied. For maintaining consistency between the FREL/FRL and MRV, repetition of the same survey is needed. However, depending on the frequency of future measurements and reporting, repetition of the same survey may not be the most sustainable option. There are some initiatives in the country to measure emissions from forest degradation by selective logging through advanced remote sensing techniques. If such options prove reasonable, Lao PDR would consider adopting such options.

- Avoidance of double-counting of emissions and removals with other GHG mitigation initiatives

Currently, two GHG mitigation initiatives are registered under the Verified Carbon Standard (VCS)[16] and being implemented in the country:

- VCS Project ID 1684 "Mitigation of GHG: Rubber based agro-forestry system for sustainable development and poverty reduction in Pakkading, Bolikhamsay Province": a project to develop rubber plantation in Bolikhamsay province. The project has an area of 969.20ha, which expects to sequestrate approximately 1,107,495 tCO2e during its 30 year project period from 2008-2037 (36,916 tCO2e/year), and;
- VCS Project ID 1398 "Reducing Emissions from Deforestation and Carbon Enhancement in Xe Pian National Protected Area": a project to provide sustainable long-term finance for an effective management of the Xe Pian National Protected Area (NPA) in Champasack province, in order to avoid deforestation and enhance carbon stocks. The Project Area presents an extent equal to 141,963 ha of the Xe Pian NPA, however, excluding the core parts of the NPA equivalent to 51,892 ha, which expects to sequestrate approximately 5,735,413 tCO2e during its 30 year project period of 2014-2043 (64,981 tCO2e/year).

These activities will be tracked and recorded in a registry (to be developed), which will be part of the national forest monitoring system (NFMS) linking to the geo-spatial database.

[16] http://www.v-c-s.org/

# Lao PDR's Forest Reference Emission Level and Forest Reference Level for REDD+ Results Payment under the UNFCCC

# Annex 1

# Activity Data Report

**January 2018**

**Department of Forestry**
**Ministry of Agriculture and Forestry, Lao PDR**

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## Acronyms

| | |
|---|---|
| AD | Activity Data |
| B | Bamboo |
| CF | Coniferous Forest |
| DBH | Diameter at Breast Height |
| DD | Dry Dipterocarp Forest |
| DOF | Department of Forestry |
| EG | Evergreen Forest |
| FCPF | Forest Carbon Partnership Facility |
| FIM | Forest Information Management Project |
| FIPD | Forestry Inventory and Planning Division |
| FREL | Forest Reference Emission Level |
| FRL | Forest Reference Level |
| FTM | Forest Type Map |
| GHG | Greenhouse Gas |
| GIS | Geographic Information System |
| IPCC | Intergovernmental Panel on Climate Change |
| IT | Information Technology |
| Lao PDR | Lao People's Democratic Republic |
| M | Million (when used for expressing units) |
| MAF | Ministry of Agriculture and Forestry |
| MCB | Mixed Coniferous Broadleaved Forest |
| MD | Mixed Deciduous Forest |
| MRV | Measurement, Reporting and Verification |
| NFI | National forest Inventory |
| NFMS | National Forest Monitoring System |
| OA | Other Agriculture |
| P | Plantation |
| REDD+ | Reducing Emissions from Deforestation and forest Degradation plus the conservation of forest carbon stocks, sustainable management of forests and enhancement of forest carbon stocks |
| RV | Regenerating Vegetation |
| UC | Upland Crop |
| UNFCCC | United Nations Framework Convention on Climate Change |

# 1. OBJECTIVES

The objectives of this report is to outline the process and result regarding the production of Activity Data (AD) for the estimation of Forest Reference Emission Level/Forest Reference Level (FREL/FRL) for Lao PDR. The report describes the two main areas of work, namely:

1) Development of Forest Type Maps (FTMs) of Lao PDR for years 2005, 2010, 2015; and

2) Development of Forest Change Maps and Forest Change Matrices of 2005-2010 and 2010-2015 which will be used for the estimation of AD.

# 2. METHODOLOGY

First, the FTMs 2005, 2010, 2015 for each province in the Lao PDR were developed. Based on the FTMs, initial Forest Change Maps and Forest Change Matrices were developed. Importantly, FTMs are developed applying the 'Level 2' of land/forest classification system, and then further stratified into the five land/forest strata. The stratified FTMs are overlaid to create second Forest Cover Change Maps and Forest Cover Change Matrices to derive the AD.

**Box 1: International support related to the development of Activity Data**

The FTMs were developed by the Forest Inventory and Planning Division (FIPD) of the Department of Forestry (DOF) under the Ministry of Agriculture and Forestry (MAF), by applying a consistent classification system, and based on past and on-going technical and financial support among six different projects as listed below.

**Forest Information Management Project (FIM) (2010 - 2012)** funded by JICA supported the construction of infrastructure required for remote sensing work in FIPD/DOF, such as remote sensing hardware, remote sensing software, server, internet and LAN network. SPOT4 / 5 MS imagery for year 2005 was procured through this project, which was then used in the development of the early version of Forest Type Map (FTM) 2005; ALOS, SPOT 5, RapidEye imagery for year 2010 was procured, which was then used for the development of early version of FTM 2010. In addition, an early version of FTM 2000 was developed by using Landsat imagery.
**Forest Preservation Program (FPP) (2011 – 2015)** funded by Japan, procured the RapidEye imagery for year 2015 through cost-sharing with FCPF Readiness Project and SUFORD-SU, which was then used in the development of FTM 2015.
**Capacity Development Project for Establishing National Forest Information System for Sustainable Forest Management and REDD (NFIS) (2013 - 2015)** under JICA succeeded the FIM project and developed the FTM 2010 as the benchmark map for producing the FTM 2005 and 2000 (however, note that the reference period of the RL of Lao PDR is 2005-2015, thus does not directly employ the results under this project).
**Sustainable Forest Development – Scaling Up Phase (SUFORD-SU) (2013 - 2018)** jointly funded by Finland and the World Bank FIP, procured the RapidEye imagery for year 2015 through cost-sharing with FPP and FCPF Readiness Project, which was then used in the development of FTM 2015. The project also technically supported the forest mapping of the Production Forest Areas (the forest type which the project targets) for the FTM 2010 and FTM2015, in close collaboration with NFIS and F-REDD Project in order to maintain the consistency in entire mapping.
**Forest Carbon Partnership Facility -Readiness Project (FCPF Readiness Project) (2014 – 2017) (additional fund of USD 4.6 million and extension till 2020 committed)** funded by the World Bank, procured the RapidEye imagery for year 2015 through cost-sharing with FPP and SUFORD-SU, which was then used in the development of FTM 2015.
**Sustainable Forest Management and REDD+ Support Project (F-REDD) (2015 – 2020)** funded by JICA further revised and finalized the FTM 2010, 2005 and 2000 developed under the support of NFIS, and newly developed the FTM 2015 by using the FTM 2010 as the benchmark. Each of the FTMs was assessed in its accuracy level. Forest change matrices for 2005-2010 and 2010-2015 were developed and uncertainty of changes was assessed, which were used as the source of AD.

## 2.1 Mapping frequency

The AD was developed for two time periods: 2005-2010; and 2010-2015. Availability of official dataset which covers the Lao PDR was the ultimate reason of selecting the two time periods. Some background in arriving at this decision is presented below:

1) In the early stages of REDD+ readiness, while preparing towards submission of the Readiness Package Proposal to the FCPF, GoL consulted strategic options regarding the FREL/FRL and

how to prepare necessary data including AD. It was agreed that a national wall-to-wall map with 2010 as the benchmark and dating back with 5-year intervals (i.e. 2005, 2000) would be appropriate. This was considered reasonable also from the perspective of the year 2000 being around the time when new major trends in land-use were observed to be emerging in the country;

2) Through the FIM project (above) satellite imagery and technical support was provided to the GoL to initiate the mapping in 2010;
3) Although not yet realized, GoL's intentions to carry out the National Forest Inventory (NFI: field-based forest survey) every 5 years were expressed, thus, wall-to-wall mapping with 5-year interval was considered appropriate to cross-reference; and
4) As large part of Lao PDR's landscape is shifting cultivation, a 5-year interval was deemed as the minimum interval to capture resulting land/forest use changes.

## 2.2 Forest definition and land/forest classification system

**Forest definition**

According to the Land Law (2003) and Forestry Law (2007), forest and forest resources in Lao PDR occur in lands that are designated by the Government as forest lands, and in areas outside forest lands, and includes stocked and temporarily un-stocked forests.

Lao PDR has a national definition of forest which is used in the planning, monitoring and evaluation of forests. A summary is shown in the following Table 1. This definition is used also in the construction of the proposed FREL/FRL.

**Table 1: Forest definition of Lao PDR**

| Items | Value |
|---|---|
| **DBH** | Minimum of 10cm |
| **Crown Density** | Minimum of 20% |
| **Area** | Minimum of 0.5 ha |

This definition was used for the past two National Communications on Climate Change, and has been agreed to be used for the future national Greenhouse Gas (GHG) inventory starting with the Third National Communication which the GoL plans to submit to the UNFCCC in early 2019.

**Land/forest classification system**

The land/forest classification system of the country applies two levels of classification, including Level 1 consisting of seven classes including "Current Forest" and "Potential Forest" among others, and Level 2 which further classifies the Level 1 current forest class into six natural and plantation classes. The relation between the national land/forest classification system and the land-use category definition of the IPCC is illustrated in Table 2 below.

When Lao PDR initiated the development of its national Forest Type Maps (wall-to-wall maps of the entire territory) in the context of REDD+ around 2010, the government and the stakeholders, first, reviewed the land/forest classification system to be applied for the mapping.

**Table 2: National level classification system of Lao PDR with IPCC definition on land use categories**

| IPCC Definition | National level classification system | | |
|---|---|---|---|
| | Level 1 | Level 2 | |
| Forest Land | Current Forest | Evergreen Forest | EG |
| | | Mixed Deciduous Forest | MD |
| | | Dry Dipterocarp Forest | DD |
| | | Coniferous Forest | CF |
| | | Mixed Coniferous and Broadleaved Forest | MCB |
| | | Forest Plantation | P |
| | Potential Forest | Bamboo | B |
| | | Regenerating Vegetation | RV |
| Grassland | Other Vegetated Areas | Savannah | SA |
| | | Scrub | SR |
| | | Grassland | G |
| Cropland | Cropland | Upland Crop | UC |
| | | Rice Paddy | RP |
| | | Other Agriculture | OA |
| | | Agriculture Plantation | AP |
| Settlement | Settlement | Urban Areas | U |
| Other land | Other Land | Barren Land and Rock | BR |
| | | Other Land | O |
| Wetland | Above-ground Water Source | River (Water) | W |
| | | Wetland (Swamp) | SW |

An important point was to ensure the classification system is in harmony with the land-use category definition of the IPCC in order to maintain consistency between the REDD+ and GHG inventory while meeting national needs in a variety of applications. Another was to determine how to categorize the temporarily un-stocked forests ("regenerating vegetation: RV") and upland crop (UC) in the classification system. This reflects the unique situation of forests and forest use in the country, and in particular, the prevalence of pioneering and shifting cultivation, and presence of vast areas of forest fallow. This land-use is seen throughout the country where a significant area is covered under forest fallow stages of shifting cultivation, regenerating through natural vegetative succession and in and out of temporarily un-stocked states.

UC and RV are predominately considered to be stages of the shifting cultivation cycle, and these lands are considered to re-grow and recover through natural vegetative succession. Through intensive discussions within DOF and with stakeholders on whether to classify these under the IPCC land use category of "Forest Land" or "Cropland", it was concluded that for the purpose of REDD+, in line with the IPCC definition, to classify RV as "Forest Land" as it they are "…vegetation that currently fall below, but are expected to exceed, the threshold of forest land category." (IPCC, 2003) and classify UC as "Cropland" as they are used, even temporarily, for cropping at the time of mapping.

The GoL has been implementing actions to reduce deforestation by stabilizing shifting cultivation, and to restore of those lands into forest through various means. However, the impact has been limited, where according to the FTM analysis over the period of 2000-2015, only approximately 100,000 ha out of 2,954,443ha (in 2015) have been restored from RV to forest which exceed the threshold of the forest definition (i.e. 3-4% of the total RV area).

Lao PDR recognizes that by applying such method of classification, a piece of land not undergoing land use change, but, only temporary land cover change (i.e. short-term changes) would be subject to designation as a change event. However, Lao PDR choses to apply this method for the REDD+

FRL/FREL and MRV. The overestimation of change resulting from method of classification is consistently and symmetrically conducted for emissions and removals. For example, when a shifting cultivation landscape undergoes change from RV (forest fallow) to UC (cropping) this short-term loss is recorded; on the other hand, when the UC (cropping) is left for fallow and regenerates into RV, this removal is also recorded; meaning that overestimation of emissions is offset by overestimation of removals, so far as the rotational agricultural practice continues.

The decision for the forest definition over a more conventional forest definition which includes a height threshold is to allow for better results in the identification of land cover classes through high resolution satellite imagery (approximately 5 m resolution). By applying this definition of a minimum average stand DBH of 10cm, some land with small diameter trees which would have been classified as forest under a height threshold definition can be excluded. The other reason for the application of this forest definition is to do with trees in rice paddy landscapes in the flatland areas. In order to avoid misinterpretation of these paddy lands (which often have canopy cover of over 10%) as forests, the 20% crown density threshold has been adopted.

## 2.3 Development of the Forest Type Maps 2005, 2010 and 2015

### 2.3.1 Satellite imagery used

The satellite imagery used for the development of FTMs for years 2005, 2010 and 2015 are summarized in following Table 3.

**Table 3: Satellite images used for the development of Forest Type Maps**

| Name | SPOT4 / 5 MS | RapidEye | RapidEye |
|---|---|---|---|
| Year | 2005 | 2010 | 2015 |
| Observation term | From Oct. 2004 to Apr. 2006 | From Nov. 2010 to Mar. 2011 for FTM 2010 | From Nov. 2014 to Feb. 2015 for FTM 2015 |
| Number of scenes | 114 | 146 | 94 |
| Resolution | 10m | 5m | 5m |
| Bands | Band1: Green<br>Band2: Red<br>Band3: NIR<br>Band4: SWIR | Band1: Blue<br>Band2: Green<br>Band3: Red<br>Band4: Rededge<br>Band5: NIR | Band1: Blue<br>Band2: Green<br>Band3: Red<br>Band4: Rededge<br>Band5: NIR |

The mapping standards were determined considering various factors, such as the appropriateness of mapping scale, resolution of satellite imagery, time resources. The mapping scale was decided to be 1/100,000, and the minimum mapping unit of 0.5 ha was consistently used for developing the FTMs.

### 2.3.2 Technical process

<u>**Overview of the process**</u>

The general process for the development of FTM 2005, 2010 and 2015 is described in Figure 1. In order to secure time-series consistency among the maps of different years, and also taking into account costs and map quality, first, the FTM 2010 was developed as the benchmark map. Next, the satellite imagery of year 2010 was compared with the satellite imagery of years 2005 and 2015 respectively to extract the changes over the two respective periods (i.e. change detection). Then, the changed areas were overlaid with the FTM 2010 to develop FTM 2005 and 2015.

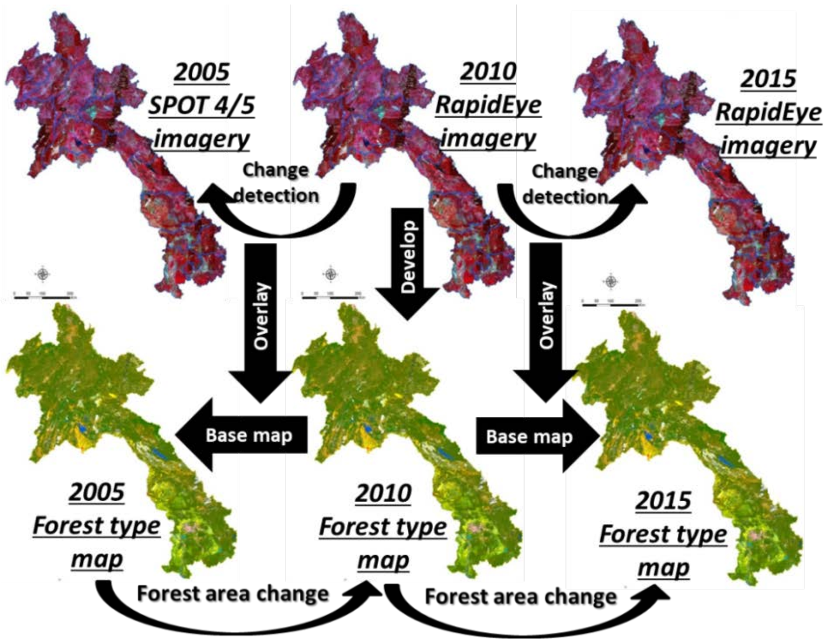


**Figure 1: Overview of the FTM development process**

For the development of FTM 2010, object-based classification was applied instead of pixel-based classification, in order to reduce the occurrence of noise ('slivers') (Figure 2). This helps to reduce 'slivers' arising when extracting the changes from two different maps (FTM 2010 and 2005; FTM 2010 and 2015), and also allows efficient 'snapping' of the polygon boundaries of other two years to the FTM 2010.

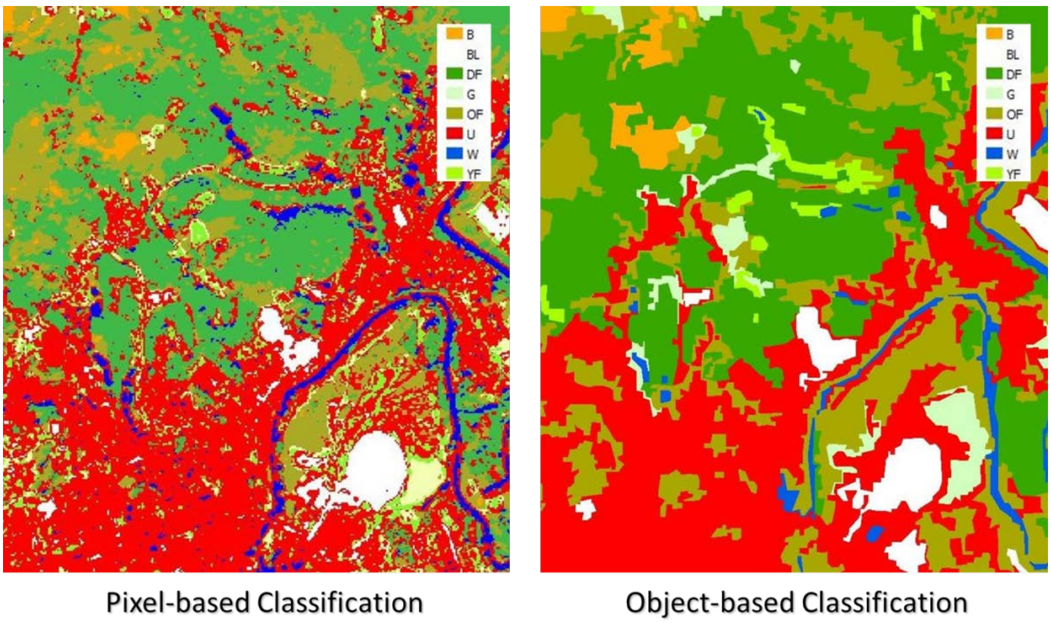


**Figure 2: Comparison of pixel-based classification and object-based classification**

**Data processing and classification**

First, each satellite imagery was pre-processed. For year 2005, SPOT4/5 MS imagery was ortho-rectified and then mosaicked. For years 2010 and 2015 where RapidEye imagery were used, absolute

position and relative position accuracy were improved by ortho-rectifying and using ground control points collected from the entire country as well as from very high resolution satellites. Afterwards they were mosaicked using the same methods with the year 2005 SPOT4/5 MS imagery.
Normalized Difference Vegetation Index (NDVI) was created for every processed imagery. Color enhancement was carried out for each mosaic imagery to evenly adjust the color tone to the extent possible, and minimize the effect of differences to the interpretation results.

Next, segmentation was carried out in order to create the 'object' units for object-based classification. During this step, the scale parameter was determined through trial-and-error, to find the most appropriate parameter for each satellite imagery with different resolution, so that the objects units could be unified as necessary and sufficient.

Then, the FTM 2010 was developed through two steps: first classified by supervised classification, then corrected by visual (manual) interpretation.

**Change detection**

By using FTM 2010 as the benchmark, FTM 2005 and 2015 were developed though change detection method. When applying change detection method, automated extraction of changes was explored. However due to the differences in the imaging conditions among images, such as sun direction, shooting angle and shooting season, it was difficult to apply automated methods with available software. Thus, the option was taken to identify and classify the changes through visual (manual) interpretation.

To control the quality of the visual (manual) interpretation, a three-fold control process was introduced.

Step 1: interpretation by FIPD remote sensing engineers. Each engineer was assigned to a specific region (a group of provinces) where his/her specialized knowledge can be utilized and further accumulated.

Step 2: quality check by FIDP senior remote sensing engineers. Any possibilities of misinterpretation and errors were returned to the Step 1 engineer for re-checking.

Step 3: sample-based random quality check by external international remote sensing engineers from F-REDD Project. Any possibilities of misinterpretation and errors were returned to the Step 1 engineer for re-checking.

As widely recommended, remote sensing exercise was combined with nation-wide ground truth survey to improve and verify the map quality, and also to build the interpretation capacity of the FIPD remote sensing engineers involved in the task. The results of ground truth survey were organized into a system for improvement, such as establishing interpretation standards for each satellite imagery and classification item, preparation/updating of interpretation cards, then shared among the interpretation team.
To avoid overestimation of emissions and removals, only the cases which could be interpreted as 'obvious change' were extracted. The detailed work flow is shown in Figure 3.

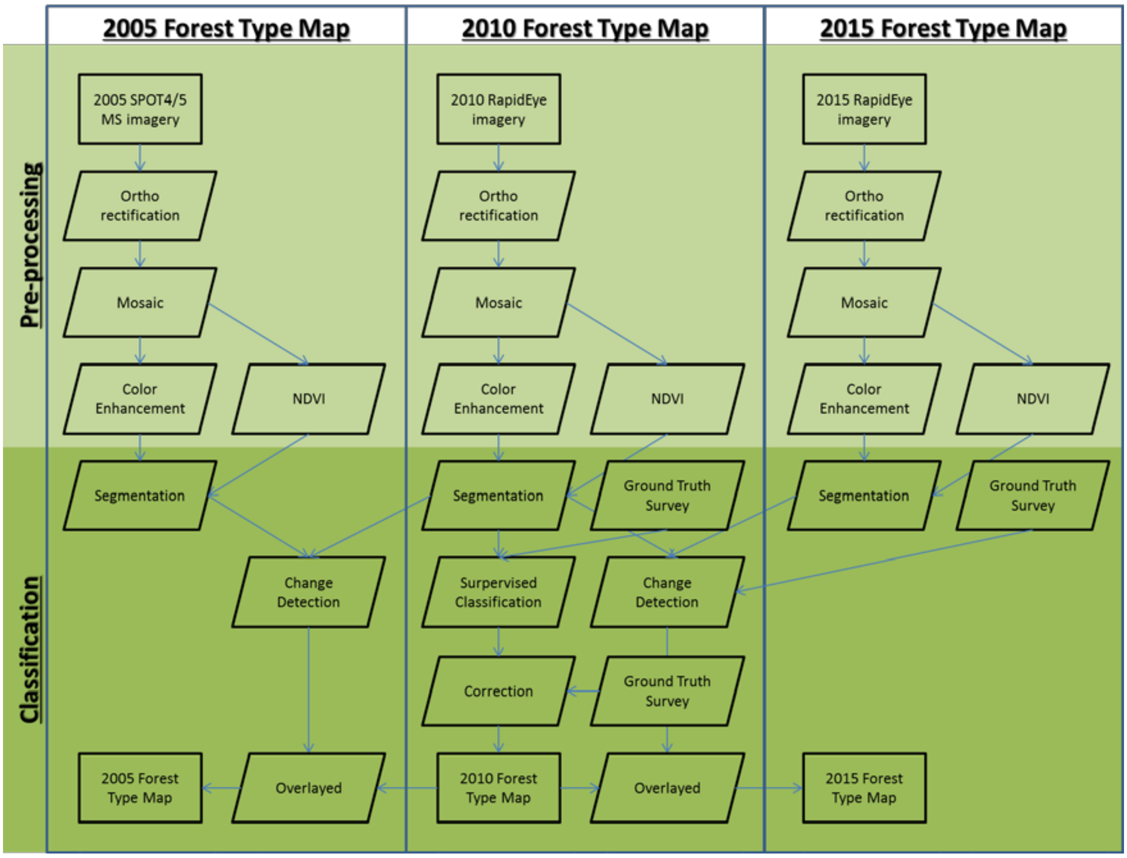


**Figure 3: Workflow for the development of Forest Type Map**

## Challenges related to the classification of land under shifting cultivation

A technical challenge faced throughout the forest mapping exercise was to accurately and consistently distinguish the Upland Crop (UC), Regenerating Vegetation (RV) and Mixed Deciduous Forest (MD).

As a supplementary measure to improve the classification accuracy and time-series consistency for UC, RV and MD classes (considered to be associated with shifting cultivation), the FIPD team made corrections to the FTM classes based on the years since the land was slashed and burnt.

This involved a survey of the number of years of fallow required to regenerate to meet the forest definition (i.e. the threshold year). The survey used the annual vegetation loss dataset by Hansen et al [1] to detect the year of loss on forest loss plots, then ground truth and measure the crown cover to find whether it has reached the status as 'forest'. The results of survey showed that the threshold number of years for a RV fallow to reach the forest threshold was on average seven years. By adding one year for cropping (classified as "UC"), it was assumed that a land slashed and burnt would regenerate into forest status in eight years (see the "RD Survey" Report [2] for details).

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[1] Hansen, M. C., P. V. Potapov, R. Moore, M. Hancher, S. A. Turubanova, A. Tyukavina, D. Thau, S. V. Stehman, S. J. Goetz, T. R. Loveland, A. Kommareddy, A. Egorov, L. Chini, C. O. Justice, and J. R. G. Townshend. (2013) "High-Resolution Global Maps of 21st-Century Forest Cover Change." Science 342 (15 November): 850–53. Data available on-line from: http://earthenginepartners.appspot.com/science-2013-global-forest.

[2] DOF, et al. (2017) "Development of a Lao-specific Equation for the Estimation of Biomass of 'Regenerating Vegetation' and Determination of the Threshold Years for its Regeneration into Forest. <http://dof.maf.gov.la/en/home/>

**Box 2: Challenges related to the classification of land under shifting cultivation**

The total area of these three land/forest classes account for nearly 70% of the land of Lao PDR and over 80% of the land of the ER-P AA. Due to the prevalence of shifting cultivation in Lao PDR and particularly in the northern region (ER-P target area), large areas of land are shifting between these three different land/forest classes. Accurate interpretation of the transition events from UC (i.e. non-forest land) to RV (i.e. forest land temporarily un-stocked and does not meet the definition as forest) and then to MD, through satellite imagery presents a technical challenge. The classification of these land/forest classes can have significant impact on uncertainty.

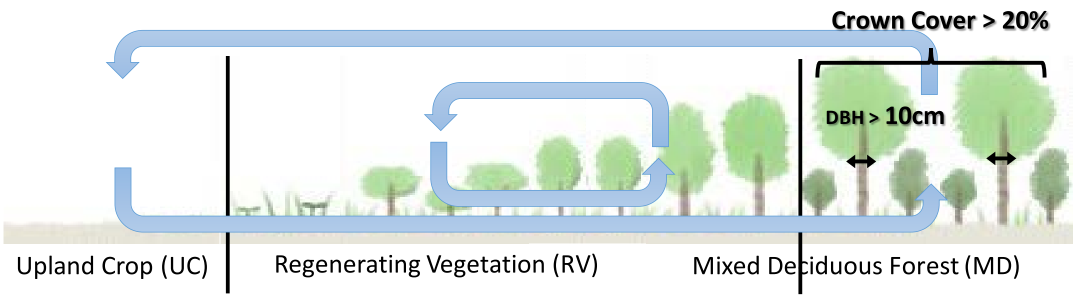


**Figure 4: Slash-and-burn cycle and land/forest classes**

Among the stages of shifting cultivation, UC is the stage of the land immediately after being slashed-and-burnt for cropping, and is relatively easy to classify due to the lack of, or reduced, vegetation cover. RV and MD are continuous phases of regeneration in many cases, and old RV and young MD have very similar color tone and texture on satellite imagery, thus, distinguishing the two in a single satellite imagery is technically challenging.

However, the two issues below related to the use of dataset from Hansen et al. were taken into account while maintaining conservativeness in estimates, and only the plots (polygons) which clearly satisfy the criteria above were revised:

1) The Hansen et al. dataset includes vegetation loss occurring outside forest land (e.g. on agriculture land). Therefore, if a land parcel (polygon) is interpreted as UC for more than 10 years (continuously interpreted as UC over the 2 time periods of 2005-2010 and 2010-2015) it was determined as permanent agricultural land and the classification of the latter year was revised to Other Agriculture (OA) class; and
2) The Hansen et al. dataset does not identify repeated loss events, thus, repeated loss could be under-estimated. Considering 8 years as the standard number of years for forest regeneration (i.e. 1 year as UC and 7 years under fallow), only the MD plots (polygons) where vegetation loss was confirmed in the past one to eight years were revised to RV (with an assumption that land will not regenerate into MD class in less than eight years).

From the draft FTMs developed above, initial Forest Change Maps for the period of 2005-2010 and 2010-2015 were generated to conduct initial analysis of forest change and collect “illogical changes” by overlaying the FTMs of the two different years. From the vector maps which recorded the forest changes for the period of 2005-2010 and 2010-2015, Forest Change Matrices were generated by exporting the attributes in the GIS, and using the Pivot Table tool of Microsoft Excel to sum up the area size of the changed polygons per each land/forest class.

**Table 4: Initial Forest Cover Change Matrix 2005 - 2010**

| ha | 2010 | EF | MD | DD | CF | MCB | P | B | RV | SA | SR | G | SW | UC | RP | OA | AP | U | BR | O | W | total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2005 | | 11 | 12 | 13 | 14 | 15 | 16 | 21 | 22 | 31 | 32 | 41 | 42 | 51 | 61 | 62 | 63 | 71 | 72 | 80 | 81 | |
| EF | 11 | 2,612,407 | 1,827 | 0 | 0 | 0 | 185 | 6 | 886 | 0 | 0 | 0 | 0 | 279 | 466 | 973 | 21 | 0 | 0 | 54 | 1,066 | 2,618,169 |
| MD | 12 | 773 | 9,401,983 | 0 | 0 | 0 | 14,557 | 10,498 | 172,818 | 0 | 0 | 0 | 0 | 19,919 | 8,461 | 43,467 | 4,153 | 272 | 0 | 262 | 7,693 | 9,684,854 |
| DD | 13 | 0 | 32 | 1,214,850 | 0 | 0 | 18,413 | 0 | 4,857 | 104 | 99 | 0 | 0 | 2,377 | 14,071 | 13,296 | 2,854 | 432 | 0 | 443 | 178 | 1,272,006 |
| CF | 14 | 0 | 0 | 0 | 125,153 | 1 | 32 | 0 | 8,617 | 0 | 0 | 0 | 0 | 27 | 52 | 168 | 5 | 0 | 0 | 0 | 0 | 134,055 |
| MCB | 15 | 0 | 4 | 0 | 0 | 108,453 | 16 | 0 | 10,181 | 0 | 0 | 0 | 0 | 57 | 234 | 147 | 4 | 135 | 0 | 293 | 22,935 | 142,458 |
| P | 16 | 0 | 0 | 0 | 0 | 0 | 22,874 | 0 | 543 | 0 | 0 | 0 | 0 | 13 | 100 | 281 | 66 | 0 | 0 | 2 | 1 | 23,880 |
| B | 21 | 0 | 0 | 0 | 0 | 0 | 93 | 65,490 | 3,275 | 0 | 0 | 0 | 0 | 15 | 0 | 117 | 0 | 0 | 0 | 0 | 0 | 68,989 |
| RV | 22 | 46 | 83,993 | 862 | 76 | 113 | 41,278 | 13,758 | 5,376,618 | 0 | 0 | 7 | 0 | 181,169 | 39,014 | 311,379 | 19,216 | 1,463 | 0 | 1,929 | 19,579 | 6,090,500 |
| SA | 31 | 0 | 0 | 0 | 0 | 0 | 79 | 0 | 0 | 102,800 | 0 | 0 | 0 | 845 | 683 | 1,303 | 115 | 28 | 0 | 9 | 0 | 105,861 |
| SR | 32 | 0 | 0 | 0 | 0 | 0 | 198 | 0 | 0 | 0 | 26,591 | 2 | 0 | 149 | 15 | 475 | 5 | 0 | 3 | 17 | 17 | 27,472 |
| G | 41 | 0 | 0 | 0 | 0 | 0 | 4,131 | 0 | 43 | 0 | 0 | 255,504 | 0 | 387 | 1,480 | 1,398 | 413 | 281 | 0 | 152 | 5,863 | 269,652 |
| SW | 42 | 0 | 0 | 0 | 0 | 0 | 89 | 0 | 0 | 0 | 0 | 0 | 9,824 | 19 | 38 | 370 | 23 | 5 | 0 | 0 | 57 | 10,425 |
| UC | 51 | 0 | 0 | 0 | 0 | 0 | 0 | 1,299 | 205,761 | 349 | 94 | 321 | 133 | 0 | 0 | 0 | 0 | 65 | 0 | 40 | 203 | 208,264 |
| RP | 61 | 0 | 0 | 0 | 0 | 0 | 2,702 | 43 | 14,995 | 0 | 0 | 0 | 0 | 0 | 1,135,429 | 16,627 | 611 | 5,726 | 0 | 1,449 | 2,946 | 1,180,530 |
| OA | 62 | 0 | 0 | 0 | 0 | 0 | 3,749 | 49 | 40,134 | 0 | 0 | 0 | 0 | 14 | 2,481 | 564,635 | 5,839 | 653 | 0 | 37 | 241 | 617,832 |
| AP | 63 | 0 | 0 | 0 | 0 | 0 | 1,628 | 0 | 1,985 | 0 | 0 | 0 | 0 | 0 | 0 | 31 | 48,653 | 0 | 0 | 0 | 1 | 52,297 |
| U | 71 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 65 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 64,237 | 0 | 53 | 0 | 64,355 |
| BR | 72 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 185,860 | 0 | 228 | 186,088 |
| O | 80 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 131 | 0 | 0 | 0 | 0 | 2 | 15 | 0 | 1 | 0 | 0 | 17,463 | 61 | 17,673 |
| W | 81 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 93 | 1 | 278,796 | 278,892 |
| total | | 2,613,226 | 9,487,839 | 1,215,712 | 125,229 | 108,567 | 110,024 | 91,143 | 5,840,908 | 103,253 | 26,784 | 255,834 | 9,957 | 205,272 | 1,202,541 | 954,666 | 81,981 | 73,296 | 185,956 | 22,204 | 339,866 | 23,054,258 |

**Table 5: Initial Forest Cover Change Matrix 2010 - 2015**

| ha | 2015 | EF | MD | DD | CF | MCB | P | B | RV | SA | SR | G | SW | UC | RP | OA | AP | U | BR | O | W | total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2010 | | 11 | 12 | 13 | 14 | 15 | 16 | 21 | 22 | 31 | 32 | 41 | 42 | 51 | 61 | 62 | 63 | 71 | 72 | 80 | 81 | |
| EF | 11 | 2,605,557 | 355 | 13 | 0 | 0 | 48 | 0 | 825 | 0 | 0 | 0 | 0 | 2,601 | 55 | 3,305 | 1 | 20 | 0 | 411 | 36 | 2,613,226 |
| MD | 12 | 0 | 9,097,386 | 313 | 0 | 40 | 7,390 | 36 | 272,089 | 0 | 0 | 73 | 0 | 45,616 | 2,718 | 52,744 | 2,200 | 517 | 0 | 3,968 | 2,748 | 9,487,839 |
| DD | 13 | 0 | 10 | 1,187,781 | 0 | 0 | 15,238 | 0 | 540 | 74 | 0 | 4 | 0 | 210 | 5,426 | 3,818 | 1,364 | 323 | 0 | 841 | 83 | 1,215,712 |
| CF | 14 | 0 | 0 | 0 | 124,772 | 0 | 0 | 0 | 58 | 0 | 0 | 2 | 0 | 203 | 2 | 156 | 0 | 0 | 0 | 37 | 0 | 125,229 |
| MCB | 15 | 0 | 7 | 0 | 0 | 107,837 | 0 | 0 | 98 | 0 | 0 | 0 | 0 | 333 | 3 | 265 | 0 | 0 | 0 | 24 | 0 | 108,567 |
| P | 16 | 0 | 0 | 0 | 0 | 0 | 108,875 | 0 | 64 | 0 | 0 | 0 | 0 | 116 | 34 | 879 | 28 | 4 | 0 | 23 | 0 | 110,024 |
| B | 21 | 0 | 23 | 0 | 0 | 0 | 9 | 88,746 | 404 | 0 | 0 | 0 | 0 | 841 | 2 | 1,043 | 0 | 3 | 0 | 70 | 0 | 91,143 |
| RV | 22 | 0 | 107,254 | 91 | 0 | 3 | 3,324 | 95 | 5,542,984 | 0 | 0 | 107 | 0 | 88,261 | 4,800 | 82,373 | 929 | 1,060 | 0 | 3,059 | 6,567 | 5,840,908 |
| SA | 31 | 0 | 0 | 0 | 0 | 0 | 233 | 0 | 0 | 102,031 | 0 | 0 | 0 | 44 | 649 | 136 | 94 | 28 | 0 | 31 | 6 | 103,253 |
| SR | 32 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 26,603 | 0 | 0 | 54 | 23 | 22 | 0 | 12 | 66 | 1 | 0 | 26,784 |
| G | 41 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 254,172 | 0 | 581 | 118 | 857 | 0 | 28 | 0 | 73 | 5 | 255,834 |
| SW | 42 | 0 | 0 | 0 | 0 | 0 | 334 | 0 | 0 | 0 | 0 | 0 | 9,561 | 29 | 17 | 5 | 1 | 0 | 0 | 0 | 10 | 9,957 |
| UC | 51 | 0 | 0 | 0 | 0 | 0 | 0 | 21 | 204,505 | 5 | 3 | 4 | 0 | 0 | 0 | 0 | 0 | 292 | 0 | 333 | 109 | 205,272 |
| RP | 61 | 0 | 0 | 0 | 0 | 0 | 1,171 | 1 | 10,432 | 0 | 0 | 0 | 0 | 571 | 1,182,402 | 5,913 | 236 | 602 | 0 | 449 | 762 | 1,202,541 |
| OA | 62 | 0 | 0 | 0 | 0 | 0 | 1,197 | 0 | 39,449 | 0 | 26 | 13 | 0 | 10,320 | 3,289 | 899,003 | 223 | 245 | 0 | 601 | 301 | 954,666 |
| AP | 63 | 0 | 0 | 0 | 0 | 0 | 104 | 0 | 1,670 | 0 | 0 | 2 | 0 | 568 | 6 | 1,246 | 78,196 | 9 | 0 | 11 | 168 | 81,981 |
| U | 71 | 0 | 0 | 0 | 0 | 0 | 16 | 0 | 182 | 0 | 0 | 0 | 0 | 102 | 183 | 241 | 32 | 72,448 | 0 | 73 | 19 | 73,296 |
| BR | 72 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 185,945 | 0 | 5 | 185,956 |
| O | 80 | 0 | 0 | 0 | 0 | 0 | 23 | 0 | 279 | 0 | 0 | 0 | 0 | 68 | 120 | 229 | 3 | 47 | 137 | 21,230 | 68 | 22,204 |
| W | 81 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 53 | 334 | 0 | 0 | 9 | 53 | 339,417 | 339,866 |
| total | | 2,605,557 | 9,205,036 | 1,188,198 | 124,772 | 107,880 | 137,965 | 88,900 | 6,073,581 | 102,110 | 26,637 | 254,376 | 9,561 | 150,519 | 1,199,903 | 1,052,569 | 83,306 | 75,638 | 186,157 | 31,289 | 350,304 | 23,054,258 |

In the initial Forest Change Matrices, all the changes which should not occur, either from ecological reason or within the period of 5 year, were identified as “Illogical changes” (see Table 6 below). Through this diagnostic check, all of these areas were double-checked and corrected. All of the changes which were unlikely to occur, although not definite, were double-checked and corrected as necessary.

**Table 6: Patterns of illogical changes**

| | | | EF | MD | DD | CF | MCB | P | B | RV | SA | SR | G | SW | UC | RP | OA | AP | U | BR | O | W |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 11 | 12 | 13 | 14 | 15 | 16 | 21 | 22 | 31 | 32 | 41 | 42 | 51 | 61 | 62 | 63 | 71 | 72 | 80 | 81 |
| Evergreen Forest | EF | 11 | O | O | △ | △ | △ | O | O | O | × | × | △ | × | O | O | O | O | O | × | O | △ |
| Mixed Deciduous Forest | MD | 12 | O | O | △ | △ | △ | O | O | O | × | × | △ | × | O | O | O | O | O | × | O | △ |
| Dry Dipterocarp Forest | DD | 13 | × | △ | O | △ | △ | O | O | O | O | O | △ | × | O | O | O | O | O | × | O | △ |
| Coniferous Forest | CF | 14 | × | × | × | O | O | O | O | O | × | × | △ | × | O | O | O | O | O | × | O | △ |
| Mixed Coniferous and Broadleaved Forest | MCB | 15 | × | △ | × | O | O | O | O | O | × | × | △ | × | O | O | O | O | O | × | O | △ |
| Forest Plantation | P | 16 | × | △ | △ | △ | △ | O | O | O | × | × | △ | × | O | O | O | O | O | × | O | △ |
| Bamboo | B | 21 | △ | △ | △ | △ | △ | O | O | O | × | × | △ | × | O | O | O | O | O | × | O | △ |
| Regenerating Vegetation | RV | 22 | △ | O | O | O | O | O | O | O | × | × | △ | × | O | O | O | O | O | × | O | △ |
| Savannah | SA | 31 | × | × | × | × | × | O | × | × | O | △ | △ | × | O | O | O | O | O | × | O | △ |
| Scrub | SR | 32 | × | × | × | × | × | O | × | × | × | O | △ | × | O | O | O | O | O | △ | O | △ |
| Grassland | G | 41 | × | × | × | × | × | O | × | × | × | × | O | × | O | O | O | O | O | × | O | △ |
| Swamp | SW | 42 | × | × | × | × | × | O | × | × | × | × | × | O | O | O | O | O | O | × | O | △ |
| Upland Crop | UC | 51 | × | × | × | × | × | O | O | O | O | O | O | O | O | O | O | O | O | × | O | △ |
| Rice Paddy | RP | 61 | × | × | × | × | × | O | O | O | × | × | × | × | × | O | O | O | O | × | O | △ |
| Other Agriculture | OA | 62 | × | × | × | × | × | O | O | O | × | × | × | × | △ | △ | O | O | O | × | O | △ |
| Agriculture Plantation | AP | 63 | × | × | × | × | × | O | O | O | × | × | × | × | △ | △ | △ | O | O | × | O | △ |
| Urban | U | 71 | × | × | × | × | × | △ | △ | △ | △ | △ | △ | △ | △ | △ | △ | △ | O | × | O | △ |
| Barren Land and Rock | BR | 72 | × | × | × | × | × | × | × | × | × | △ | × | × | × | × | × | × | × | O | × | △ |
| Other Land | O | 80 | × | × | × | × | × | △ | △ | △ | △ | △ | △ | △ | △ | △ | △ | △ | △ | △ | O | △ |
| Water | W | 81 | × | × | × | × | × | × | × | × | × | × | △ | △ | × | △ | △ | × | × | O | △ | O |

X: illogical changes which should not occur

∆: changes unlikely to occur, although not impossible

O: possible changes

**Forest Type Maps (FTMs)**

Figure 5, Figure 6 and Figure 7 show the final FTMs for year 2005, 2010 and 2015 for the Lao PDR.

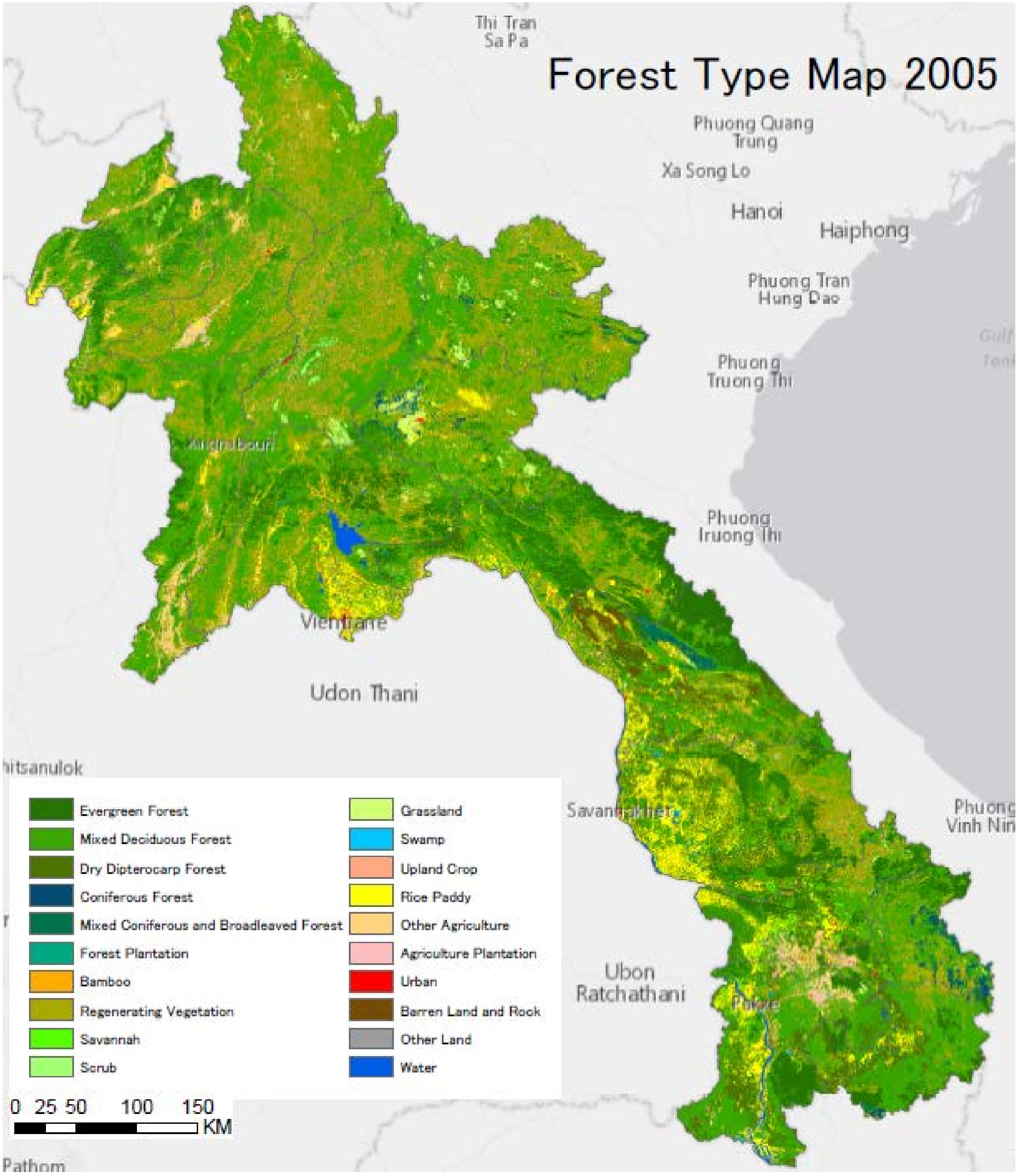


**Figure 5: Forest Type Map 2005**

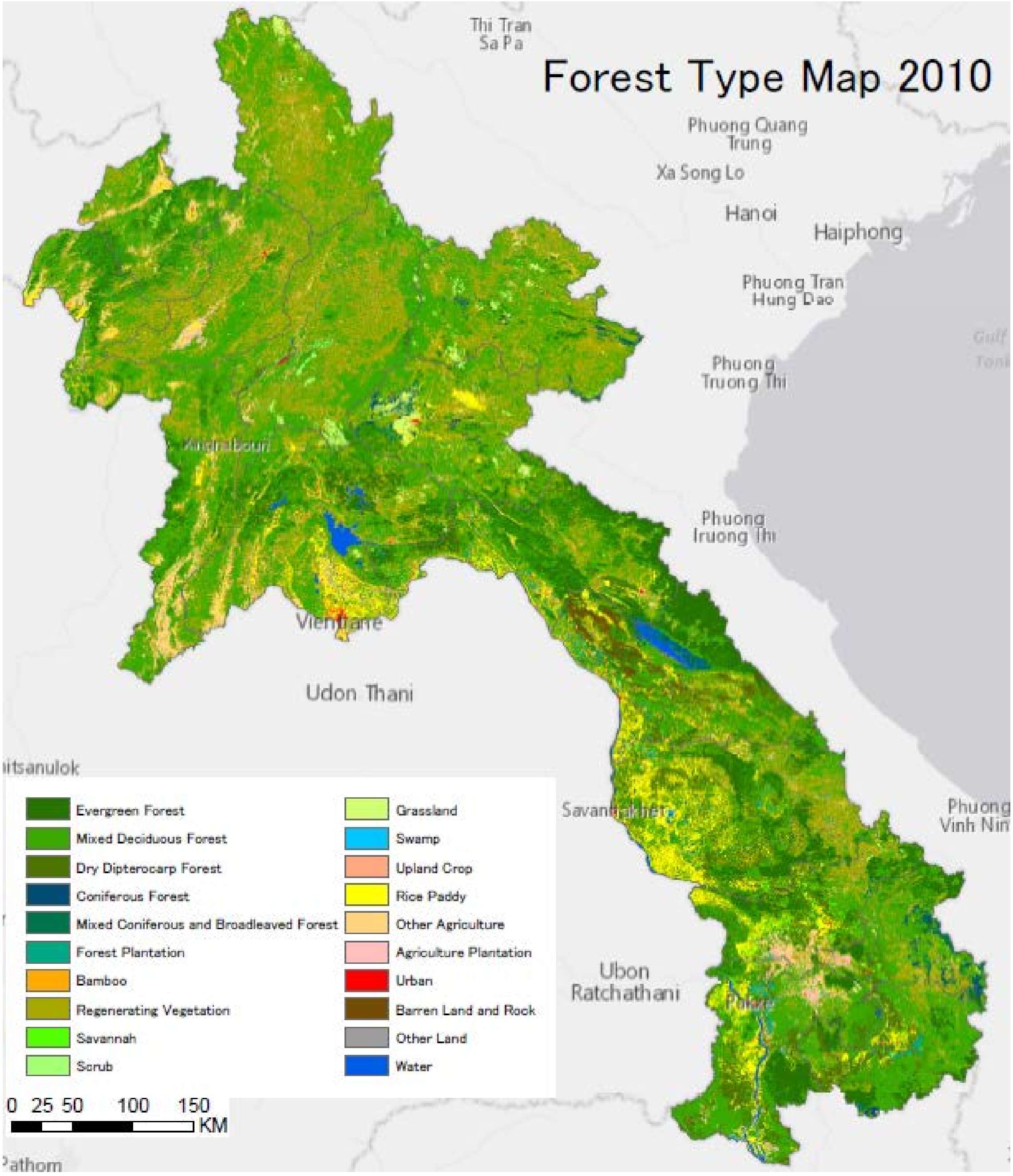


**Figure 6: Forest Type Map 2010**

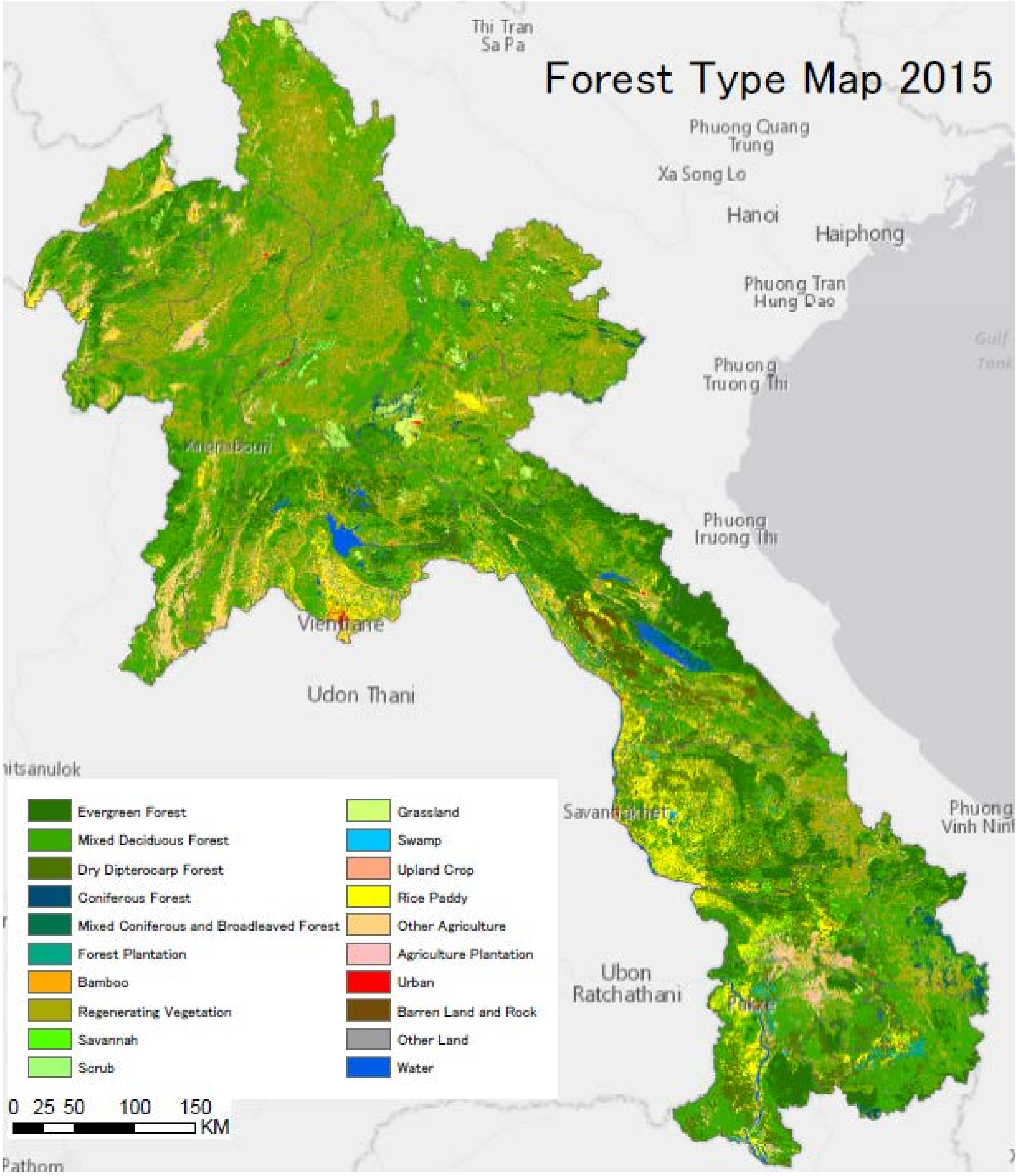


**Figure 7: Forest Type Map 2015**

## 2.4 Stratification of land/forest classes

In order to reduce uncertainty of emissions and removals while balancing the accuracy of sampling and the cost/efforts required, the land/forest classification explained in Section 2.2 was further stratified into five strata as below and as summarized in Table 7:

- Evergreen Forest (EG) has distinctly high carbon stocks (200.00tC), thus, separated as an independent stratum – Stratum 1 (expanse: 2,605,557ha, 11.3% of the total land area).
- Mix Deciduous Forest (MD), Conifer Forest (CF) and Mixed Coniferous and Broadleaved Forest (MCB) will form one stratum on the basis of similarity in carbon stocks per hectare (87.7tC, 92.6tC, 114.7tc). – Stratum 2 (expanse: 9,437,688ha, 40.9% of the total land area ).
- Dry Dipterocarp Forest (DD) will form one stratum due to the difference in carbon stock from other forest classes (43.2tC), and also due to the fact that they are mostly distributed in the low-lands and prone to conversion to other land use – Stratum 3 (expanse: 1,188,198, 5.2% of the total land area).
- Plantation (P), Bamboo (B) and Regenerating Vegetation (RV) will form one strata on the basis of similarity in average carbon stock (37.2tC, 24.4tC, 17.4tC) and the limited area of P and B – Stratum 4 (expanse: 6,300,445ha, 27.3% of the total land area).
- The remaining 12 non-forest classes will form one stratum – Stratum 5 (expanse: 3,522,370ha, 15.3% of the total land area).

**Table 7: Land/forest classes and stratification**

| Land/forest classes | | | Area (ha) | % of total area | Strata |
|---|---|---|---|---|---|
| Level 1 | Level 2 | | | | |
| Current Forest | Evergreen Forest | EG | 2,605,557 | 11.3% | 1 |
| | Mixed Deciduous Forest | MD | 9,437,688 | 40.9% | 2 |
| | Coniferous Forest | CF | | | |
| | Mixed Coniferous and Broadleaved Forest | MCB | | | |
| | Dry Dipterocarp Forest | DD | 1,188,198 | 5.2% | 3 |
| | Forest Plantation | P | 6,300,445 | 27.3% | 4 |
| Potential Forest | Bamboo | B | | | |
| | Regenerating Vegetation | RV | | | |
| Other Vegetated Areas | Savannah | SA | 3,522,370 | 15.3% | 5 |
| | Scrub | SR | | | |
| | Grassland | G | | | |
| Cropland | Upland Crop | UC | | | |
| | Rice Paddy | RP | | | |
| | Other Agriculture | OA | | | |
| | Agriculture Plantation | AP | | | |
| Settlement | Urban Areas | U | | | |
| Other Land | Barren Land and Rock | BR | | | |
| | Other Land | O | | | |
| Above-ground Water Source | Wetland (Swamp) | SW | | | |
| | River (Water) | W | | | |
| Total | | | 23,054,258 | 100% | |

**Stratified Forest Type Maps (FTMs)**

Figure 8, Figure 9 and Figure 10 show the stratified FTMs for year 2005, 2010 and 2015 respectively, and Table 8 summarizes the area and percentage of each stratum for different years.

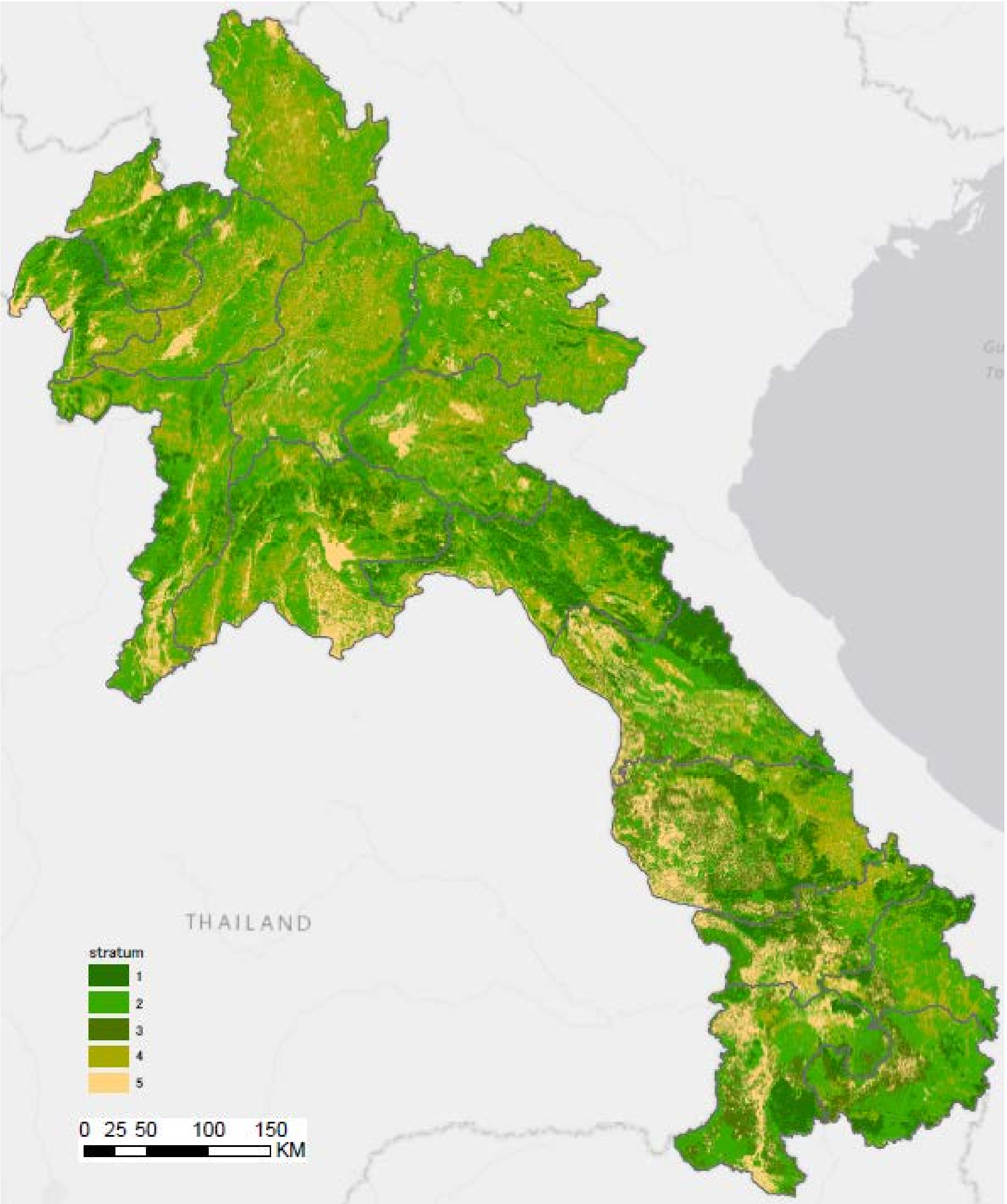


**Figure 8: Stratified Forest Type Map 2005**

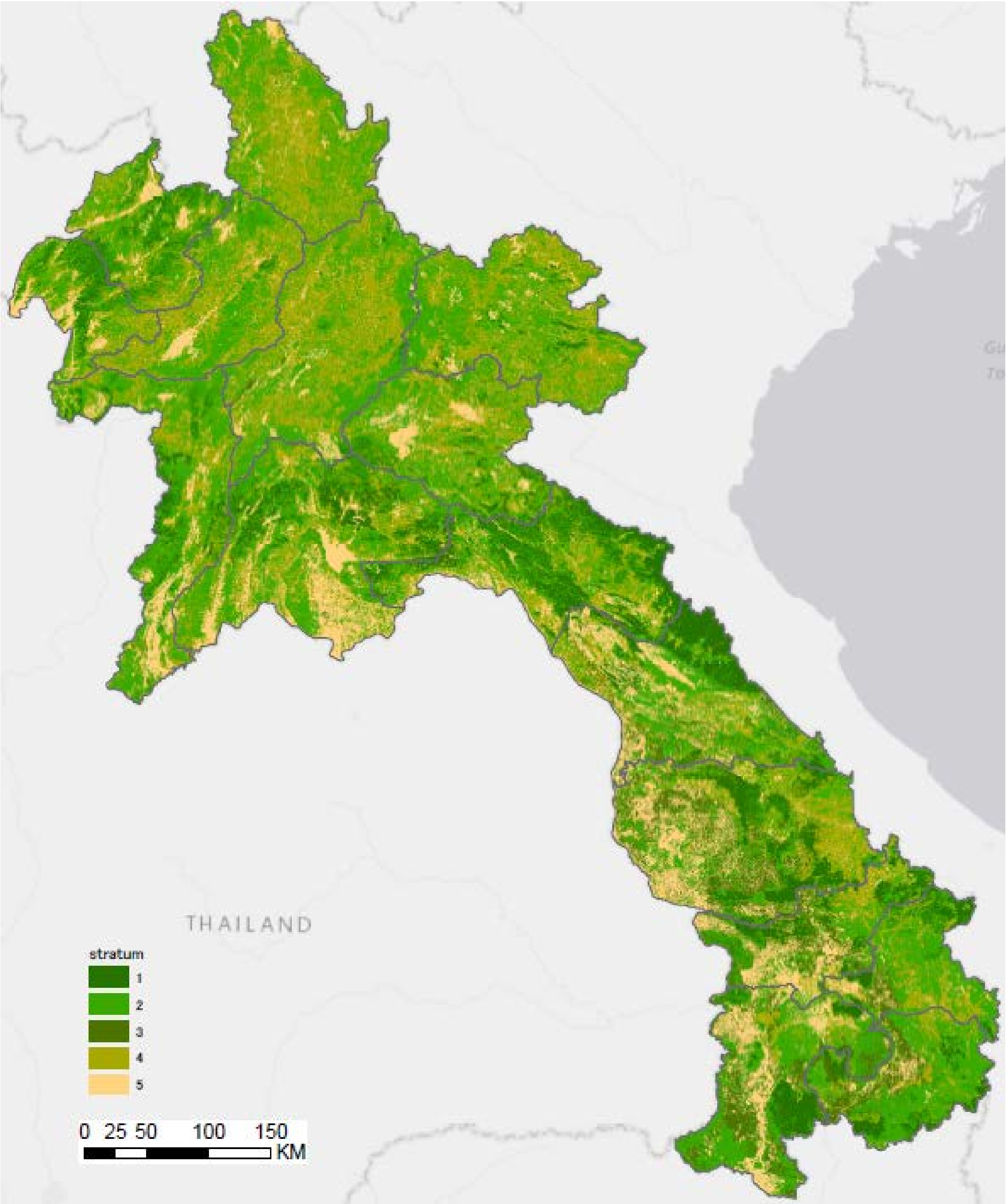

**Figure 9: Stratified Forest Type Map 2010**

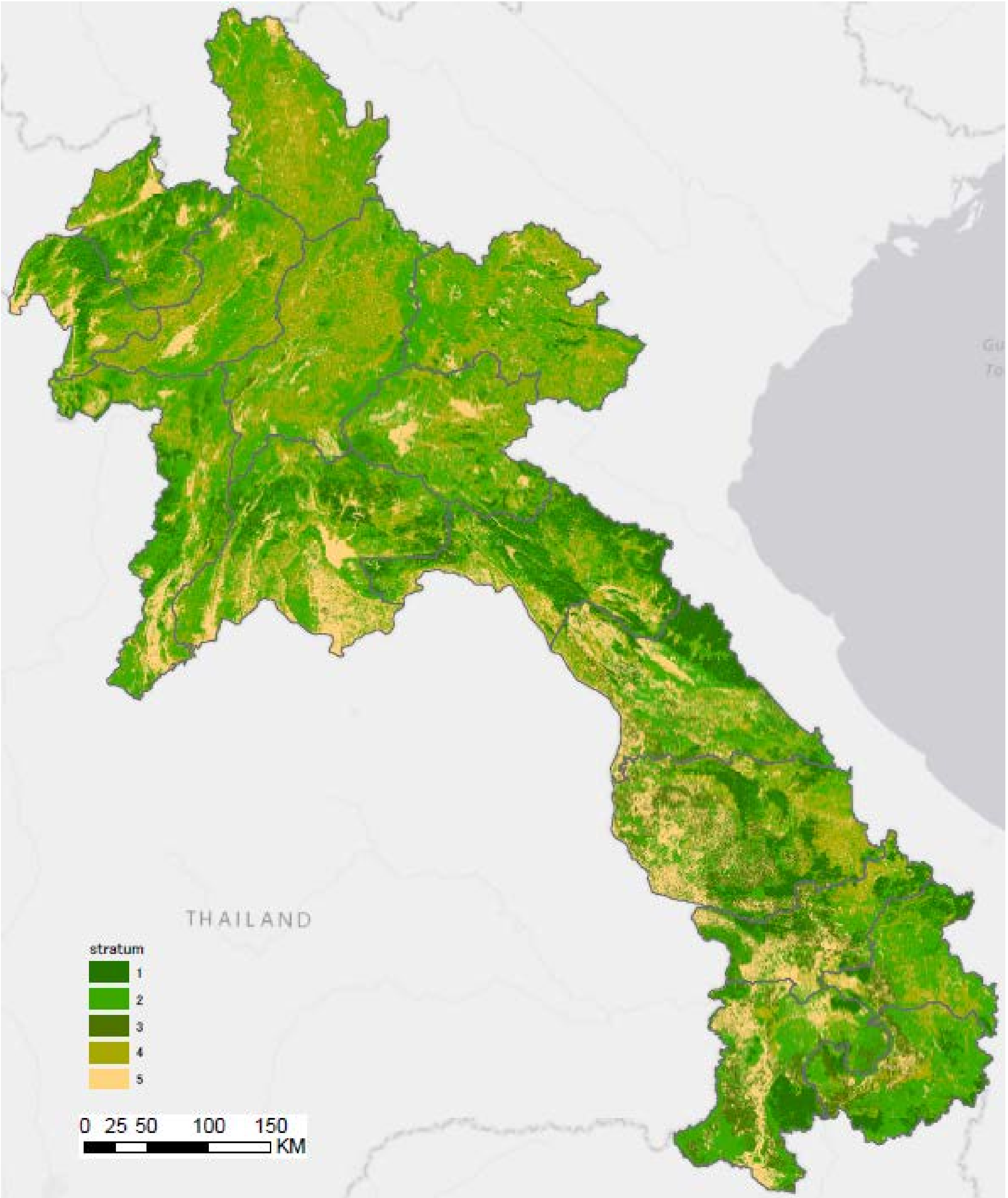


**Figure 10: Stratified Forest Type Map 2015**

**Table 8: Area and percentage per stratum for 2005, 2010 and 2015**

Unit: ha, percentage

| | 2015 | % | 2010 | % | 2005 | % |
|---|---|---|---|---|---|---|
| **Stratum 1** | 2,605,557 | 11.3% | 2,613,226 | 11.3% | 2,618,169 | 11.4% |
| **Stratum 2** | 9,437,688 | 40.9% | 9,721,635 | 42.2% | 9,961,368 | 43.2% |
| **Stratum 3** | 1,188,198 | 5.2% | 1,215,712 | 5.3% | 1,272,006 | 5.5% |
| **Stratum 4** | 6,300,445 | 27.3% | 6,042,075 | 26.2% | 6,183,370 | 26.8% |
| **Stratum 5** | 3,522,370 | 15.3% | 3,461,610 | 15.0% | 3,019,344 | 13.1% |
| **Total** | 23,054,258 | 100% | 23,054,258 | 100% | 23,054,258 | 100% |

## 2.5 Activity Data

AD is derived from the second Forest Cover Change Matrices based on the stratified FTMs for the period 2005-2010 and 2010-2015 as shown in Table 9 and Table 10 below.

**Table 9: Activity data after stratification 2005 - 2010**

| | | 2010 | | | | |
|---|---|---|---|---|---|---|
| | ha | Stratum 1 | Stratum 2 | Stratum 3 | Stratum 4 | Stratum 5 |
| 2005 | Stratum 1 | 2,612,407 | 1,827 | 0 | 1,076 | 2,859 |
| | Stratum 2 | 773 | 9,635,593 | 0 | 216,717 | 108,284 |
| | Stratum 3 | 0 | 32 | 1,214,850 | 23,270 | 33,855 |
| | Stratum 4 | 46 | 84,183 | 862 | 5,523,929 | 574,350 |
| | Stratum 5 | 0 | 0 | 0 | 277,082 | 2,742,262 |
| | | | | | Total | 23,054,258 |

Deforestation
Degradation
Restoration
Reforestation
No Change

**Table 10: Activity data after stratification 2010 - 2015**

| | | 2015 | | | | |
|---|---|---|---|---|---|---|
| | ha | Stratum 1 | Stratum 2 | Stratum 3 | Stratum 4 | Stratum 5 |
| 2010 | Stratum 1 | 2,605,557 | 355 | 13 | 873 | 6,429 |
| | Stratum 2 | 0 | 9,330,042 | 313 | 279,672 | 111,608 |
| | Stratum 3 | 0 | 10 | 1,187,781 | 15,778 | 12,143 |
| | Stratum 4 | 0 | 107,280 | 91 | 5,744,502 | 190,201 |
| | Stratum 5 | 0 | 0 | 0 | 259,621 | 3,201,989 |
| | | | | | Total | 23,054,258 |

Deforestation
Degradation
Restoration
Reforestation
No Change

## 2.6 Sources and sinks selected

The emissions and removals are estimated by first applying Emission Factors to the area estimates of the AD[3]. Then, the results were aggregated into the selected four (4) sources and sinks associated with the REDD+ Activities over two different periods (i.e. 2005-2010 and 2010-2015).

In Lao PDR's carbon accounting, all the emissions from deforestation and forest degradation are regarded as anthropogenic, for the reasons that, the forest area is home to many different mountain ethnic minorities groups in and interacting with the forests in their daily lives; and large-scale natural disasters in forest areas or forest diseases are not common. In addition there is no suitable technology yet to clearly distinguish anthropogenic and non-anthropogenic emissions:

- **Emissions from Deforestation (DF),** caused by loss of forest carbon stock due to conversion of a forest land stratum to non-forest land stratum;
- **Emissions from Forest Degradation (DG)**, caused by downward shift of a forest stratum from a higher carbon stock strata to another forest stratum with lower carbon stock[4];
- **Removals from Forest Enhancement (Restoration) (RS)**, caused by upward shift of a forest land stratum with lower carbon stock to another forest/land stratum with higher carbon stock; and
- **Removals from Forest Enhancement (Reforestation) (RF)**, caused by gain of forest carbon stock due to conversion of non-forest land stratum to a forest land stratum.

In addition, there are two (2) stable types of land/forest classes which do not impact emissions or removals, which are:

- **Stable Forest (SF)**, where there is no change in the forest stratum; and.
- **Stable Non-Forest (SNF)**, where there is no change in the non-forest land stratum.

Accordingly the AD will derived as amount of changes in forest areas which relate to any of the four (4) sources and sinks as shown in following Figure 11.

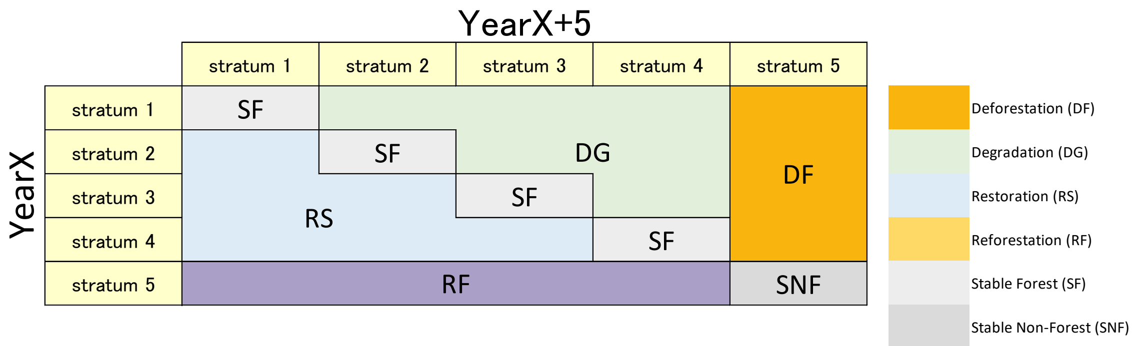


**Figure 11: Sources and sinks associated with REDD + activities**

[3] In the future, Lao may include restoration from improved Regenerating Vegetation management and forests remaining in the same category with increased carbon stock in this category – but for now, this is not possible due to lack of datasets. For the same reason, emissions from degradation occurring in forests remaining in the same category is also not accounted, except for the emission from selective logging estimated through measurement of tree stumps as a proxy indicator.

[4] In addition to the use of stock difference method with the use of activity data and emission factors, impact of logging is estimated through field survey of tree stumps. This captures degradation not only caused by downward shift of a forest stratum, but also those in same forest land stratum. Possible double-counting of emissions from degradation arising from the use of two different methods are avoided in the accounting.

**Sources and sinks maps**

The maps which shows the sources and sinks associated with REDD+ activities for 2005-2010 and 2010-201 are shown in Figure 12 and Figure 13.

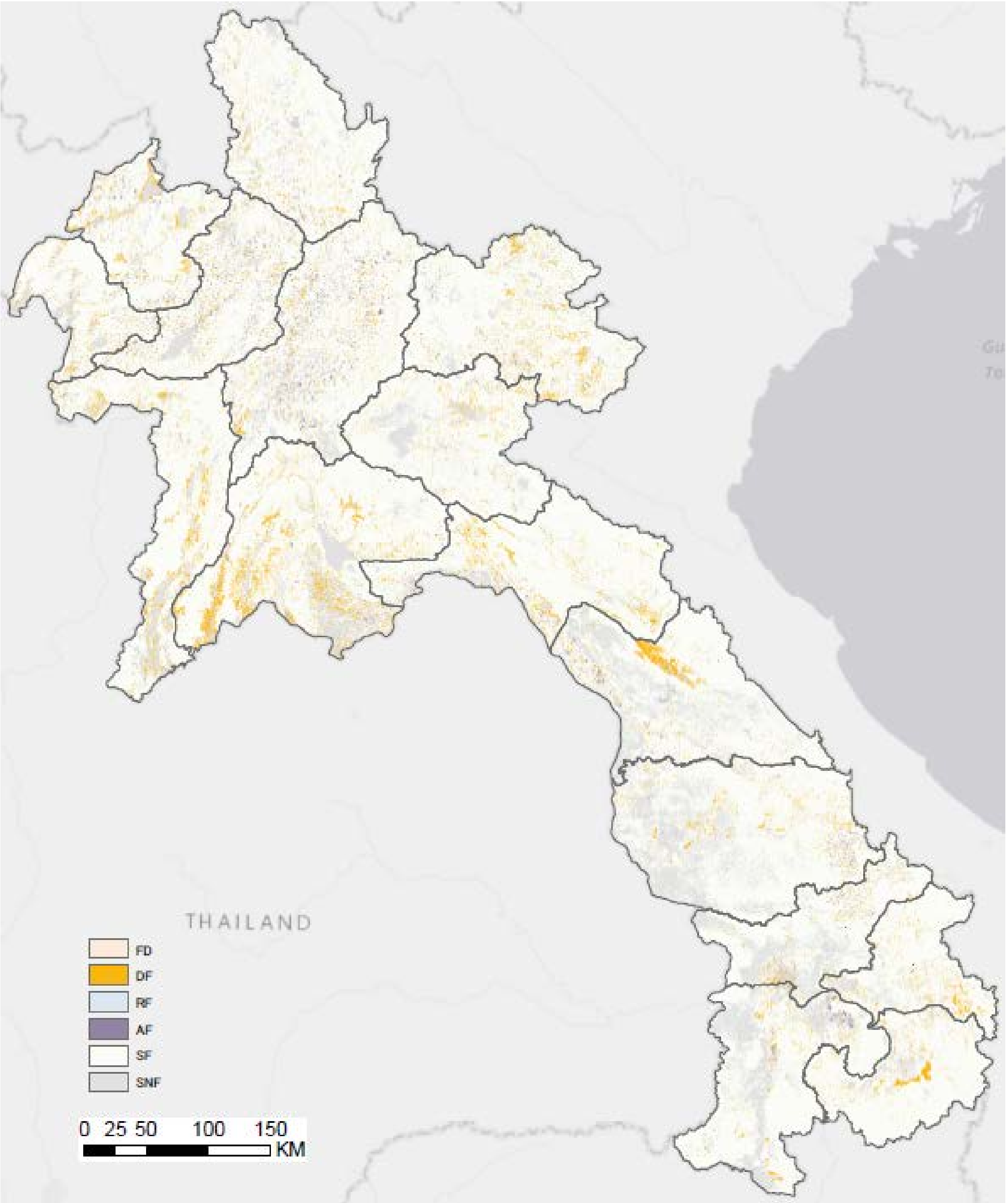


**Figure 12: Sources and Sinks Map 2005 - 2010**

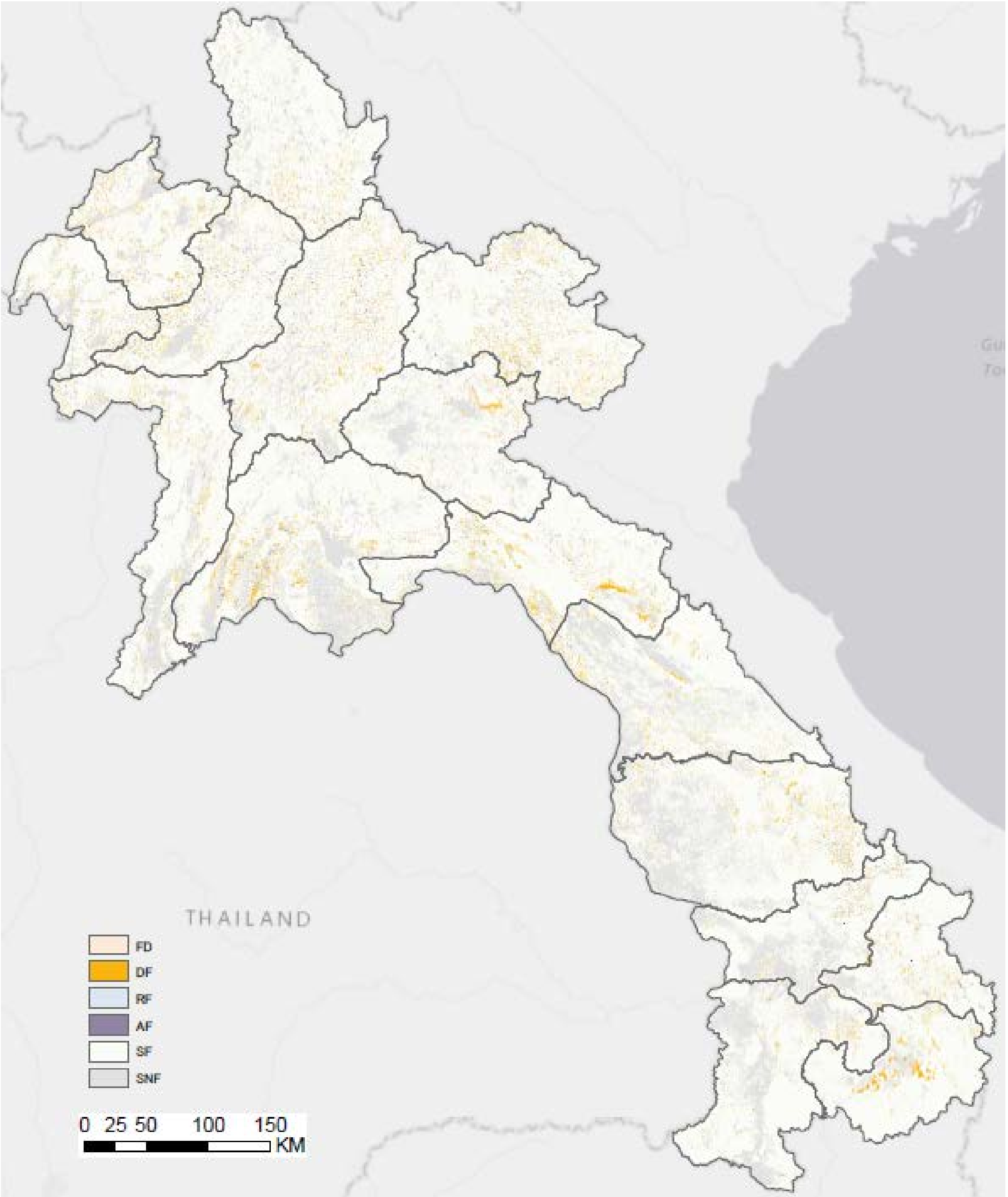


**Figure 13: Sources and Sinks Map 2010 - 2015**

# 3. CONCLUSIONS AND AREAS FOR FUTURE IMPROVEMENT

The FTMs (wall-to-wall maps) for year 2005, 2010 and 2015 were developed through consistent method, and the forest cover change for the period 2005-2010 and 2010-2015 were assessed with spatially explicit observations of land use and land-use change, satisfying "Approach 3" of the IPCC[5]. The accuracy of the resulting data was assessed and the changed areas were adjusted accordingly to develop the final AD. From this, the uncertainty of AD was estimated.

The data are made accessible to public (although with different levels of access rights, depending on the viewer/user) through the NFMS Web portal to ensure transparency.

Three areas for future improvement are suggested to aim step-wise improvement as well as to further reduce the uncertainty of AD:

1) Improvement of classification between MD and RV

   The RV study, based on analysis of historical tree loss dataset from Hansen et al. combined with field surveys to study the time required for regeneration to meet the forest definition after slash and burning found seven years as the threshold year. This information was used to improve the accuracy of classification between RV and MD, which is a continuous phases of regeneration. At the same time, because of its characteristics, the data of Hansen et al. data does not detect repeated slash and burn incidents, which is a typical land-use practice in the Lao PDR. For the future forest mapping, Lao PDR will attempt to explore methods to detect repeated slash and burn practices in order to enable further analysis of land/forest cover change over time.

2) Updating FTM 2015 map and FTMs

   As explained in Section 2.3.2, distinguishing UC and OA was also a challenge, as they have very similar texture on satellite imagery. Therefore, in the current mapping method, if a land parcel (polygon) is interpreted as UC for more than 10 years (continuously interpreted as UC over the 2 time periods of 2005-2010 and 2010-2015) it was determined as permanent agricultural land and the classification of the latter year was revised to OA class. This is an example of challenges of conducting forest mapping with satellite imagery of a single year.

   In the future, Lao PDR may explore using options, such as the technologies to analyze 'big data', multi-temporal satellite dataset available, and GIS data from different sources (e.g. land concession data), which meet its needs.

3) Further capacity building of the remote sensing, GIS and IT engineers

   FIPD/DOF has been increasing their remote sensing capacity with the technical and financial support from development partners and projects. However, under rapid innovation of remote sensing, GIS and IT technologies, demand for sufficient number of competent engineers/team is increasing. Particularly the skills and knowledge of the skilled senior engineers needs to systematically be passed on to the younger generation. Also, there is an emerging need for IT engineers who can manage and operate database systems which handle large and diverse range of digital data.

   In order to periodically develop the AD for the MRV, continuous capacity building efforts is inevitable. Development partners can continue to play an important role on systemizing the know-how, training on planning, development and analysis of data, and support the FIPD/DOF staff to catch-up with the innovative technologies.

[5] GPG LULUCF, (2003)

# Lao PDR's Forest Reference Emission Level and Forest Reference Level for REDD+ Results Payment under the UNFCCC

# Annex 2

# Emission/Removal Factors Report

**January 2018**

**Department of Forestry**
**Ministry of Agriculture and Forestry, Lao PDR**

## Table of Contents

## List of Tables



## List of Figures

## Acronyms

| | |
|---|---|
| AE | Allometric Equation |
| AGB | Above Ground Biomass |
| B | Bamboo |
| BGB | Below Ground Biomass |
| CF | Coniferous Forest |
| CI | Confidence Interval |
| DAFO | District Agriculture and forest Office |
| DBH | Diameter at Breast Height |
| DD | Dry Dipterocarp Forest |
| DOF | Department of Forestry |
| DW | Dead Wood |
| EF | Emission Factor |
| EG | Evergreen Forest |
| E/R F | Emission and Removal Factor |
| FIPD | Forestry Inventory and Planning Division |
| FREL | Forest Reference Emission Level |
| FRL | Forest Reference Level |
| F-REDD | Sustainable Forest Management and REDD+ Support Project in the LAO PDR |
| GIS | Geographic Information System |
| GL | Guideline |
| IPCC | Intergovernmental Panel on Climate Change |
| Lao PDR | Lao People's Democratic Republic |
| JICS | Japan International Cooperation System |
| MAF | Ministry of Agriculture and Forestry |
| MCB | Mixed Coniferous Broadleaved Forest |
| MD | Mixed Deciduous Forest |
| NFI | National forest Inventory |
| NFIS | National Forest Information System project |
| NTV | Non-Tree Vegetation |
| PAFO | Provincial Agriculture and Forest Office |
| REDD+ | Reducing Emissions from Deforestation and Forest Degradation and the role of conservation of forests and enhancement of forest carbon stock |
| RF | Removal Factor |
| RV | Regenerating Vegetation |
| StD | Standard Deviation |
| StE | Standard errors |
| UNFCCC | United Nations Framework Convention on Climate Change |

# 1. Introduction

## 1.1 Objectives

This report aims to describe the methods and the final results of the development of Emission and Removal Factors (E/R factors) used in the construction of Forest Reference Emission Level (FREL)/Forest Reference Level (FRL) for the national level to be submitted to the United Nations Framework Convention on Climate Change (UNFCCC).

The main inputs for the development of the E/R factors are:

- The 2nd National Forest Inventory (NFI) conducted between 2015 and 2017 by the Forest Inventory and Planning Division (FIPD) of the Department of Forestry (DOF) under the Ministry of Agriculture and Forestry (MAF).[1] The purpose of the 2nd NFI was to measure forest biomass of the five forest classes: Evergreen Forest (EG), Mixed Deciduous Forest (MD), Dry Dipterocarp Forest (DD), Coniferous Forest (CF) and Mixed Coniferous Broadleaf (MCB) (Section 2.1).
- A survey for the Regenerating Vegetation (RV) class (which was outside the scope of the 2nd NFI), conducted by FIPD to study the years for a forest fallow (classified as "regenerating vegetation": RV) to reach the forest status according to Lao's forest definition, as well as to measure the biomass of this vegetation class (Section 2.2).
- To improve the accuracy of forest biomass estimation, Lao PDR developed country-specific allometric equations for the three major forest classes: EG, MD and DD (Section 2.3). Other land/forest classes use IPCC default values or biomass data from neighboring Vietnam.

In this report, the above results were combined under the methodologies to estimate biomass, carbon stock to determine the E/R factors as presented in Chapter 3. The report also presents actual results of estimation and the final E/R factors in Chapter 4. The issues related to the use of the 1st NFI[2], and accounting of Dead Wood (DW) are discussed in Chapter 5, and lastly, the conclusion and areas for future improvement are summarized in Chapter 6.

## 1.2 Notes on analytical considerations

This report is written based on the following understandings (details are discussed in Chapter 5):

a) Lao PDR conducted its 1st NFI in 1990s. Review of the 1st NFI data found that they are not suitable due to the limitation in data representativeness, and the gap of nearly 20 years between the 1st NFI and the 2nd NFI. Therefore, only the data from the 2nd NFI are used for the development of E/R factors.
b) The 2nd NFI measured Dead Wood (DW) in the five forest classes (EG, MD, DD, CF, MCB). The result showed that DW are not significant source of emissions (approximately 2.3% of the total emissions in the national area). Also, the biomass survey of RV (different from the 2nd NFI) did not measure DW

[1] The 2nd NFI was technically and financially supported by "Sustainable Forest Management and REDD+ Support Project in the Lao PDR (F-REDD)" under JICA.

[2] Lao PDR conducted its 1st NFI in the late '90s, however, the results are decided not to be used in the development of E/R factors. See Section 5.1 for the details.

which makes the estimation inconsistent. Therefore, it was concluded not to account DW in the development of E/R factors.

# 2. Dataset used

## 2.1 Forest biomass data from the 2nd NFI[3]

**Background**

Lao PDR conducted its 1st NFI in 1991-1999, covering the entire country. However, the data archiving was weak and insufficient to retroactively manipulate, in addition, methodologies applied for the 1st NFI needed improvement to make the results suitable for the use under REDD+. Improved NFI methodologies were developed through field testing in 2013 - 2015[4] and a manual was developed[5]. Then, a full NFI campaign was conducted over the two dry seasons of 2015-2016 and 2016-2017.

**Objectives**

The objectives of the 2nd NFI was to survey the forest biomass[6] of the five natural forest classes of the whole country. (Excluding forest plantations due to its relatively small area and possible use of IPCC default factors; and bamboo (B) and regenerating vegetation (RV) which do not currently meet the status as forest under the Lao forest definition[7].) A standardized methodology and sample-based field measurements were applied.

**Survey outline**

**Survey schedule**

To meet Lao PDR's target to complete the national FREL/FRL by the end of 2017:

- A part of the three natural forest classes (EG, CF, MCB) were surveyed in the dry season of 2015-16 with Forest Type Map (FTM) 2010 for distributing the sampling plots (as FTM 2015 was not yet completed); and

- Remaining part of EG, CF and MCB plus all MD and DD natural forest classes were surveyed in the dry season of 2016-17 with FTM 2015 for distributing the sampling plots.

A total of 560 survey plots were distributed across the five forest classes through systematic-random-sampling (see Figure 2-1). Lands classified as non-forest were not sampled. It is recognized that this may bias the resulting estimates, but the bias is not expected to be significant.

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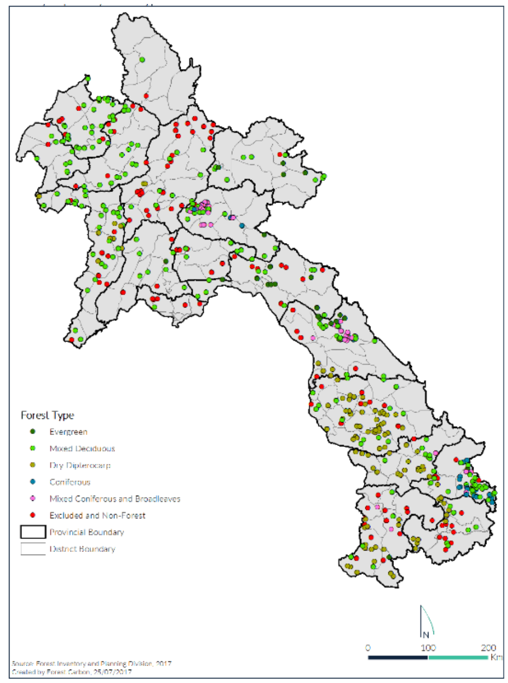
[3] See DOF, et al. (2017). "The 2nd National Forest Inventory Survey <http://dof.maf.gov.la/en/home/> for more details.
[4] Capacity Development Project for Establishing National Forest Information System for Sustainable Forest Management and REDD (NFIS) (2013 – 2015) under JICA.
[5] Lao PDR National Forest Inventory Standard Operating Procedures (SOP) Manual for Terrestrial Carbon Measurement.
[6] The main target of the survey was to measure the forest biomass, however, other information, such as observed disturbances were also recorded.
[7] Lao's forest definition includes: Minimum DBH of 10cm, minimum crown density of 20%, minimum area of 0.5ha.

Figure 2-1: Surveyed plot by forest class in the 2nd NFI




**Survey team**

The survey teams were composed of different institutions including FIPD as the responsible agency, and Provincial Agriculture and Forest Office (PAFO), District Agriculture and Forest Office (DAFO) and villagers as the partners in each province. In total, six survey teams were formed to execute the field survey.

**Plot design**

The 'floating cluster design' as described in Figure 2-2 was used, where the first sub-plot (sub-plot A) was laid out with an anchor point placed in the plot center, and three additional sub-plots (B, C, D) were randomly placed within a 300 m radius of the anchor point, however, the sub-plot centers could not be closer than 75 m from each other nor the anchor point.

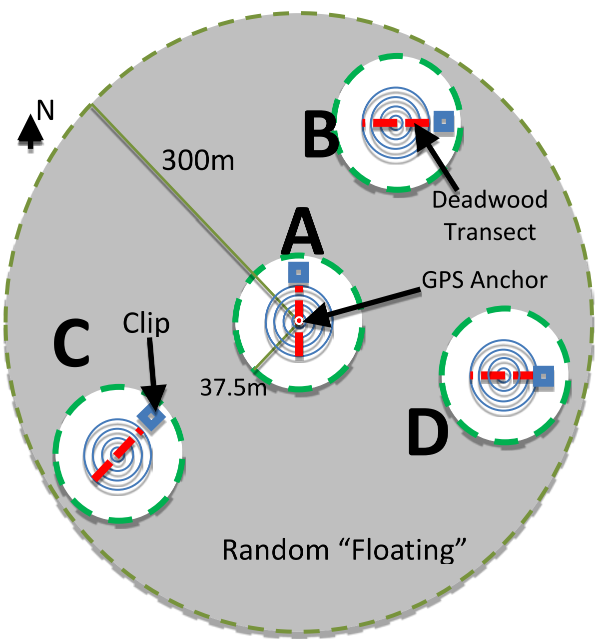



**Figure 2-2: Floating cluster design**

The following circular nest sizes are shown for each stratum as below. Each stratum was given different tree DBH groups to measure (See Figure 2-3).

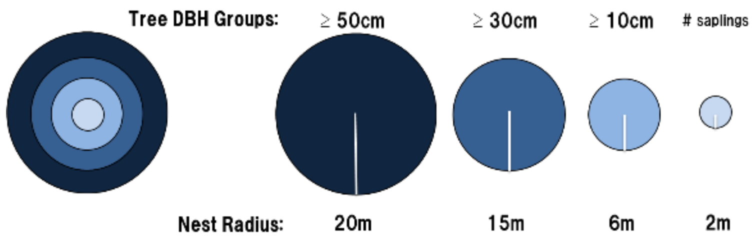



**Figure 2-3: Nested circle plots**

**Carbon pools measured**

AGB (standing trees, saplings, non-tree vegetation (NTV), bamboo) and Dead Wood (standing and lying deadwoods, tree stumps), were measured.

**Results**

Across the five forest classes surveyed, among the 559 plots distributed, a total of 420 plots were included in the estimation of forest carbon stocks. The remaining 139 plots were not included because of their land condition (contrary to the identification from the FTM, the land was actually found as non-forest in the field survey), and conflict in forest classes (the plots with 2 x forest class A and 2 x forest class B were excluded). The resulting average forest carbon stock by forest class, for the national level are shown in the Annex 1.

## 2.2 Biomass data of Regenerating Vegetation from the "RV survey"[8]

**Background**

In Lao PDR, annually around 100,000-150,000 ha of forest lands are burned for shifting cultivation (including rotational and pioneering practices). The area is cultivated for a short period, often one year, and then left to as fallow to regenerate as "Regenerating Vegetation (RV)" which covered around 25% of the total area of Laos in 2015. Quantification of biomass from this landscape had been a challenge due to limited availability of data and allometric models[9]. Furthermore, distinguishing RV class from 'forest' classes through remote sensing poses a big challenge[10].

[8] See, DOF, et al. (2017). Development of a Lao-specific Equation for the Estimation of Biomass of 'Regenerating Vegetation' and Determination of the Threshold Years for its Regeneration into Forest. <http://dof.maf.gov.la/en/home/> for more details.

[9] Kiyono, et.al (2017) developed predicting models of biomass from the data of 'abandoned year' (fallowed year) and 'abandoned year average carbon stocks'. But this survey was conducted only in Luangprabang province, a northern province, thus, not suitable to represent the entire country.

[10] Among the stages of shifting cultivation, RV and Mixed Deciduous Forest (MD) are continuous phases of regeneration in many cases, and old RV and young MD have very similar color tone and texture on satellite imagery, thus, distinguishing the two in a single satellite imagery faces technical challenges. This is in part addressed through analysis using multi-temporal remote sensing imagery.

**Objectives**

The objective of the 'RV Survey' was to survey the number of years of fallow required to regenerate to meet the forest definition (i.e. the threshold year), and also to survey the biomass of RV of different fallow years to estimate the average biomass.

**Survey outline**

Survey clusters were selected from the annual vegetation loss dataset of Hansen et al[11] to detect the year of loss on forest loss plots, then ground truthed and measured the crown cover to determine whether it had reached the forest status[12] or not. For each survey plot, the year of forest loss was further verified by interviewing the villagers. Only the plots confirmed as RV were measured. A total of 120 survey plots (40 survey clusters with three survey plots each) were surveyed in five provinces (Table 2-1).

**Table 2-1: Number of RV Survey clusters in each region/province**

| Region | Province | Years after cropping | Number of Cluster | Subtotal |
|---|---|---|---|---|
| North | Bokeo | 1,2,3,4,5,6,7,8 | 1 x 8 | 8 |
| North | Xayabouly | 1,2,3,4,5,6,7,8 | 1 x 8 | 8 |
| North | Xiengkhouang | 1,2,3,4,5,6,7,8 | 1 x 8 | 8 |
| Central | Bolikhamxay | 1,2,3,4,5,6,7,8 | 1 x 8 | 8 |
| South | Xekong | 1,2,3,4,5,6,7,8 | 1 x 8 | 8 |
| | | | **Total** | **40** |

Below figure shows the plot design. In each plot (10 m*10 m square design)and DBH (≧5 cm) for all trees was recorded, and all other vegetation were cut at their base in the four corners of the sub-plots (size of 1m*1m or 2m*2m depending on the vegetation height to weigh the non-tree biomass).

Since the most common forest type for RV to regenerate into is MD forests, the tree biomass of RV was estimated by applying the allometric equation developed for MD forest class (AGB=0.407*DBH^2.069), and the biomass of NTV (DBH < 5cm) were also estimated by using dry-wet ratio originating from the samples of the MD forest class.

Unmanned aerial vehicles (UAV) were used to take aerial photographs of the plots in order to estimate the crown cover rate, which was then used for identifying the number of years for RV to reach the forest

[11] Hansen, M. C., P. V. Potapov, R. Moore, M. Hancher, S. A. Turubanova, A. Tyukavina, D. Thau, S. V. Stehman, S. J. Goetz, T. R. Loveland, A. Kommareddy, A. Egorov, L. Chini, C. O. Justice, and J. R. G. Townshend. 2013. "High-Resolution Global Maps of 21st-Century Forest Cover Change." Science 342 (15 November): 850–53. Data available on-line from: http://earthenginepartners.appspot.com/science-2013-global-forest.

[12] Minimum DBH of 10cm, Minimum crown density of 20%, minimum area of 0.5ha.

threshold. Only the biomass from RV plots which were below 7 years of fallow was counted in the calculation (i.e. the plots which were already beyond 7 years of fallow were regarded as MD class and not included in the calculation).

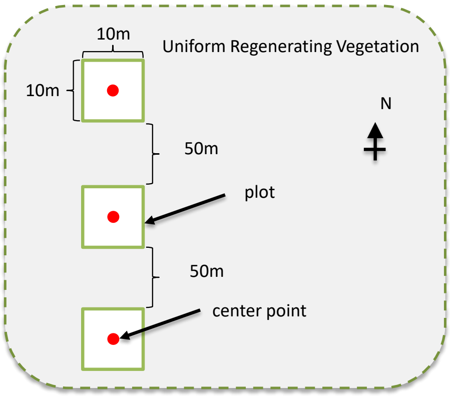



**Figure 2-4: Clusters with three ranged square plots**

**Results**

The following model using the number of years under fallow was developed.

*AGB = 1.7573e$^{0.4107Y}$ ($R^2$ = 0.7224)*

The results of survey showed that the number of years for RV to reach the forest threshold was on average 7 years. By adding one year for cropping (classified as "UC"), it was assumed that a land slashed and burnt could potentially regenerate into forest status in 8 years if left undisturbed.

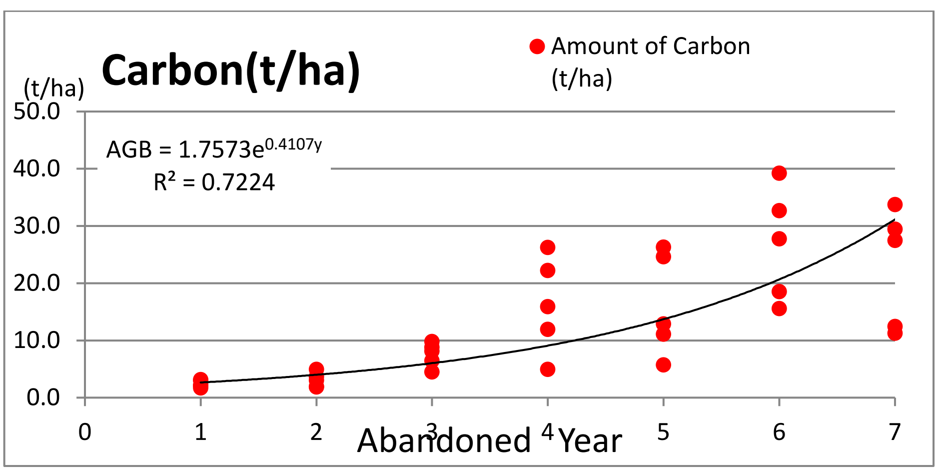



**Figure 2-5: Carbon stock of plots**

The total area of each age class of RV (1 year, 2 year, etc.) is not even, since different amount of lands are subject to slash and burn every year. This survey distributed an equal number of 5 clusters for each year of the RV age class without considering variations in size of age classes.

## 2.3 Allometric equations for the three major forest classes[13]

**Background**

For REDD+, a country is requested, as feasible, to accurately estimate its forest carbon stock and changes, by using country-specific data and periodic measurement of the parameters. Development of country-specific allometric equations enable Lao PDR to improve the estimates of forest biomass in combination with the data collected through the 2nd NFI.

**Objectives**

To improve the accuracy of forest biomass estimation, conduct destructive measurement of trees to develop country-specific allometric equations for the three major forest classes[14]; Evergreen Forest (EG), Mixed Deciduous Forest (MD) and Dry Dipterocarp Forest (DD).

**Survey outline**

The allometric equations were developed by taking a total of 36 sample trees from each forest class (i.e. EG, MD and DD) with a variety of DBH and regional balance (See Table 2-2). Deadwood and saplings were also sampled.

All destructive field and laboratory sampling methods for trees, deadwood and saplings are based on Winrock International's standard operating procedures (Walker et al. 2014) and the FIPD/DOF survey teams were trained on the survey methods according to its procedures.
The samples were dried at 100°C using drying ovens to measure the dry weight.
Several regression models were applied to develop the allometric equations with R software.

**Table 2-2: Survey sites for each forest type in AE survey**

| Forest class | Province | Region | Number of Tree | Minimum DBH(cm) | Maximum DBH(cm) |
|---|---|---|---|---|---|
| EG | Xayabouly | North | 12 | 14.0 | 59.3 |
| | Bolikhamxay | Central | 12 | | |
| | Attapeu | South | 12 | | |
| MD | Bokeo | North | 12 | 15.0 | 85.0 |
| | Khammouane | Central | 12 | | |
| | Attapeu | South | 12 | | |
| DD* | Khammouane | Central | 18 | 16.0 | 67.0 |
| | Attapeu | South | 18 | | |

* DD occurrence in the Northern region is limited.

[13] See DOF, et al. (2017). "Development of country-specific allometric equations in Lao PDR" <http://dof.maf.gov.la/en/home/> for more details.
[14] The 3 forest classes cover 66% of the total forest land of Lao PDR (EG: 13%, MD: 47%, DD: 6%) in 2015.

**Results**

The allometric equations were developed for each forest class as regression lines with a power approximation under the FAO manual (Picard et al. 2012). Among 10 possible regression lines for each forest class, one regression model was selected as below. Compared to the allometric equations developed for other forests in South-East Asia[15], the Lao-specific equations result in estimating lower biomass. Although the original data from this survey show that the highest biomass is approximately 4,300 kg, it seems reasonable and conservative to apply the equations to the obtained data that is out of DBH range.

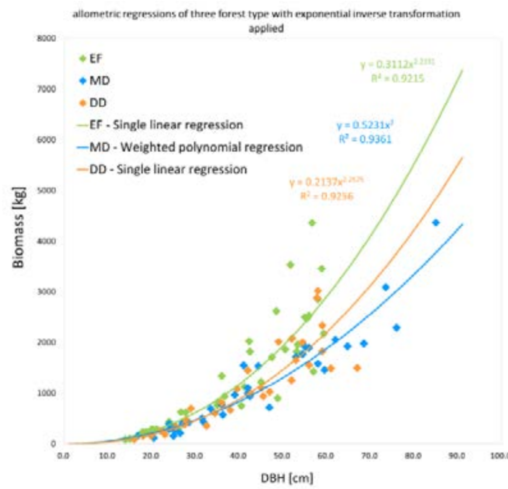



**Figure 2-4: Allometric regressions of three forest types**

**Table 2-3: Allometric equation for three forest types**

| Forest Type | Equation | Number of sample trees | $R^2$ | AIC |
|---|---|---|---|---|
| EG | $AGB = 0.3112\ x\ DBH^{2.2331}$ | 36 | 0.9215 | 18.84 |
| MD | $AGB = 0.5231\ x\ DBH^{2}$ | 35 | 0.9081 | 477.24 |
| DD | $AGB = 0.2137\ x\ DBH^{2.2575}$ | 35 | 0.9256 | 10.53 |

## 3. Estimation Methods of biomass and carbon stock

The following parts explain the methodologies applied for converting the measured forest biomass into carbon stock and then to tCO2e.

### 3.1 Estimation of biomass by land/forest class

Three carbon pools were considered for the measurement of forest biomass: Above Ground Biomass (AGB) from direct measurement and including living trees, saplings, bamboo and other non-timber vegetation (NTV); Dead Wood (DW) from direct measurement and including standing DW, stumps and lying DW; and Below Ground Biomass (BGB) using the IPCC default values.

As explained in Chapter 2, the biomass of the five forest classes were estimated from the measurement results of the 2nd NFI. Meanwhile, the biomass of RV was estimated separately using the measurement results from the RV survey. These two results are explained separately in the following sections.

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[15] Allometric equations for Lao(Luang Prabang) Evergreen and Mix deciduous forest (PAREDD+,2015); Cambodia Dry Dipterocarp forest (Monda et al, 2016)

### 3.1.1 Above Ground Biomass (AGB)

#### 3.1.1.1 AGB of the five forest classes

The biomass of a plot surveyed in the 2nd NFI is calculated from the average stock of sub-plots. Then, average biomass stock for each forest class is calculated from the average stock of all plots.

LIVING TREES

The calculation of the biomass in kg for each tree by applying the appropriate allometric equations to the trees in different forest classes (See Table 3-1). The allometric equations for EG, MD and DD forest class were developed for Lao PDR, and the allometric equations developed in neighboring Vietnam were used for CF and MCB forests. Secondly, the biomass per tree is then converted into biomass per ha, and summed for subplots.

**Table 3-1: List of allometric equation for calculating tree AGB.**

| C pool | Forest class | Equation | Source |
|---|---|---|---|
| **AGB (living trees and dead standing trees)** | EG | *AGB (kg/tree) =0.3112 x DBH^2.2331* | JICS (2017), Development of specific allometric equations in Lao PDR. |
| | MD | *AGB (kg/tree) =0.523081 x DBH^2* | |
| | DD | *AGB (kg/tree) =0.2137 x DBH^2.2575* | |
| | CF | *AGB (kg/tree) =0.1277xDBH^2.3944* | Hung et al (2012), Tree allometric equation development for estimation of forest above-ground biomass in Viet Nam. |
| | MCB | *AGB (kg/tree) =0.1277xDBH^2.3944* | |

SAPLINGS

The saplings are defined as trees with height >1.3 m and 0 < DBH <10 cm. The biomass of saplings are estimated from the number of saplings in the first nest multiplied by the average dry weight of saplings of the same forest class (See Table 3-2). Average dry weight were measured only for the EG, MD and DD forests, and the average value of these three forest classes were used for the other two (i.e. CF, MCB).

**Table 3-2: Average dry weight/tree of saplings by forest type**

| Forest class | Average dry weight | Source |
|---|---|---|
| **EG** | 113 g | JICS (2017), Development of specific allometric equations in Lao PDR". |
| **DD** | 252 g | |
| **MD** | 191 g | |
| **Others** | 184 g | |

BAMBOO

For the measurement of biomass of bamboo poles, average diameter of five bamboo poles sampled per sub-plot was calculated and the allometric equation for bamboo developed in Vietnam was used[16]. Then the biomass of individual poles was multiplied by the number of poles of the clump and an expansion factor (Equation 1) to estimate the bamboo biomass per ha.

**Equation 1: Allometric equation for bamboo biomass (kg) from Hung et al. (2012) [17]**

$$GB\ (kg/pole) = 0.1006 \times D^{2.222}$$

Where:

D = diameter of the bamboo pole (cm)

NON TREE VEGETATION (NTV)

NTV were measured in each sub-plot by establishing a small plot (50cm*50cm). All vegetation, except for the living trees, saplings and bamboos were taken and measured for weight. Samples were brought back to the laboratory to measure the dry-wet ratio.

**Table 3-3: Average carbon stock of non-timber vegetation (NTV) by forest class**

| Forest class | Sample size | C stock (tC/ha) | Source |
|---|---|---|---|
| **EG** | 78 | 1.12 | JICA(2017), 2nd National Forest Inventory Survey in Lao People's Democratic Republic |
| **MD** | 358 | 1.09 | |
| **DD** | 84 | 0.5 | |
| **CF** | 133 | 0.75 | |
| **MCB** | 764 | 0.57 | |

### 3.1.1.2 AGB of Regenerating Vegetation (RV)

The biomass of RV, including trees, NTV, bamboo and saplings, were measured through the "RV Survey" (see Section 2.2). The estimation of carbon stock of RV, however, has a higher degree of uncertainty due to the high diversity of different vegetation species (including bamboo), topographic factors, and human factors associated to the land.

## 3.1.2 Dead Wood

Dead Woods (DW) consists of standing trees, stumps and lying trees.

STANDING DEADWOOD

Standing DW were separated into two categories, i.e. Category 1: dead trees with twigs and branches; and Category 2: dead standing trees without branches, which was further separated into short trees and

[16] Hung et al. (2012). This equation was developed by using the 120 sample trees and expected value of error (%) is 0.327.

tall trees. The Category 2 trees were treated as conical cylinders, and the biomass of the Category 1 trees was calculated with respective allometric equations (See Table 3-1).

STUMPS

The biomass of stumps was calculated assuming a cylindrical shape multiplied by wood density Equation 2):

**Equation 2: Equation for the estimation of stump biomass ($B_{stump}$ in kg) [18]**

$$B_{stump} = \left( \left( \left( D_{mean}/2 \right)^2 \times \pi \right) \times H_{stump} \right) \times WD \times 0.001$$

Where:

$D_{mean}$ = mean diameter (cm)

$H_{stump}$ = height of the stump

WD = wood density (0.57 $g/cm^3$)

LYING DEADWOOD

Lying DW was separated into 2 categories, i.e. hollow and solid, and the latter was further separated by three density classes (i.e. sound, intermediate, and rotten; Table 3-4). The volume of solid dead wood was calculated as a cylinder, whereas hollow dead wood was calculated as the difference between the outer cylinder and inner cylinder.

**Table 3-4: Lying deadwood densities ($g/cm^3$) by density class and forest type**

| Forest type | Density class | Density ($g/cm^3$) | Source |
|---|---|---|---|
| **EG** | Sound | 0.39 | JICS (2017), Development of specific allometric equations in Lao PDR. |
| | Intermediate | 0.34 | |
| | Rotten | 0.26 | |
| **DD** | Sound | 0.44 | |
| | Intermediate | 0.35 | |
| | Rotten | 0.32 | |
| **MD** | Sound | 0.45 | |
| | Intermediate | 0.3 | |
| | Rotten | 0.29 | |
| **Other** | Sound | 0.44 | |
| | Intermediate | 0.33 | |
| | Rotten | 0.3 | |

[18] Goslee, et al (2015), P.37, equation 53.

### 3.1.3 Below Ground Biomass (BGB)

The BGB was estimated by using the best available Root-to-Shoot (R/S) ratios corresponding to each forest class and their average AGB.

**Table 3-5: Root-to-Shoot rations by forest type and AGB threshold**

| Forest type | AGB threshold | Root-to-Shoot ratio (R/S ratios) | Source |
|---|---|---|---|
| **EG, DD, MD, and MCB** | AGB < 125t/ha | 0.20 | IPCC GL 2006 for National Greenhouse Gas Inventories (Chapter 4: Forest land, Table 4.4) |
| | AGB > 125t/ha | 0.24 | |
| **CF** | AGB < 50t/ha | 0.46 | 2003 IPCC Good Practice Guidance for LULUCF (Chapter 3: LULUCF Sector Good Practice Guidance, Table 3 A.1.8) |
| | AGB = 50 - 150t/ha | 0.32 | |
| | AGB > 150t/ha | R/S = 0.23 | |
| **Plantation** | AGB<50t/ha | 0.46 | 2003 GPG(Anx_3A_1_Data_Tables3A.1.8) |
| | AGB=50-150t/ha | 0.32 | 2003 GPG(Anx_3A_1_Data_Tables3A.1.8) |
| | AGB>150t/ha | 0.23 | 2003 GPG(Anx_3A_1_Data_Tables3A.1.8) |
| **Bamboo** | | 0.82 | Junpei Toriyama (http://www.ipcc-nggip.iges.or.jp/EFDB/main.php) |
| **RV** | AGB<20t/ha | 0.56 | IPCC GL 2006 (V4_04_Ch4_Table4.4) |
| | AGB>20t/ha | 0.28 | IPCC GL 2006 (V4_04_Ch4_Table4.4) |

## 3.2 Conversion of biomass to carbon stock

The estimated biomass was converted into carbon stock with the generic formula below:

$$Ci = TBi \times CF$$

Where:

*TBi* = total biomass of plot *i* (include AGB and BGB), expressed in kg.

*CF* = IPCC default carbon fraction value 0.46 or 0.47 depending on the land/forest class (2006 IPCC GL Volume 4, Chapter 4)

The detailed table summarizing the results is shown in the Annex 2 of this report.

## 3.3 Conversion of carbon stock (tC) into tCO2e

The generic formula suggested in the IPCC GL 2006 below was used to convert carbon stock (tC) into tCO2e, and then the final E/R factors were determined.

$$EF\ or\ RFij\ (tCO2e/ha) = (Ci - Cj\ ) \times 44/12$$

Where:

*EF or RFij* = is EF or RF when the change incurred from land use *i* to land use *j*.

*Ci* and *Cj* = is carbon stock per ha of land/forest class *i* and *j* corresponding to the changes;

44/12 is the ratio of carbon mass to CO2 mass.

If C*i* > C*j*, such change is considered emissions;

If C*i* < C*j*, such change is considered removal.

## 3.4 Estimation of carbon stock after stratification

In order to reduce uncertainty of emissions and removals while balancing the accuracy of sampling and the cost/efforts required, the land/forest classification was collapsed into five strata as below:

- Evergreen Forest (EG) has distinctly high carbon stocks (200.0tC), thus, separated as an independent stratum – Stratum 1 (expanse: 2,605,557ha, 11.3% of the total land area).

- Mix Deciduous Forest (MD), Conifer Forest (CF) and Mixed Coniferous and Broadleaved Forest (MCB) will form one stratum on the basis of similarity in carbon stocks per hectare (87.7tC, 92.6tC, 114.7tc). – Stratum 2 (expanse: 9,437,688ha, 40.9% of the total land area).

- Dry Dipterocarp Forest (DD) will form one stratum due to the difference in carbon stock from other forest classes (43.2tC), and also due to the fact that they are mostly distributed in the low-lands and prone to conversion to other land use – Stratum 3 (expanse: 1,188,198ha, 5.2% of the total land area).

- Plantation (P), Bamboo (B) and Regenerating Vegetation (RV) will form one strata on the basis of similarity in average carbon stock (37.2tC, 24.4tC, 17.4tC) – Stratum 4 (expanse: 6,300,445ha, 27.3% of the total land area).

- The remaining 12 non-forest classes will form one stratum – Stratum 5 (expanse: 3,522,370ha, 15.3% of the total land area).

The average carbon stock for the new strata was calculated by using weighted value as follows:

$$Cstrata\ (tC/ha) = (C1*A1+ C2*A2+....+Cn*An)/(A1+A2+....+An)$$

Where:

*Cstrata* = average carbon stock (tC/ha) of new strata calculated from biomass and area of land/forest class;

*Ci* = carbon stock of land/forest class (tC/ha);

*Ai* = area (ha) of land/forest class in 2015.

# 4. Result

## 4.1 Average carbon stock

The average carbon stock of the five forest classes from the 2nd NFI data are shown in Table 4-1. Only AGB and BGB were selected as the carbon pools to be accounted and DW is not accounted. The average carbon stock (and tCO2e) for the remaining land/forest classes are calculated based on the IPCC default value (IPCC GL 2006) and other available sources, except for RV which uses the results of the "RV Survey".

**Table 4-1: Average carbon stock (tC/ha) of the 5 strata**

| Strata | tC/ha |
|---|---|
| **Stratum 1 (EG)** | 200.0 |
| **Stratum 2 (MD/CF/MCB)** | 88.1 |
| **Stratum 3 (DD)** | 43.2 |
| **Stratum 4 (P/B/RV)** | 17.9 |
| **Stratum 5 (NF)** | 4.9 |

## 4.2 Emission/Removal Factors

The E/R Factors are developed by taking the difference in average carbon stock (as tCO2e) of each forest/land strata as shown in following Table 4-2.

**Table 4-2: Emission/Removal Factors (tCO2e/ha)**

| | Stratum 1 (EG) | Stratum 2 (MD/CF/MCB) | Stratum 3 (DD) | Stratum 4 (P/B/RV) | Stratum 5 (NF) |
|---|---|---|---|---|---|
| **Stratum 1 (EG)** | | -410.5 | -575.1 | -667.6 | -715.4 |
| **Stratum 2 (MD/CF/MCB)** | 410.5 | | -164.6 | -257.1 | -304.9 |
| **Stratum 3 (DD)** | 575.1 | 164.6 | | -92.6 | -140.3 |
| **Stratum 4 (P/B/RV)** | 667.6 | 257.1 | 92.6 | | -47.8 |
| **Stratum 5 (NF)** | 715.4 | 304.9 | 140.3 | 47.8 | |

# 5. Discussion

## 5.1 Usability of the 1st NFI data

The 1st NFI conducted in 1991-1999 measured the forest biomass of the entire country, however, applying a different methodology from the 2nd NFI. Table 5-1 shows the comparison of survey contents and design between the 1st and 2nd NFIs. Some surveyed items are comparable, however, many others are not, and some of the results from the 1st NFI are not sufficient against the requirements under REDD+.

The major shortcoming of the 1st NFI is that the survey plots were selected only from easily accessible area, thus have significant problems in data representativeness. Also, there is a gap of nearly 20 years between the 1st NFI and the 2nd NFIs, and the forests of Lao PDR have experienced significant changes during this period.

For the reasons above, Lao PDR considered that the 1st NFI shall not be used in the construction of both, the national FREL/FRL.

**Table 5-1: Comparison of the 1st and 2nd NFIs**

| | 1st NFI | 2nd NFI |
|---|---|---|
| **Main Objectives** | - Estimate growing stock<br>- Development of volume functions<br>- Use for reviewing the forest definition | - Estimate forest biomass/carbon stock |
| **Target area** | Nation wide<br>(Only easily accessible areas, random sampling) | Nation wide<br>(areas of five natural forest classes covering 13,231,443ha (57.4% of the national land area), random sampling) |
| **Implementation Year** | 1991-1999 | 2016-2017 |
| **Number of plots** | Forest: 2,368 plots | Forest: 420 plots |
| **Survey class** | 6 natural forest, 4 potential forests and others | 5 natural forests |
| **Plot design, shape, location, etc.** | | |
| **Single plots** | | |
| **Cluster plots** | X | X |
| **Rectangular plots** | X | |
| **Circular plots** | | X |
| **Forest classification** | X | X |
| **Location information (Latitude/longitude coordinates)** | Province name only | X |
| **Photographs of the plots** | | X |
| **Living trees** | X | X |

| | | |
|---|---|---|
| DBH | X | X |
| Diameters at middle and top of bole | X | |
| Tree height | X | |
| Tree quality | X | |
| Population of saplings | X | X |
| Canopy density | X | |
| Non-forest class | X | X |
| Forest structure | X | |
| Species (local name) | X | X |
| Species (Scientific name) | | X |
| Slope | X | X |
| **Stumps** | X | X |
| Diameter | X | X |
| Height | X | X |
| **Non-tree vegetation** | | X |
| Fresh mass | | X |
| Dry mass | | X |
| **Standing dead trees** | | X |
| DBH | | X |
| Height | | X |
| **Lying Dead Wood** | | X |
| Diameter | | X |
| Density | | X |
| Decomposition class | | X |
| **Litter** | | |
| Fresh mass | | |
| Dry mass | | |
| **Soil** | X | |
| Soil type | X | |
| Bulk density | | |
| Organic carbon content | | |
| **NTFP** | X | X |
| **Rattan** | X | |
| **Bamboo** | X | X |

## 5.2 Exclusion of Deadwood from the carbon pool

The 2nd NFI included measurement of DW. As shown in Table 5-3, historical results showed that emissions from DW through deforestation accounts for only 2.3% of the sum of the AGB, BGB, and DW, therefore, considered insignificant. It should also be noted that the uncertainty of DW was relatively high.

**Table 5-2: Carbon stock and uncertainty by different pools**

| | AGB+BGB | DW | | DW/(AG+BG+DW) |
|---|---|---|---|---|
| | Average (tC/ha) | Average (tC/ha) | Uncertainty (95%) | Ratio (%) |
| **EG** | 200.0 | 10.4 | 28.5 | 4.9 |
| **MD** | 87.7 | 6.4 | 21.7 | 6.8 |
| **DD** | 43.2 | 2.4 | 20.5 | 5.3 |
| **CF** | 92.6 | 3.0 | 64.3 | 3.1 |
| **MCB** | 114.7 | 9.0 | 49.8 | 7.3 |

**Table 5-3: Emission from deforestation by DW pool**

| | AG+BG MtCO2/year | DW MtCO2/year | DW/ (AG+BG+DW) |
|---|---|---|---|
| **National** | 25.02 | 0.59 | 2.3% |

Emission from DW pool shown in Table 5-3 does not include emission from forest degradation for the reason that main source of emission from forest degradation is caused by conversion of forest to RV. Nevertheless, there is no measurement data of DW in RV (therefore, not accounted). There is a concern that inclusion of DW in forest degradation may result in inconsistent estimation and causing possibility of overestimation. Therefore, DW is determined not to be included in the current estimation of E/R factors.

# 6. Conclusion and areas for future improvement

This report presented the E/R Factor estimated by the 2nd NFI data, RV survey and allometric equations including country-specific ones for Lao PDR. The potential use of a) data from the 1st NFI and c) inclusion of DW as a carbon pool were considered.

As a result, from the perspective of data representativeness of the 1st NFI and the time gap between the 1st and the 2nd NFI, Lao PDR considers that the 1st NFI data should not be used for constructing E/R factors. Emissions from DW have historically been recorded to be insignificant and therefore omitted.

Potential improvements in future E/R factor as below.

- Carbon stock of RV

  The carbon stock of Regenerating Vegetation (RV) was calculated from the average carbon stock of each year. Since this survey distributed five clusters for each year of fallow, variations in the area of RV for each year are not considered. Therefore, there is a limitation in the representativeness of data and resulting uncertainty was relatively high. For future NFIs, the number of years after abandonment is suggested to include as survey item with support from remote sensing. The future survey of the carbon stock of RV should also consider including measurement of DW.

- Continuous improvement of E/R factors

  Default value from the IPCC GLs were used to estimate carbon stock for some of the land/forest classes where country-specific data do not exist. These are potential areas for improvement in order to reduce the uncertainty of E/R factors. As allometric equations for minor forest classes used ones from neighboring country (i.e. Vietnam), developing country-specific allometric equation for minor forest classes shall contribute to reducing the uncertainty. Also, as Lao PDR considers to account non-CO2gas from field burning, developing a country-specific biomass combustion factor which can be applied for slash and burn activities shall be considered

## 7. References


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## Annex 1: Carbon Stocks per Land/Forest classes and sources of data

| IPCC definitions | Level 1 | Level 2 | tC/ha | tCO2/ha | Data source |
|---|---|---|---|---|---|
| Forest Land | **Current Forest** | Evergreen Forest | 200.0 | 733.4 | 2nd NFI_Lao original AE |
| | | Mixed Deciduous Forest | 87.7 | 321.5 | 2nd NFI_Lao original AE |
| | | Dry Dipterocarp Forest | 43.2 | 158.3 | 2nd NFI_Lao original AE |
| | | Coniferous Forest | 92.6 | 339.6 | 2nd NFI_Vietnam AE |
| | | Mixed Coniferous and Broadleaved Forest | 114.7 | 420.7 | 2nd NFI_Vietnam AE |
| | | Forest Plantation | 37.2 | 136.5 | GPG GL(2003) Anx_3A_1_Data_Tables(Other species) |
| | **Potential Forest** | Bamboo | 24.4 | 89.5 | Vietnam modified REL report |
| | | Regenerating Vegetation | 17.4 | 63.8 | RV survey |
| Grassland | **Other Vegetated Areas** | Savannah | 16.4 | 60.0 | IPCC EF DB 513130 |
| | | Scrub | 38.6 | 141.7 | 2006 IPCC guideline V4 Chp4 Table4.7 |
| | | Grassland | 7.4 | 27.2 | LULUCF Sector Good Practice Guidance P3.109 Table3.4.2 |
| Wetland | | Swamp | 0 | 0 | No default value |
| Cropland | **Cropland** | Upland Crop | 5.0 | 18.3 | LULUCF Sector Good Practice Guidance P3.88 Table3.3.8 (Annual) |
| | | Rice Paddy | 5.0 | 18.3 | LULUCF Sector Good Practice Guidance P3.88 Table3.3.8 (Annual) |
| | | Other Agriculture | 2.6 | 9.5 | LULUCF Sector Good Practice Guidance P3.88 Table3.3.8 (Perenial) |
| | | Agriculture Plantation | 38.8 | 142.3 | IPCC EF DB 511318 other species |
| Settlements/ Other land /Wetlands | **Non Vegetated Areas** | Non Vegetated Areas/Other/Water | - | - | - |

# Annex 2: List of equation, root shoot ratio and carbon fraction

| | | AGB | | AGB→BGB | | | Biomass→Carbon | |
|---|---|---|---|---|---|---|---|---|
| **Level 1** | **Level 2** | Allometric Equation | Data source | Condition | Conversion Factor | Data source | Conversion Factor | Data source |
| **Current Forest** | Evergreen Forest | AGB=0.3112 x DBH^2.2331 | JICS Forest Preservation Programme TA6 Final report | AGB<125t/ha | 0.20 | 2006 GL(V4_04_Ch4_Table4.4) | 0.47 | 2006 IPCC GL for National GHGi_V4_04_Ch4_Forest_Land |
| | | | | AGB>125t/ha | 0.24 | 2006 GL(V4_04_Ch4_Table4.4) | 0.47 | 2006 IPCC GL for National GHGi_V4_04_Ch4_Forest_Land |
| | Mixed Deciduous Forest | AGB=0.523081 x DBH^2 | JICS Forest Preservation Programme TA6 Final report | AGB<125t/ha | 0.20 | 2006 GL(V4_04_Ch4_Table4.4) | 0.47 | 2006 IPCC GL for National GHGi_V4_04_Ch4_Forest_Land |
| | | | | AGB>125t/ha | 0.24 | 2006 GL(V4_04_Ch4_Table4.4) | 0.47 | 2006 IPCC GL for National GHGi_V4_04_Ch4_Forest_Land |
| | Dry Dipterocarp Forest | AGB=0.2137 x DBH^2.2575 | JICS Forest Preservation Programme TA6 Final report | AGB<125t/ha | 0.20 | 2006 GL(V4_04_Ch4_Table4.4) | 0.47 | 2006 IPCC GL for National GHGi_V4_04_Ch4_Forest_Land |
| | | | | AGB>125t/ha | 0.24 | 2006 GL(V4_04_Ch4_Table4.4) | 0.47 | 2006 IPCC GL for National GHGi_V4_04_Ch4_Forest_Land |
| | Coniferous Forest | AGB=0.1277xDBH^2.3944 | UN-REDD Programme, Hanoi, Viet Nam(2012). | AGB<50t/ha | 0.46 | 2003 GPG(Anx_3A_1_Data_Tables3A.1.8) | 0.47 | 2006 IPCC GL for National GHGi_V4_04_Ch4_Forest_Land |
| | | | | AGB=50-150t/ha | 0.32 | 2003 GPG(Anx_3A_1_Data_Tables3A.1.8) | 0.47 | 2006 IPCC GL for National GHGi_V4_04_Ch4_Forest_Land |
| | | | | AGB>150t/ha | 0.23 | 2003 GPG(Anx_3A_1_Data_Tables3A.1.8) | 0.47 | 2006 IPCC GL for National GHGi_V4_04_Ch4_Forest_Land |
| | Mixed Coniferous and Broadleaved Forest | AGB=0.1277xDBH^2.3944 | UN-REDD Programme, Hanoi, Viet Nam(2012). | AGB<125t/ha | 0.20 | 2006 GL(V4_04_Ch4_Table4.4) | 0.47 | 2006 IPCC GL for National GHGi_V4_04_Ch4_Forest_Land |
| | | | | AGB>125t/ha | 0.24 | 2006 GL(V4_04_Ch4_Table4.4) | 0.47 | 2006 IPCC GL for National GHGi_V4_04_Ch4_Forest_Land |
| | Forest Plantation | Use IPCC default value | IPCC EF DB 511220 Broad leaf) | AGB<50t/ha | 0.46 | 2003 GPG(Anx_3A_1_Data_Tables3A.1.8) | 0.47 | 2006 IPCC GL for National GHGi_V4_04_Ch4_Forest_Land |
| | | | | AGB=50-150t/ha | 0.32 | 2003 GPG(Anx_3A_1_Data_Tables3A.1.8) | 0.47 | 2006 IPCC GL for National GHGi_V4_04_Ch4_Forest_Land |
| | | | | AGB>150t/ha | 0.23 | 2003 GPG(Anx_3A_1_Data_Tables3A.1.8) | 0.47 | 2006 IPCC GL for National GHGi_V4_04_Ch4_Forest_Land |
| **Potential Forest** | Bamboo | | | | 0.82 | Junpei Toriyama(http://www.ipcc-nggip.iges.or.jp/EFDB/main.php) | 0.46 | 2006 IPCC GL for National GHGi_V4_04_Ch4_Forest_Land |
| | Regenerating Vegetation | AGB = 1.7573e0.4107Y Where: Y is abandoned years after cropland | FPP TA6 Final report | AGB<20t/ha | 0.56 | 2006 GL(V4_04_Ch4_Table4.4) | 0.46 | 2006 IPCC GL for National GHGi_V4_04_Ch4_Forest_Land |
| | | | | AGB>20t/ha | 0.28 | 2006 GL(V4_04_Ch4_Table4.4) | 0.46 | 2006 IPCC GL for National GHGi_V4_04_Ch4_Forest_Land |
| **Other Vegetated Areas** | Savannah | | | | 0.50 | GPG(Chp3_4_Grassland_Table3.4.3) | 0.46 | 2006 IPCC GL for National GHGi_V4_04_Ch4_Forest_Land |
| | Scrub | | | | 2.80 | GPG(Chp3_4_Grassland_Table3.4.3) | 0.46 | 2006 IPCC GL for National GHGi_V4_04_Ch4_Forest_Land |
| | Grassland | | | | 1.60 | GPG(Chp3_4_Grassland_Table3.4.3) | 0.46 | 2006 IPCC GL for National GHGi_V4_04_Ch4_Forest_Land |
| | Swamp | | | | | | | |
| **Cropland** | Upland Crop | | | According to GPG2000 Chp4 p.4.63, In the IPCC Guidelines' method for incorporation of crop residues, the contribution from root biomass from the harvested crop is not accounted for. Ideally, both the aboveground and the root biomass should be accounted for to include nitrogen from the total plant, but the root biomass cannot readily be estimated. | | | | |
| | Rice Paddy | | | | | | | |
| | Other Agriculture | | | | | | | |
| | Agriculture Plantation | | | AGB<50t/ha | 0.46 | 2003 GPG(Anx_3A_1_Data_Tables3A.1.8) | | |
| | | | | AGB=50-150t/ha | 0.32 | 2003 GPG(Anx_3A_1_Data_Tables3A.1.8) | | |
| | | | | AGB>150t/ha | 0.23 | 2003 GPG(Anx_3A_1_Data_Tables3A.1.8) | | |