Update of the Biomass Prediction Model for ‘Regenerating Vegetation’ in Lao PDR

And

Confirmation of the Threshold Years for its Regeneration into Forest

October 2019

Contents

Abbreviations

Abbreviation	Name
AGB	Above Ground Biomass
BGB	Blow Ground Biomass
CCR	Crown Cover Rate
CF	Current Forest
DAFO	District Agriculture and Forest Office
DBH	Diameter at Breast Height
DCA	Department of Civil Aviation
DOF	Department of Forestry
EG	Evergreen Forest
FIPD	Forestry Inventory and Planning Division
FREL/FRL	Forest Reference Emission Level/Forest Reference Level
GIS	Geographical Information System
MD	Mixed Deciduous Forest
NUoL	National University of Laos
PAFO	Provincial Agriculture and Forest Office
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
SOP	Standard Operation Procedure
StD	Standard Deviation

1. Executive Summary

Background

In the Lao People's Democratic Republic (hereafter referred to as "Lao PDR"), up to sixty to seventy thousand hectares (ha) of forest areas are affected by shifting cultivation every year. In shifting cultivation, an area is cultivated for a short period, often for one year, and then abandoned to regenerate as "Regenerating Vegetation" (RV). More than 25% of the total area of Lao PDR was covered by RV in 2019. Quantifying tree biomass in this landscape is limited by the availability of reliable allometric models. Furthermore, distinguishing between RV and "Current Forest" (CF) through remote sensing is very difficult.

To address this issue, the idea of using the number of years after the abandonment of upland cropping, sometimes referred as "fallow age", was applied in designing a survey. This survey is called the "1st RV Survey", and it was conducted in 2017. The purposes of the 1st RV Survey were as follows: 1) to develop a biomass prediction model in RV based on the number of years after the abandonment of cultivation on a national scale; and 2) to clarify the threshold number of years, the "threshold age", at which RV becomes CF on a national scale. The 1st RV Survey resulted in a biomass prediction model and showed that the threshold age is 7 years.

Even though the threshold age was determined to be 7 years on a national scale, it was pointed out that there should be regional differences. Thus, the regression model of Crown Cover Ratio (CCR) of three regions, North, Central and South, of Lao PDR should be developed and the threshold year of each region should be discussed. Given this, and because there are few data sets to use for discussion of regional difference, another survey called the "2nd RV Survey" was planned and conducted in 2019. Another concern is that deadwood biomass was not measured in the 1st RV survey and the biomes between RV and CF cannot be compared. The biomass estimation, including deadwood also in RV area, is important for the further improvement of carbon accounting in Lao PDR. The main purposes of the 2nd RV Survey were as follows: 1) to confirm the developed national threshold age at which RV becomes CF and also confirm regional threshold ages in North, Central and South; and 2) to develop a RV biomass prediction model based on the fallow age at a national scale, including for deadwood biomass.

Survey Method

In the 2nd RV Survey, survey clusters were selected by Hansen Tree Loss data, with further verification carried out and also reviewed with local residents to check whether the number of years since abandonment was appropriate in a real field situation. One cluster was laid out for each fallow age, from 1 year to 9 years after the abandonment of upland cropping, in the following seven provinces: Luang Namtha, Oudomxay, Houaphane, Khammouane, Savannakhet, Salavan and Attapeu. One cluster was composed of three circle plots. In each circle plot with a radius of 6 m, trees with a Diameter at Breast Height (DBH) $\geq$ 5 cm were recorded in circle plots; all other vegetation was cut at the base in square sub-plots for developing a biomass prediction model. At the same time, aerial photographs of plots were taken by drones in order to identify CCR, which was used for identifying the threshold number of years since abandonment — that is, the threshold age at which RV becomes CF.

Results

None of the developed CCR regression models exceeded 20% except for the North region. Despite the regression model for 2017 exceeding 20% CCR at a fallow age of 7 years, the regression models for 2019 did not even exceed 20% CCR even after a fallow age of 9 years. Moreover, the regression models, which were developed with all of the data for 2017 and 2019, did not exceed 20% CCR.

The average carbon stocks of the 2nd RV survey in 2019 was 8.14 Ct/ha, which was apparently smaller than that of the 1st RV survey in 2017, which was 13.58 Ct/ha, even though the result for 2019 contains an additional carbon pool, deadwood biomass. The biomass prediction model for 2019 was also developed as Above Ground Biomass (AGB) = 1.35 x $e^{0.37Y}$, with Y representing the fallow age, was always lower than for 2017, AGB = 1.75 x $e^{0.41Y}$.

2. Introduction

2.1 Background

Shifting cultivation is one of the major drivers of deforestation in the upland area of Lao PDR. Up to sixty to seventy thousand hectares of forest areas are affected by slash and burn agriculture every year. In shifting cultivation, an area is cultivated for a short period, often for one year, and then abandoned to generate as "Regenerating Vegetation" (RV). More than 25% of all land in Lao PDR was covered by RV in 2019. Figure 1 gives an overview of the extent of the RV area in Lao PDR.

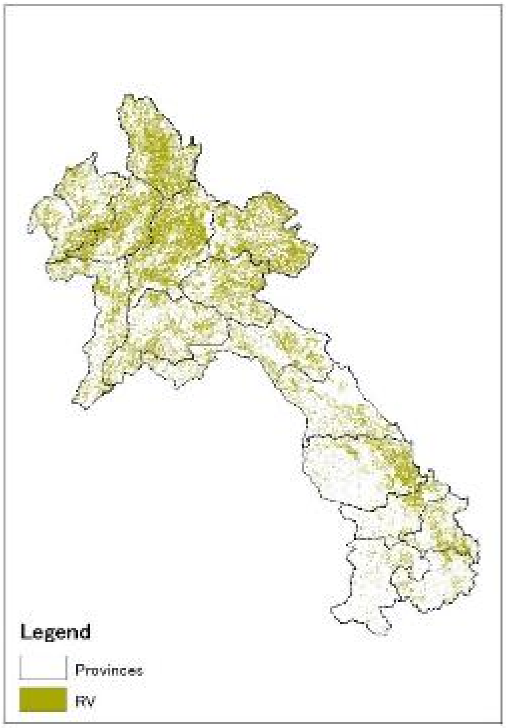


Figure 1: RV area in Lao PDR (2019)

To implement 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 — carbon stock information in each land cover type is necessary. A carbon stock estimation in RV, however, has a large degree of uncertainty due to the variety of tree species, differences in the amount of bamboo dominant, and geographical elements. In northern Lao PDR, a biomass prediction model was developed which shows the relationship between fallow age and fallow-age-average carbon stocks (Kiyono, *et.al.* 2007).

On the other hand, it is very difficult to distinguish RV and CF by remote sensing, and it is said that there are substantial uncertainties in distinguishing RV and CF by interpretation work on satellite images. Most of the cases of misinterpretation seem to happen on between Mixed Deciduous Forest (MD) and RV. As supplemental information to classify between RV and CF, recording the abandoned years since upland cropping can be helpful. The "threshold age" for fallowed upland crop field to regenerate to MD is assumed to be around 6 years, according to forestry officials in Lao PDR.

Although DBH and land area can be measured by field survey, it is difficult to measure the CCR at ground level. Therefore, drones were introduced to identify the CCR of the surveyed plots to examine whether they fulfilled the forest definition in Lao PDR (Table 1).

Table 1: Forest Definition in Lao PDR

Minimum Threshold of Forest Definition		
DBH	Crown Cover Rate	Minimum Area
10cm	20%	0.5ha

The 1st RV Survey was conducted in 2017 in order 1) to clarify the threshold age at which RV becomes CF and 2) to develop the biomass prediction model in RV area on a national scale. The threshold age was determined to be 7 years and the biomass prediction was developed as follows: $AGB = 1.7573e^{0.4107Y}$. Here, Y represents the fallow age after cropping abandonment. This model can be applied to RV area until a fallow age of 7 years.

It is said that more slash and burn agriculture occurred in northern Lao PDR and surveys in the same style are required to develop regional threshold ages for when RV becomes CF.

The national FREL/FRL report, which was approved in January 2018, does not include deadwood carbon pool. One of the reasons that deadwood carbon pool could not be compared between RV and CF was that deadwood was not measured in the RV area. Therefore, the 2nd RV Survey in 2019 also aims to measure deadwood biomass for the further improvement of carbon accounting.

2.2 Objectives

The objectives of the 2nd RV, 2019, are:

I. To confirm threshold age of abandoned years at which RV becomes CF at a national scale and also in each of three regions: North, Central, and South.

II. To develop a RV biomass prediction model based on the fallow age at a national scale, including for deadwood biomass.

3. Preparation

3.1 Survey Sites

All vegetation, including trees, non-timber vegetation, bamboo, and sampling in the RV area shall be measured for carbon stock estimation. The target provinces were selected considering high RV occurrence in the northern region of Lao PDR; three are in the North region, two are in the Central region, and two are in the South region (Figure 2). The RV periods used in shifting cultivation were about 20 years in the 1970s, but decreased to 5 years in the 1990s, mainly due to increased population density (Roder 1997). According to the 1st RV Survey, 2017, the threshold age is 7 years. Considering these results, nine clusters, one cluster for each fallow age, from 1 year to 9 years after the abandonment of upland cropping, were distributed in each province (Table 2).

Hansen Tree Loss data was applied to detect appropriate areas with expected fallow age, which are the candidate survey sites. Hansen Tree Loss data shows a time-series analysis of Landsat images in characterizing global forest area and its change from 2000 through 2018. The survey team double-checked if the fallow age is appropriate for the survey during in-field interviews of local forestry officials and residents.

Table 2: Distributed Clusters in Each Province

Region	Province	Age of abandoned year	Number of clusters
North	Luang Namtha	1 - 9	9
North	Oudomxay	1 - 9	9
North	Houaphane	1 - 9	9
Central	Khammouane	1 - 9	9
Central	Savannakhet	1 - 9	9
South	Salavan	1 - 9	9
South	Attapeu	1 - 9	9
		Total	**63**

Figure 2: Cluster location

3.2 Equipment and Drone Registration

The equipment list is shown in Attachment 8.3, including field survey equipment and drones. The process of acquiring permission to use drones in Lao PDR were as follows. Phantom 3 was used for the 2nd RV Survey (specifications can be confirmed at the following link: http://www.dji.com/phantom-3-standard/info#specs). The surveying agency (Forest Investment Planning Division (FIPD)/Department of Forestry (DOF)) submitted a letter of request to the Department of Civil Aviation (DCA). In total, it took four weeks to get permission. The contents of the letter were as follows:

- Purpose of the survey
- Survey sites (provinces)
- Survey method

3.3 Training and Preliminary Survey

Even though the survey was conducted by the same survey team that conducted the 1st RV Survey, 2017, a classroom training was provided for the team in October 2018 by the Japanese expert from Kokusai Kogyo Co., Ltd. In March 2019, a review lecture was also provided and a preliminary survey were conducted in Tha Heua, Vangvieng District, Vientiane Province, to learn the updated survey method and review how to fly drones.

4. Survey and Analysis Method

4.1 Field Survey

RV grows mainly in the abandoned fields of slash and burn farming; it does not yet fulfill the criteria for the forest definition, especially in terms of CCR. However, RV will become CF in the future. The biomass of RV can be estimated by two survey components: biomass measurement consisting of tree measurement and sample collection of other vegetation and CCR analysis. Tree biomass is estimated by applying an allometric equation for trees with DBH 5 cm, while other vegetation biomass is estimated by sampling in sub-plots.

At the same time, CCR is utilized for identifying threshold age after the abandonment of shifting cultivation. See "Standard Operation Procedure (SOP) Regenerating Vegetation Survey version 2017" for details on the procedure of survey and lab work.

4.1.1 Establishment of Plots

In the 2nd RV Survey, the location information of predetermined candidate clusters were put into GPS devices for navigation. In the field, the first plots were carefully selected so that all three plots fell within a uniform RV area (Figure 3). Three circle plots were set in each cluster. If the sampling area was not large enough for making a range of three plots, a cluster was able to have plots 30 m apart.

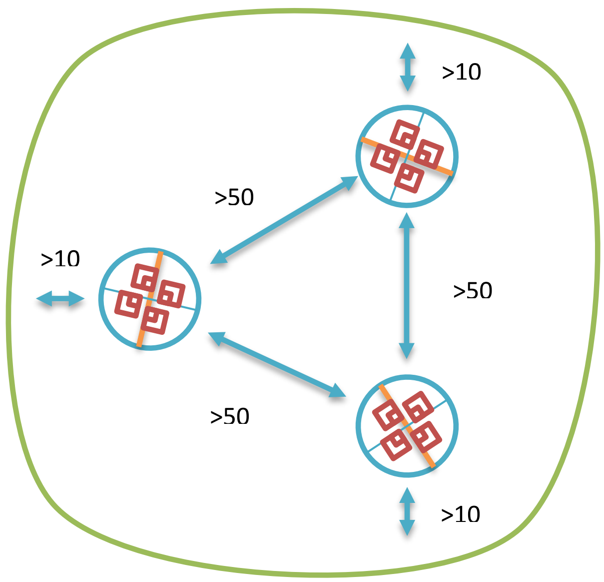


Figure 3: A cluster with three circle plots in uniform RV area

Four sub-plots were also set-up in each plot for biomass estimation, except for trees with DBH < 5 cm. Sub-plots were 1 m apart from the center of the plot and the sizes were dependent on the average height of vegetation. If the height was lower than 1 m, it was 1 m x 1 m. If the height was more than 1 m, it was 2 m x 2 m (Figure 4).

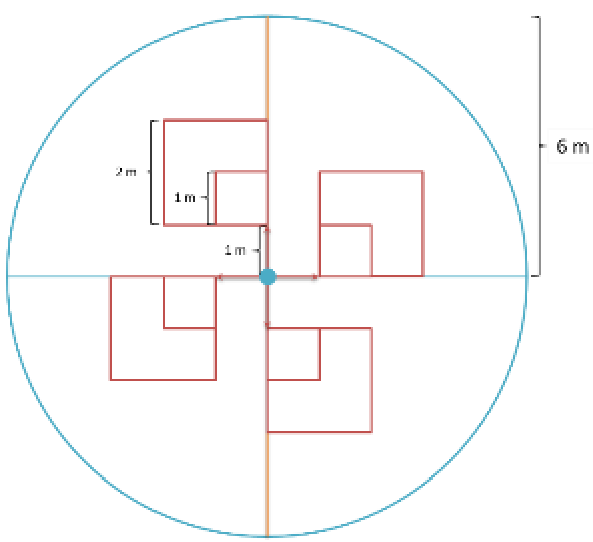


Figure 4: A plot (blue circle) with four square sub-plots (red squares) and transect for lying deadwood measurement (orange line).

4.1.2 Field Measurement

Living Trees and Other Vegetation

The first DBH were measured for all trees with DBH ≥ 5 cm and the positions were also recorded. The tree data were used for the development of biomass prediction and trees with DBH ≥ 10 cm and their positions were used for CCR analysis.

For each sub-plot:

a. Above ground vegetation, including trees with DBH < 5 cm, saplings, grass, and bamboo inside of sub-plots were cut down at the base.
b. All harvested vegetation was placed on plastic sheets and weighed.
c. A representative sub-sample was collected, including all types of vegetation. They were cut into small pieces.
d. A sub-sample of up to 500 g was weighed and recorded.
e. All sub-samples were taken back to the office for estimation of whole samples in each plot.
f. All sub-samples were taken back to the office for drying. Later, some of them were dried at 100°C so that they were a constant weight. The ratio of the dry weight to fresh weight was calculated to estimate whole sample biomass.

Standing Deadwood

In the 2nd RV Survey, the method for measuring standing deadwood and lying deadwood, described below, follows the same methodology as 3rd NFI, which was developed based on "Standard Operating Procedures (SOP) Manual for Terrestrial Carbon Measurement, December 2018 Version".

Standing deadwood refers to trees that have died but are still upright; this includes deadwood stumps from trees that were greater than DBH 10 cm when alive but have a current height of less than 1.3 m. Thus, in the 2nd RV Survey, all standing deadwood with a diameter greater than DBH 10 cm or at stump height had to be measured. The standing deadwood were classified into three classes (see Figure 5 below):

- Class 1: Standing dead trees with branches and twigs that resemble live trees except for the absence of leaves (confirm that the trees are dead and not deciduous).
- Class 2: Standing dead trees containing large branches or no branches at all and are higher than 1.3 m.
- Class 3: Standing dead trees lower than 1.3 m, called stumps.

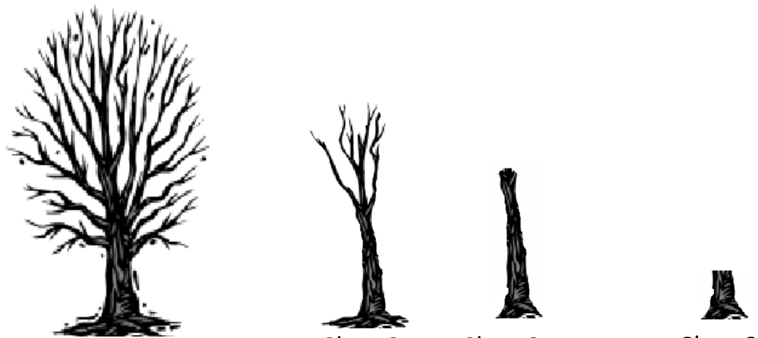


Figure 5: Example of trees in Class 1, Class 2 and Class 3

The measurement of standing deadwood for Class 1, Class 2 and Class 3 were done by following the respective procedures for each class.

Class 1:

1. Measure the standing dead trees with a DBH of more than 10 cm.

Class 2 (see figure below):

1. The biomass of these trees is based on estimating the volume of a remaining tree and multiplying the volume by the wood density.
2. Measure DBH using methods for live trees.
3. Measure the diameter at the base of the tree. ($\mathbf{D}_{base}$)
4. Measure the height of the stem (H) using either a clinometer and measuring tape or a laser range finder (see the measurement of tree height in the SOP Manual for Terrestrial Carbon Measurement 2018 Version) or through direct measurement using a tape measure (e.g. when deadwood is less than 2 m high).
5. Measure the diameter at the top of the stump ($\mathbf{D}_{top,}$) either through direct measurement (e.g. when the diameter at the top can be reached directly). Alternatively, do not take a measurement at the top of the stump and write 'None' or 'NA' on the datasheet.

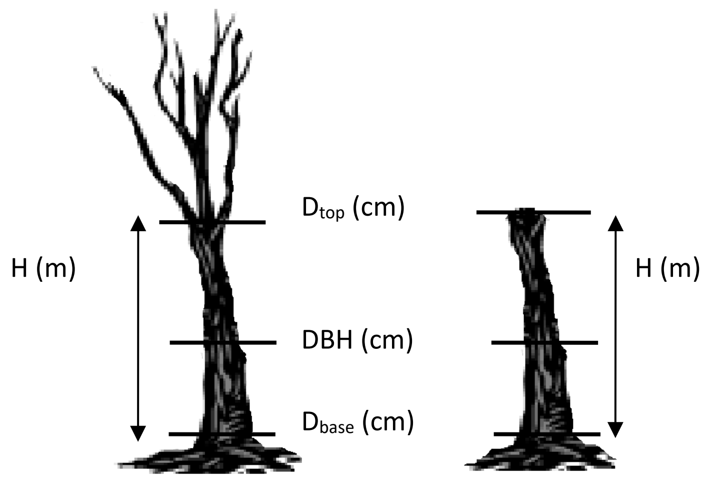
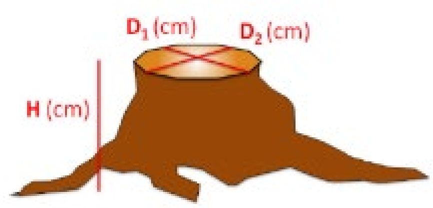


Figure 6: Standing dead tree measurement locations

Class 3 (stumps):

Stumps are standing deadwood trees that fall below 1.3 m and contain no branches; they are typically the result of logging. Measure stumps if either D_1 or D_2 meet the minimum diameter requirement, which is 10 cm. Measure the following three measurements for stumps:

1. Height (H) — this will be below 1.3 m
2. Smallest Diameter (D_1) — this is the smallest diameter across the top of the stump
3. D_2 — the diameter at a 90^o angle to D_1.



Lying Deadwood

In the 2nd RV Survey, lying deadwood was also measured along the orange transect which lays down in the direction of the slope (Figure 4). The measurement of lying deadwood was carried out by following the SOP Manual for Terrestrial Carbon Measurement 2018 Version and the respective procedures as follows:

1. Along the length of the line, measure the diameter of each intersecting piece of coarse deadwood (> 10 cm diameter) (see figure below). Calipers work best for measuring the diameter.

Figure 7: Use of calipers to measure the diameter of lying deadwood along line transect

When measuring the diameter of deadwood, it is not always possible to place a diameter tape around the log. It can also be dangerous because logs are usually home to snakes, spiders, and other dangerous creatures. If you are going to measure the diameter of the piece of dead wood with a diameter tape, make sure the route is clear before placing your hand underneath the log.

2. A piece of deadwood should only be measured if: (a) more than 50% of the log is aboveground, and (b) the sampling line crosses through at least 50% of the diameter of the piece — see the examples in Figure 8.

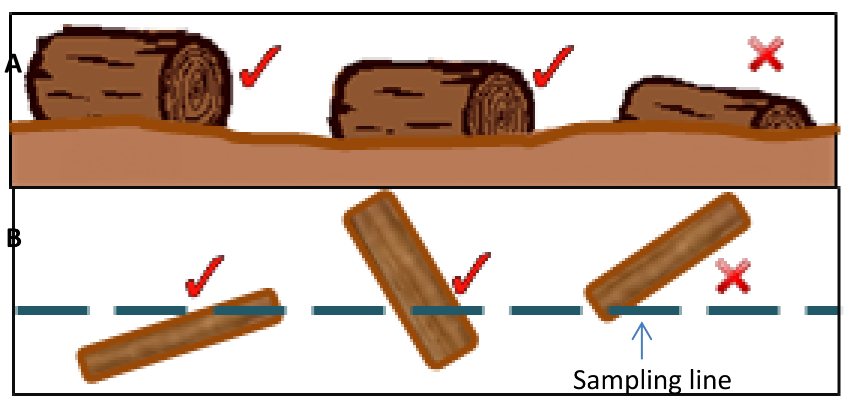


Figure 8: (A) Schematic of which deadwood should be measured. The first two logs should be measured because they are more than 50% above ground, but the third log should not be measured. The horizontal line represents the soil surface. (B) Schematic of which deadwood should be

measured. The first two logs should be measured because the sampling line crosses more than 50% of the diameter of the logs. Conversely, the third log should not be measured because the sampling line does not cross more than 50%.

3. If the log is hollow at the intersection point, measure the diameter of the hollow portion in two directions; the hollow portion is excluded from the volume estimates.

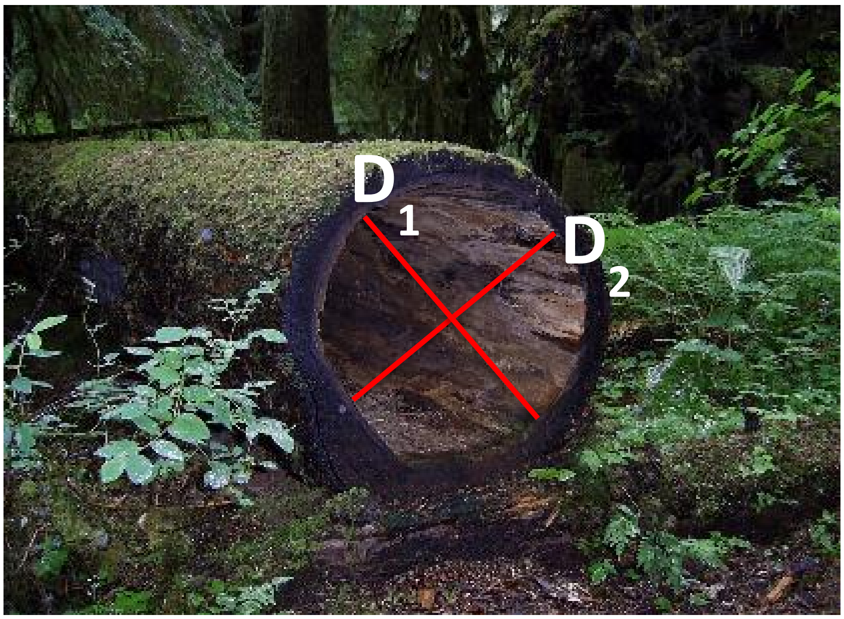


Figure 9 Hollow Log. Two measurements of the diameter of the hollow shall be taken

4. Assign each piece to one of three density classes: sound, intermediate, or rotten. To determine what density class a piece of deadwood fits into, each piece is struck with a machete. If the machete does not sink into the piece (if it bounces off), classify it as sound. If the machete sinks partly into the piece and there has been some wood loss, classify it as intermediate. If the machete sticks into the piece, if there is more extensive wood loss, and the piece crumbles easily, classify it as rotten. Record on data sheet.
5. The volume of lying deadwood and then carbon stocks are estimated using the diameter of each piece of wood and the length of the line transect.

Crown Cover Rate (CCR) Survey

The CCR survey was done by following the respective procedures for each plot as follows:

a. Two extensible rods whose tops were tied up with red cloths, were set up for each plot; one is in the center of the plot and the other in the northernmost point on the plot circle line.

b. Both of the rods were extended vertically until the tops exceeded the tree canopy of the plots, so that the locations of the rods could be detected on the below-mentioned pictures.
c. Vertical aerial photographs at the center of the plot, including the tops of both rods in the frame, were taken by drones at different elevations (20 m, 25 m, 30 m or 35 m).
d. The directions of each picture were also recorded.

4.2 Analysis Method

4.2.1 Biomass Prediction Model

Living Trees and Other Vegetation

Tree biomass with DBH $\geq$ 5 cm was estimated by applying the following Lao PDR-specific allometric equation for MD.

AGB = 0.407*DBH^2.069

At the same time, the sample biomass was also estimated with a fresh-dry ratio, which was calculated using some sub-samples that were dried in an oven.

Four sub-samples were collected from each sub-plot in order to obtain the fresh-dry ratio for estimating the dry weight of sub-samples. When making these estimates, more than 756 samples should be dried in the oven, but there is no oven in Lao PDR with sufficient capacity to dry such a large number of samples. Therefore, one sub-sample from each plot was selected in order to be dried in the oven at more than 100°C.

The average biomass of each cluster is obtained by the average of the three plots. A biomass prediction equation was developed by using the number of abandoned years since cropping as a parameter.

Standing Deadwood

The volume of standing deadwood can be estimated with the options below. However, nothing from Class 1 or Class 2 was found in the RV area. Only some from Class 3 were found; the volume was estimated as cylinder shape. Lao PDR does not have a specific deadwood density for all species or forest types. The deadwood density of 0.57g/cm^3 from Global Forest Resources Assessment 2000 (FAO) was applied to estimate biomass from volume.

Option 1: Diameter at top (D_{top}) was measured directly:

Volume estimated assuming tree is a truncated cone:

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

Option 2: Diameter at top (D_{top}) estimated using a taper equation:

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

Volume estimated assuming tree is a truncated cone:

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

Option 3: Diameter at top (D_{top}) is assumed to be zero.

Volume estimated assuming tree is a cone.

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

Lying Deadwood

Lying deadwood was surveyed with the line transect method. However, there were no significant samples found. The calculation method is described in "Leaf Technical Guidance Series for the Development of a Forest Carbon Monitoring System REDD+", which was developed by Winrock International.

4.2.2 Crown Cover Rate (CCR)

Trees with DBH ≥ 10 cm were identified on the aerial photos by referring to the field data sheets. Each tree crown was digitized with GIS software and the CCR was calculated in each plot. The average CCR of each cluster was calculated and plotted on graphs in order to identify the threshold age of the abandoned year at which RV becomes CF.

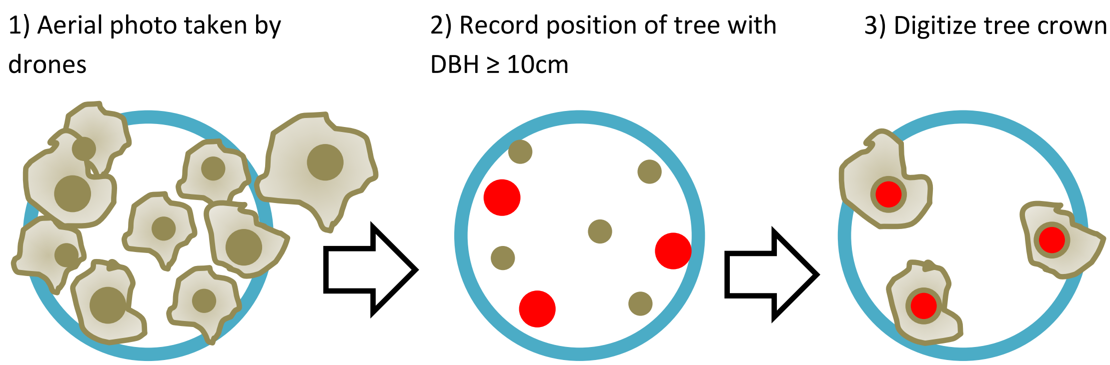


Figure 10: Analysis process for CCR survey

Figure 11: An example of CCR analysis. Red figures show the drawn tree crown consisting of trees with DBH ≥ 10 cm.

5. Survey Implementation

5.1 Implementation Structure (Team Organization)

The survey team was organized with the following members.

Table 3: Survey Team Members

Institution	Number of Staff
FIPD (Forest Inventory and Planning Division)	2
Driver	2
PAFO (Provincial Agriculture and Forest Office)	1
DAFO (District Agriculture and Forest Office)	1
Villager	1
Drone expert	1

5.2 Schedule

The survey was implemented over a total of 19 days, not including traveling and coordinating days. Details of the schedule can be confirmed in the following table.

Table 4: Schedule

Province	Schedule
Luang Namtha	14-Mar-2019 to 17-Mar-2019 (4 days)
Oudomxay	19-Mar-2019 to 20-Mar-2019 (2 days)
Houaphane	22-Mar-2019 to 23-Mar-2019 (2 days)
Salavan	29-Mar-2019 to 30-Mar-2019 (2 days)
Attapeu	1-Apr-2019 to 4-Apr-2019 (4 days)
Savannakhet	6-Apr-2019 to 8-Apr-2019 (3 days)
Khammouane	27-Apr-2019 to 28-Apr-2019 (2 days)

6. Result and Discussion

6.1 Crown Cover Rate

Table 5 shows the average CCR of each cluster. Some clusters show very low or zero CCR even at old fallow ages, especially in the Central and South regions.

Table 5: Average Crown Cover Rate in Each Region and Clusters

North Region								
Luang Namtha			Oudomxay			Houaphane		
Cluster	Year	CCR (%)	Cluster	Year	CCR (%)	Cluster	Year	CCR (%)
Lm1	1	0.0	Ou1	1	0.0	Ho1	1	0.0
Lm2	2	0.0	Ou2	2	0.0	Ho2	2	0.0
Lm3	3	0.0	Ou3	3	0.0	Ho3	3	0.0
Lm4	4	6.9	Ou4	4	0.0	Ho4	4	2.8
Lm5	5	9.7	Ou5	5	3.2	Ho5	5	2.6
Lm6	6	10.4	Ou6	6	1.2	Ho6	6	11.6
Lm7	7	20.3	Ou7	7	5.5	Ho7	7	0.0
Lm8	8	35.1	Ou8	8	33.6	Ho8	8	15.3
Lm9	9	39.1	Ou9	9	4.7	Ho9	9	32.6

Central Region					
Khammouane			Salavan		
Cluster	Year	CCR (%)	Cluster	Year	CCR (%)
Kh1	1	0.0	Sl1	1	0.0
Kh2	2	0.0	Sl2	2	0.0
Kh3	3	0.0	Sl3	3	0.0
Kh4	4	0.0	Sl4	4	2.7
Kh5	5	26.4	Sl5	5	1.9
Kh6	6	1.7	Sl6	6	0.0
Kh7	7	0.0	Sl7	7	3.8
Kh8	8	10.2	Sl8	8	6.0
Kh9	9	0.0	Sl9	9	10.6

South Region					
Savannakhet			Attapeu		
Cluster	Year	CCR (%)	Cluster	Year	CCR (%)
Sv1	1	0.0	At1	1	0.0

Sv2	2	0.0	At2	2	0.0
Sv3	3	0.0	At3	3	0.0
Sv4	4	0.0	At4	4	0.0
Sv5	5	6.1	At5	5	0.0
Sv6	6	1.9	At6	6	0.0
Sv7	7	15.0	At7	7	0.0
Sv8	8	5.1	At8	8	1.1
Sv9	9	10.4	At9	9	5.6

Average CCRs for each cluster were plotted based on data from the 2nd RV Survey, 2019, (Figure 11) and also based on all data from the 1st RV Survey, 2017, and the 2nd RV Survey, 2019 (Figure 12).

Regression models were developed for the data set from the 2nd RV Survey, 2019, and all of the data including the 1st RV Survey, 2017, and the 2nd RV Survey, 2019, (Figure 11 and Figure 12). None of the regression models exceed 20% even for a fallow age of 9 years, with the exception of North region models, which do not exceed 20% through a fallow age of 7 years, but do at a fallow age of 8 years.

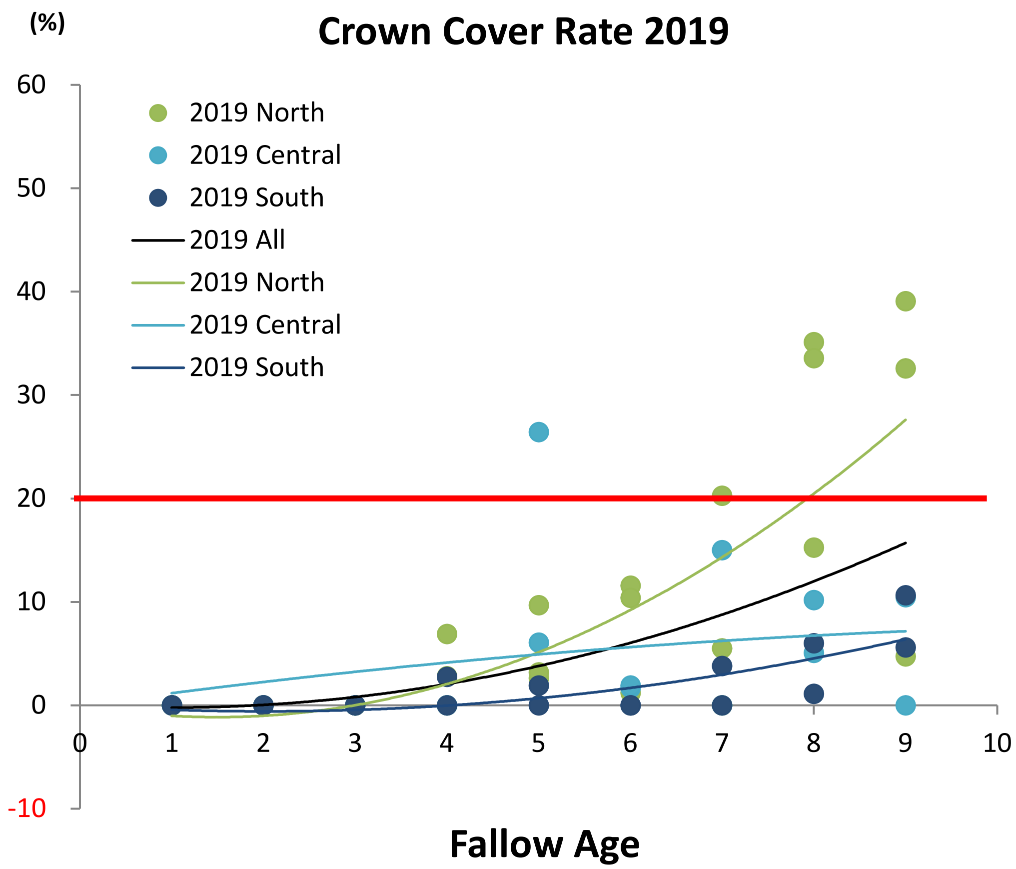


Figure 12: Crown Cover Rate and regression models in the 2nd RV Survey, 2019. 2019 All: CCR = $0.25y^2 - 0.47y$ ($R^2 = 0.32$), 2019 North: CCR = $0.51y^2 - 1.52y$ ($R^2 = 0.61$), 2019 Central: CCR = $-0.05y^2 + 1.22y$ ($R^2 = 0.14$), 2019 South: CCR = $0.14y^2 - 0.58y$ ($R^2 = 0.61$). The y represents fallow age.

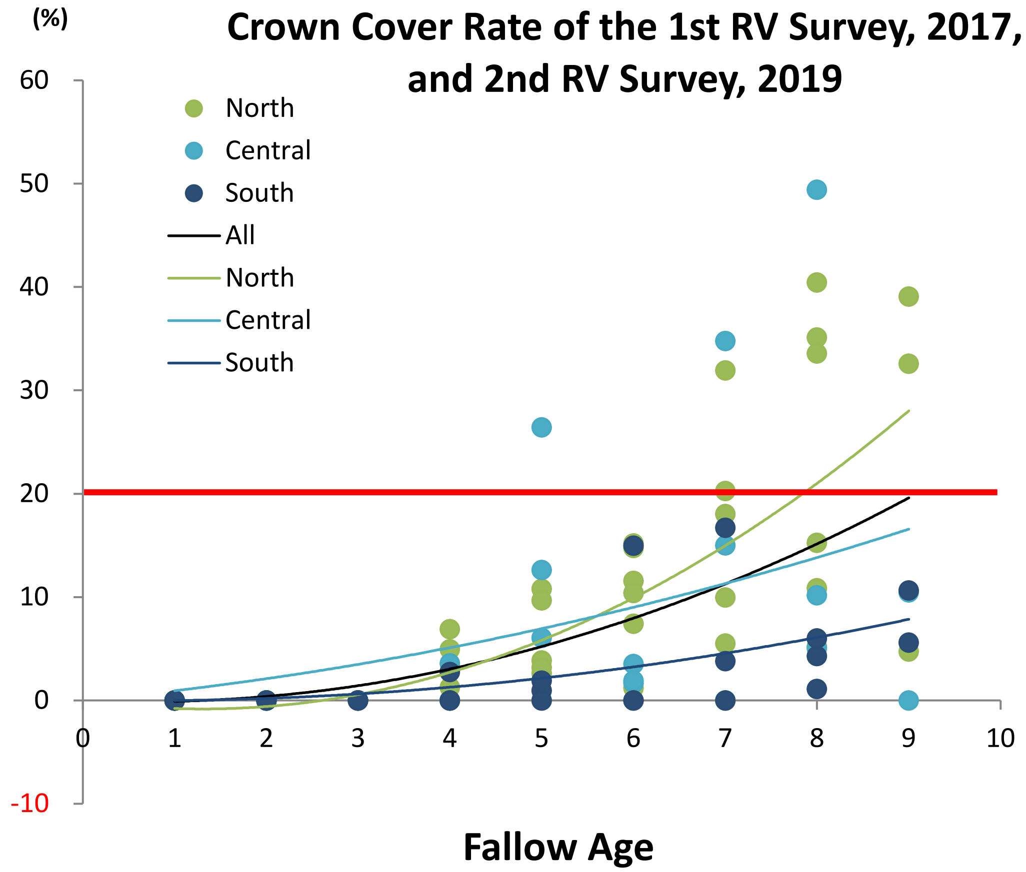


Figure 13: Crown Cover Rate and regression models in the 1st RV survey, 2017, and 2nd RV Survey, 2019. All: CCR = $0.28y^2 - 0.38y$ ($R^2 = 0.35$), North: CCR = $0.491y^2 - 1.27y$ ($R^2 = 0.59$), Central: CCR = $0.11y^2 + 0.82y$ ($R^2 = 0.20$), South: CCR = $0.11y^2 - 0.12y$ ($R^2 = 0.30$). The y represents fallow age.

The CCR varies more widely at a fallow age of 4 years or older because the CCR is dependent on living tree growth, which may have a variety of barriers. For instance, if bamboo dominates the abandoned area in the early fallow age, tree growth may become slow. Living trees are also affected by human activity such as logging, wood collection, or repeated slash and burn agriculture.

The regional difference of CCR in 2nd RV Survey, 2019, is related to living tree densities. To discuss the relationship between CCRs and living tree densities, living trees in clusters from fallow ages of 7 to 9 years were also summarized in the 2nd RV survey.

Table 6 shows the number of living trees from sites for fallow ages of 7 to 9 years in two DBH categories: less than 10 cm and 10 cm or more. It also shows the density of living trees in the three regions. There is no substantial difference among the densities of living trees less than DBH 10 cm. However, focusing on living trees with DBH 10 cm or more, which are taken into account for CCR calculation, North region data shows a high density of living trees with DBH 10 cm or more. However, this decreases in the Central and South regions. The North, Central and South regions show 226, 162 and 108 trees per hectare, respectively (Table 6).

Table 6: Number and Densities of Living Trees with Fallow Ages of 7 to 9 years

	North		Central		South	
DBH	< 10 cm	10 cm ≤	< 10 cm	10 cm ≤	< 10 cm	10 cm ≤
7 years	184	16	52	14	75	2
8 years	70	29	78	12	80	6
9 years	125	24	102	7	105	14
7 to 9 years	379	69	232	33	260	22
density (ha^{-1})	1,241	226	1,140	162	1,277	108

As mentioned above, only living trees with DBH 10 cm or more are taken into account for calculating CCR based on the forest definition in Lao PDR. The CCRs in clusters that have a fallow age of older than 7 years and densities of living trees with DBH 10 cm or more are summarized in Table 7.

Focusing on the living trees with 10 cm DBH or more, the density in the North region is greater than that of the other regions; there are also greater CCRs in older fallow ages. On the other hand, the CCRs in Central and South regions are smaller than the data for the North region. Moreover, there are no CCRs greater than 20% in Central and South regions.

Table 7: CCRs and Living Tree Densities

Region	North	North	North	Central	Central	South	South
Province	Luang Namtha	Oudomxay	Houaphane	Khammouane	Salavan	Savannakhet	Attapeu
Fallow age of 7 years	20.3	5.5	0.0	0.0	3.8	15.0	0.0
Fallow age of 8 years	35.1	33.6	15.3	10.2	6.0	5.1	1.1
Fallow age of 9 years	39.1	4.7	32.6	0.0	10.6	10.4	5.6
Density (trees/ha)	226			162		108	

6.2 Biomass Prediction Models

Figure 13 shows the relationship between fallow age and carbon stock (assuming that carbon fractions account for 0.49 of biomass (IPCC National Greenhouse Gas Inventories Programme 2006)).

$AGB = 1.76e^{0.41Y}$ (1st RV Survey, 2017)

$AGB = 1.35e^{0.37Y}$ (2nd RV Survey, 2019)

Y represents fallow age after the abandonment of cropping. The model was developed using the condition that fallow age does not exceed 7 years, which is the same as the conclusion of the 1st RV Survey, 2017.

The developed model aims to predict RV biomass through a fallow age of 7 years and regression is originally thought to increase in geometric manner. Considering this, the exponential approximation would be appropriate for the model during the period of relatively young fallow age.

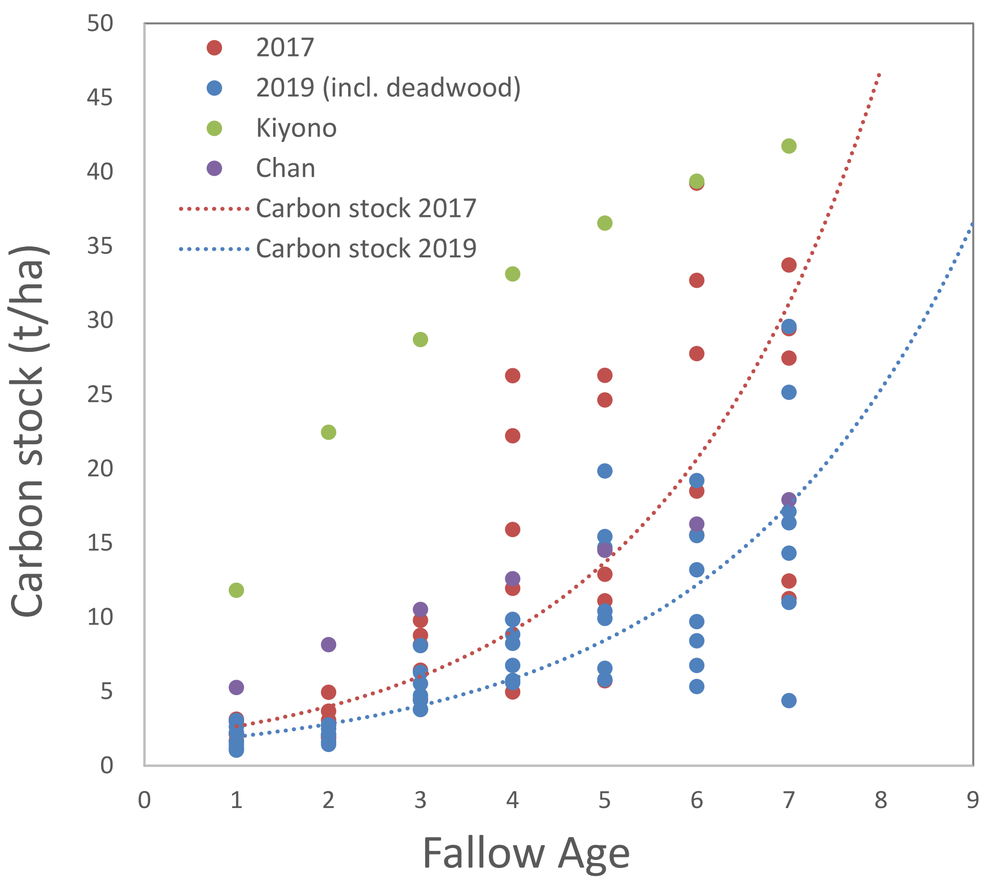


Figure 14: Relationship between fallow age and carbon stock (t/ha). Carbon stock 2017: AGB = $1.76e^{0.41y}$ (R^2 = 0.72), Carbon stock 2019: AGB = $1.35e^{0.37y}$ (R^2 = 0.74). Fallow age is shown by y.

Although the biomass prediction model was developed in the 1st RV Survey, 2017, it was not actually used for the estimation of RV biomass in the national FREL/FRL report due to a high level of uncertainty. Alternatively, the average of all fallow ages — 13.58 Ct/ha with a standard deviation of 10.90 — was applied to estimate RV carbon stock for the national FREL/FRL report. The RV carbon stock needs to be updated for the 1st National REDD+ Result Report, which is necessary for Lao PDR to apply for REDD+ results-based payment. Average RV carbon stocks obtained from the 1st and 2nd RV Survey are also shown in Table 8.

Table 8: RV Carbon Stocks

	Including deadwood		Without deadwood	
1st RV Survey 2017	Carbon stock (Ct/ha)	StD	Carbon stock (Ct/ha)	StD
North	-	-	13.37	11.72
Central	-	-	14.64	11.04
South	-	-	13.19	10.61
Average	-	-	13.58	10.90
2nd RV Survey 2019	Carbon stock (Ct/ha)	StD	Carbon stock (Ct/ha)	StD
North	8.96	6.54	8.95	6.54
Central	8.64	8.44	8.61	8.42
South	6.43	3.98	6.42	3.98
Average	8.14	6.46	8.13	6.45

Comparison with the results of the 1st RV Survey, 2017

Overall, the biomass prediction model developed in the 2nd RV Survey in 2019 is apparently lower than that of the 1st RV Survey in 2017, even though the 2nd RV Survey contains a deadwood carbon pool. One possible reason is that the resource harvest cycle, influenced by human activities in RV area, has become faster than it was in 2017. This may be because the harvest from forest area was strictly limited — as a result of the Prime Minister's Order No. 15 issued in 2016 — thus consecutively, the resource harvest activities may become stronger in non-forest area or RV area. This hypothesis should be confirmed in the near future.

Regional Difference

Although there is no regional difference among average carbon stocks in the results of the 1st RV Survey, the 2nd RV Survey shows that carbon stocks in the South region are apparently smaller than in other regions (Table 8). NFI data were also analyzed under the hypothesis that Mixed Deciduous Forest has a similar tendency. Unlike the hypothesis, there is no clear difference in the amount of carbon by region.

As shown in Table 8, standard deviations of carbon stocks are not low in each value. This is probably due to the bias of sampling sites and an insufficient number of samples, but that is not certain. These points should be taken into consideration when planning the next RV survey.

7. References

- Kiyono *et al*. (2007) Predicting chronosequential changes in carbon stocks of pachymorph bamboo communities in slash-and-burn agricultural fallow, northern Lao People's Democratic Republic

- Roder W (1997) Slash-and-burn rice systems in transition: challenges for agricultural development in the hills of Northern Laos. Mountain Res Dev 17:1–10

- Nyein Chan *et al*. (2013) Establishment of allometric models and estimation of biomass recovery of swidden cultivation fallows in mixed deciduous forests of the Bago Mountains, Myanmar

- SOP (Standard Operation Procedure) Regenerating Vegetation Survey version 2017

- Standard Operating Procedures (SOP) Manual for Terrestrial Carbon Measurement, December 2018 Version

8. Attachment

8.1 Data List

No.	Region	Cluster ID	Fallow age	Province	District	Survey Date	Biomass (t/ha)	Carbon Stock (t/ha)
1	north	LM1	1	Luangnamtha	Viengphoukha	2019/03/14	4.8	2.2
2	north	LM2	2	Luangnamtha	Viengphoukha	2019/03/15	5.9	2.7
3	north	LM3	3	Luangnamtha	Viengphoukha	2019/03/15	12.0	5.5
4	north	LM4	4	Luangnamtha	Viengphoukha	2019/03/14	19.2	8.8
5	north	LM5	5	Luangnamtha	Viengphoukha	2019/03/15	22.7	10.4
6	north	LM6	6	Luangnamtha	Viengphoukha	2019/03/16	41.8	19.2
7	north	LM7	7	Luangnamtha	Viengphoukha	2019/03/16	37.2	17.1
8	north	LM8	8	Luangnamtha	Viengphoukha	2019/03/17	44.4	20.4
9	north	LM9	9	Luangnamtha	Viengphoukha	2019/03/16	47.9	22.0
10	north	OU1	1	Qudomxay	La	2019/03/19	5.7	2.6
11	north	OU2	2	Qudomxay	La	2019/03/19	4.5	2.1
12	north	OU3	3	Qudomxay	La	2019/03/20	17.6	8.1
13	north	OU4	4	Qudomxay	La	2019/03/20	14.7	6.8
14	north	OU5	5	Qudomxay	La	2019/03/19	33.6	15.5
15	north	OU6	6	Qudomxay	La	2019/03/19	18.3	8.4
16	north	OU7	7	Qudomxay	La	2019/03/20	35.6	16.4
17	north	OU8	8	Qudomxay	La	2019/03/20	63.2	29.1
18	north	OU9	9	Qudomxay	La	2019/03/19	49.7	22.8
19	north	HO1	1	Houaphan	Sam neua	2019/03/22	6.6	3.1
20	north	HO2	2	Houaphan	Sam neua	2019/03/22	4.6	2.1
21	north	HO3	3	Houaphan	Sam neua	2019/03/22	8.2	3.8
22	north	HO4	4	Houaphan	Sam neua	2019/03/22	18.0	8.3
23	north	HO5	5	Houaphan	Sam neua	2019/03/23	14.3	6.6
24	north	HO6	6	Houaphan	Sam neua	2019/03/23	28.7	13.2
25	north	HO7	7	Houaphan	Sam neua	2019/03/23	54.7	25.2
26	north	HO8	8	Houaphan	Sam neua	2019/03/22	28.2	13.0
27	north	HO9	9	Houaphan	Sam neua	2019/03/23	86.0	39.6
28	central	KH1	1	Khammouane	Boualapha	2019/04/28	2.6	1.2
29	central	KH2	2	Khammouane	Boualapha	2019/04/28	3.5	1.6
30	central	KH3	3	Khammouane	Boualapha	2019/04/28	9.6	4.4
31	central	KH4	4	Khammouane	Boualapha	2019/04/27	12.2	5.6
32	central	KH5	5	Khammouane	Boualapha	2019/04/27	43.2	19.9
33	central	KH6	6	Khammouane	Boualapha	2019/04/27	11.6	5.3

34	central	KH7	7	Khammouane	Boualapha	2019/04/27	9.6	4.4
35	central	KH8	8	Khammouane	Boualapha	2019/04/28	43.9	20.2
36	central	KH9	9	Khammouane	Boualapha	2019/04/28	18.3	8.4
37	central	SV1	1	Savannakhet	Nong	2019/04/06	2.3	1.0
38	central	SV2	2	Savannakhet	Nong	2019/04/06	3.1	1.4
39	central	SV3	3	Savannakhet	Nong	2019/04/07	13.7	6.3
40	central	SV4	4	Savannakhet	Nong	2019/04/07	21.5	9.9
41	central	SV5	5	Savannakhet	Nong	2019/04/06	32.0	14.7
42	central	SV6	6	Savannakhet	Nong	2019/04/07	33.7	15.5
43	central	SV7	7	Savannakhet	Nong	2019/04/06	64.4	29.6
44	central	SV8	8	Savannakhet	Nong	2019/04/08	26.3	12.1
45	central	SV9	9	Savannakhet	Nong	2019/04/07	53.1	24.4
46	south	SL1	1	Salavan	Ta Oy	2019/03/30	3.5	1.6
47	south	SL2	2	Salavan	Ta Oy	2019/03/30	6.0	2.8
48	south	SL3	3	Salavan	Ta Oy	2019/03/29	10.3	4.7
49	south	SL4	4	Salavan	Ta Oy	2019/03/30	21.4	9.8
50	south	SL5	5	Salavan	Ta Oy	2019/03/29	21.6	9.9
51	south	SL6	6	Salavan	Ta Oy	2019/03/30	14.7	6.8
52	south	SL7	7	Salavan	Ta Oy	2019/03/30	31.2	14.3
53	south	SL8	8	Salavan	Ta Oy	2019/03/30	31.2	14.3
54	south	SL9	9	Salavan	Ta Oy	2019/03/29	59.0	27.1
55	south	AT1	1	Attapue	Sanxay	2019/04/02	3.1	1.4
56	south	AT2	2	Attapue	Sanxay	2019/04/01	5.4	2.5
57	south	AT3	3	Attapue	Sanxay	2019/04/03	8.3	3.8
58	south	AT4	4	Attapue	Sanxay	2019/04/01	12.5	5.7
59	south	AT5	5	Attapue	Sanxay	2019/04/02	12.6	5.8
60	south	AT6	6	Attapue	Sanxay	2019/04/02	21.1	9.7
61	south	AT7	7	Attapue	Sanxay	2019/04/02	23.9	11.0
62	south	AT8	8	Attapue	Sanxay	2019/04/01	24.6	11.3
63	south	AT9	9	Attapue	Sanxay	2019/04/02	38.5	17.7

* The carbon stock for fallow ages of 8 and 9 years were not considered for the development of the regression model.

8.2 Activity Photos


Team members


Drone practice
(Houaphane Province)


Measuring a tree's DBH
(Oudomxay Province)


Setting a DME responder
(Houaphane Province)

8.3 Equipment List

Field Equipment:

Hand-held GPS
50 m measure tape
Pole (>10 m)
Flag and reflection for poles (e.g. CD-R)
Handsaws
Machetes
Pruning scissors
Sharpener
DBH tape
50 kg scale
1~2 kg scale
Calibration weights
Durable plastic tarp (2m x 2 m)
10m of rope, 1 - 2 cm thick (to tie up scale and to weigh branches)
Cloth sample bags for sub-samples
Marker (to label bags and samples)
Clipboards and pens
Field data sheet
Digital camera
Drones (Phantom 3 or higher specification)
Extra drones, if necessary
Extra batteries for drones (At least 6 flights)
Spare parts for drones

Laboratory Equipment:
Drying oven
Laboratory scale

8.4 Field Data Sheet

RV DESTRUCTIVE SAMPLING DATA SHEET

1. Cluster Information

Cluster ID: ____________________

District: ____________________

Village: ____________________

Date: __________

Time start: __________

Time end: __________

Photo ID (overview): __________

Preparation

Weight of plastic sheet A: __________ g

Weight of plastic sheet B: __________ g

Weight of plastic sheet C: __________ g

Calibrating 50 kg scale:

Object weight: ____________________ g

Name of object: ____________________ g

Calibrating 1 kg scale:

Object weight: ____________________ g

Name of object: ____________________ g

Calibrating 500 g scale:

Object weight: ____________________ g

Name of object: ____________________ g

Note:

2. Plot Measurement

Plot ID ____________________

Sheet 1

2.1 Basic Information

Photo ID Overview: ____________________

Photo ID North: ____________________

Photo ID East: ____________________

Photo ID South: ____________________

Photo ID West: ____________________

GPS waypoint at center

ID: ____________________

Lat: ____________________

Long: ____________________

2.2 Tree DBH ≥ 5 cm

Tree ID	DBH (cm)	Species
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
17		
18		
19		
20		

Tree ID	DBH (cm)	Species
21		
22		
23		
24		
25		
26		
27		
28		
29		
30		
31		
32		
33		
34		
35		
36		
37		
38		
39		
40		

2. Plot Measurement

Plot ID ______________________________

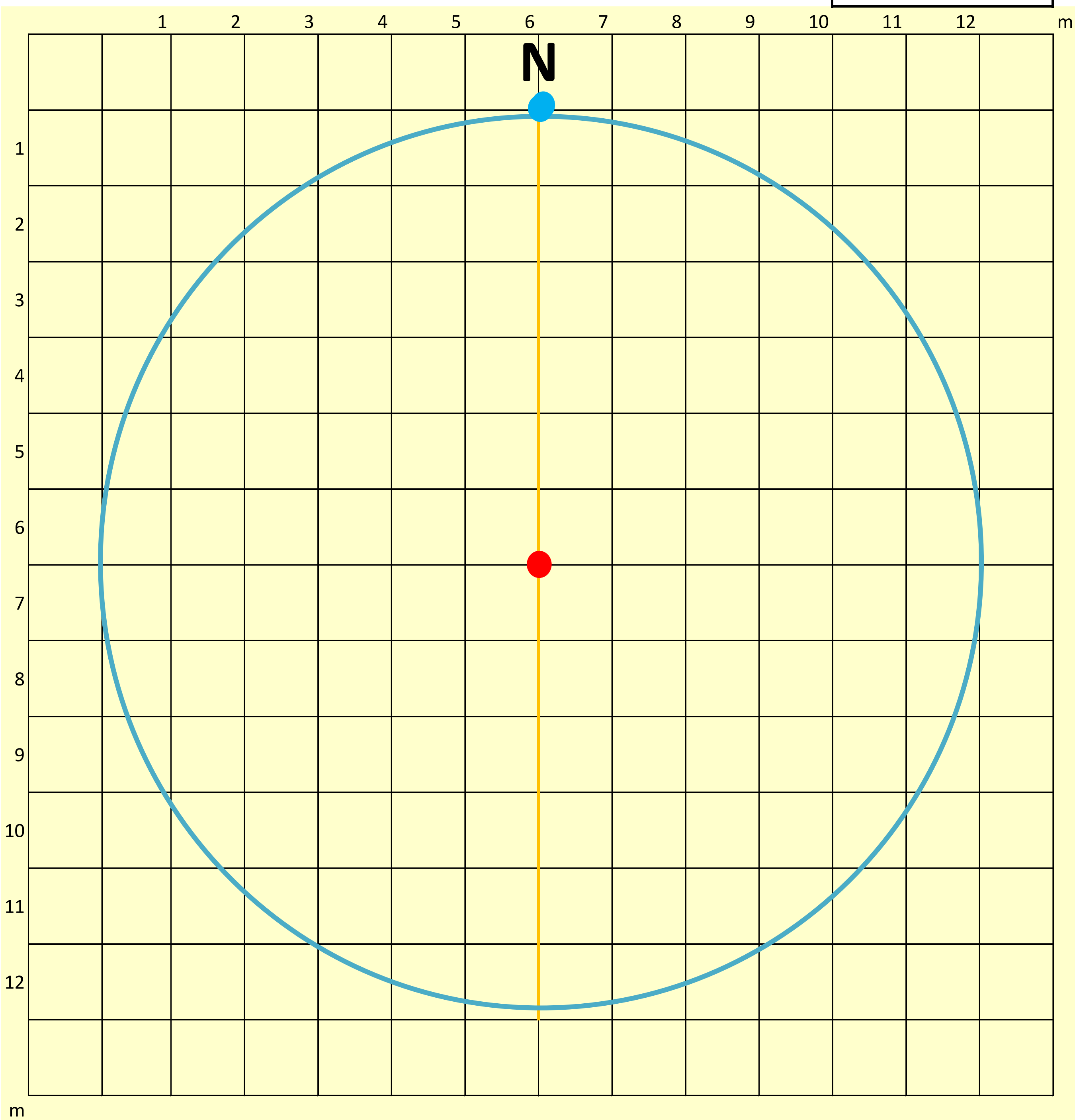
Sheet 2

Slope Direction:

2.3 Tree location for Canopy Cover Rate (CCR)

Record tree location with DBH ≥10 cm and write "Tree ID" and DBH beside the points.

Drone photo ID: ____



2. Plot Measurement

Plot ID ____________________ Sheet 3

2.4 Vegetation Harvest

Cut and weigh all living vegetation: (tree DBH > 5 cm, grass and bamboo)

Sub-plot 1
Size: _____ m x _____ m

No.	Vegetation weight (kg)	Plastic Sheet
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

Sub-plot 2
Size: _____ m x _____ m

No.	Weight of vegetation (kg)	Plastic Sheet
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

Sub-plot 3
Size: _____ m x _____ m

No.	Weight of vegetation (kg)	Plastic Sheet
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

Sub-plot 4
Size: _____ m x _____ m

No.	Weight of vegetation (kg)	Plastic Sheet
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

weigh bag and sample + bag

bags (g)	sample + bags (g)

bags (g)	sample + bags (g)

bags (g)	sample + bags (g)

bags (g)	sample + bags (g)

2. Plot Measurement

Plot ID ________________ Sheet 4

2.5 Deadwood

Class 1

No.	DBH (cm)
1	
2	
3	
4	
5	

Class 3 (stump)

No.	D_1 (cm)	D_2 (cm)	Height (cm)	Reason
1				
2				
3				
4				
5				

Class 2

No.	D_{base} (cm)	D_{top} (cm)	Height (cm)	Distance (m)	S_{top} (%)	S_{bottom} (%)
1						
2						
3						
4						
5						

Lying deadwood

No.	D_1 (cm)	D_2 (cm)	Decay status	Hollow
1				
2				
3				
4				
5				