Summary Report

Mapping Forest Cover Change 2014-2018

Bolikhamxay Province, Lao PDR.

FOREST CARBON

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About Forest Carbon: Founded in 2007 in Jakarta, Forest Carbon is a Southeast Asian-based firm that addresses the need for a regionally focused team capable of providing technical services for carbon forestry projects in tropical rainforest countries. Our team of experts work one-on-one with governments, non-profits and private sector clients across Asia, Africa and South America on the development of field-level projects and jurisdictional programs for reducing emissions from deforestation and degradation including reforestation, conservation and sustainable management of forests (REDD+). Forest Carbon is a subsidiary of Equator Group PTE LTD, Singapore.

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BACKGROUND

In Bolikhamxay Province the Wildlife Conservation Society (WCS) works in partnership with the Provincial Agriculture and Forestry Office (PAFO) through the Integrated Ecosystem and Wildlife Management Program (IEWMP) to support the management of a variety of provincial and national protected areas.

PAFO and WCS have the need to complete land cover classifications and the identification of land cover changes in the Bolikhamxay landscape, including the different protected areas in which the IEWMP is involved. The objective is to provide data on forest cover trends, monitor deforestation and assess the impact of protected area management.

In 2014, Forest Carbon produced an accurate land cover map of the province using Landsat imagery for the entire province. This 2014 land cover map served as the base map for a land cover change analysis from 2003 to 2014 that assessed the deforestation that occurred in the province during this period. There is now a need to update this mapping exercise with data from 2018 to further assess trends and the impact of management activities.

WCS solicited Forest Carbon to conduct a land cover change analysis to assess deforestation in Bolikhamxay province and the following protected areas:

- Nam Kading National Protected Area (NK NPA);
- Nam Gnouang South Protection Forest Area (NGS PFA);
- Phou ChomVoy Provincial Protected Area (PCV PPA);
- Nhot Nam Mouan Provincial Protection Forest (NNM PPF);
- Phou Sithone ESCA (PST ESCA) and the forest delineated for Payment of Environmental Services (in Khamkhuna and Nacheng villages).

The following report outlines the methodological approach taken to conduct the change analysis to produce the 2018 land cover map and calculate the associated changes in land cover.

METHODOLOGY

The main steps of the methodological approach taken to conduct the change analysis and update the land cover map are outlined below and described in more detail in the following sections:

1. Collate historical data
2. Procure Landsat imagery
3. Conduct land cover change detection
4. Produce 2018 land cover classification
5. Produce forest cover change map
6. Conduct accuracy assessment
7. Finalize forest cover change map and produce figures

COLLATE HISTORICAL DATA

The first step consisted in collecting the various boundaries of interest. In this analysis the latest available boundaries were used. Forest Carbon also retrieved the previous data produced in the context of the assessment of deforestation trends between 2003-2014 for Bolikhamxay Province, especially the land cover map 2014, the 2014 satellite image mosaic, and the provincial boundary.

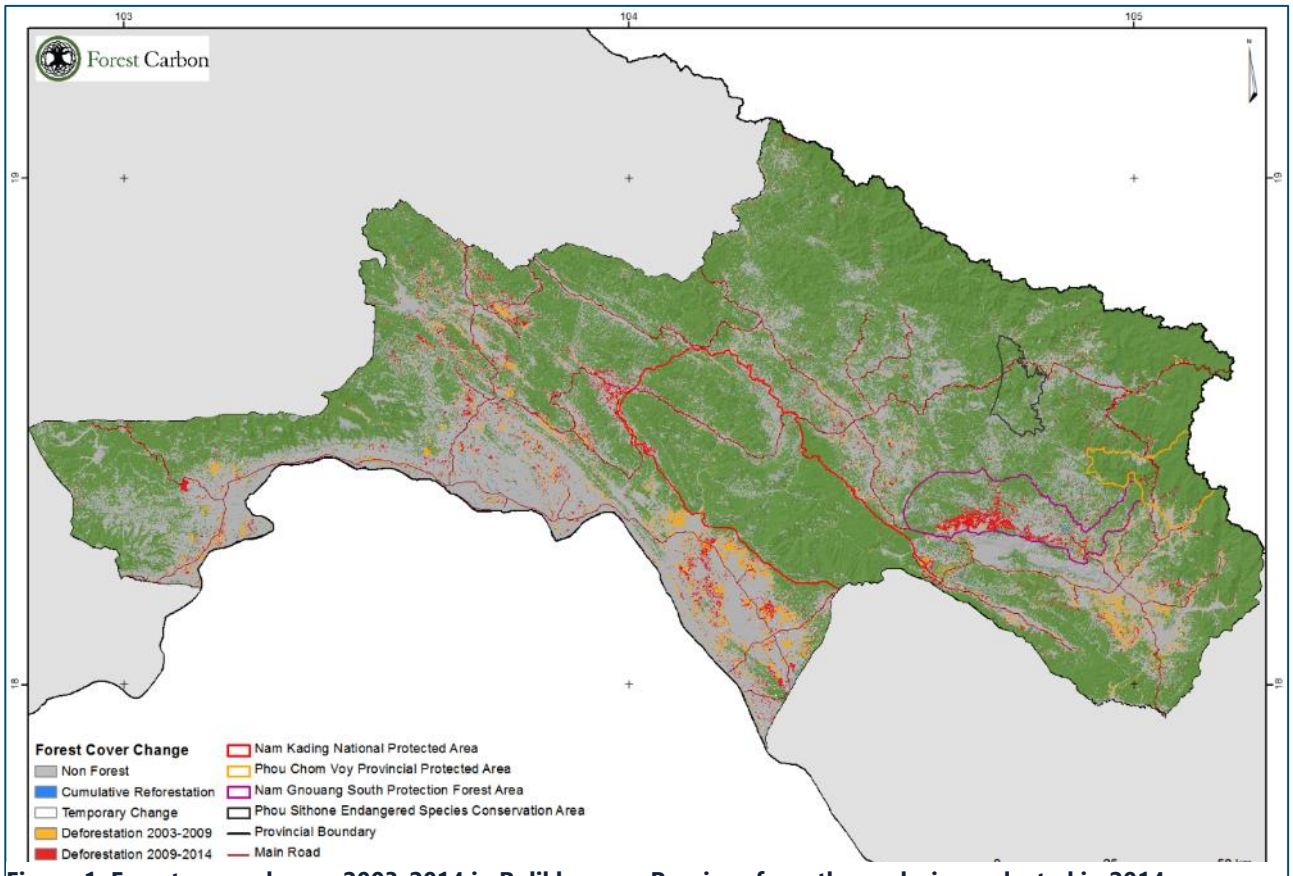

Figure 1. Forest cover change 2003-2014 in Bolikhamxay Province from the analysis conducted in 2014

PROCURE LANDSAT IMAGERY

For the 2014 study, various Landsat scenes were combined to produce cloud-free mosaic for the years 2003, 2009 and 2014. This process was quite laborious as it consisted of merging three different Landsat images (Path/Row: 128/47, 127/48, 127/47) and multiple Landsat7 images to fill cloudy areas and the inherent Landsat7 gaps caused by stripes due to a sensor malfunction.

Nowadays, Google Earth Engine offers access to the whole Landsat archive and functionalities to compute cloud-free mosaic images. A simple script was run (see Annex A) to produce a cloud-free and processed mosaic for 2014 and 2018 (Figure 2. 2018 Landsat 8 mosaic.

For 2014 and 2018, the mosaics are mainly built of the following scenes shown in Table 1.

Table 1. Main Landsat scenes used for mosaics

Path/Row	2014	2018
128/47	February 2012	March 2018
127/47	February 2014	April 2018
127/48	January 2014	April 2018

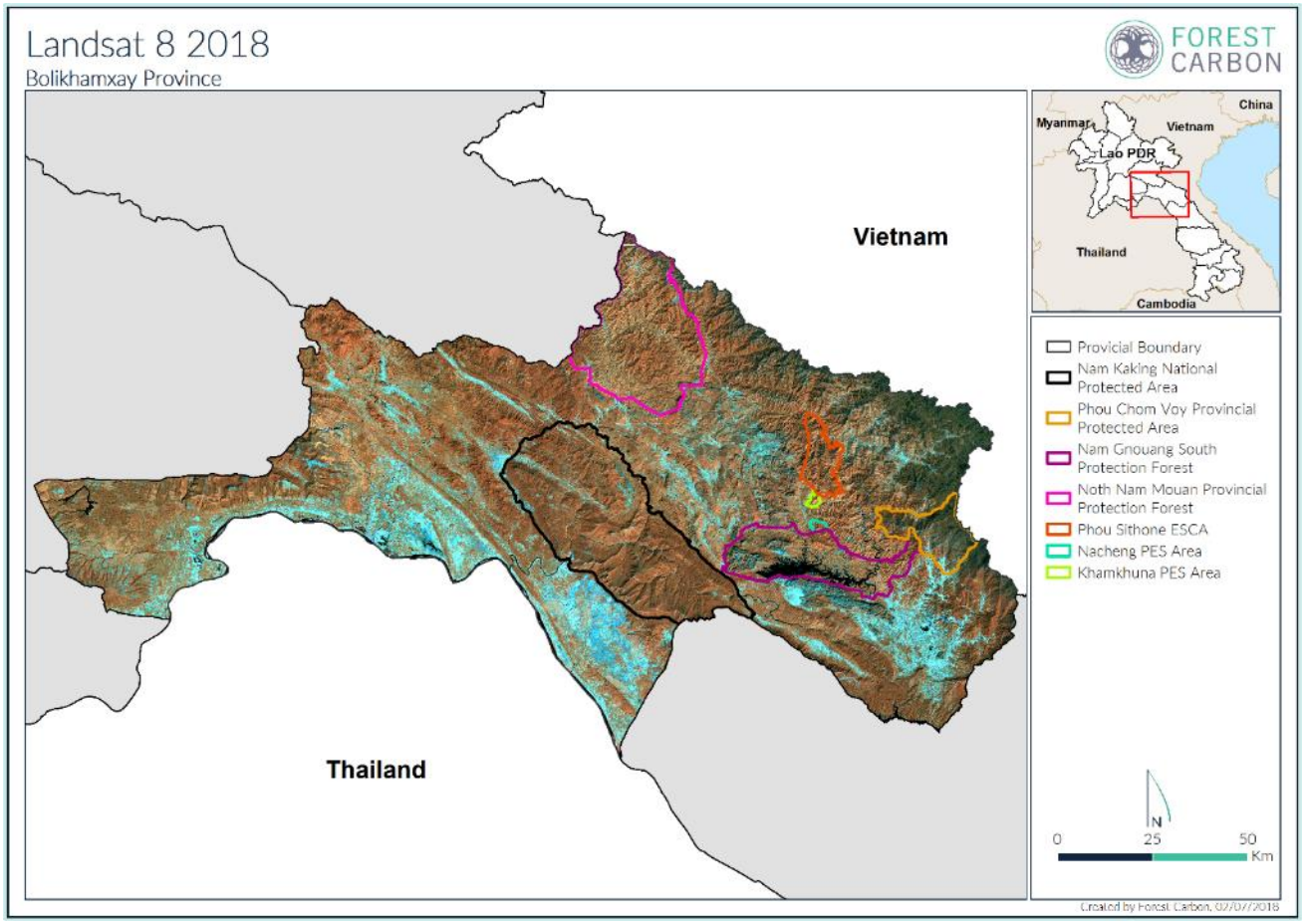

Figure 2. 2018 Landsat 8 mosaic

CONDUCT THE CHANGE DETECTION

Following the procurement of the Landsat mosaic, two vegetation indices were computed directly in the Google Earth Engine interface:

- NDVI, Normalized Difference Vegetation Index that uses Red and Near Infra-Red bands.

$$\frac{NIR - Red}{NIR + Red}$$

- NBR, Normalized Burn Ratio that uses Near Infra-Red and Short Wave Infra-Red bands.

$$\frac{NIR - SWIR}{NIR + SWIR}$$

NDVI is one the most straightforward and used vegetation indices to measure photosynthesis activity. Healthy vegetation absorbs most of the visible light (red band) that hits it, and reflects a large portion of the near-infrared light. Unhealthy or sparse vegetation reflects more visible light and less near-infrared light. Therefore, healthy vegetation has positive values around 0.7 - 0.8 while sparse vegetation shows values around 0.3. Non-vegetated areas have low values (around 0.1) to negative values. Water areas have negative values.

NBR is usually used to identify burn scars but can also be very useful to monitor vegetation health as it is very sensitive to moisture and enables a clear separation of various vegetation state. In contrast to NDVI, it does not use band in the visible light, and this is less affected by haze and clouds. However, water is not well detected with this index as it has similar value than vegetated land.

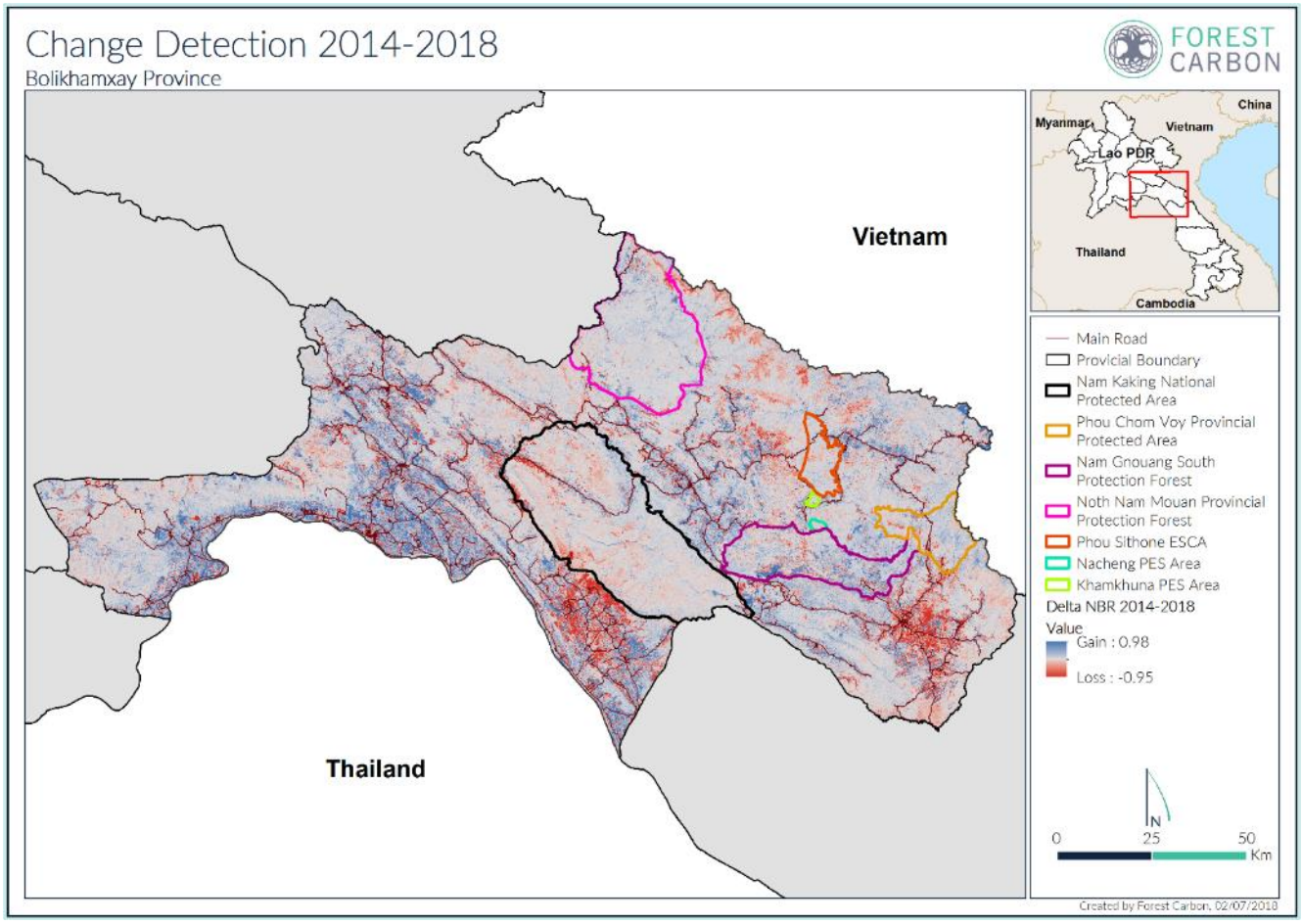

Figure 3. Loss and gain in vegetation between 2014 and 2018

Computing those indexes for both 2014 and 2018 and comparing their evolution over the period helped to assess loss and gain in vegetation and therefore land cover change.

The loss and gain were primarily computed from the difference between NBR values (NBR 2018 minus NBR 2014) as shown in Figure 3. The difference between NDVI values was used to complement the previously identified loss and gain with the changes that involved water areas, such as the new reservoir. To ensure that changes of loss and regrowth that would have occurred between 2014 and 2018 would not be dismissed by the analysis, the loss and gain layer was consolidated with the pixels of loss for 2014, 2015 and 2016 from the Tree Cover Loss 2000-2016 layer from the University of Maryland[1]. This global dataset computes potential vegetation loss and gain for each year and offers an additional source of information on potential land cover transitions. A thorough visual check of this dataset was conducted with a Landsat mosaic from 2016 to verify that any identified changes corresponded with changes visible in the underlying imagery.

Finally the pixels of loss and gain were classified according to their NDVI values to describe the land cover change trajectory as follows:

1. Loss to bare land: the pixel value decreased considerably to a typical value for non-vegetated areas (NDVI value will go from 0.75 in 2014 to 0.3 in 2018).

[1] http://earthenginepartners.appspot.com/

2. Loss to regenerating vegetation: the pixel value showed a decrease to a typical value for shrubland or fallow land (NDVI will go from 0.75 to around 0.5 - 0.6).
3. Gain to regenerating vegetation: the pixel value showed an increase from low value, usually bare land to higher value (NDVI will go from 0.3 to around 0.6).
4. Gain to Forest Plantation: changes due to this transition show pixel values similar to regenerating vegetation, however due to the specific nature of this transition these were visually identified.
5. Change to Water: the pixel value showed a decrease to a negative value.

This change detection layer was then converted to a shapefile and manually checked and "cleaned" by removing all artefact polygons due to Landsat stripes or clouds.

PRODUCE THE LAND COVER 2018

The following part of the analysis consisted of combining the land cover map 2014 with the change layer to produce an updated 2018 land cover map. For example, if the change layer identified a forest area from the 2014 map as undergoing a transition to bare land, then the 2018 land cover classification would be updated to show bare land in this specific area. To make the analysis and the final deliverable in line with the current Lao national classification system and forest definition, the shrub/fallow class was renamed "Regenerating vegetation", and the Lao minimum area threshold for forest of 0.5ha applied.

The land cover 2014 produced in the context of the "Deforestation Mapping for Bolikhamxay Province 2003-2014" did not follow the minimum area for forest and therefore the minimum mapping unit was one pixel. For the need of the updated change analysis, the 0.5ha threshold was also applied to the 2014 map and the maps from 2003 and 2009 as well for the latter analysis on forest cover change from 2003 to 2018.

PRODUCE THE FOREST COVER CHANGE MAP AND FIGURES

For consistency purpose, this analysis used the same approach that was followed for the work conducted in 2014; forest is considered as the land cover types that describe Current Forest as outlined by the Lao national classification system level 1 in Figure 4 below. Deforestation is therefore any transition from Current Forest to any non-forest land cover type, including the Regenerating Vegetation class, which is also sometimes called Potential Forest in Lao classification systems. Regeneration Vegetation are fallow land that might recover to forest if they are not cleared again.

The land cover maps 2014 and 2018 were classified into Forest and Non-forest classes and the comparison of these two maps gave the deforestation and reforestation over the 2014-2018 period.

It should be noted that since 2014 the Government of Lao PDR (GoL) has made significant progress in the implementation of its national REDD+ program, including the development of its national Forest Reference Emission Level (FREL)[2]. Within the FREL, the GoL considers Regenerating Vegetation as a forest class and thus the transition from Current Forest to Regenerating Vegetation is not considered as forest loss. This in an important distinction to take note of when presenting the results of this report to GoL counterparts.

[2] http://redd.unfccc.int/files/2018_frel_submission_laopdr.pdf

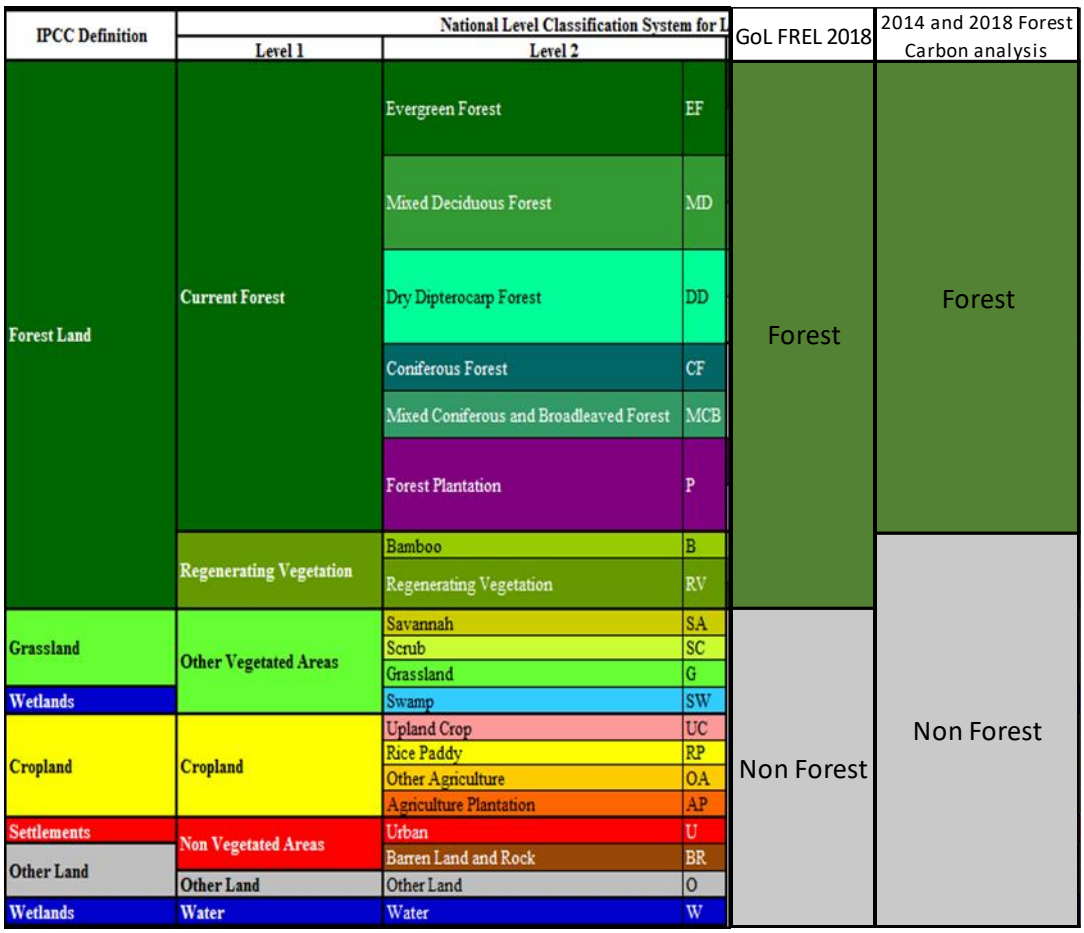

Figure 4. Lao PDR National land cover system

ACCURACY ASSESSMENT

In remote sensing, accuracy assessments are a compulsory step to validate the produced map and determine whether the various land cover classes were accurately mapped. In the context of REDD+, the Global Observation of Forest Cover and Global Observation of Land Dynamics recommends in its sourcebook [3]using the results of the accuracy assessment not only to validate the map but also, if using the results to generate activity data for GHG emissions estimates, to adjust the area estimates and quantify the related uncertainty. Adjusting area estimates on the basis of a rigorous accuracy assessment represents an improvement over simply reporting the areas of map classes as described in Olofsson's publication[4]. In this way, emissions estimates can be adjusted to ensure conservativeness. Generating conservative GHG emission estimates was not within the scope of this study, however this best practice approach to conducting an accuracy assessment was followed nonetheless.

To implement the accuracy assessment, a stratified random sampling approach was followed; the first step was to calculate the number of required sample plots for each strata of the 2014 – 2018 forest cover change map:

- Forest: forest in 2014 that remained forest in 2018;

[3] http://www.gofcgold.wur.nl/redd/sourcebook/GOFC-GOLD_Sourcebook.pdf
[4]https://www.researchgate.net/publication/260138121_Good_Practices_for_Assessing_Accuracy_and_Estimating_Area_of_Land_Change

- Non-forest: non-forest in 2014 that remained non-forest in 2018;
- Deforestation: forest loss between 2014 and 2018; and
- Reforestation: non-forest in 2014 that became forest in 2018.

The total size of the stratified sample is given by a formula[5] that considers the area proportion of the four strata in the forest cover change map 2014-2018, and the expected accuracy of each strata.

Table 2. Accuracy assessment sample design

Sample design	Forest (in 2014 and 2018)	Non-Forest (in2014 and 2018)	Deforestation	Reforestation	Total
Area (%)	57	40	2	0.8	100
Expected accuracy %	83	97	80	80	
Option 1	499	345	18	7	869
Option 2	425	294	100	50	869

The expected accuracy for Forest and Non-forest classes was taken from the accuracy assessment results on the 2014 land cover map; for the Deforestation and Reforestation classes a reasonable accuracy of 80% was considered. According to the formula, the total number of required sample plots was calculated to be 869 to be distributed between the four strata. Option 1, as outlined in Table 2, considered distributing these plots proportionally between classes, however it was determined that this would not allocate enough plots to the loss and gain classes. Therefore, it was decided to allocate a minimum of 100 and 50 plots respectively to the deforestation and reforestation strata, with the remaining plots being proportionally spread between forest and non-forest strata (Option 2). The plots were then randomly created with ArcGIS as shown in Figure 5.

For each sample point, the "trajectory" of forest change was visually checked with Google Earth and Sentinel-2 imagery[6] and compared with the strata given by the map to build the accuracy assessment matrix (Annex G).

[5] *https://www.researchgate.net/...sample.../Cochran_1977_Sampling+Techniques.pdf*
[6] Available at www.rfo-sea.org/mapviewer

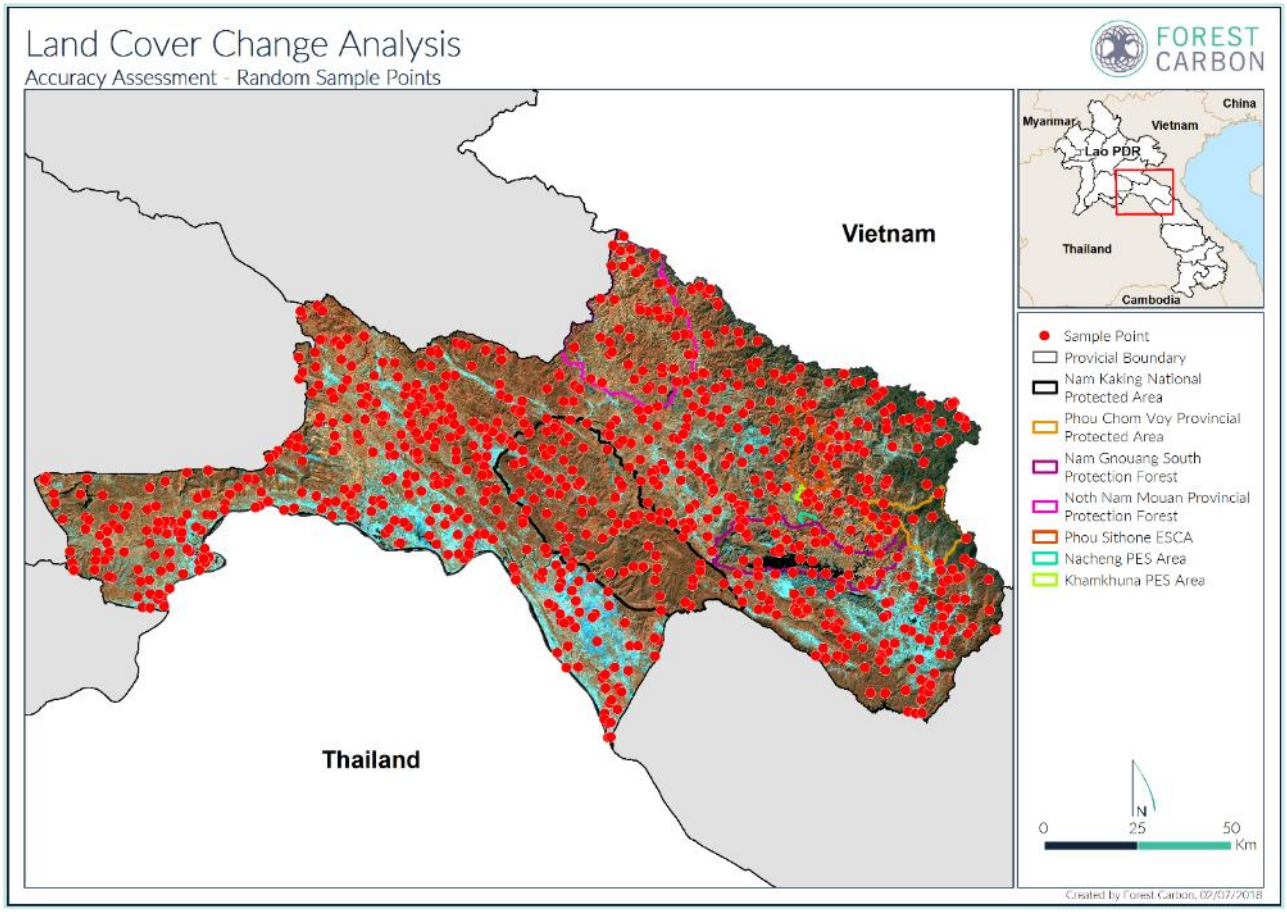

Figure 5. Random sampling for the accuracy assessment

RESULTS

LAND COVER 2018

As Table 3 and Table 4 demonstrate, Bolikhamxay province is primarily covered with forest (57.9%) composed primarily of mixed deciduous forest and evergreen forests. The evergreen forest occurs primarily in the east of the province close to the Annamite range along the Vietnamese border. Plantation forest, mainly rubber and acacia, are found in the flatter areas and represent nearly 1% of the total forest cover. The Regenerating Vegetation describes fallow lands, both young and old, that can also be non-mature forest plantation areas or stable bamboo forest.

Table 3. Land cover 2018 breakdown areas

Land Cover Type	Bolikhamxay Province		Nam Kading NPA		Nam Gnouang South PFA		Phou Chom Voy PPA	
Level 2	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
Evergreen Forest	89,724	5.8%	0	0.0%	12	0.0%	13,072	52.6%
Mixed Deciduous Forest	802,508	51.4%	127,431	78.1%	24,172	44.3%	7,983	32.1%
Plantation Forest	11,670	0.7%	2	0.0%	0	0.0%	0	0.0%
Total Current Forest	*903,902*	*57.9%*	*127,433*	*78.1%*	*24,184*	*44.3%*	*21,054*	*84.7%*
Regenerating Vegetation	343,551	22.0%	26,568	16.3%	14,561	26.7%	1,893	7.6%
Grassland	2,040	0.1%	0	0.0%	27	0.0%	1	0.0%
Bare Land	263,171	16.9%	8,539	5.2%	3,628	6.6%	1,888	7.6%
Water	28,531	1.8%	563	0.3%	10,130	18.6%	25	0.1%
Rock	19,115	1.2%	0	0.0%	2,036	3.7%	0	0.0%
Total	**1,560,312**	**100.0%**	**163,104**	**100.0%**	**54,567**	**100.0%**	**24,860**	**100.0%**

The Nam Kading NPA, Phou Sithone ESCA, Nhot Nam Mouand PPF and Nacheng PES are mostly covered by mixed deciduous forest in similar proportions. The Phou Chom Voy PPA has the highest forest cover of any of the protected areas; half of the protected area is covered in evergreen forest while an additional third is covered by mixed deciduous forest. The Nam Gnouang South Protection Forest Area is a combination of the THXP reservoir, agricultural land, perennial grassland and mixed deciduous forest on its west side. The Khamkhuna PES area has nearly 37% of its area covered by regenerating vegetation suggesting it may be the most disturbed of all the protected areas.

Table 4. Land cover 2018 breakdown areas (cont.)

Land Cover Type	Phou Sithone ESCA		Khamkhuna PES		Nacheng PES		Nhot Nam Mouan	
Level 2	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
Evergreen Forest	0	0.0%	0	0.0%	0	0.0%	1,695	1.7%
Mixed Deciduous Forest	10,980	77.4%	555	62.1%	758	77.5%	77,375	79.0%
Plantation Forest	0	0.0%	0	0.0%	0	0.0%	0	0.0%
Total Current Forest	*10,980*	*77.4%*	*555*	*62.1%*	*758*	*77.5%*	*79,069*	*80.7%*
Regenerating Vegetation	3,040	21.4%	329	36.8%	220	22.5%	15,176	15.5%
Grassland	0	0.0%	0	0.0%	0	0.0%	0	0.0%
Bare Land	167	1.2%	9	1.1%	0	0.0%	3,607	3.7%

Water	1	0.0%	0	0.0%	0	0.0%	50	0.1%
Rock	0	0.0%	0	0.0%	0	0.0%	87	0.1%
Total	**14,187**	**100.0%**	**893**	**100.0%**	**977**	**100.0%**	**97,990**	**100.0%**

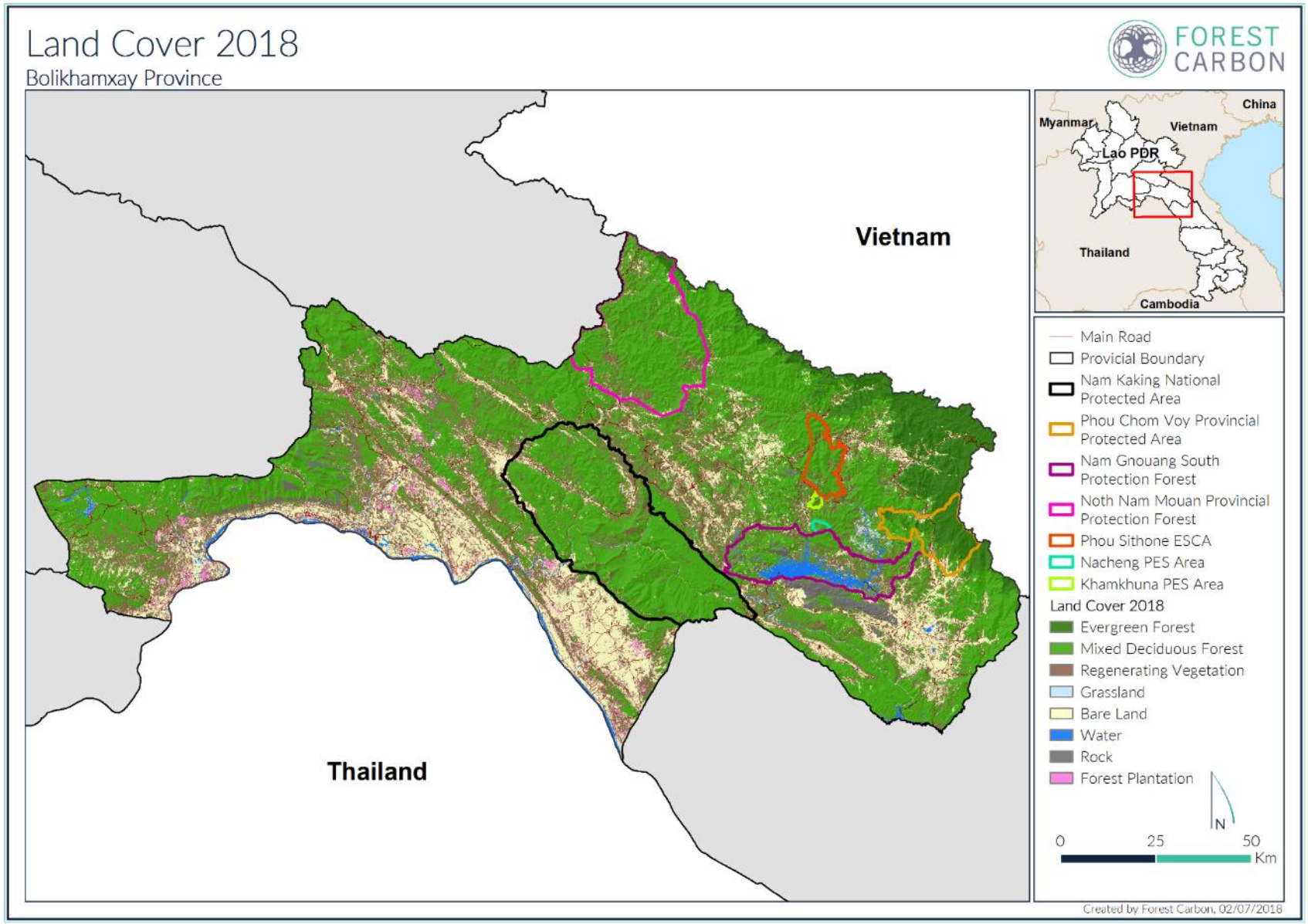

Figure 6. Land cover map 2018

ACCURACY ASSESSMENT

For Bolikhamxay province, Table 5 below displays the overall accuracy, the producer accuracy and the user accuracy for each of the four strata of the forest cover change map: i) Forest remaining forest; ii) non-forest remaining non-forest; iii) deforestation; and iv) reforestation. The overall map reaches an accuracy of 85%. The producer accuracy reaches 80% for deforestation and 88% for the reforestation which means that both forest cover change trends witnessed on the ground are accurately reported on the map. For example, a reforestation event seen on the ground, like the establishment of a forest plantation concession, has 88% chance to be reported on the map. The user accuracy reaches 81% for deforestation and 71% for reforestation which means that both of these forest change trajectories seen on the map correspond to a real event on the ground. For example, if the user of the map were to go the location where the map identifies deforestation, they would have 81% chance to see deforestation at this location. These numbers illustrate that the change map is reliable.

Table 5. Accuracy assessment and area estimates for forest cover change 2014-2018

Strata	Producer accuracy	User accuracy	Area from the map (ha)	Adjusted Area (ha)	95% CI (ha)	Uncertainty
Forest in 2014 and 2018	89%	87%	892,277	914,531	±39,223	4%
Non-forest in 2014 and 2018	79%	83%	623,201	598,580	±39,925	7%
Deforestation	80%	81%	33,209	32,748	±7,760	24%
Reforestation	88%	71%	11,626	14,452	±6,060	42%
Overall accuracy		85%				

Table 5 also provides the adjusted areas for each strata. From the count of the accuracy sample plots (Annex G), the area proportion of a strata is inferred with the proportion of match between the map and the reference data. For instance, for the forest strata, the initial area proportion of the whole province given by the map is 0.57. Inferred with the reference data, the proportion of the forest strata that matches with sample plots identified as forest is 0.5085. Then we add to this estimated area proportion, the estimated area proportion of Non-forest that corresponds to sample plots identified as forest (0.0756), the estimated area proportion of Deforestation that corresponds to sample plots identified as forest (0.0017), the estimated area proportion of Reforestation that corresponds to sample plots identified as forest (0.0004) to arrive to the estimated area proportion for the forest strata equal to 0.5861. This proportion is then multiplied Fwith the province total area to obtain the adjusted area for forest strata shown in Table 5 (914,531 ha) which represents the area of forest revised according to the reference data.

Based again on the sample counts matrix, the 95% confidence interval is computed for each strata. That means that the true value for the strata area has 95% chance to be in the range of the adjusted area plus or minus the 95% CI. The uncertainty is directly derived as it is the ratio of the CI with the adjusted area. For instance the area given by the map for deforestation is just slightly bigger than the adjusted area and sits within the range defined by the adjusted area and the confidence interval. Finally, the high accuracy numbers and the rather moderate uncertainty numbers lead to the conclusion that the map is valid and the given areas trustworthy. The adjusted area in combination with the Confidence Interval give a quantitative and meaningful approach of the map accuracy.

FOREST COVER CHANGE 2014-2018

Table 6 provides a summary of the forest cover in 2014 and 2018 period for the various areas of interest. Current forest considers forested areas that currently meet the Lao definition of forest while forest land, in line with the IPCC land-use (Figure 4) includes regenerating vegetation or potential forest land which may reach in the future the forest definition. Between 2014 and 2018, the current forest area for the whole province decreased by more than 20,000 ha which is equivalent to a net deforestation of 5,396 ha/year. Almost all of the IEWMP's areas of interest saw a net loss of forest. The Nam Kading NPA and Nam Gnouang South PFA were the most affected, while losses in the two PES areas and the Phou Sithone ESCA were nil to negligible

Table 7 and Table 8 describe the forest cover change with the rates of gross deforestation, gross reforestation, and net deforestation. At the provincial level, the deforestation is driven by the extension of agricultural lands, the development of infrastructures like hydropower dams (Nam Mang 1, Nam Ngiep 1, Nam Theun 1) or new roads, such as the road east of Lak Sao.

Table 6. Current forest and forest land area in 2014 and 2018

		Current Forest		Forest Land	
		2014	2018	2014	2018
Bolikhamxay Province	Area (ha)	925,486	903,902	1,262,307	1,247,454
	%	59%	58%	81%	80%
Nam Kading NPA	Area (ha)	130,309	127,433	155,999	154,002
	%	80%	78%	96%	94%
Nam Gnouang South PFA	Area (ha)	24,935	24,184	38,548	38,746
	%	46%	44%	71%	71%
Phou Chom Voy PPA	Area (ha)	21,337	21,054	23,278	22,947
	%	86%	85%	94%	92%
Phou Sithone ESCA	Area (ha)	10,990	10,980	14,004	14,019
	%	77%	77%	99%	99%
Khamkhuna PES	Area (ha)	555	555	883	883
	%	62%	62%	99%	99%
Nacheng PES	Area (ha)	759	758	977	977
	%	78%	78%	100%	100%
Nhot Nam Mouan	Area (ha)	80,496	79,069	94,874	94,245
	%	82%	81%	97%	96%

Of all the protected areas, the Nam Kading NPA, is the area where the deforestation rate, in hectares per year, is the highest. In recent years, this area was under pressure from the extension of agricultural land in its

northern part and the construction of the dam on the Nam Kading river. The Nam Gnouang South PFA, on the other hand, experienced the highest deforestation rate as a percentage of its total available forest area (0.75%). This forest loss was due to agricultural activity principally in the south east of the area. In the same period, forest was lost in the Phou Chom Voy PPA due to road enhancement work and the unseasonably cold weather experienced in January 2015 which led to frost and impacted high elevated and exposed forest areas. As mentioned earlier, forest loss occurred but at minor levels in the PES areas and Phou Sithone ESCA. The Nhot Nam Mouan PPF lost 357 ha/year of forest from agriculture expansion in its south part along the main road that goes to Xiengkouang province and in its northern part nearby the Vietnamese border.

In addition to deforestation, the analysis attempted to identify areas of reforestation. However, the short timeframe (4 years from 2014 and 2018) did not allow for the identification of reforestation from natural regeneration as this process usually takes around 8-10 years. On the other hand, the analysis was able to pick up reforestation due to the establishment of commercial forest plantations through visual checks. This reforestation due to commercial plantations can be seen at the provincial level but not in any of the IEWMP areas of interest.

Table 7. Forest cover change areas 2014-2018

Forest Cover Change 2014-2018		Bolikhamxay Province	Nam Kading NPA	Nam Gnouang South PFA	Phou Chom Voy PPA	Phou Sithone ESCA
Gross Deforestation	ha/year	8,302	719	188	71	3
	%/year	0.90%	0.55%	0.75%	0.33%	0.02%
Gross Reforestation	ha/year	2,906	1	-	-	-
	%/year	0.46%	0.00%	0.00%	0.00%	0.00%
Net Deforestation	ha/year	5,396	719	188	71	3
	%/year	0.58%	0.55%	0.75%	0.33%	0.02%

Table 8. Forest cover change areas 2014-2018 (cont.)

Forest Cover Change 2014-2018		Khamkhuna PES	Nacheng PES	Nhot Nam Mouan
Gross Deforestation	ha/year	0	0	357
	%/year	0.01%	0.04%	0.44%
Gross Reforestation	ha/year	-	-	-
	%/year	0.00%	0.00%	0.00%
Net Deforestation	ha/year	0	0	357
	%/year	0.01%	0.04%	0.44%

Forest Cover Change 2014-2018

Bolikhamxay Province

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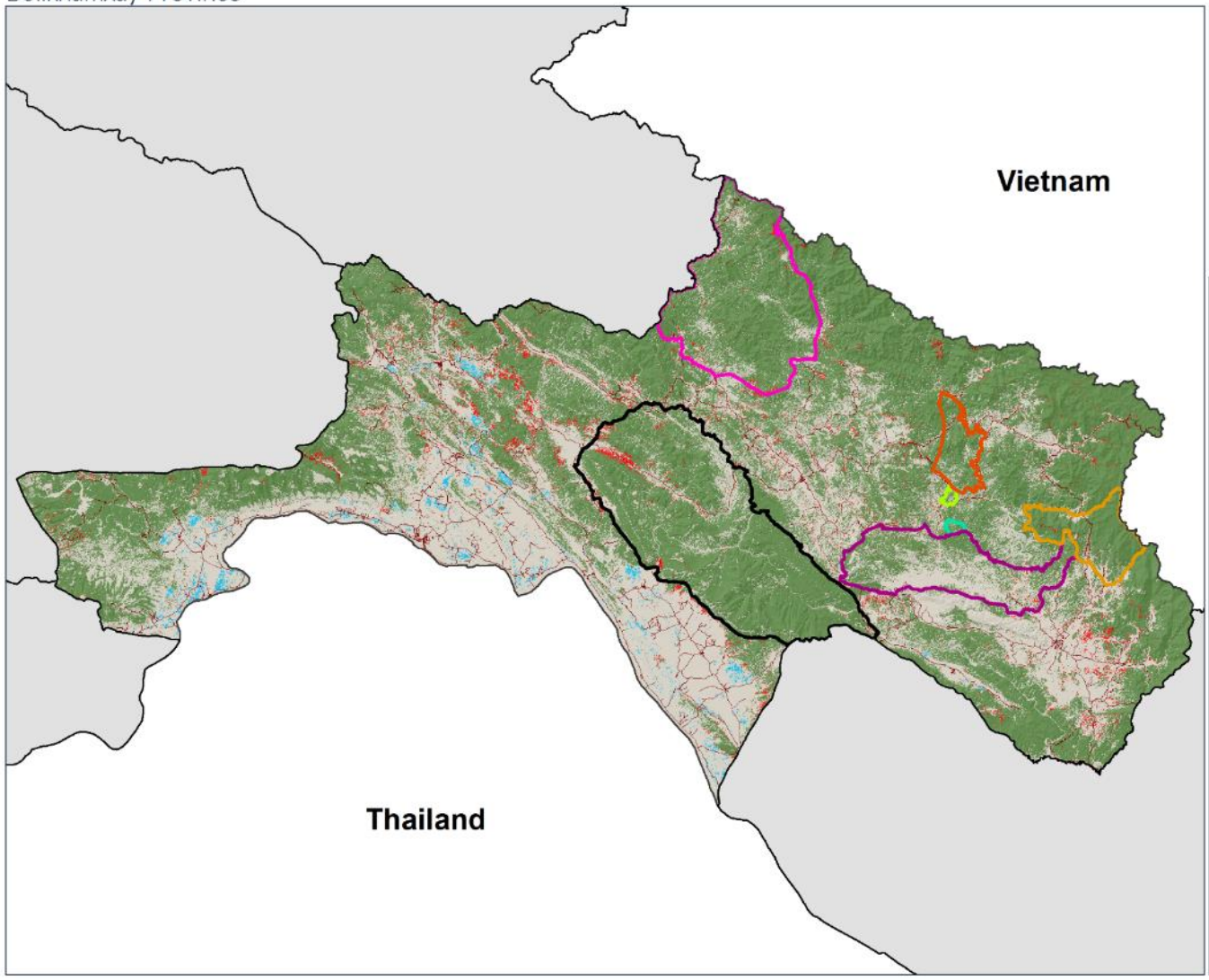


- Main Road
- Provicial Boundary
- Nam Kaking National Protected Area
- Phou Chom Voy Provincial Protected Area
- Nam Gnouang South Protection Forest
- Noth Nam Mouan Provincial Protection Forest
- Phou Sithone ESCA
- Nacheng PES Area
- Khamkhuna PES Area

Forest Cover Change 2014-2018

- Non Forest
- Reforestation
- Deforestation
- Forest

N

0 25 50 Km

Created by Forest Carbon, 02/07/2018

Figure 7. Forest cover change 2014-2018 - Bolikhamxay province

ALIGNING FOREST COVER CHANGE 2003-2014 AND 2014-2018

To align the current analysis with the one conducted in 2014, the figures for the forest cover change 2003-2014 were recomputed by using up-to date boundaries and revised forest/non-forest layers for the years 2003 and 2009 that were adjusted by applying a threshold of 0.5ha for forest areas. The whole forest cover change trajectory from 2003 to 2018 is assessed by looking at the gross deforestation rate as shown in Table 9, the gross reforestation rate shown in **Error! Reference source not found.** and the net deforestation rate shown in Table 11.

At the provincial level, the assessment of the forest cover change trend over the last 15 years demonstrates a sustained pressure on natural landscape with an increase in the gross deforestation rate during the last period, a trend that is also reflected in the various protected areas. However, this is balanced in the latest period by a reforestation rate of nearly 3,000 ha/year which comes principally from commercial plantation forest reaching maturity and thus matching the forest definition.

Within the protected areas, the increase in deforestation was most dramatic in the Nam Kading NPA and Nhot Nam Mouan PPF (when expressed as percentage of forest deforested per year). The Nam Gouang South Protection Forest Area is a specific case as the THXP reservoir caused important forest loss in the 2009-2014 period. However, the deforestation rate in the latest period is higher than it was between 2003 and 2009 probably due to the increasing pressure from the displaced population in relocated villages in the south-east of this area. The Phou Chom Voy PPA saw a slight decrease in its deforestation rate during the 2014 – 2018 period. In Phou Sithone and the Khamkhuna PES area, the deforestation rate is low and decreasing. The Nacheng PES saw negligible forest cover loss. In those areas, the reforestation would be the result of natural regeneration of fallow land to forest. This continuous process that can take six to ten or more years depending on the landscape and bioclimatic factors is challenging to capture with remote sensing imagery when the analysis timeframe is short. As shown in the Table 10, reforestation from natural regeneration was more prevalent in the first, longer period 2003-2009 than in the two shorter periods that followed.

Error! Reference source not found. charts the net deforestation rate (expressed as % forest loss per year) for each of the protected areas as well as the entirety of Bolikhamxay province. It should be noted, however, that the figure below only uses the figures from the first and the latest period for the Nam Gnouang South PFA as the exceptionally high figure for the 2009-2014 period would distort the chart and make comparisons difficult.

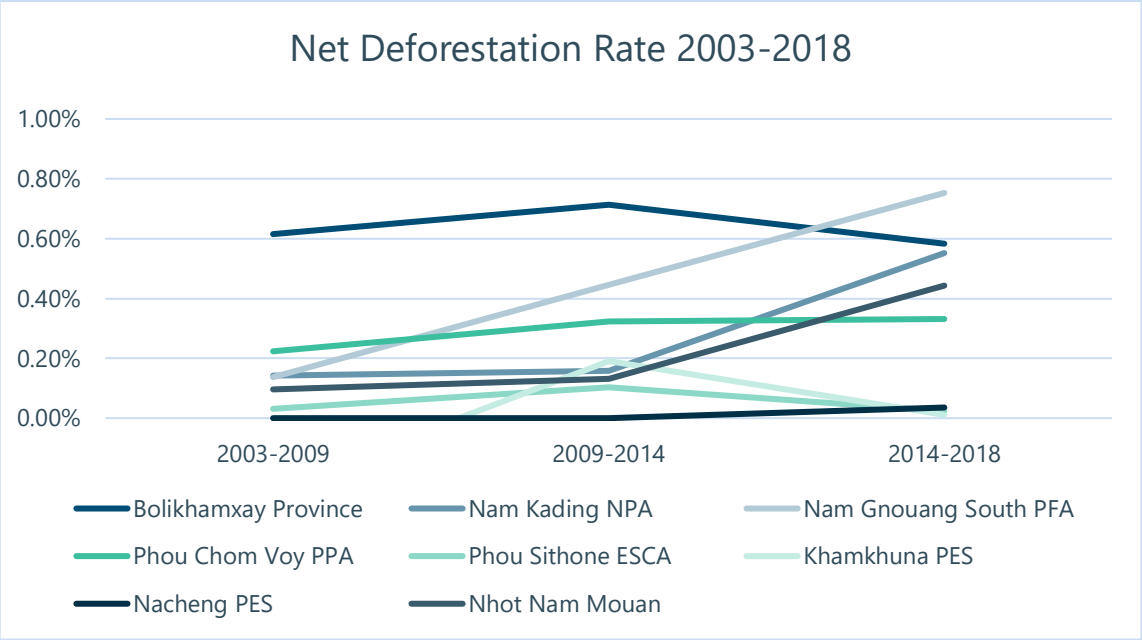


Figure 8. Chart of net deforestation rates from 2003 to 2018

Table 9. Gross deforestation rate 2003 to 2018

Gross Deforestation		Bolikhamxay Province	Nam Kading NPA	Nam Gnouang South PFA	Phou Chom Voy PPA	Phou Sithone ESCA	Khamkhuna PES	Nacheng PES	Nhot Nam Mouan
2003-2009	ha/year	6,615	195	128	62	10	0.2	-	90
	%/year	0.66%	0.15%	0.41%	0.28%	0.09%	0.04%	0.00%	0.11%
2009-2014	ha/year	7,040	211	1,239	91	12	1.1	-	112
	%/year	0.73%	0.16%	3.98%	0.42%	0.10%	0.19%	0.00%	0.14%
2014-2018	ha/year	8,302	719	188	71	3	0.1	0.3	357
	%/year	0.90%	0.55%	0.75%	0.33%	0.02%	0.01%	0.04%	0.44%

Table 10. Gross reforestation rate 2003 to 2018

Gross Reforestation		Bolikhamxay Province	Nam Kading NPA	Nam Gnouang South PFA	Phou Chom Voy PPA	Phou Sithone ESCA	Khamkhuna PES	Nacheng PES	Nhot Nam Mouan
2003-2009	ha/year	482	6	85	13	6	1.5	-	11
	%/year	0.09%	0.02%	0.37%	0.44%	0.20%	0.45%	0.00%	0.07%
2009-2014	ha/year	195	2	0	21	0.1	-	-	5
	%/year	0.03%	0.00%	0.00%	0.65%	0.00%	0.00%	0.00%	0.03%
2014-2018	ha/year	2,906	1	-	-	-	-	-	-
	%/year	0.46%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

Table 11. Net deforestation rate 2003 to 2018

Net Deforestation		Bolikhamxay Province	Nam Kading NPA	Nam Gnouang South PFA	Phou Chom Voy PPA	Phou Sithone ESCA	Khamkhuna PES	Nacheng PES	Nhot Nam Mouan
2003-2009	ha/year	6,133	188	43	49	3	-1.3	-	78
	%/year	0.62%	0.14%	0.14%	0.22%	0.03%	-0.24%	0.00%	0.10%
2009-2014	ha/year	6,845	209	1,239	70	11	1.1	-	107
	%/year	0.71%	0.16%	3.98%	0.32%	0.10%	0.19%	0.00%	0.13%
2014-2018	ha/year	5,396	719	188	71	3	0.1	0.3	357

%/year	0.58%	0.55%	0.75%	0.33%	0.02%	0.01%	0.04%	0.44%

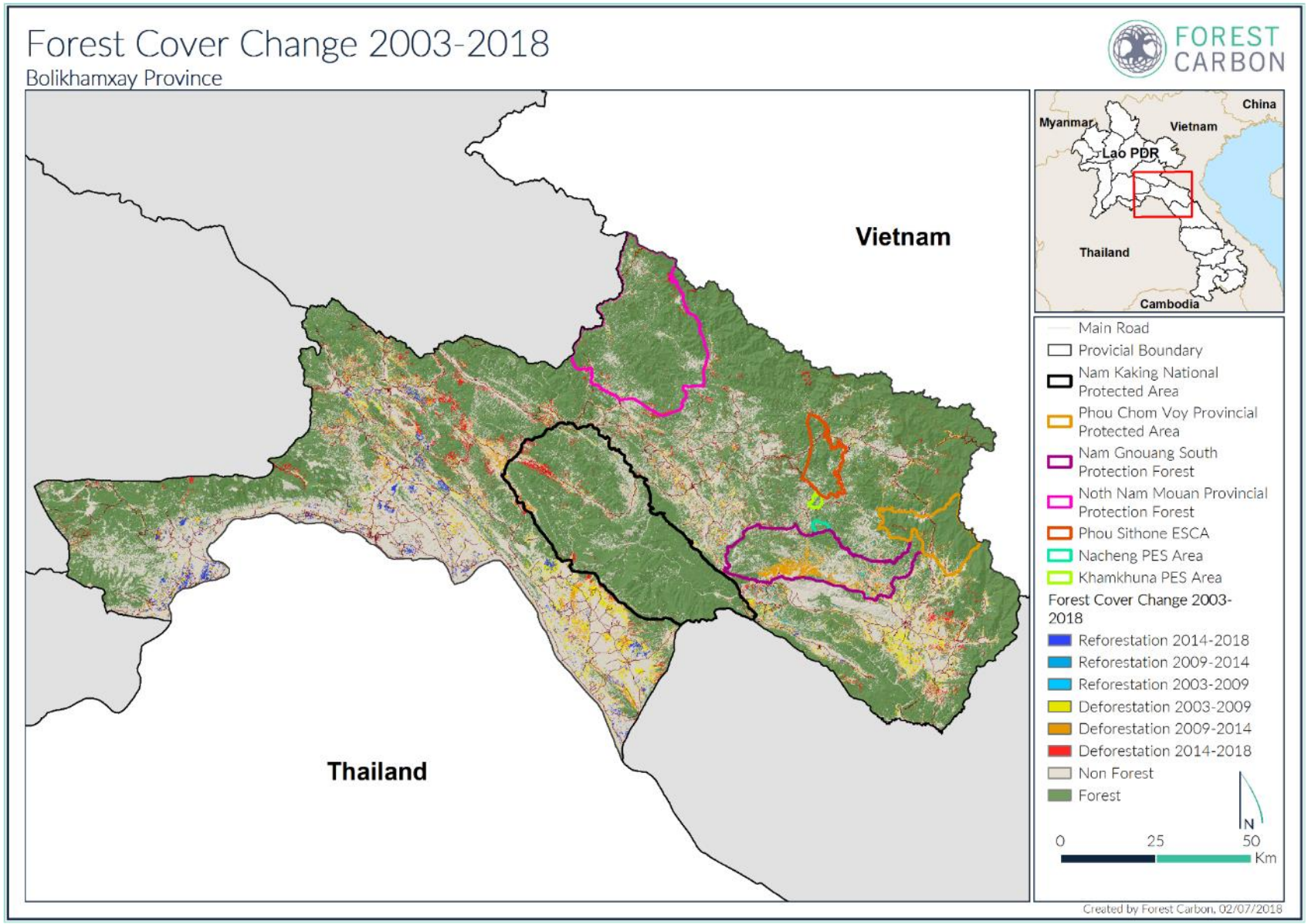


Figure 9. Forest cover change 2003-2018

TRAINING AND TECHNICAL ASSISTANCE

In parallel with the implementation of the above change analysis work for Bolikhamxay province, Forest Carbon trained the WCS GIS Officer on each of the steps required to conduct the provincial land cover change analysis, as well as the procedure to generate a land cover map specific for the two PES areas (Khamkuna and Nacheng) as described in the following sections.

TRAINING SCHEDULE AND CONTENT

Forest Carbon conducted the training at the WCS office and followed the schedule below:

- 11 April: Introduction of the methodology and the various steps
- 26 April: Image procurement and change detection. Conduction of an unsupervised classification for the PES areas.
- 3 May: Discussion on the field survey approach for the PES areas. Identification of the ground truthing locations.
- 15 May: Review of the field survey data. Review of the provincial level loss and gain map.
- 31 May: Initiation of the supervised classification for the PES areas.
- 8 June: Review of the training areas for the supervised classification. Introduction to segmentation. Manual cleaning of the loss and gain for the provincial analysis.
- 15 June: Review of the process to go from the loss and gain maps to a land cover change map.
- 4 July: Manual editing of the landcover map of the PES areas.
- 12 July: Conducting the accuracy assessment on the Khamkhuna PES map.

The main steps followed in the analysis were compiled in a training presentation shared with the WCS GIS Officer.

PRODUCTION OF A BASE LAND COVER MAP – CASE STUDY ON THE PES AREA

WCS requires a detailed current land cover classification of the PES area (in Khamkhuna and Nacheng villages) for which it is initiating rehabilitation activities. Forest Carbon guided the WCS GIS Officer in the

production of a base land cover map of the PES area. This technical assistance followed the steps below:

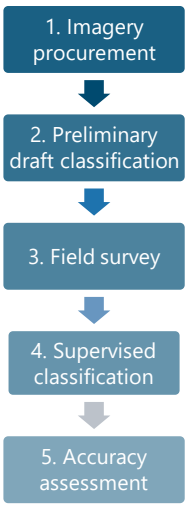


Figure 10. PES Land Cover Mapping Workflow

IMAGERY PROCUREMENT

Sentinel-2 imagery was freely procured from the Sentinel-hub.com website. This imagery combines 10 meter resolution for the visible bands and the near-infrared band, with a short acquisition timeframe; every five days a new image is available for any location worldwide. A first image from 9 April 2018 was procured and used for the preliminary draft classification. After a fire event was reported in Khamkhuna, a new image from the 24 April was procured and used for the rest of the analysis.

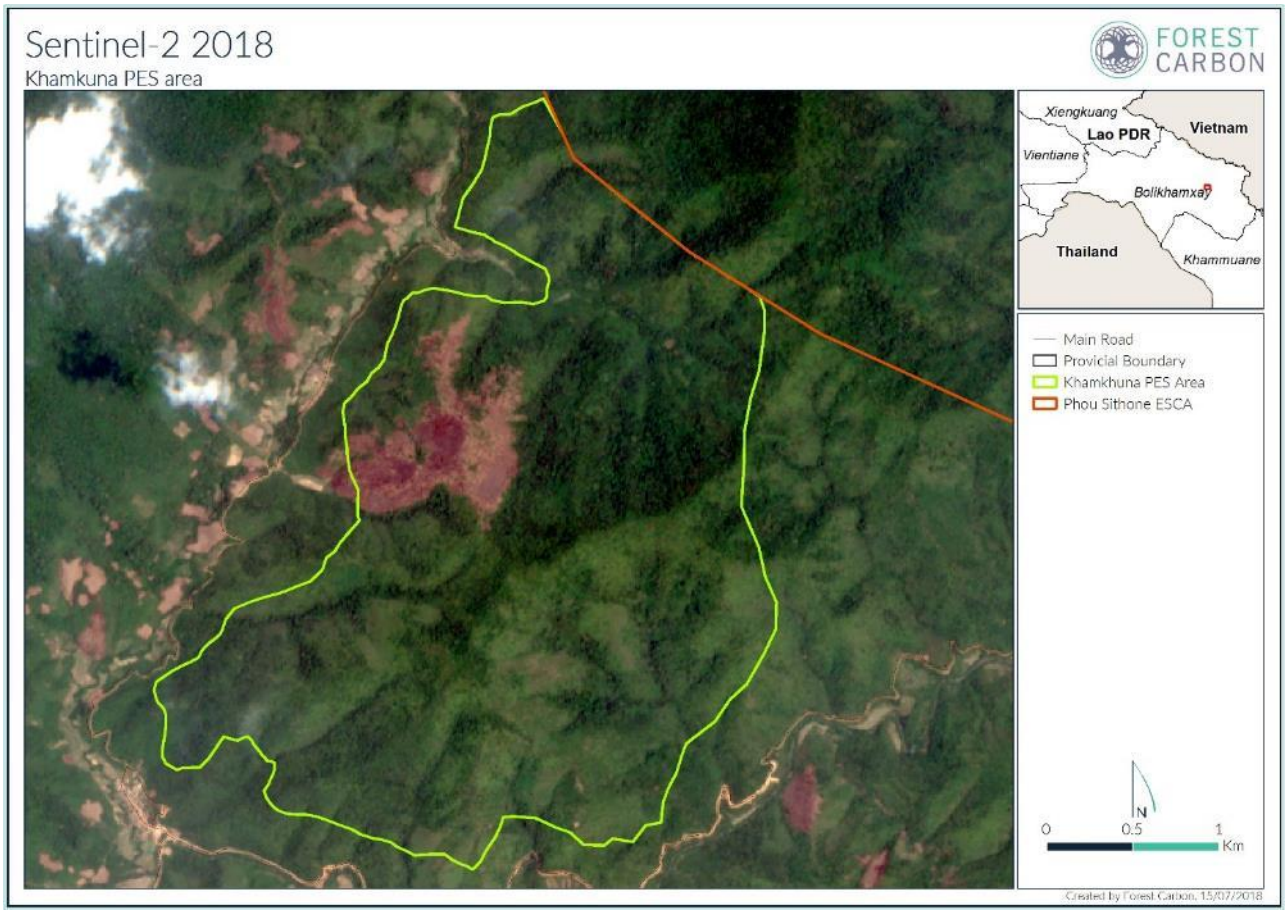


Figure 11. Sentinel-2 imagery over Khamkhuna PES

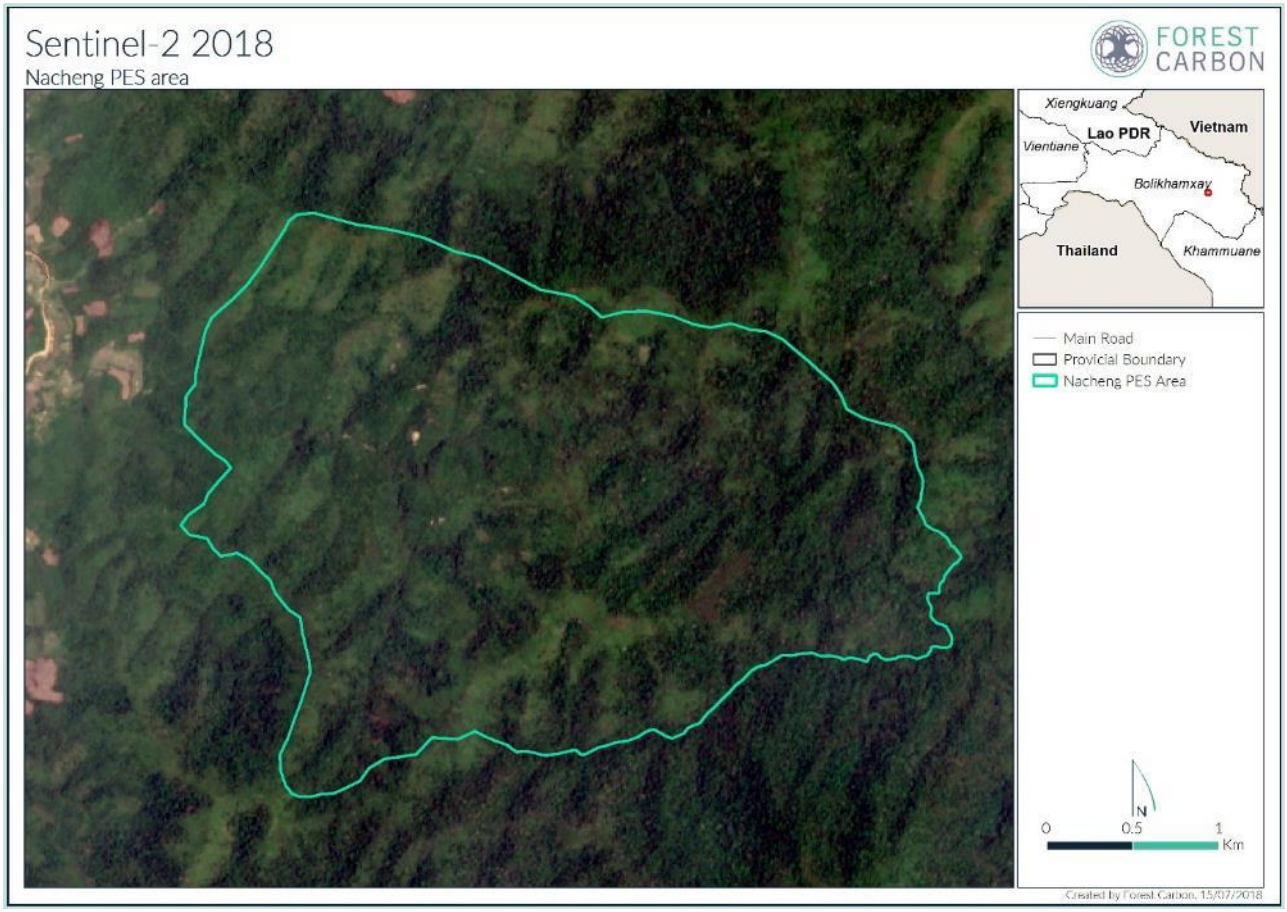


Figure 12. Sentinel-2 imagery over Nacheng PES

PRELIMINARY DRAFT CLASSIFICATION

The aim of this step was to assess which land cover types can be identified with the imagery. This also helped to identify where ground-truthing should be conducted. As such, an unsupervised classification was conducted with Erdas software which automatically identifies and separates the image pixels into various classes. For this exercise, forty classes were automatically processed and visually reclassified by the WCS GIS Officer. With its knowledge of the landscape, the WCS GIS Officer merges the forty classes in a decade of classes that are likely to be found and confirmed by the field survey. For instance, the class good forest comes from the merging of six initial classes which only slightly differ on illumination This step confirmed how challenging it is to separate in classes the continuing process of the regeneration of fallow lands into forest.

FIELD SURVEY

Forest Carbon advised the WCS GIS Officer on how to prepare and conduct a ground-truthing survey. The discussion focused first on the field survey form to define its structure and the type of information to be collected by the field surveyors. The final field survey included questions on the underlying historical narrative given by the villagers for each plot as well as structural and physical features of the plot, especially the canopy cover and the average size of the trees (both height and diameter). Additionally, Forest Carbon provided support to the WCS GIS Officer to identify suitable locations to conduct the field survey.

SUPERVISED CLASSIFICATION

Following the field survey, the collected information was thoroughly scrutinized to first identify the various land cover types found in the PES areas, and secondly to identify training areas to train the algorithm to conduct the supervised classification. The supervised classification used the following land cover classes:

- Good forest, non-disturbed forest with large standing trees;
- Open forest, forest that has evidence of past or current use for NTFP collection or cattle grazing;
- Bamboo, fallow land with a majority of bamboo or bamboo forest area that would not evolve in to a good forest state;
- Old fallow, fallow lands for more than five years;
- Young fallow, fallow land for less than five years;
- Grassland, areas consistently remaining as grass,
- Bare land, areas of new bare land, current agricultural land or urban areas.

The outcome of the supervised classification was visually checked and edited when required with the support of very high-resolution imagery (SPOT from 2016) and the collected information from the field to finalize the land cover map for the PES areas.

ACCURACY ASSESSMENT

An accuracy assessment based on visual checking of the SPOT image from 2016 was conducted on the extent of Khamkhuna with a random sample of 50 plots. For each of these locations, the WCS GIS Officer compared the land cover visually identified with the produced map. Table 12 outlines the results of the accuracy assessment which demonstrates that the map is reliable with and overall accuracy of 78% and a forest/non-forest accuracy of 84%. This later number considers The Current Forest which is constituted of the classes Good forest and Open forest that match the Lao definition of current forest in terms of canopy cover and tree size (20% of minimum canopy cover and 10 cm minimum for the DBH, Diameter at breast height). Bare land and grassland did not have sample points but the accuracy of these land cover types is usually very high as they are easy to identify both visually and through the ensuing the algorithm based on training areas.

Table 12. Accuracy assessment results for the PES land cover map

Land Cover Type	Producer accuracy	User accuracy
Good forest	56%	100%
Open forest	80%	80%
Bamboo	100%	50%
Old fallow	73%	62%
Young fallow	100%	100%
Grassland	0%	0%
Bare Land	0%	0%
New bare land	100%	100%
Total accuracy		78%
Current Forest/Non Forest		84%

RESULTS

The land cover of both sites is very similar. Both sites show a patchwork of forest interspersed with non-forest or recovering forest areas. Half of both PES areas are covered in current forest. The Nacheng PES area has good forest on 28% of it extent while Khamkhuna has only 17%. In the context of the Payment for Environmental Services, the villagers agree to let the fallow lands regrowth. It is interesting to note that the 58ha of new bareland in the Khamkhuna PES area was due to a large fire experienced in mid-April.

Table 13. Land cover area breakdown for both PES areas

Land Cover Type	Khamkhuna Area (ha)	%	Nacheng Area (ha)	%
Good Forest	147.69	17%	275.76	28%
Open Forest	295.97	33%	220.21	23%
Current Forest	*443.66*	*50%*	*495.97*	*51%*
Bamboo	58.35	7%	45.48	5%
Old Fallow	257.64	29%	328.86	34%
Young Fallow	52.95	6%	100.04	10%
Forest Land	*812.60*	*91%*	*970.34*	*99%*
Grassland	21.89	2%	6.36	1%
Bareland	0.79	0%	0.74	0%
New Bareland	57.40	6%	-	0%
Total	892.68	100%	977.44	100%

As mentioned in the previous section, the Current Forest is the sum of the classes Good forest and Open forest which are the only to match the Lao definition of current forest in terms of canopy cover and tree size. The Forest Land is the addition of the Current forest with the classes that can potentially reach the definition of forest which are the Old and Young Fallow classes and the Bamboo. As illustrated by Figure 4, the Government of Lao PDR uses the Forest Land to define the forest cover changes (Deforestation, Forest degradation, Forest regeneration, Reforestation) considered in the REDD+ national program.

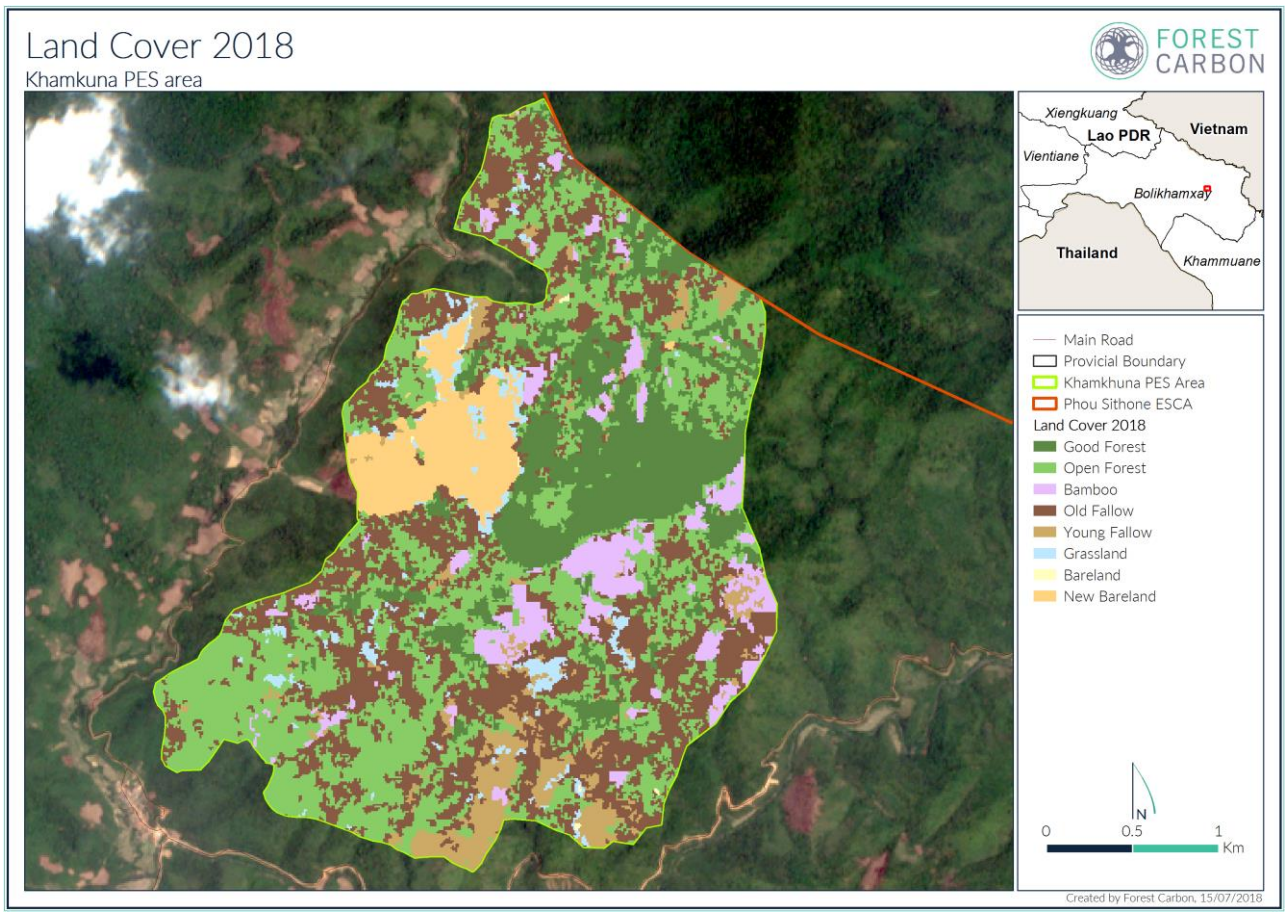


Figure 13. Land cover 2018 Khamkhuna PES

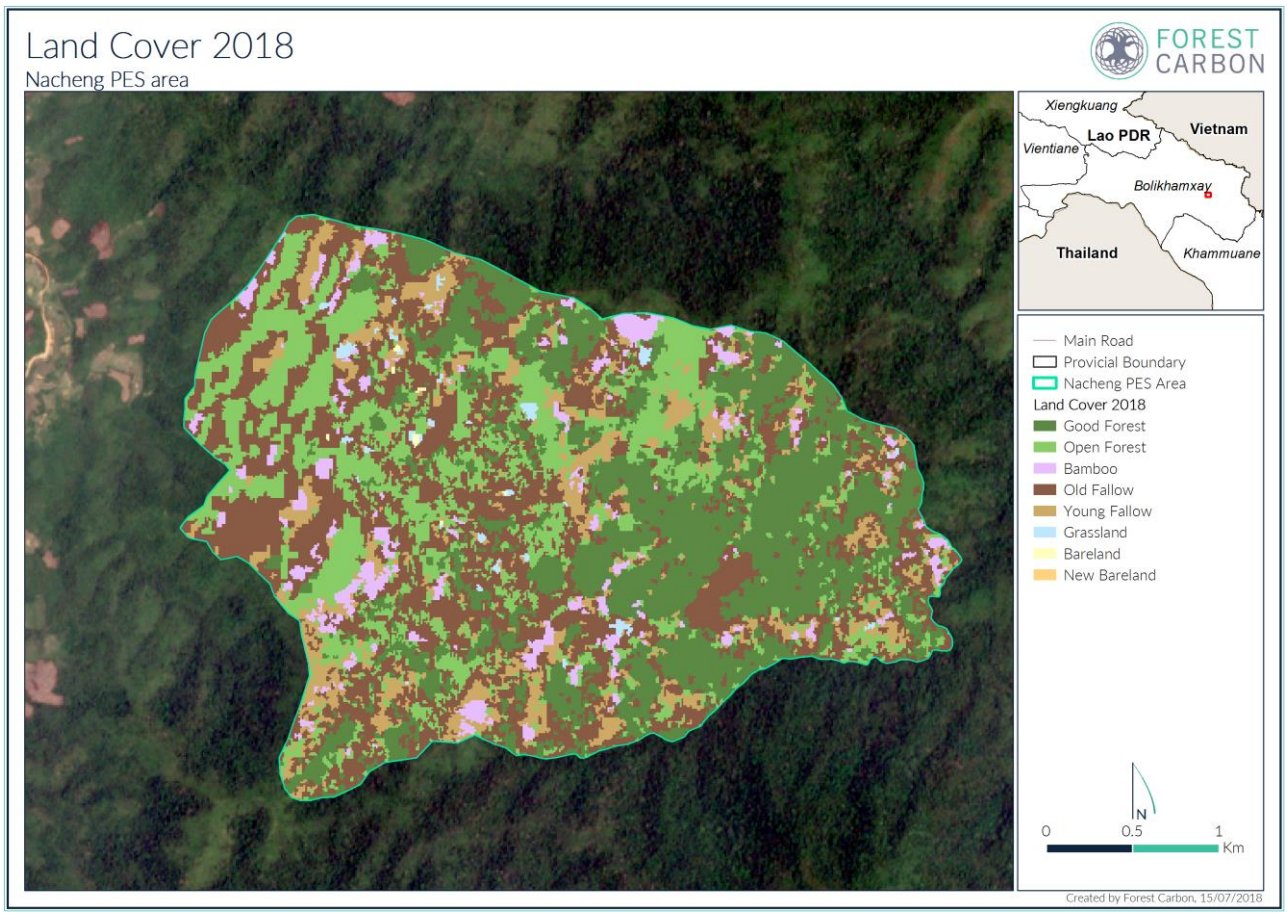


Figure 14. Land cover 2018 Nacheng PES

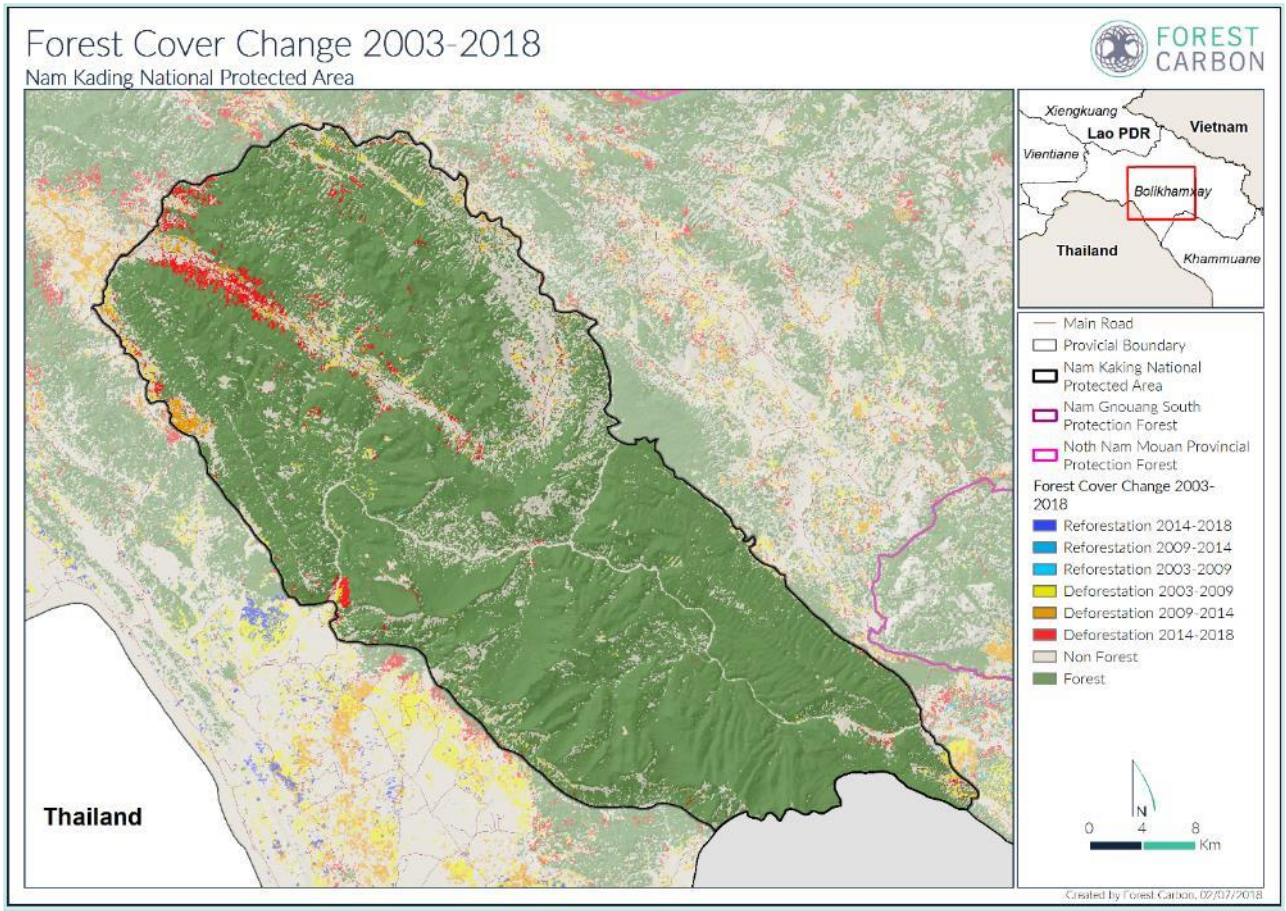
ANNEX

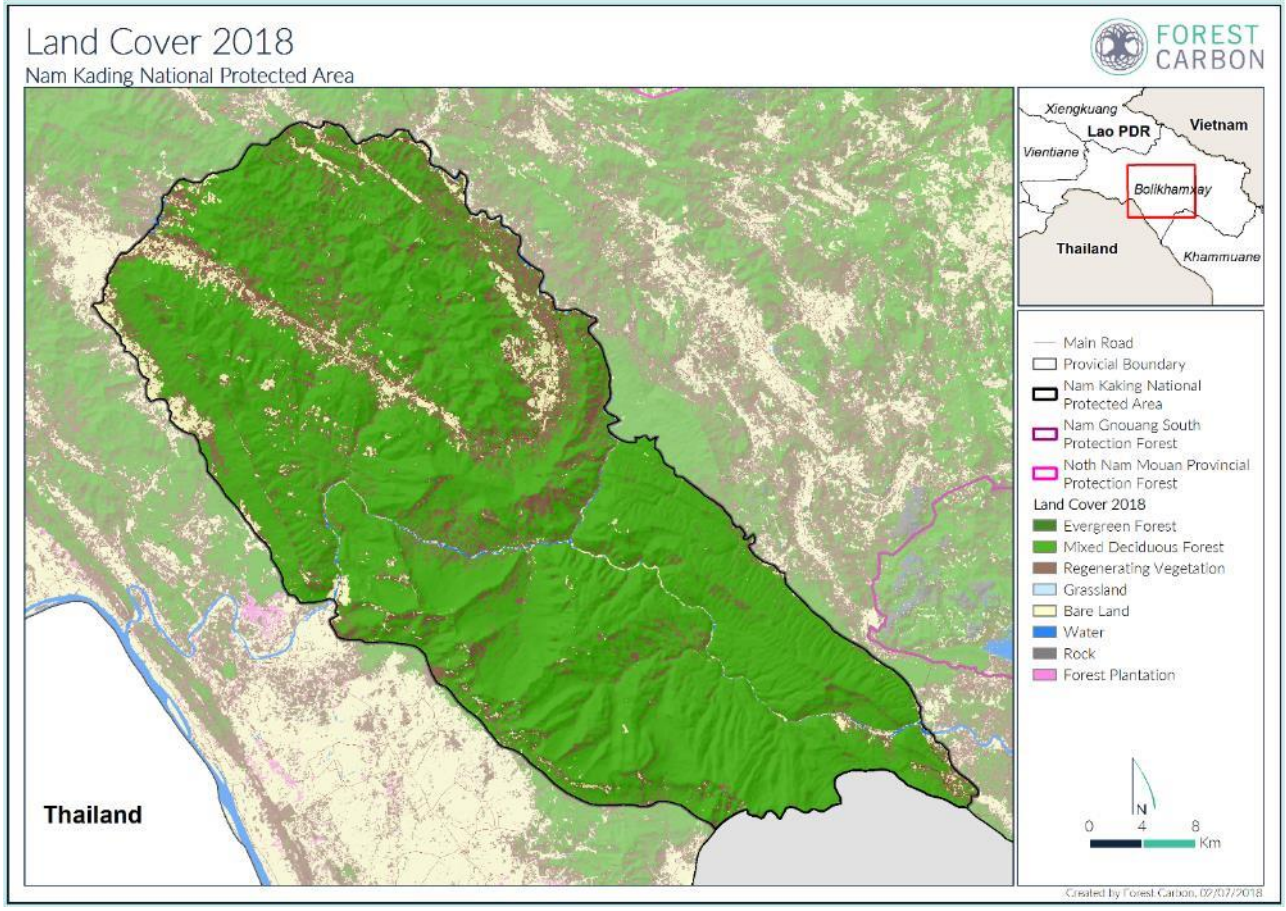
ANNEX A: GOOGLE EARTH ENGINE SCRIPT

```
//--------------------------Mosaic 2014
var aoi = ee.Geometry.Rectangle(102.6, 19.2, 105.4, 17.75);
Map.setCenter(104.3, 18.4, 9);
//Choose a Landsat collection

var L2014 = ee.ImageCollection.fromImages([ee.Image

('LANDSAT/LC8_L1T/LC81270472014051LGN00'),ee.Image

('LANDSAT/LC8_L1T/LC81280472014026LGN00'),ee.Image

('LANDSAT/LC8_L1T/LC81270472014003LGN00'),ee.Image

('LANDSAT/LC8_L1T/LC81270482014035LGN00')]);

var compL2014 = ee.Algorithms.Landsat.simpleComposite(L2014, 50, 10, 40, false).clip(aoi);


//Display the mosaic
Map.addLayer(compL2014, {'bands':['B5', 'B6', 'B7'],},"Mosaic2014");
//Export.image.toDrive({'image':compL2014,'maxPixels':5e10, 'crs':'EPSG:32648','scale':30});


//--------------------------Mosaic 2018
Map.setCenter(104.3, 18.4, 9);
//var aoi = ee.Geometry.Rectangle(102.6, 19.2, 105.4, 17.75);

var L2018 = ee.ImageCollection('LANDSAT/LC08/C01/T1_RT').filterBounds(ee.Geometry.Rectangle

(102.6, 19.2, 105.4, 17.75)).filterDate('2017-12-01', '2018-04-24');

var L2018 = ee.ImageCollection.fromImages([ee.Image

('LANDSAT/LC08/C01/T1_RT/LC81280472018069LGN00'),ee.Image
```

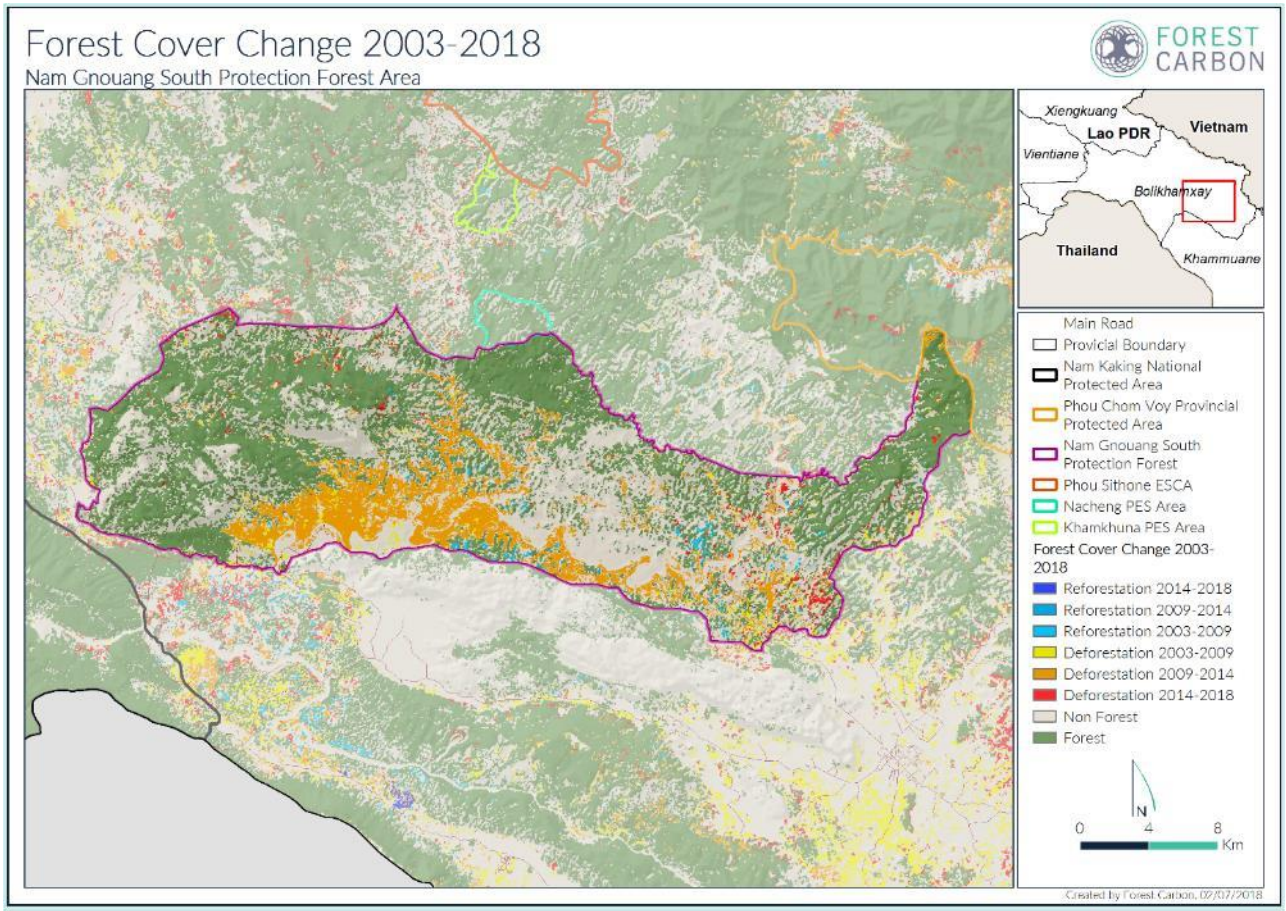
```
('LANDSAT/LC08/C01/T1_RT/LC81270482018094LGN01'),ee.Image
('LANDSAT/LC08/C01/T1_RT/LC81270472018094LGN01')]);

//var compL2018 = ee.Algorithms.Landsat.simpleComposite(L2018, 50, 10, 40, false).clip(aoi);


//Display the mosaic
Map.addLayer(compL2018, {'bands':['B5', 'B6', 'B7'],},"Mosaic2018");
//Export.image.toDrive({'image':compL2018,'maxPixels':5e10, 'crs':'EPSG:32648','scale':30});

//---------------------------NDVI and NBR 2014
var ndvi2014 = compL2014.normalizedDifference(['B5', 'B4']);
var nbr2014 = compL2014.normalizedDifference(['B5', 'B7']);

var ndviParams = {min: -1, max: 1, palette: ['blue', 'white', 'green']};
Map.addLayer(ndvi2014, ndviParams, 'NDVI 2014');
Map.addLayer(nbr2014, ndviParams, 'NBR 2014');
//Export.image.toDrive({'image':ndvi2014,'maxPixels':5e10, 'crs':'EPSG:32648','scale':30});

//---------------------------NDVI and NBR 2018
var ndvi2018 = compL2018.normalizedDifference(['B5', 'B4']);
var nbr2018 = compL2018.normalizedDifference(['B5', 'B7']);

var ndviParams = {min: -1, max: 1, palette: ['blue', 'white', 'green']};
Map.addLayer(ndvi2018, ndviParams, 'NDVI 2018');
Map.addLayer(nbr2018, ndviParams, 'NBR 2018');
//Export.image.toDrive({'image':ndvi2018,'maxPixels':5e10, 'crs':'EPSG:32648','scale':30});

//---------------------------Gain&Loss
var ndvi_diff = ndvi2018.subtract(ndvi2014);
var nbr_diff = nbr2018.subtract(nbr2014);
var diffndviParams = {min: -1, max: 1, palette: ['red', 'white', 'blue']};
Map.addLayer(ndvi_diff, diffndviParams, 'NDVI 20142018');
Map.addLayer(nbr_diff, diffndviParams, 'NBR 20142018');
//Export.image.toDrive({'image':ndvi_diff,'maxPixels':5e10, 'crs':'EPSG:32648','scale':30});
//Export.image.toDrive({'image':nbr_diff,'maxPixels':5e10, 'crs':'EPSG:32648','scale':30});
```

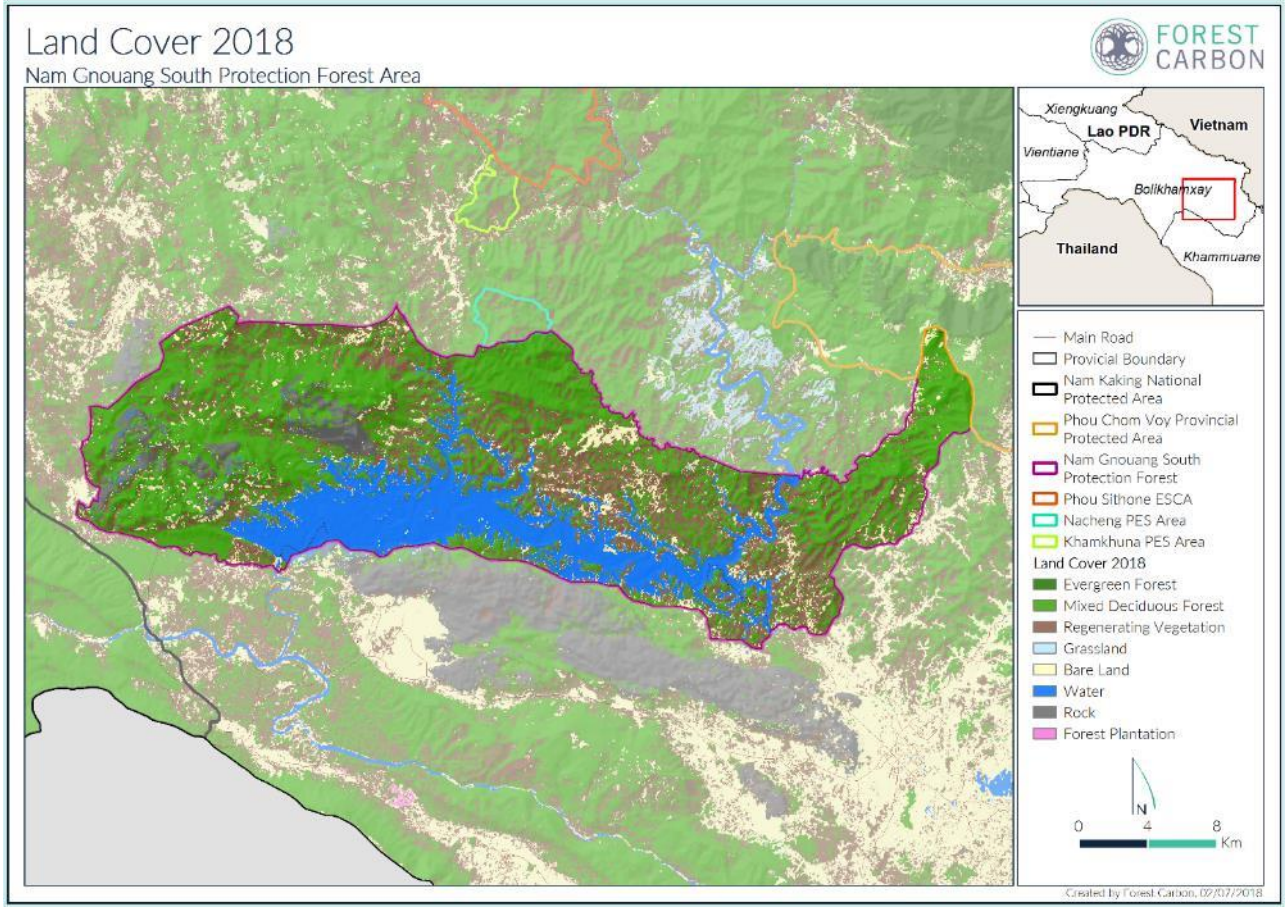
ANNEX B: MAPS OF NAM KADING NPA



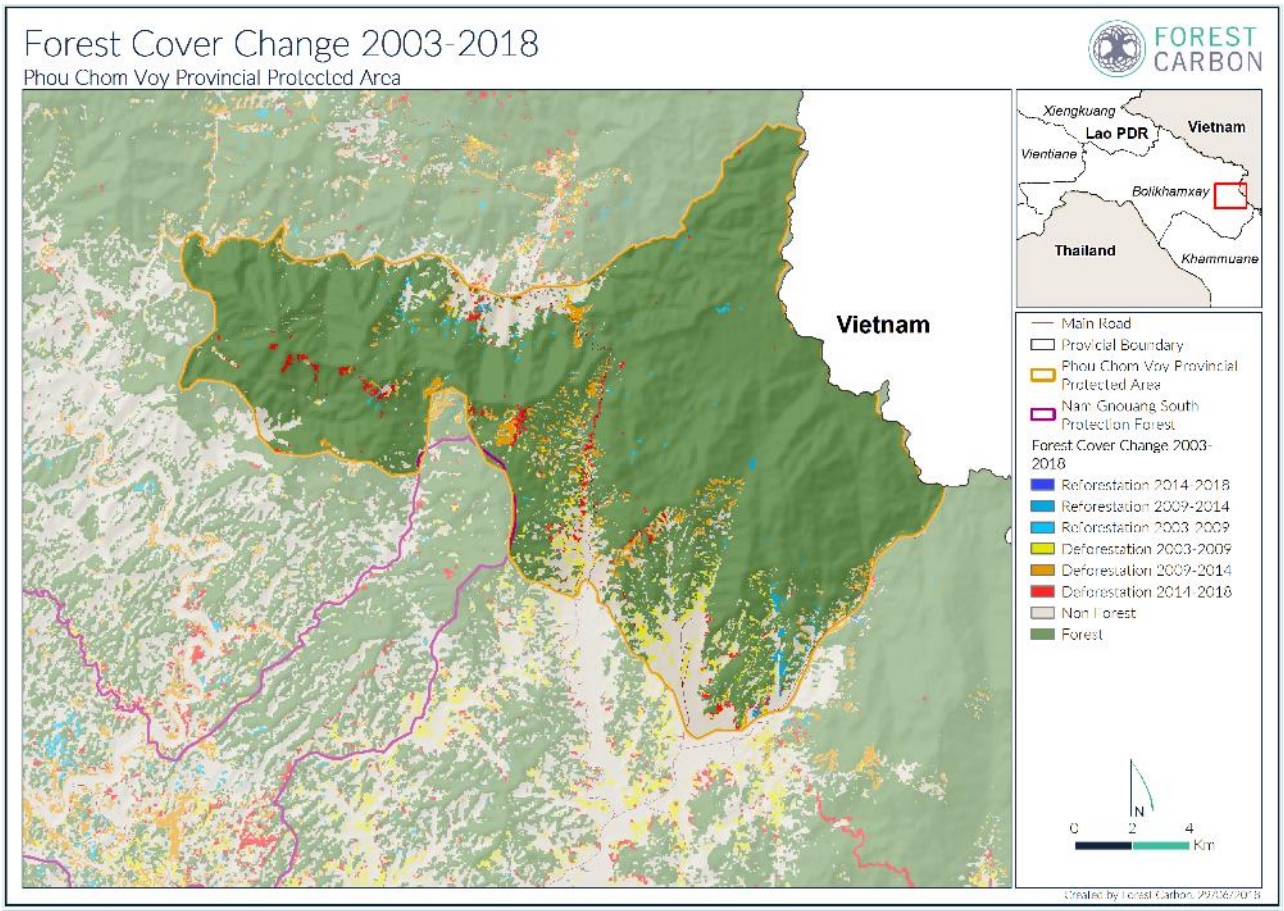


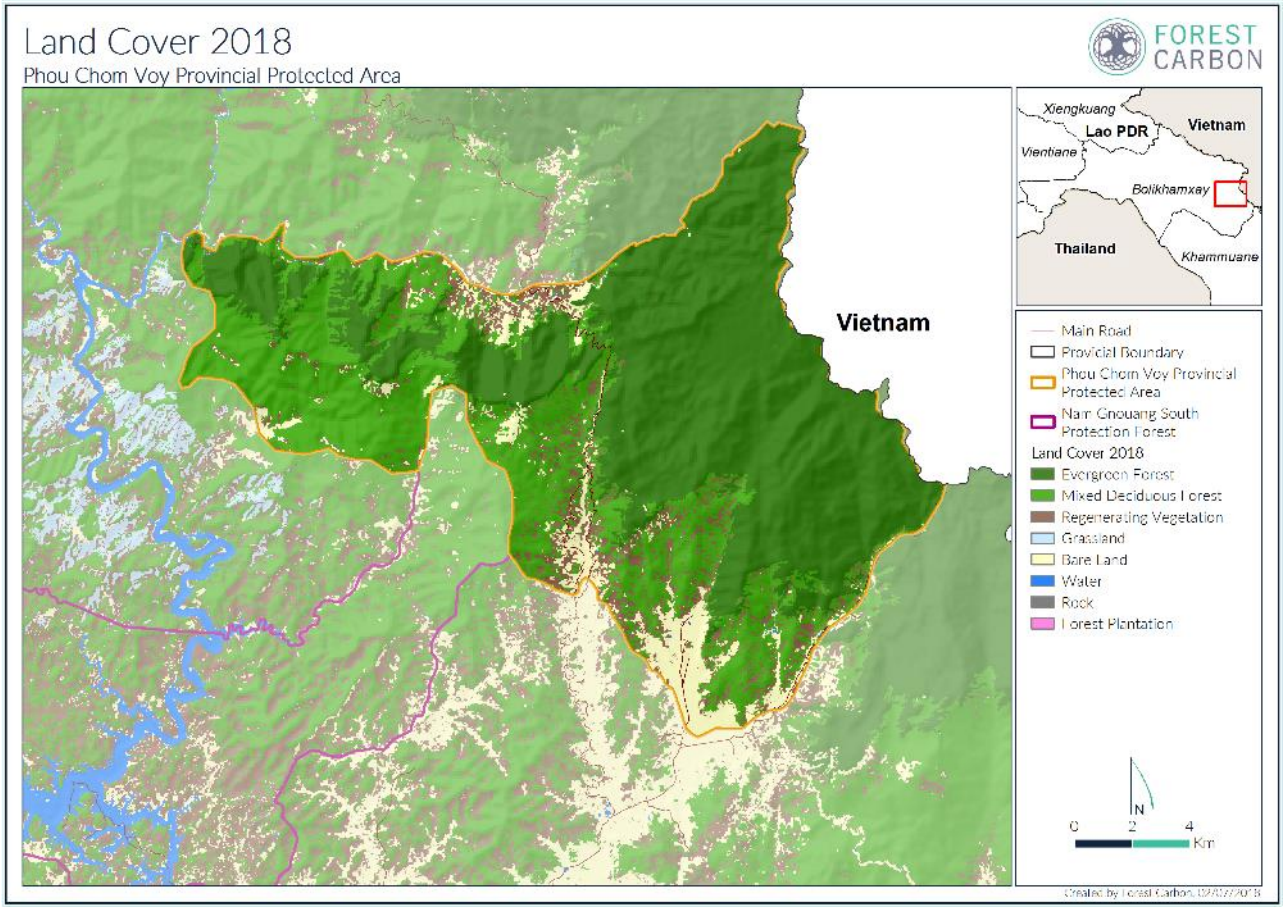
ANNEX C: MAPS OF NAM GNOUANG SOUTH PFA



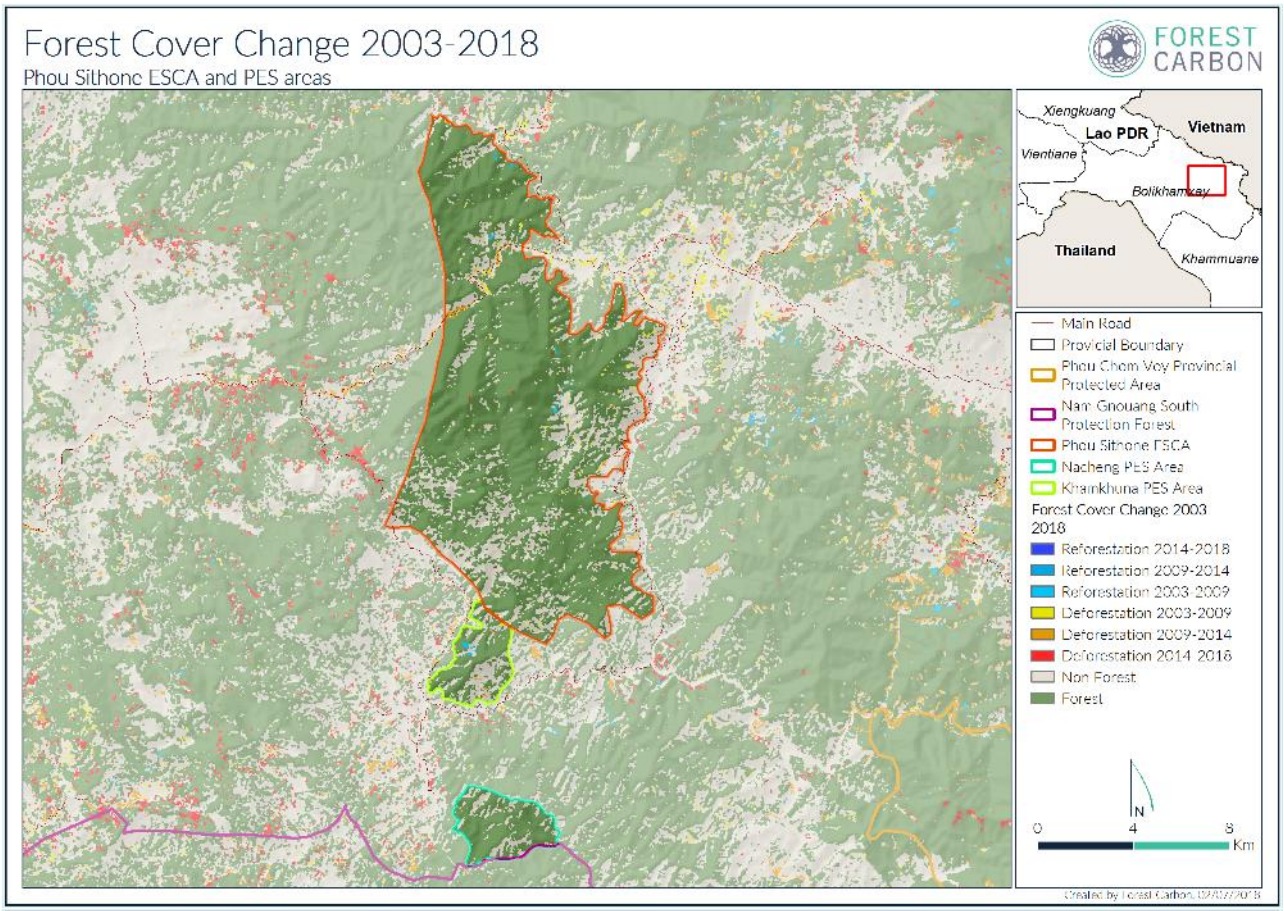


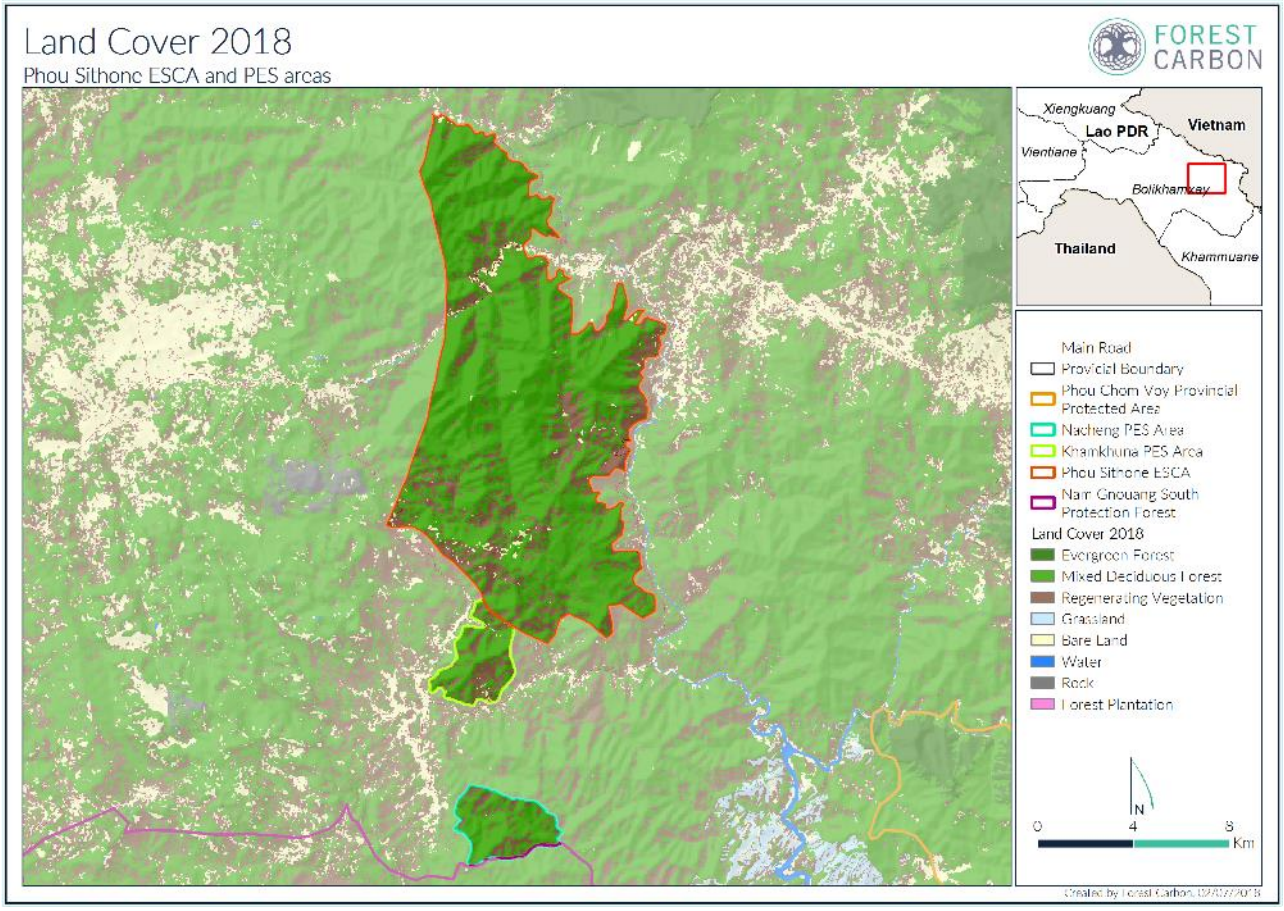
ANNEX D: MAPS OF PHOU CHOM VOY PPA



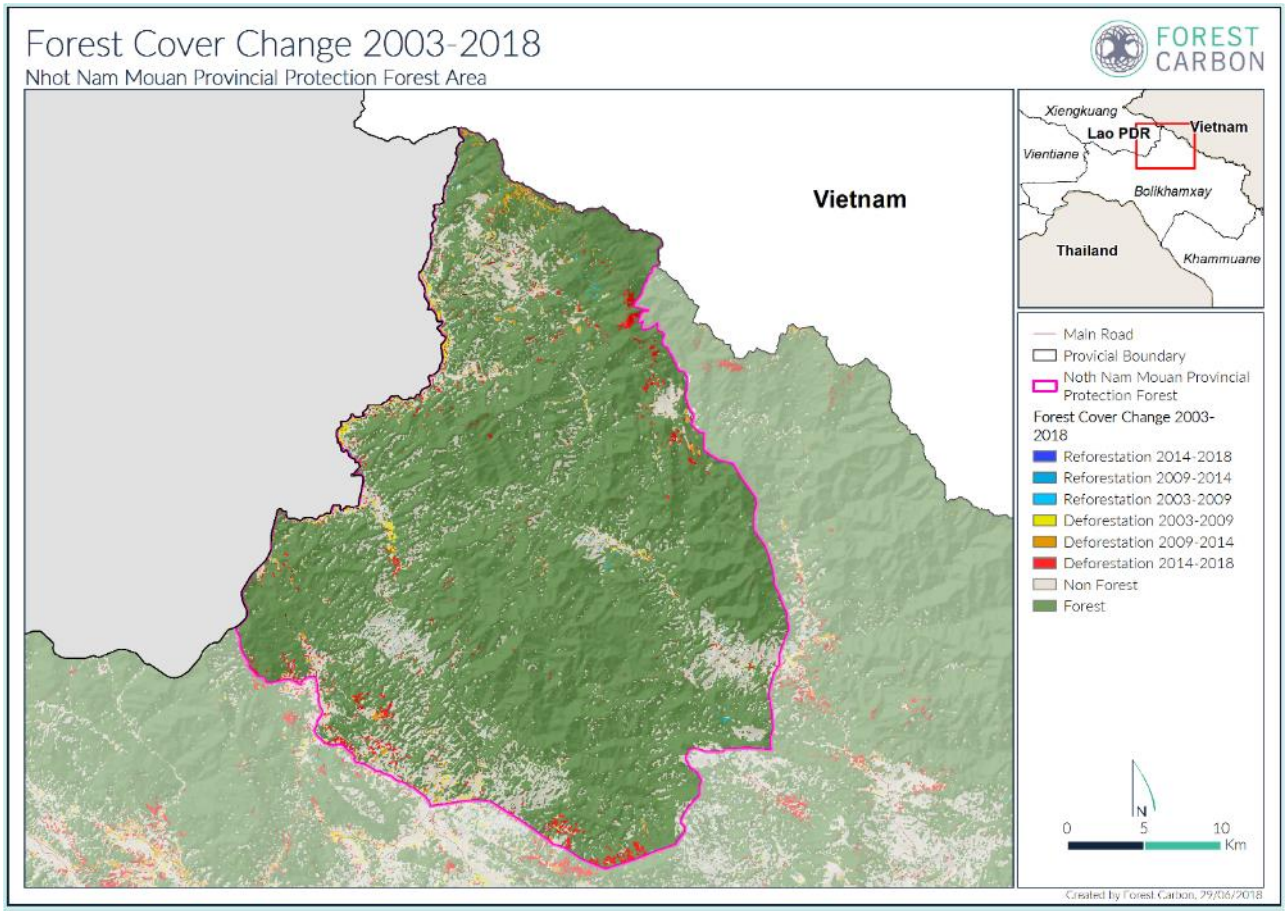


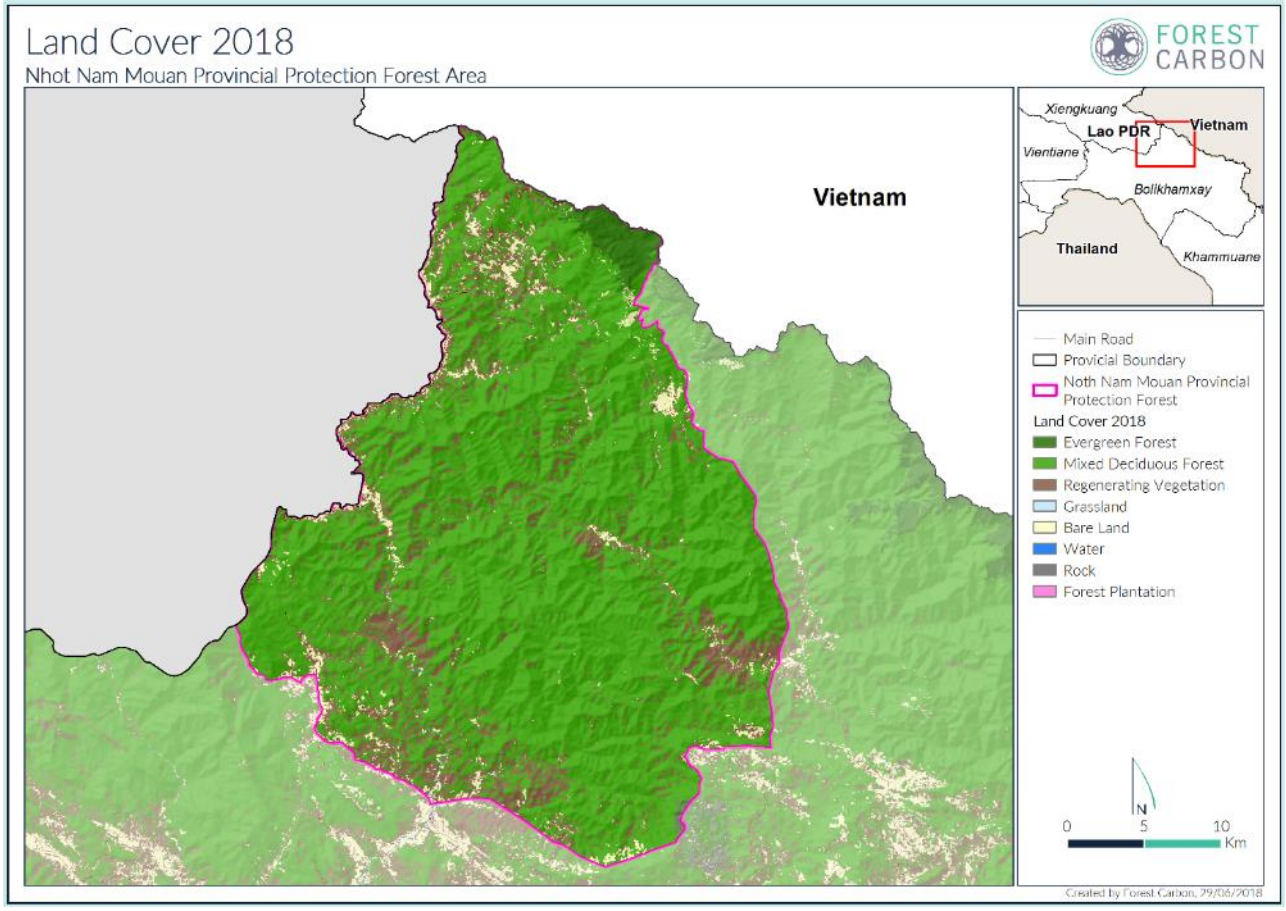
ANNEX E: MAPS OF PHOU SITHONE ESCA AND PES AREAS





ANNEX F: MAPS OF NAM MOUAN PROVINCIAL PROTECTION FOREST AREA





ANNEX G: ACCURACY ASSESSMENT MATRIX FOREST COVER CHANGE

Sample counts

Map \ Reference	FF	NF	Loss	Gain	Total		Area	Area proportion
FF	385	48	0	0	433	89%	892,277	0.57
NF	56	235	3	2	296	79%	623,201	0.40
Loss	8	12	78		98	80%	33,209	0.02
Gain	2	3		37	42	88%	11,626	0.01
Total	451	298	81	39	869		1,560,312	1
	85%	79%	96%	95%	735	85%		

Estimated area proportions

	FF	NF	Loss	Gain	Total
FF	0.5085	0.0634	0.0000	0.0000	0.5719
NF	0.0756	0.3171	0.0040	0.0027	0.3994
Loss	0.0017	0.0026	0.0169	0.0000	0.0213
Gain	0.0004	0.0005	0.0000	0.0066	0.0075
Total	0.5861	0.3836	0.0210	0.0093	1
User Acc	0.89	0.79	0.80	0.88	
Prod Acc	0.87	0.83	0.81	0.71	
Overall Acc	0.85				

error adjusted area per class (ha)	914,531	598,580	32,748	14,452
Standard error	0.0126	0.0128	0.0025	0.0019
Standard error of area estimate (ha)	19,611	19,962	3,880	3,030
95% confidence interval (ha)	39,223	39,925	7,760	6,060

ANNEX F: ACCURACY ASSESSMENT MATRIX PES LAND COVER

ການກວດສອບຄວາມຖືກຕ້ອງ ແລະ ຊັດເຈນ ຜົນການປະເມີນຜາບຖ່າຍກັບພື້ນທີ່ຕົວຈິງ										
	Visual check									
Map	Good forest	Open fores	Bamboo	Old fallow	Young fall	Grassland	Bare Land	New bare land	Total	User accur
Good forest	5								5	100%
Open forest	2	16		2					20	80%
Bamboo		1	2	1					4	50%
Old fallow	2	3		8					13	62%
Young fallow					6				6	100%
Grassland									0	
Bare Land									0	
New bare land								2	2	100%
Total	9	20	2	11	6	0	0	2	50	
Producer accuracy	56%	80%	100%	73%	100%			100%		
(ເປີເຊັ້ນຄວາມຊັດເຈນຂອງປະເພດການປົກຫຸ້ມ ສົມທຽບຈາກພື້ນທີ່ຕົວຈິງໃສ່ແຜນທີ ກົງກັນຂ້າມກັບ User accuracy)									78%	

	Visual									
Map	Forest	Non-Fores	Total	User accuracy						
Forest	23	2	25	92%						
Non-Forest	6	19	25	76%						
Total	29	21	50							
Producer accuracy	79%	90%	84%							

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