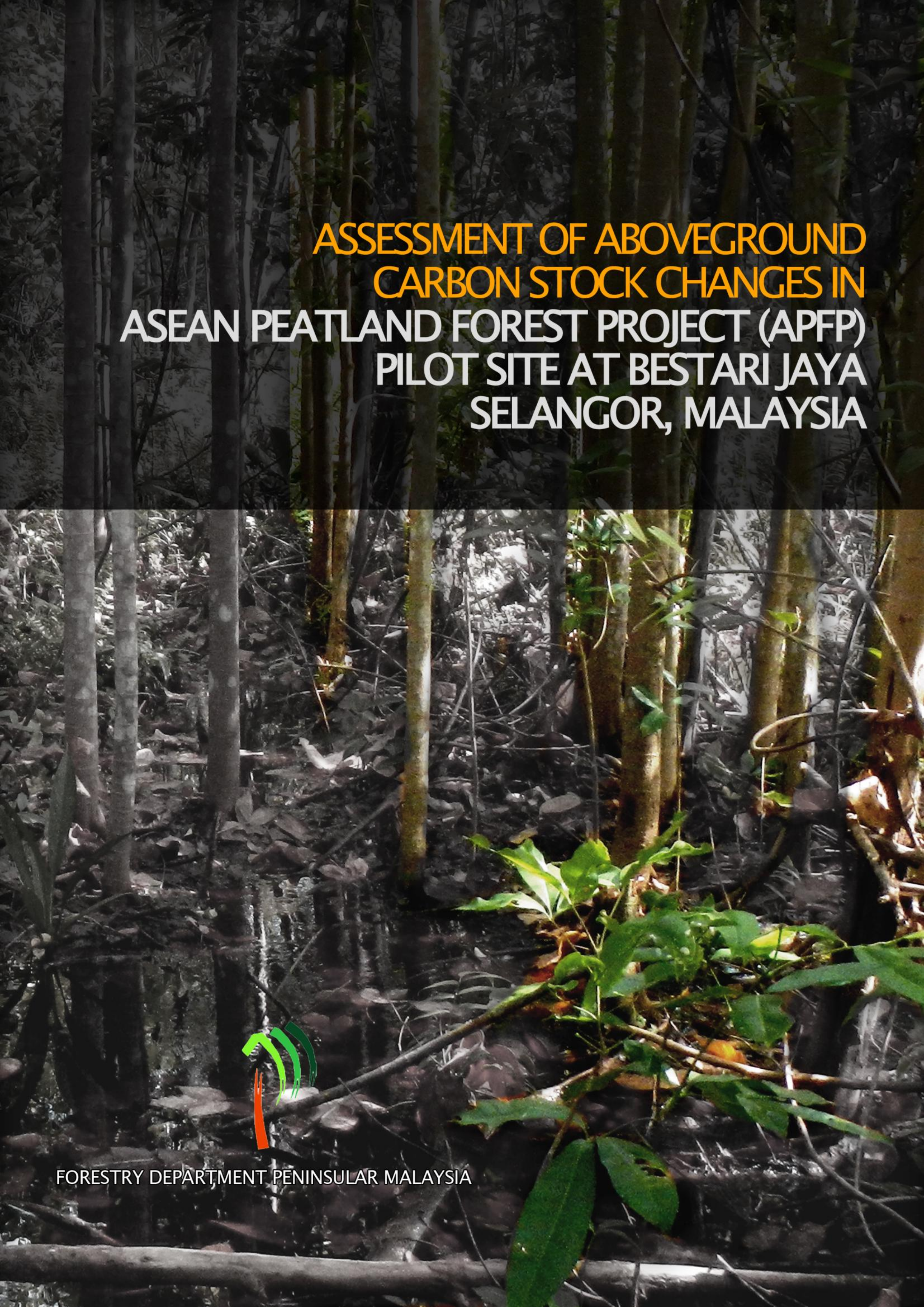
ASSESSMENT OF ABOVEGROUND CARBON STOCK CHANGES IN ASEAN PEATLAND FOREST PROJECT (APFP) PILOT SITE AT BESTARI JAYA SELANGOR, MALAYSIA



FORESTRY DEPARTMENT PENINSULAR MALAYSIA

ASSESSMENT OF ABOVEGROUND CARBON STOCK CHANGES IN ASEAN PEATLAND FOREST PROJECTS (APFP) PILOT SITE AT BESTARI JAYA, SELANGOR, MALAYSIA

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Executive Summary

The main output of this project is the estimation of aboveground carbon stock changes in peat swamp forests (PSF) areas of ASEAN Peatland Forest Projects (APFP) pilot site at Bestari Jaya, Selangor, Malaysia. The APFP pilot site covers an area of about 4,000 ha of which about half (2,000 ha) is located within the Raja Musa Forest Reserve (RMFR) while the rest comprise a mixture of other land uses. In this project, satellite data were covering different time periods were used to monitor the changes in the extent of PSF and aboveground carbon stocks. The PSF areas were categorised into low, medium and dense PSF based on its tree density value of Normalised Difference Vegetation Index (NDVI). Satellite images of 1989, 2001 and 2010 were used to determine these changes n covering a 30-year period. It was found that in 1989, the PSF in the APFP pilot site occupied about 2,447 ha or 61% of the total PSF in the pilot site. However in the year 2001 the extent of the PSF had reduced to 1,545 ha (39% of the total PSF). The large reduction of 902 ha was mainly due to the big forest fire that ravaged the site in year 1992 reducing the burnt forest landscape into grassland and shrubs. Fortunately, some of these areas had regenerated with the PSF trees, thus increasing the total extent of PSF areas to 1,803 ha (45%) by the year 2010. The used of technologies by using satellite images have successfully shown the distribution over the certain years and allowed aboveground carbon stock changes assessment in the APFP pilot site. In addition, validation and verification results showed that estimation error and accuracy are in acceptable levels. This project found that total the PSF of APFP pilot site has lost about 342,756 tonnes of aboveground carbon stock from the year 1989 (387,266.60 tonnes) to 2001 (44,510.42 tonnes) due the forest. However, the aboveground carbon stock started to recover back due to natural regeneration as it increased about 57,337 tonnes from the year 2001 to 2010 (101,847.49 tonnes). The distribution of aboveground carbon stocks in the PSF in APFP that ranged mainly from 80 – 184 t ha^{-1} in year 1989 had decreased to 0 – 40 t ha^{-1} in the year 2001 and increased back to 20 – 40 t ha^{-1} in 2010. In terms of total carbon in the vegetation which include both above and below ground carbon of the trees, it was found that the PSF in the APFP pilot site had about 122,318 ton (aboveground carbon = 101,847 tonnes and belowground carbon = 20,471 tonnes) or about 11.35 t ha^{-1} . This is fairly low as more than 70% of the areas are low PSF.

Contents

List of Tables

List of Figures

Abbreviations

APFP	ASEAN Peatland Forest Projects
CO_2	Carbon dioxide
DBH	Diameter at breast height
FR	Forest reserve
ha	hectare
m	meter
NDVI	Normalised Different Vegetation Index
PSF	Peat swamp forest
RMFR	Raja Musa FR
t	tonne

Chapter 1

Introduction

1.1 Background

Peat swamp forests (PSF) are tropical moist forests where water logged soils prevent dead leaves and wood from fully decomposing, which over time creates a thick layer of acidic peat. These forests are normally located immediately behind the coastline and extends inland along the lower reaches of the main river systems. It is well recognised that the PSF are a significant carbon sink for the earth (ESA 2003). Carbon dioxide (CO_2) is emitted in a number of ways. It is emitted naturally through the carbon cycle and through human activities like the burning of fossil fuels. Natural sources of CO_2 occur within the carbon cycle where billions of tons of atmospheric CO_2 are removed from the atmosphere by oceans and growing plants, also known as 'sinks', and are emitted back into the atmosphere annually through natural processes also known as 'sources'. The total CO_2 emissions and removals from the entire carbon cycle are roughly balance when CO_2 are in balance. Anthropogenic activities such as the burning of oil, coal and gas and deforestation, have increased CO_2 concentrations in the atmosphere.

Recognition of the function as carbon sink as it gained an importance in recent years due to the implication of raised CO_2 levels in contributing to global warming. Large quantities of carbon are stored in tropical peat lands due large amount of organic matters in its soils. It was estimated that 5,800 tonnes of carbon per ha can be stored in a 10-metre deep peat swamp compared to 300-500 tonnes per hectare for other types of tropical forest (UNDP 2006). Tropical peat lands, besides acting as stores of carbon, actively accumulate carbon in the form of peat. Because decomposition is incomplete, carbon is locked up in organic form in complex substances formed by incomplete decomposition. Drainage of peat swamps destroys this useful function and may contribute to global warming through the release of CO_2 into the atmosphere.

Different percentages of forest cover store different amounts of carbon and the changes in forest cover are used mathematical models to calculate the annual changes of carbon. Currently, there is a tremendous amount and diversity of efforts being carried out related to forest and carbon accounting with a variety methods used for measurement. Remote sensing methods provides local or global estimates of carbon stocks in forests. This technology can fill in gaps where inventory information is unavailable. Remote sensing applications could be very valuable in carrying out assessments of how climate change might be having an impact on forests by tracking major disturbances, changes in the growing season, and Net Primary Productivity (NPP). Carbon accounting is needed to support the objectives of international agreement to mitigate global climate change (UN 1998). In conjunction with other spatial datasets such as climate, soil type, and tree height, forest coverage is important for the carbon cycle model (DeFries *et al.* 2000).

Nonetheless, the peat lands might also become significant sources of CO_2 resulting from human activities and forest fires. The occurrence of forest fires is not new in the ASEAN region and is still an important issue relates to environment and health.

The devastation seems to be critical in drier periods of *El-Nino/Southern Oscillation* (ENSO) episodes. In Malaysia, forest fires pose a major threat to the management and conservation of peat lands which at this stage has been very much reduced in extent and quality (Samsudin & Ismail 2003, Ismail *et al.* 2011). Forest fires have not only directly destroyed the flora and fauna of the peat land ecosystem, but their resulting haze is also detrimental to health and contributes to the accumulation of green house gases in the atmosphere. Records have shown that most of the forest fires occur during the prolonged annual dry spells between the months of January to March, and June to August. The fire occurs sporadically in the natural forests, particularly in the degraded PSF. The root cause seemed to be human interventions, either as a result of their negligence or uncontrolled use of fire coupled with unplanned agricultural activities.

Southeast Asian peatland forests are among the last vast tracks of rainforest in the region. Malaysia is the third largest after Indonesia and Papua New Guinea in terms of extent of tropical PSF in the world and the forest serves the most important function to control the global warming (Anon 2012). About 60% of Malaysia or about 19.5 million ha, is under forest cover of one type or another. Peat swamp forests constitute a significant component of this forest cover with an estimated 1.54 million ha still remaining. More than 70% of these PSF are in Sarawak, less than 20% in Peninsular Malaysia and the remainder in Sabah.

There are also significant extent of PSF found in Selangor. Out of a total of 238,748 ha of permanent forest reserve (PFR) which is equivalent to 31.6% of total land area of Selangor in the year 2010, the PSF covers an area of about 83,000 ha (**Table 1**). PSF in Selangor are found in four forest reserves (FR) in the Districts of Kuala Langat (South and North Kuala Langat FRs) Kuala Selangor and Sabak Bernam (Raja Musa and Sungai Karang FRs). These PSF are recognized as having important functions i.e. regulate sound environment such as flood and climate change control, supply water for domestic consumption and farming areas, and biodiversity conservation (Zulkifli *et al.* 1999).

Table 1 Different types of forest in Selangor for the year 2010

Forest types	Total (ha)
Dryland	148,240.46
Peat swamp	82,890.25
Mangroves	18,998.00
Total (ha)	**250,128.71**

Source: Forestry Department Peninsular Malaysia (FDPM) 2011

1.2 Project site

This project is in the peatland area of ASEAN Peatland Forest Project (APFP) at the pilot site Bestari Jaya, Selangor which partly covers Raja Musa Forest Reserve (RMFR). The APFP pilot site is located in the southern part of RMFR (**Figure 1**), covering an area of about 4,000 ha. The site is located inside the following corners of coordinates [Malaysian Rectified Skew Orthomorphic (MRSO) Projection]:

Upper left	:	871 813.1	382 944.3
Upper right	:	380 629.8	382 944.3
Lower right	:	380 614.4	378 383.2
Lower left	:	371 813.9	378 398.3

In this project about 2,000 ha of RMFR is inside the APFP pilot site. The RMFR with an extent of 23,486 ha, is located in the North Selangor Peat Swamp Forest (NSPSF) in the north western part of Selangor .Prior to its gazettement as permanent reserved forest in 1990, RMFR was part of stateland forest and was intensively subjected to logging since 1950s.

The forest is heavily disturbed and the forest stand has only of low to medium density tree stocking. Under the "Integrated Management Plan of the NSPSF (2001 - 2010)", 70% of RMFR was classified as production forest, 27% as forest sanctuary for wildlife and the remaining 3% as research forest (JPNS 2000).

In general, RMFR support tree species with small to medium sized crowns, typically reaching 30 m in height. Emergent trees are scattered throughout the area. Kempas (*Koompassia malaccensis*), Meranti bakau (*Shorea uliginosa*), Kedondong (*Santiria* spp.), Kelat (*Syzgium* spp.) and Ramin melawis (*Gonystylus bancanus)* are the dominant tree species within the forest. Part of the north-east corner of RMFR is known for its high water table as it is located near the peat dome in the central RMFR and dominated by palms and pandanus. Another 2,000 ha of APFP pilot site is located outside the RMFR where main landuses are agricultural areas and stateland PSF.

The major issues with regards to the management and conservation of RMFR are forest fires and encroachment. The occurrence of forest fire is closely related to the heavily drained and degraded condition of the forest areas in RMFR. RMFR suffers from ear frequent fires almost every year particularly during prolonged dry spells in the months of February until March and June until August. The other issue related to RMFR is encroachment. Illegal occupation of government lands was rampant from the late 1990's up to mid 2000's. The degraded condition of the forest land due to burning provided an excuse for illegal settlers to encroach into the forest reserve for settlement and agriculture. Nevertheless, these areas are outside from the APFP’s pilot site. Efforts have been undertaken by the Selangor State Forestry Department to address the illegal encroachment problems. Consequently, several individuals forcefully evacuated from the affected sites within RMFR and these areas have now been allocated for forest rehabilitation activities.

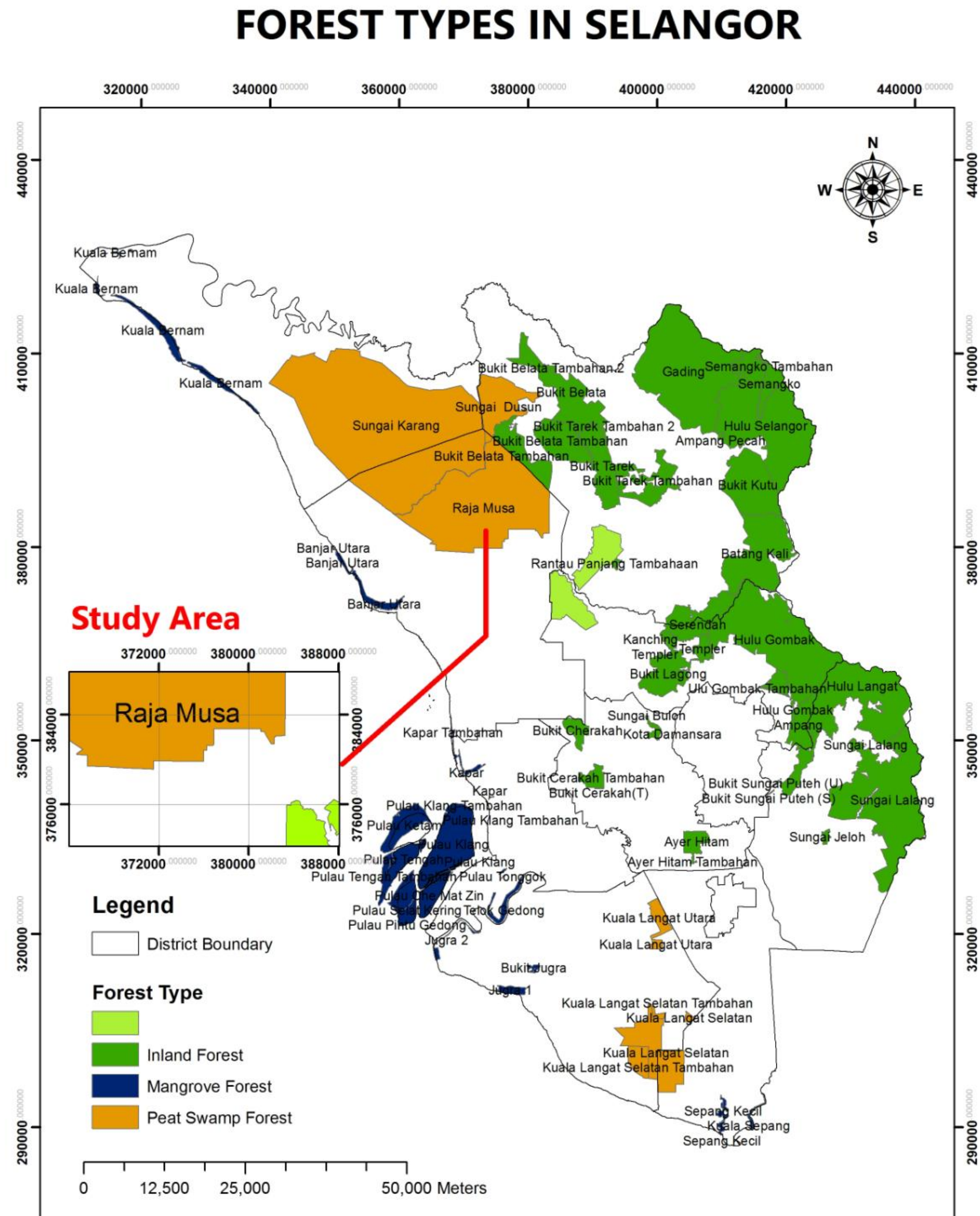


Figure 1 Forest type classifications in the State of Selangor and location of APFP pilot site

1.3 Scope and outputs of the project

The scope and outputs of this project were as follows:

i. Determine landuse in the APFP pilot site.
ii. Conduct aboveground carbon stock assessment for PSF areas in the APFP pilot site. The assessment of changes of aboveground carbon stock measured and determined based on vegetative response from remote sensing images, which are were Landsat-TM for years 1989 and 2001, and SPOT-5 for 2010.
iii. Produce information and maps on aboveground carbon stock and their changes pattern for PSF areas in the APFP pilot site.

Chapter 2

Methodology and Findings

2.1 Data types

Two types of data were used in this study namely secondary and satellite data. Secondary data comprised external forest reserve boundary, compartment boundary and external APFP boundary. These were all acquired from Selangor State Forestry Department. Satellite data comprising Landsat-TM and SPOT-5 imageries over the years 1989, 2001 and 2010, were used as shown in **Table 2**. The images for the years 1989, 2001 and 2010 are depicted in **Figures 2 - 4** respectively.

Table 2 Satellite data used in the study

Year	Satellite	Date of image	Spatial resolution (m)
1989	Landsat-TM	07/02/1989	30
2001	Landsat-TM	09/12/2001	30
2010	SPOT	24/01/2010	5

SATELLITE IMAGE OVER THE YEAR 1989

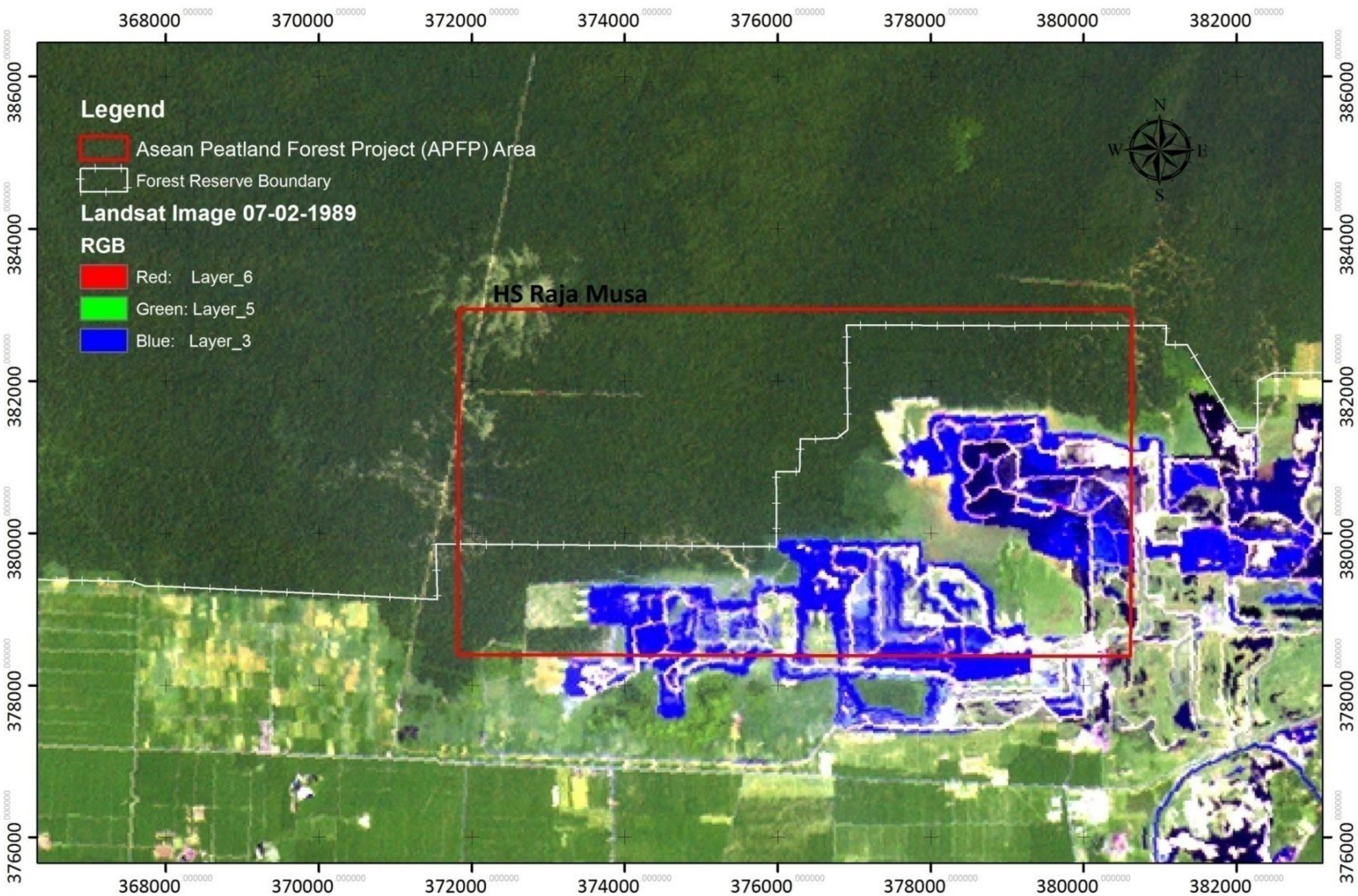


Figure 2 Satellite image over the year 1989

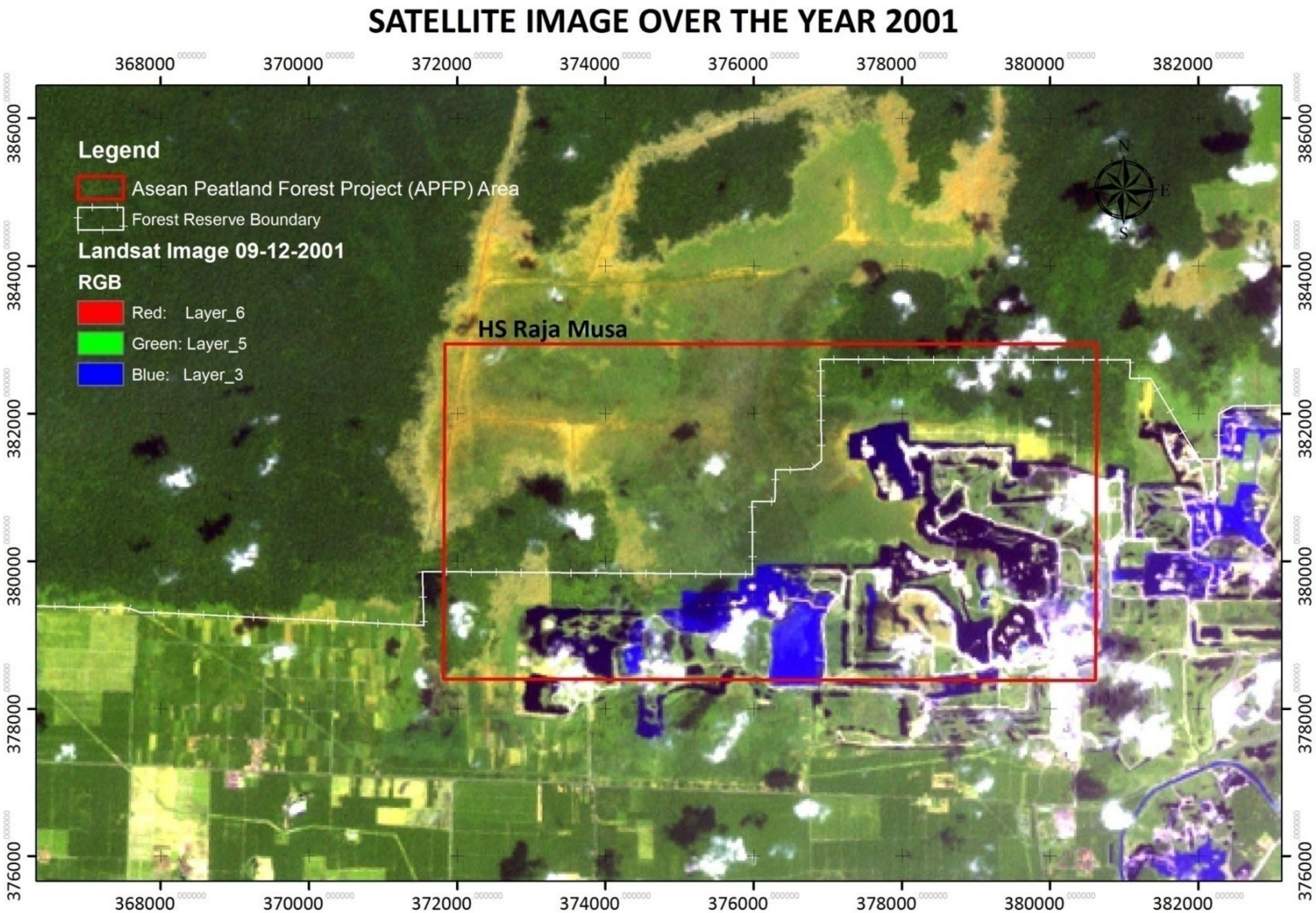


Figure 3 Satellite image over the year 2001

SATELLITE IMAGE OVER THE YEAR 2010

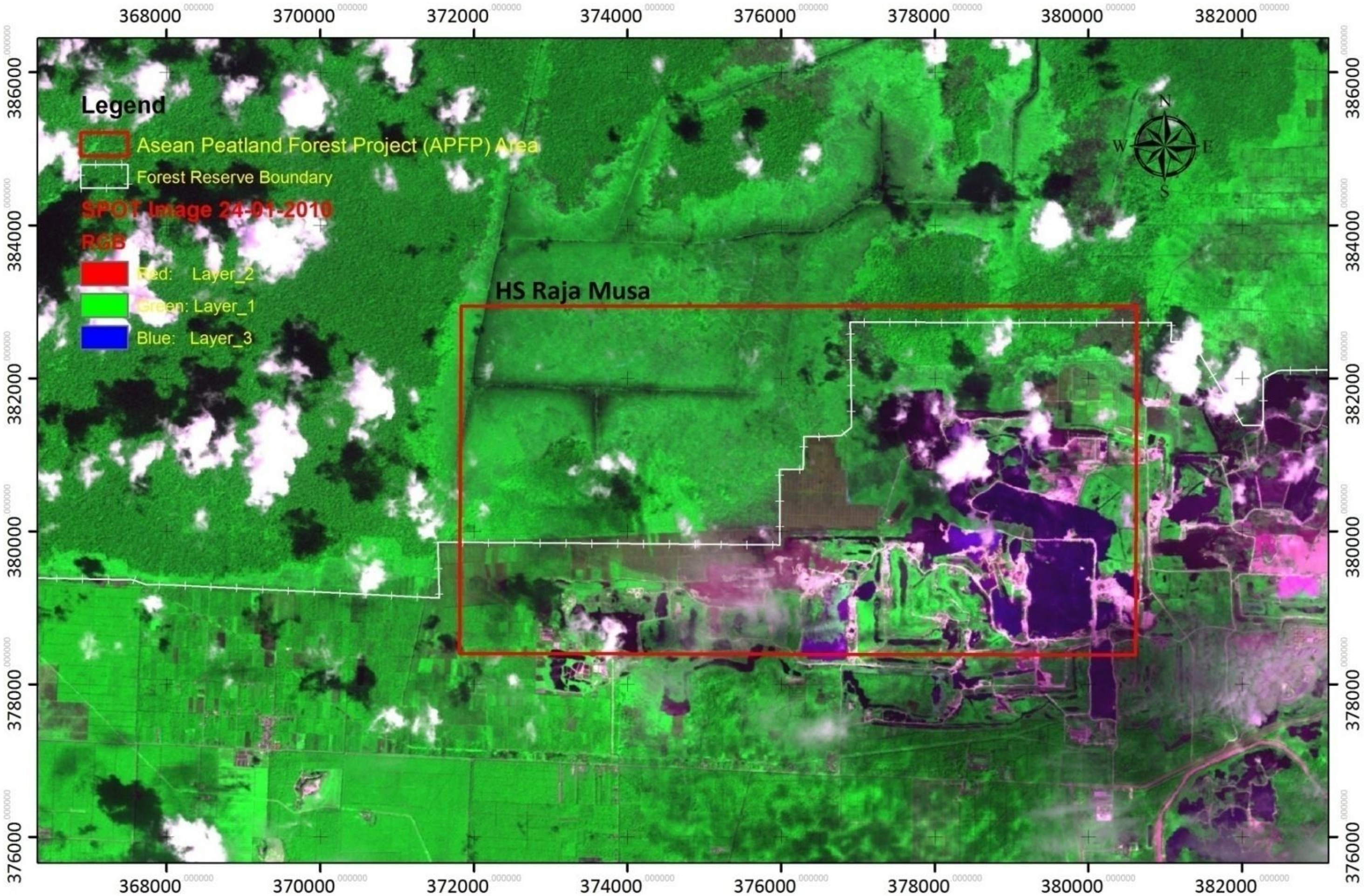
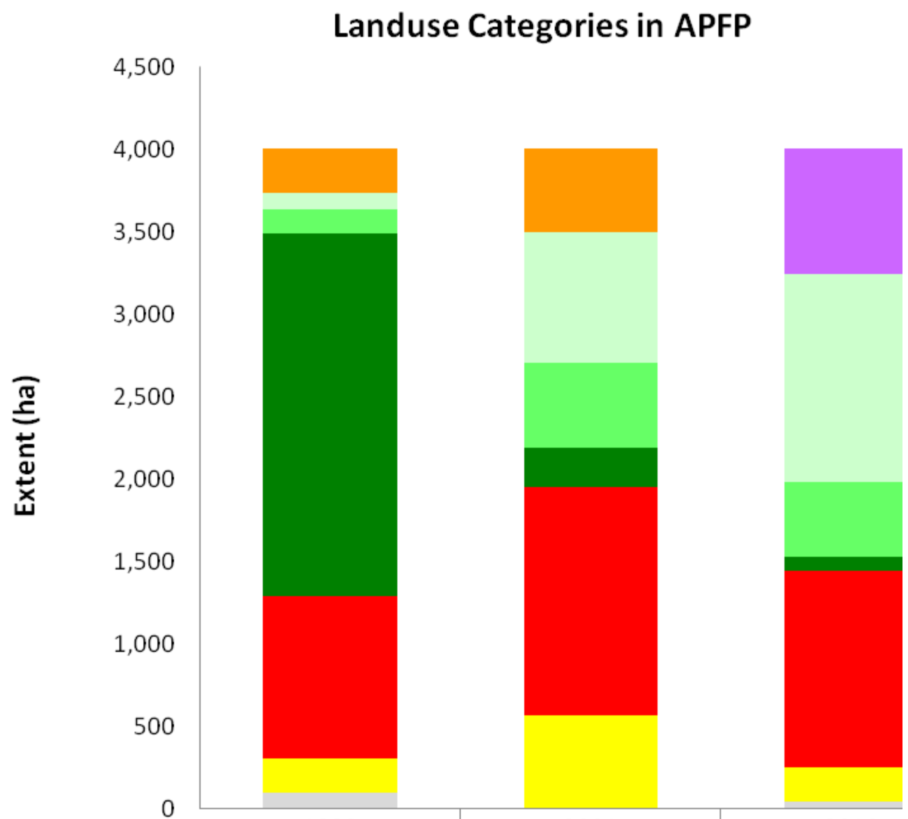


Figure 4 Satellite image over the year 2010

2.2 Landuse classification in the APFP

Landuse classification was applied to the satellite images to identify and classify the extent of landuse/land cover classes in the study area. By using an appropriate classification algorithm, several classes of landuse of the pilot site of approximately about 4,000 ha have been classified and the extent of each landuse category was quantified (**Figure 5**). In additional to the different landuse classes, the PSF itself was categorised into three categories according to its tree density in Normalised Difference Vegetation Index (NDVI); namely low, medium and dense PSF. NDVI is found ranged from 0.1-0.5 in the PSF. This range was divided into three, which are (i) 0.1-0.2, (ii) 0.2-0.3 and (iii) 0.3-0.5, that represent low, medium and dense, respectively. This categorization was useful to provide information of on trees and carbon stocking as well as the impact of forest fires that occurred in 1992 (*pers. comm.,* Forestry Department of Selangor). The PSF in the study area was considerably dense before the forest fire event as indicated on the satellite image for 1989. The classification results were spatially mapped as shown in **Figures 6 – 8** for the years 1989, 2001 and 2010 respectively.



	1989	2001	2010
Oil palm plantation	0.00	0.00	760.35
Shrubs	269.82	513.38	0.00
PSF: Low	105.24	788.70	1,266.97
PSF: Medium	140.72	512.40	452.69
PSF: Dense	2,200.61	244.22	83.74
Mining sites	986.72	1,378.84	1,188.95
Grassland	203.52	568.53	212.00
Cleared land	99.42	0.00	41.34
Total:	**4006.05**	**4006.05**	**4006.05**

Figure 5 Landuse classes in the pilot site on different years (1989, 2001 & 2010)

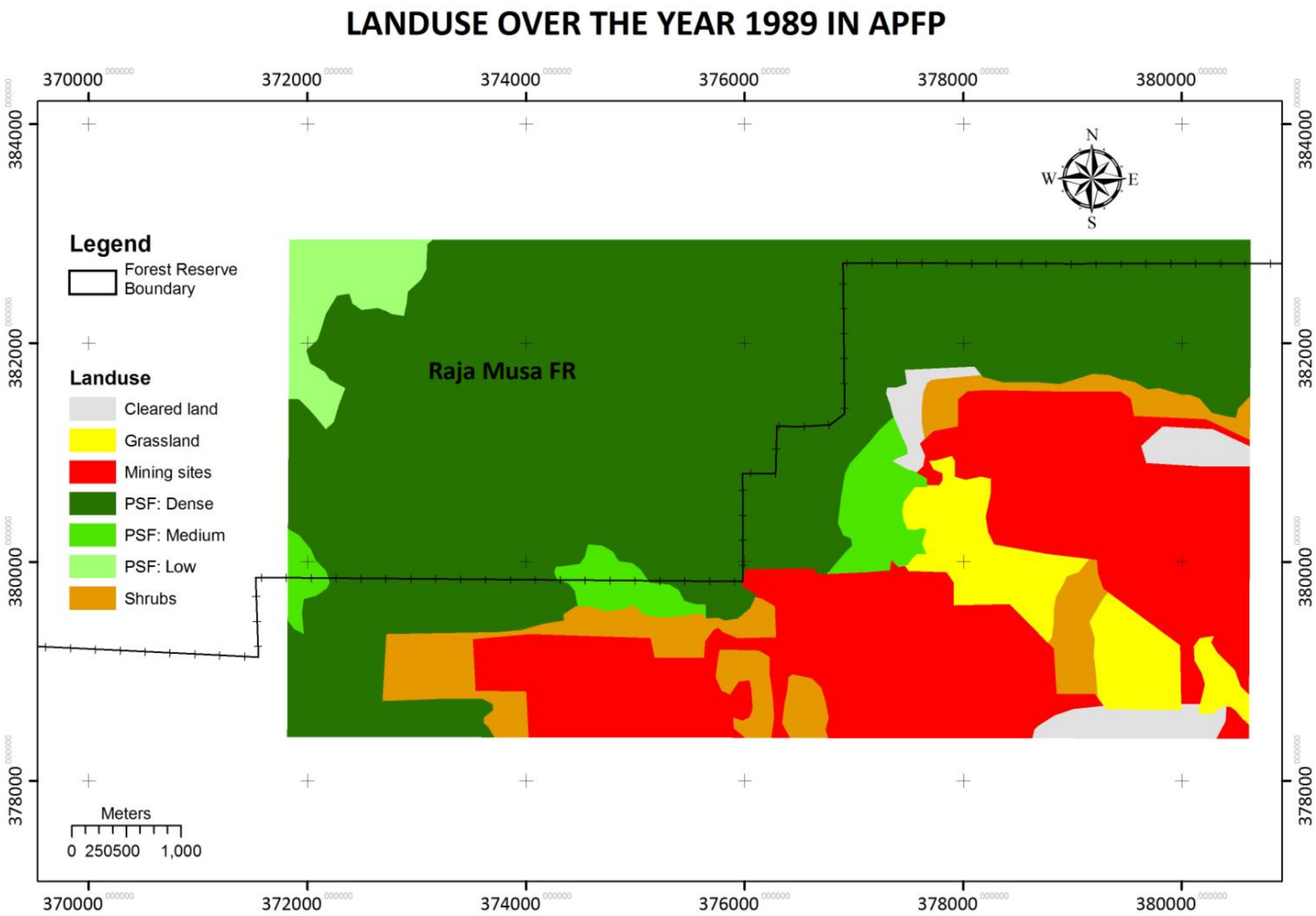


Figure 6 Landuse classes in year 1989

LANDUSE OVER THE YEAR 2001 IN APFP

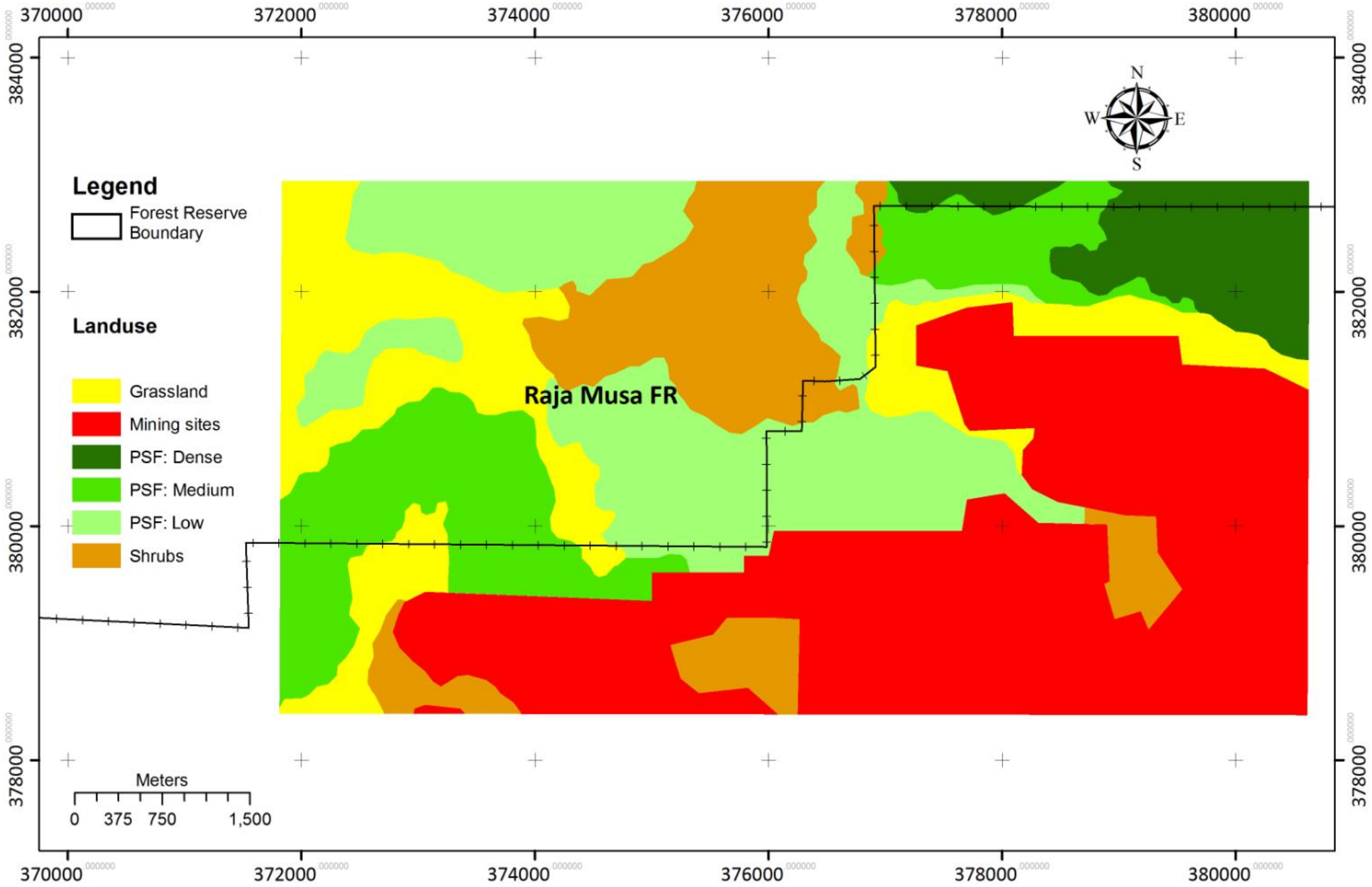


Figure 7 Landuse classes in year 2001

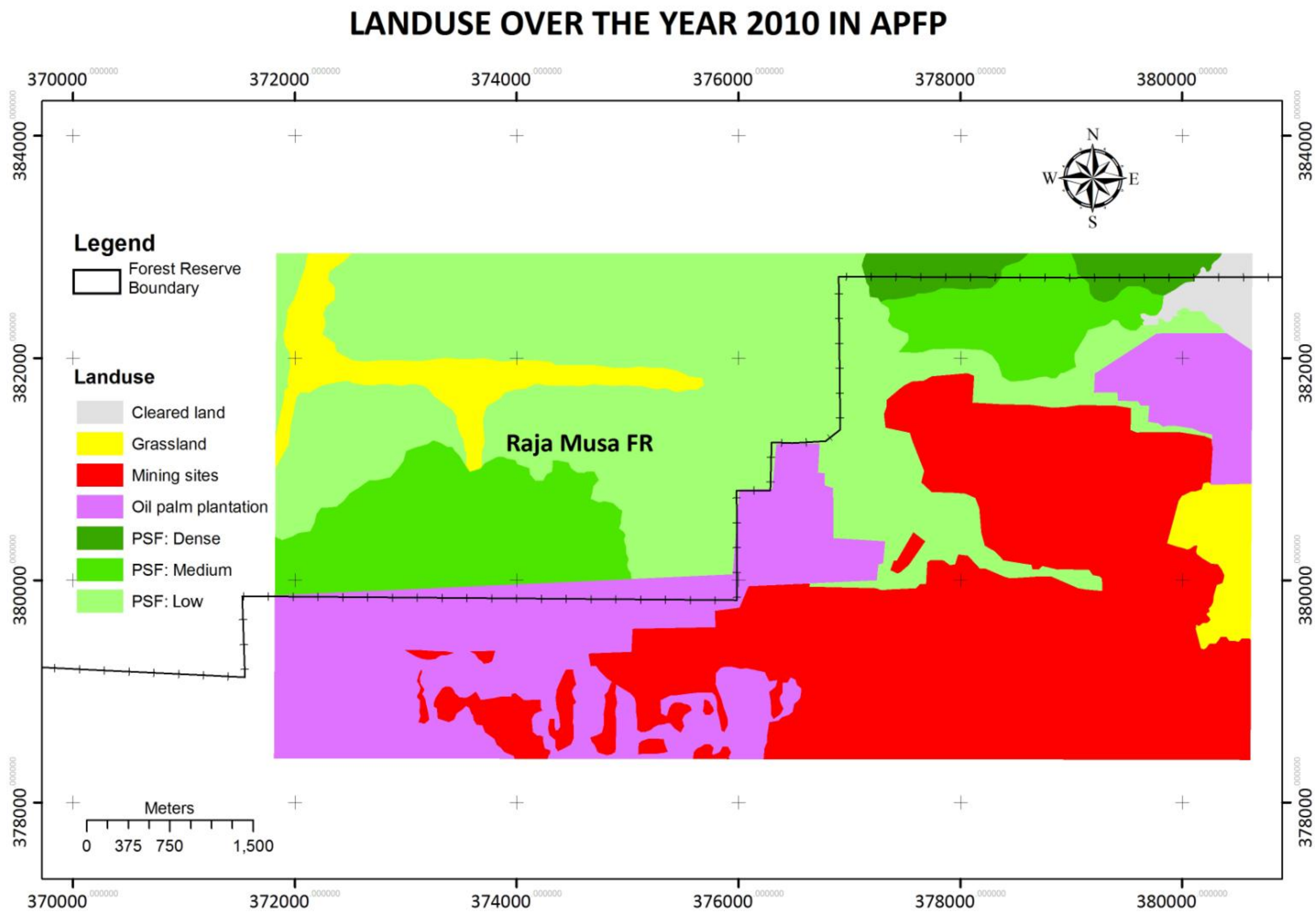


Figure 8 Landuse classes in year 2010

It was found that oil palm plantation only appeared on the satellite image in the year 2010. It occupied about 760 ha fringing the central horizontal line of the APFP pilot site. Another landuse class that occupied a significant extent of pilot site is mining areas. These mining areas were probably PSF sometimes ago. However they were converted into water bodies and grassland areas after they were left abandon following the completion of the mining activities were completed. These mining sites are dominant in the southern part of APFP pilot site.

Peat swamp forest that was pristine in the APFP pilot site occupied about 2,447 ha (61%) in the year 1989. However they were significantly reduced to 1,545 ha (39%) in the year 2001. This was due to the forest fire in which turned the PSF into grassland and shrubs. However, some of these affected areas have regenerated back into PSF thus increasing the total extent of PSF to 1,803 ha (45%) in 2010. The changes in the extent of PSF is shown in **Figure 9.**

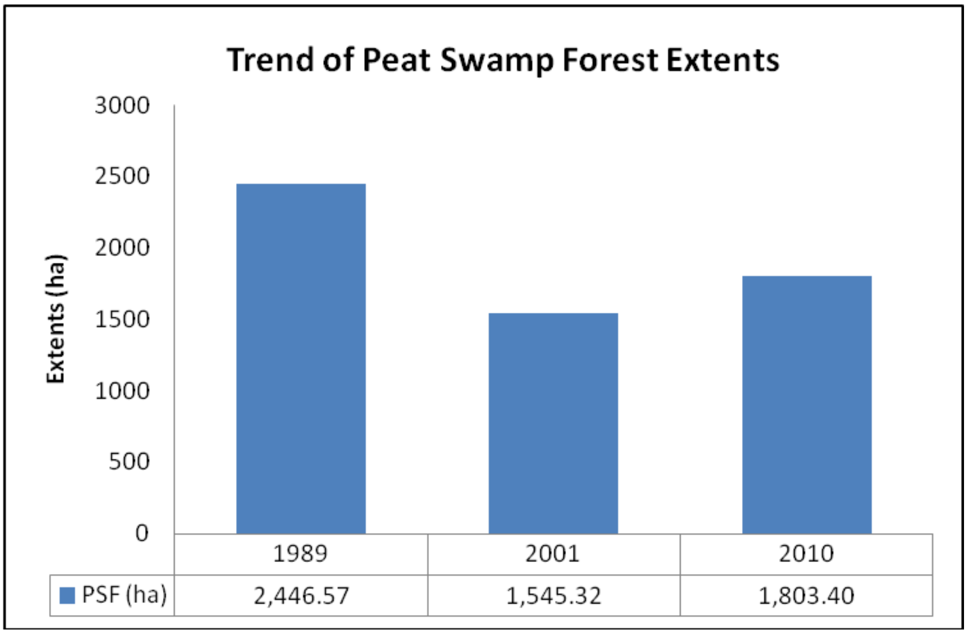


Figure 9 Trend of changes in peat swamp forest areas in APFP's pilot site

2.3 Aboveground carbon stocks in APFP

This project used secondary data to estimate aboveground carbon stock in the APFP pilot site due to limited resources available for field inventory. This was the optimum effort feasible within the short time frame of this project. A more detailed and precise calculation of the carbon stocks would require long-term measurements and detailed forest inventories. An additional uncertainty is that the resolution of the remote sensing data used (i.e. 30 x 30 m) does not allow further detailed assessment.

A set of ground inventory data adopted from JPNS (2000) was used to generate aboveground carbon stock prediction equation over the study area. Landsat-TM image over the year 2001 was used to perform this process. Since only standing volume (m^3 ha^{-1}) was given, the parameter has been converted to total carbon stock by using the following equation (simplified from IPCC, 2006):

C = A x V x BCEF x CF

Where,

C total carbon in carbon stock, in t

A area of land of certain land use class, in ha

V merchantable growing stock volume, in m^3 ha^{-1}

BCEF Biomass conversion and expansion factor (IPCC 2006)

CF carbon fraction of dry matter [the carbon fraction (CF) of dry matter was chosen to be 50%, as recommended by IPCC]

The ground data set and the generated NDVI from the satellites images is listed in **Table 3** and the correlation between these two parameters at corresponding locations is shown in **Figure 10.**

Table 3 Ground inventory data and generated NDVI from satellite images

Compartment	Estimated standing Volume (m^3 ha^{-1})*	Aboveground C stock (t ha^{-1})	Mean NDVI (Year 2001)
75	79.36	66.27	0.2722
88	79.36	66.27	0.2357
90	60.89	50.84	0.1561
91	79.36	66.27	0.2585
92	0.00	0.00	0.0009
93	79.36	66.27	0.2936
99	0.00	0.00	0.0000
101	60.89	50.84	0.1959

*Note: Measurement was made in the year 2000 for the trees ≥ 15.0 cm DBH

The NDVI was used as the indicator/predictor for the aboveground carbon stocks in the study area. This index can be generated from both Landsat and SPOT image, which enabled the carbon stock estimation over the time series of satellite images. The aboveground carbon stock estimation that have calculated based on the satellite images have successfully shown the distribution over the certain years and further allowed carbon stock changes assessment in the APFP pilot site. However, these results include some level of uncertainty that need to be assessed. Therefore, a field survey was conducted in the study area to determine estimation error and accuracy of the estimated aboveground carbon stock for the purpose validation and verification (**Appendix 1**).

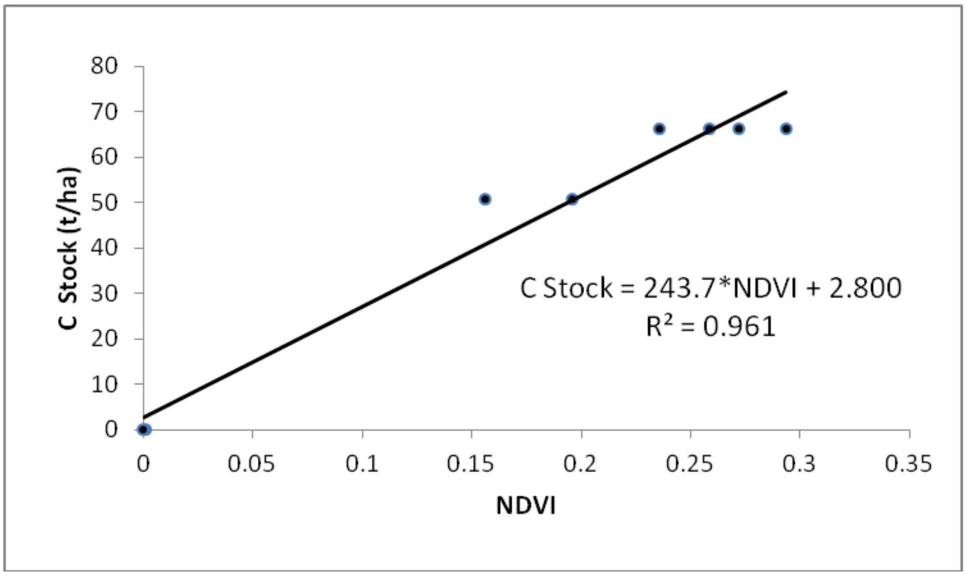


Figure 10 Relationship between aboveground carbon stock and NDVI

2.4 Causes of aboveground carbon changes

The NDVI images that were converted to aboveground carbon stock have allowed the calculation of total aboveground carbon stock in the study area over the three series of years. It was found that the total aboveground carbon stock in APFP area has lost about 342,756 tonnes from the year 1989 to 2001 due to the forest fire in year 1992. However the aboveground carbon stock started to recover back as it increased about 57,337 ha from the year 2001 to 2010. The distribution of carbon stocks in the PSF in APFP pilot site that ranged mainly from 80 – 184 t ha^{-1} in year 1989 has decreased to 0 – 40 t ha^{-1} in the year 2001 and increased back in 2010 at the range from 20 – 40 t ha^{-1}. The statistics of assessed aboveground carbon stock in APFP pilot site is shown in **Table 4** and its trend of changes is shown in **Figure 11.**

Table 4 Basic statistics of assessed aboveground carbon stock in APFP pilot site

Year	Minimum ($t\ ha^{-1}$)	Maximum ($t\ ha^{-1}$)	Mode ($t\ ha^{-1}$)	Average ($t\ ha^{-1}$)	Total (tonne)
1989	0.00	154.61	124.61	96.67	387,266.60
2001	0.00	61.11	37.38	11.11	44,510.42
2010	0.00	70.00	36.78	25.42	101,847.49

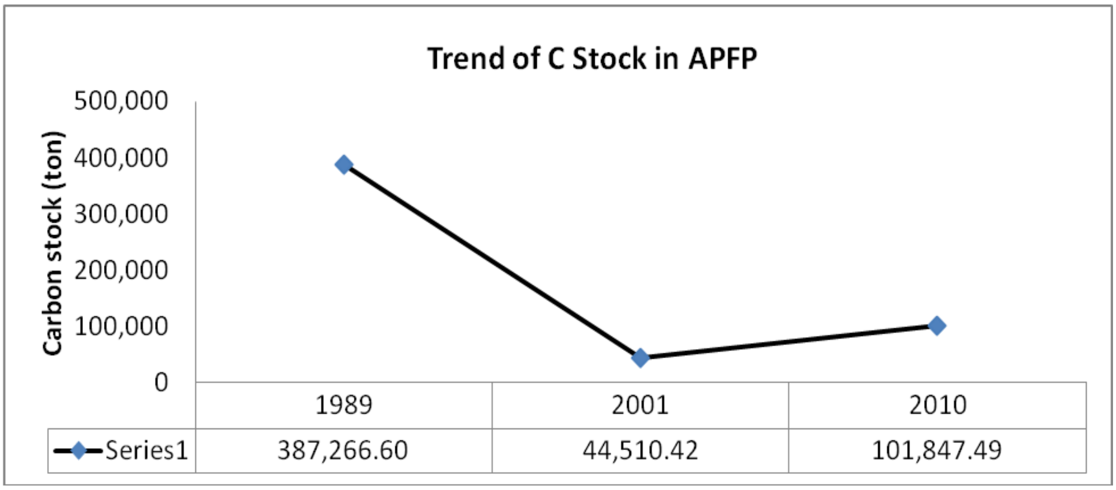


Figure 11 Trend of changes in aboveground carbon stock in APFP from 1989 to 2010

The study shows that the forest fire events that occurred in year 1992 in PSF have caused considerable amount of carbon lost. This carbon lost can occur within short period of time during the fires episodes, but the forest ecosystem has to take tens of years to recover the carbon storage. While **Figures 12 - 14** show the spatial distribution of aboveground carbon stock for the years 1989, 2001 and 2010. In addition, aboveground carbon stock changes of the APFP pilot site from the year 1989 to 2010 is shown in percentage in **Figure 15**. Most of the central and south west areas were totally (100%) changed due to the land conversion from PSF to oil palm plantation (outside the forest reserve).

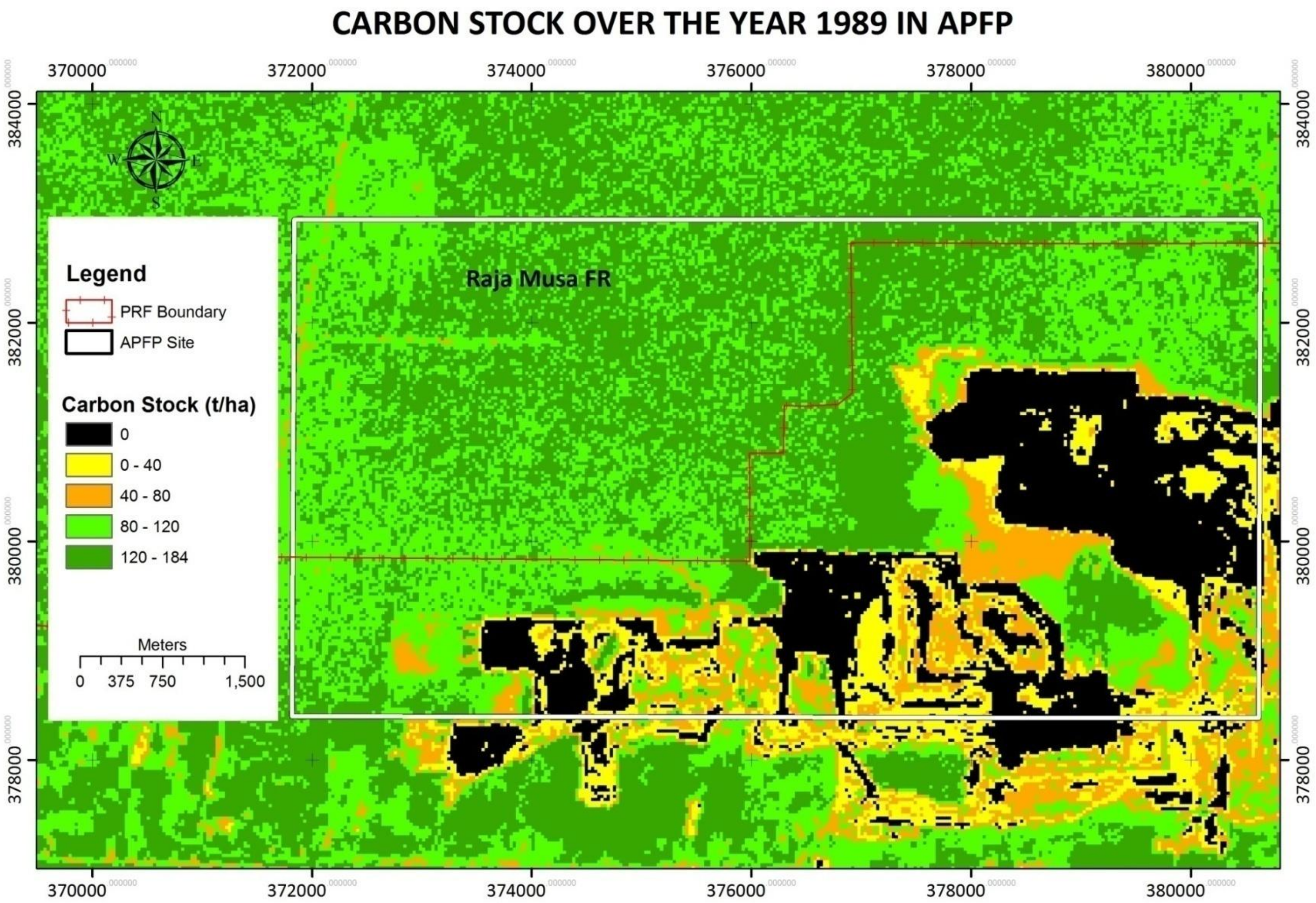


Figure 12 Distribution of aboveground carbon stock in year 1989

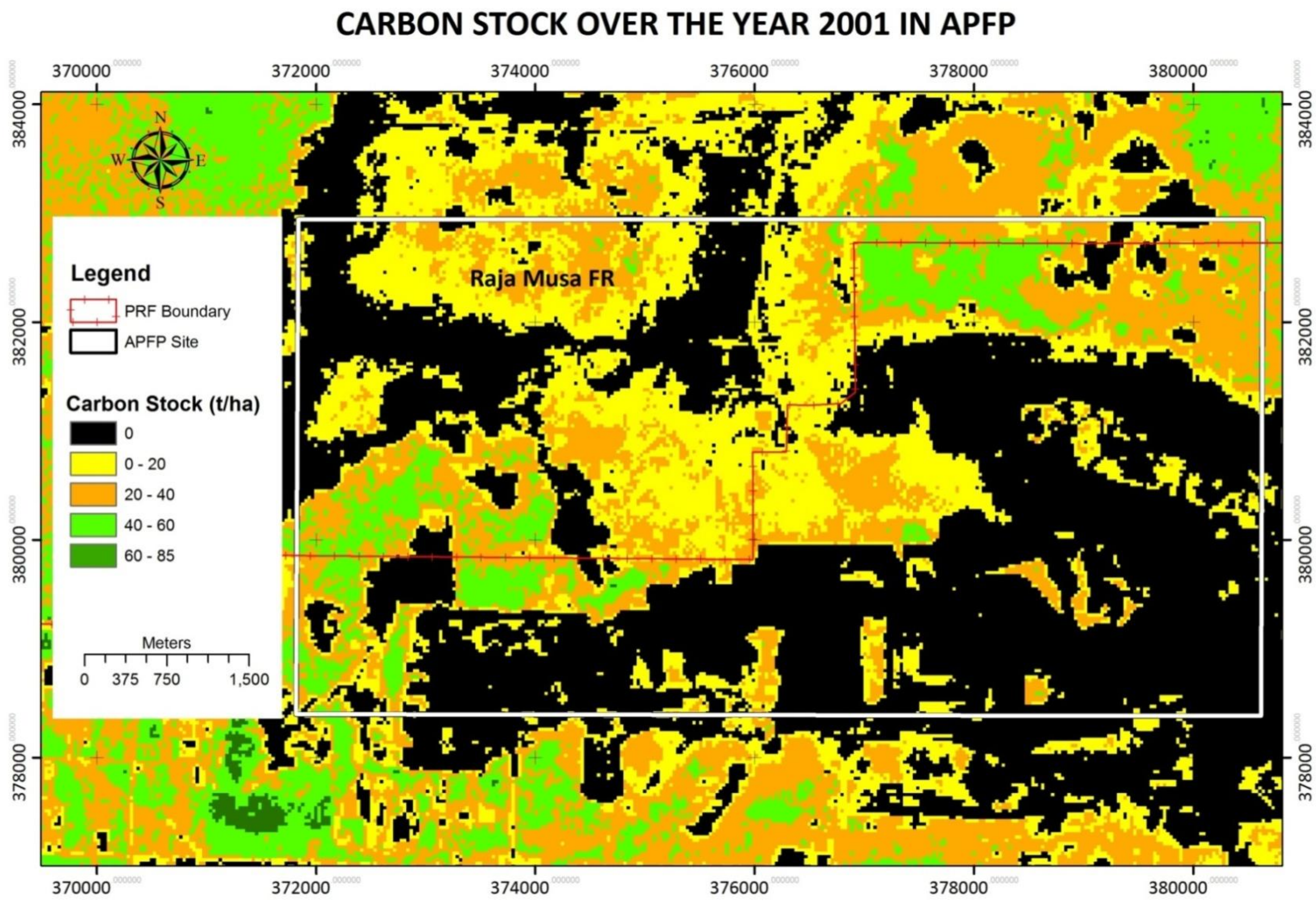


Figure 13 Distribution of aboveground carbon stock in year 2001

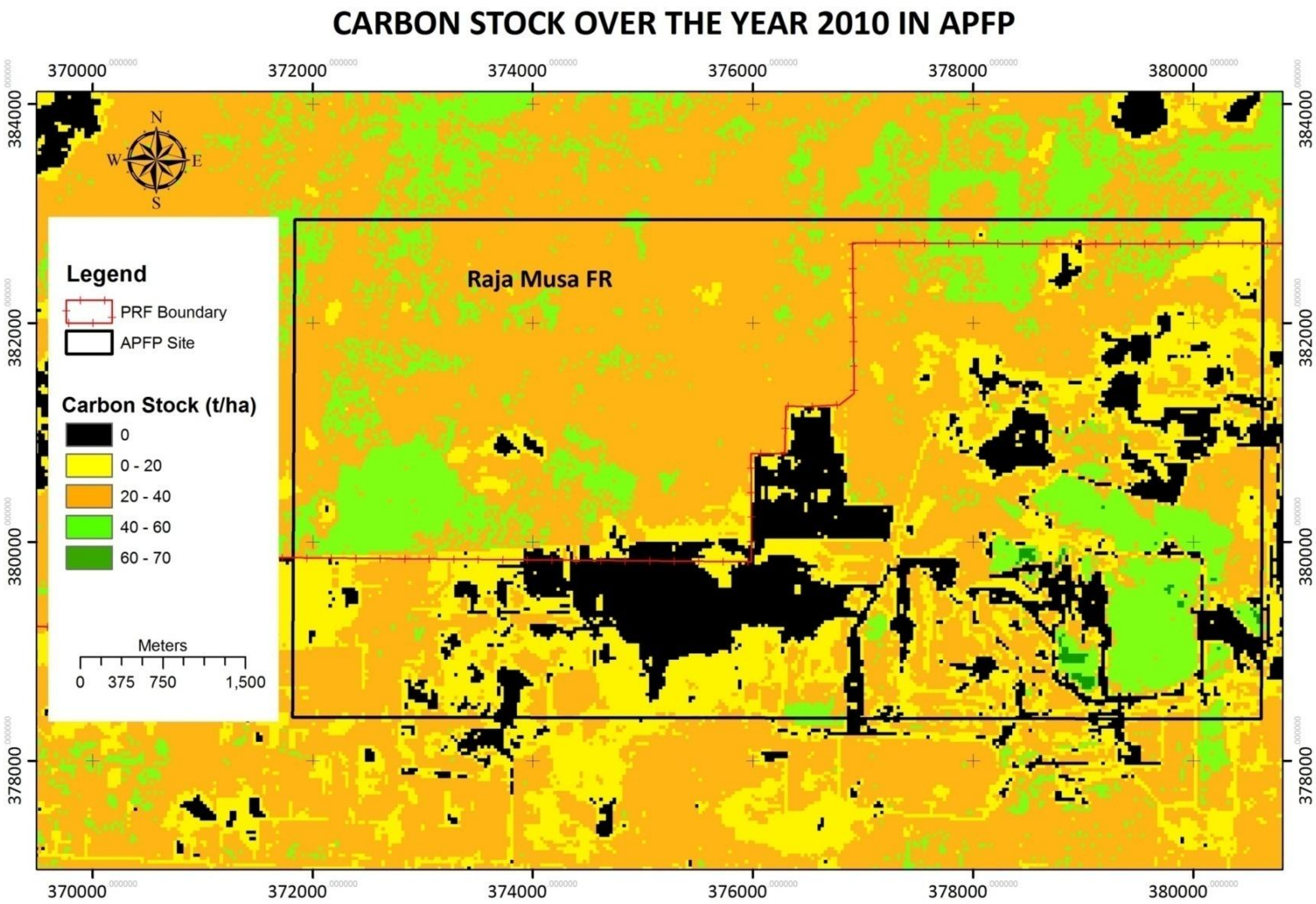


Figure 14 Distribution of aboveground carbon stock in year 2010

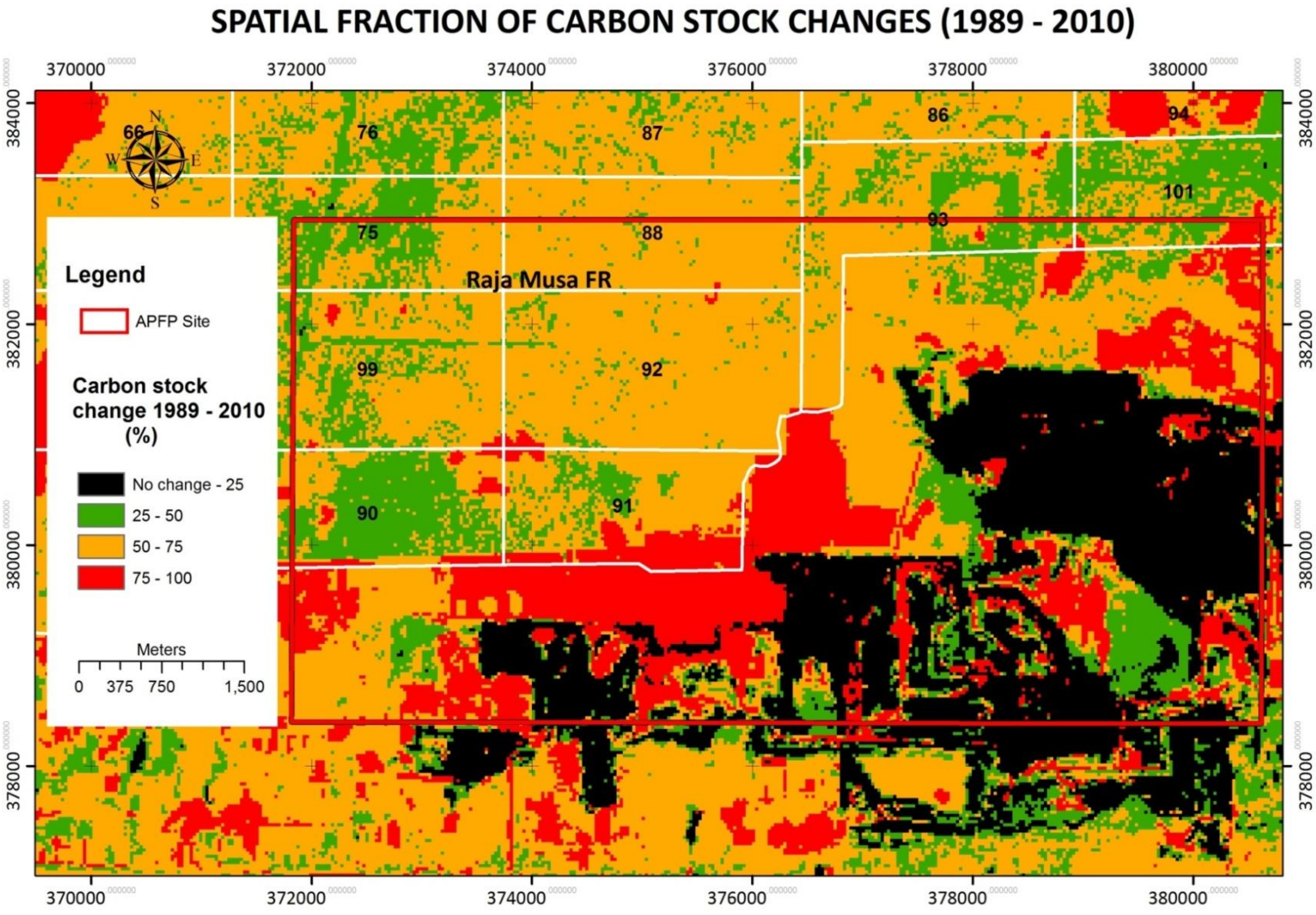


Figure 15 Fraction of aboveground carbon stock changes between year of 1989 and 2010

Chapter 3

Conclusions and Recommendations

3.1 Conclusions

Remote sensing technology has proven to be successful in relatively short duration in estimating aboveground carbon stock over the certain years. The methodology was used to estimate the aboveground carbon stock changes in the PSF areas of APFP pilot site at Berjunati Bestari, Selangor of Malaysia. Validation and verification results showed that estimation error and accuracy of the calculation of aboveground carbon stock in the APFP pilot site are of acceptable levels. The method adopted in this study has been found to be a cost-effective way to estimate the aboveground carbon and its pattern of changes. Detail field inventory in term of ground vegetation is needed for more accurate estimation of the aboveground carbon, nonetheless, provided field inventory data for all investigated years are also available to compare their pattern. Field inventory in the APFP pilot site if conducted would only be able provide estimates of the current vegetation information to be used for estimate the current carbon stock.

Based on project's findings, it was found that total aboveground carbon stock in PSF areas of APFP pilot site has lost about 342,756 tonnes from the year 1989 (387,266.60 tonnes) to 2001 (44,510.42 tonnes) due the forest fires in this area. However, the aboveground carbon stock started to recover back as it increased about 57,337 ton from the year 2001 to 2010 (101,847.49 tonnes). Study by Istomo (2006) in PSF of Sumatera, found that about 20.1% of aboveground carbon in PSF is belowground carbon. Based on that information, therefore as for 2010, the total vegetation carbon of PSF in the APFP pilot site was about 122,318 tonnes (aboveground = 101,847 tonnes, belowground = 20,471 tonnes) or about 11.35 t ha^{-1} (total area of PSF for 2010 ~ 1,803 ha). The low stocking of vegetation carbon stock was because more than 70% of total PSF areas consisted of low PSF areas that very little vegetation. As for comparison, an intact PSF in Pekan FR, Pahang could stock vegetation carbon at about 414.6 t ha^{-1} (Khali Aziz *et al.* 2009).

3.2 Recommendations

This study has provided useful information on the changes in carbon stocks in the study site for a 20-year period. Some useful lessons and experience were gained. Consequently the following recommendations are proposed:

i. Forest fire was found as the main threat to the PSF areas in the APFP pilot site. Therefore, it is suggested permanent water level station be installed to measure water table and create buffer zone of forest reserve to prevent and control fires. It is suggested that the APFP project conduct special study to develop forest fire management plan that will have forest fire prevention measures.
ii. Implement of fire preventions measures for the APFP pilot site particularly good water management (canal blocking) strategies.
iii. Increase the number of regular monitoring by forestry department's personnel particularly during dry season in It would be good to get the involvement of local community fire brigade;
iv. Conduct detail carbon assessment for PSF areas in the APFP pilot site including its soil via field inventory in order to determine total carbon stock of the area;
v. Conduct comprehensive rehabilitation program particularly in open PSF areas inside the RMFR to assist their regeneration, prevent fires and increase the carbon stock;
vi. Assign the APFP pilot site as model for long-term management site for peat land in Malaysia. It is an ideal site to show good coordination and cooperation of stakeholders for integrated management of the peat lands. It also can be a suitable place for a Centre of Excellence for Peat land in Malaysia;
vii. Provide continuous training to the staffs of forestry departments in the management of PSF as well in controlling and preventing forest fires in PSF; and
viii. Conduct assessment of aboveground carbon stock for the whole RMFR or even all PSF forest reserve in Selangor by using the remote sensing technologies in order to estimate their contribution on stocking of carbon for environment stability.

Glossary

Carbon dioxide (CO_2): CO_2 is a colorless, odorless, non-poisonous gas that is a normal part of the ambient air. Of the six greenhouse gases normally targeted, CO_2 contributes the most to human-induced global warming. Human activities such as fossil fuel combustion and deforestation have increased atmospheric concentrations of CO_2 by approximately 30 percent since the industrial revolution. CO_2 is the standard used to determine the "global warming potentials" (GWPs) of other gases. CO_2 has been assigned a 100-year GWP of 1 (i.e., the warming effects over a 100-year time frame relative to other gases)

Carbon sink: Any process or mechanism of absorbing carbon dioxide and retaining stocks of carbon in organic matter such as forests, oceans and soil more than it is released back into the atmosphere

Carbon stocks: The quantity of carbon contained in a "pool", meaning a reservoir or system which has the capacity to accumulate or release carbon. In the context of forests it refers to the amount of carbon stored in the world's forest ecosystem, mainly in living biomass and soil, but to a lesser extent also in dead wood and litter

Climate change: A change in the mean meteorological parameters that define climate of their variability. Climate is not the same as weather, but rather, it is the average pattern of weather for a particular region. These parameters include temperature, rainfall and wind speed. In the UNFCCC, on climate change issues caused by anthropogenic (human-induced) factors are included

Deforestation: The change of forested land to non-forested (treeless) land. This is often cited as one of the major causes of the enhanced greenhouse effect for two reasons: 1) trees that are burned or decompose release carbon dioxide; and, 2) trees that are cut no longer remove carbon dioxide from the atmosphere

Forest: FAO defines forests as: land spanning more than 0.5 hectares with trees higher than 5 meters and a canopy cover of more than 10 percent, or trees (including areas with bamboo and palms) able to reach these thresholds in situ. It does not include land that is predominantly under agricultural or urban land use. For AR CDM purposes, participating countries are required to submit their definition of forest to the Executive Board, which registers CDM projects to enable generation of carbon credits. Malaysia's definition of forest is: land area more than 0.5 hectares with trees higher than 5 meters and canopy cover of more than 30%

Global warming: The progressive gradual rise of the Earth's average surface temperature thought to be caused in part by increased concentrations of GHGs in the atmosphere which leads to climate change

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Appendices

Appendix 1. Validation and verification process

In order to validate the results, four (4) check plots distributed within the study area were randomly selected. All check plots are located inside Compartment 14 in the RMFR. These plots were established independently, specifically for validation process. An absolute accuracy was calculated for the resulted carbon stock distributions (note: absolute accuracy is a measure of the error between a derived/predicted carbon stock from satellite image and the actual carbon stock measured on the ground.) To produce a prediction with good absolute accuracy, reliable ground control (coordinate of the plot centre) can be used to reduce biases. Absolute accuracy (as shown in **Table 5**) is expressed as the vertical root mean square error (RMSE) of the vertical error measured at geographic coordinates given by

$$RMSE = \sqrt{\left[\frac{1}{n}\sum_{i=1}^{n}\left((b_i - b_i^{'}) - \mu\right)^2\right]}$$

where,

n	=	the number of check plots
b_i	=	measured carbon stock at check plot i
b'_i	=	derived/predicted carbon stock at position i
μ	=	average of carbon stock difference

Table 5 Absolute accuracy of the predicted aboveground carbon stock

Plot ID	Measured biomass, b (t ha^{-1})	Predicted biomass, b' (t ha^{-1})	Magnitude of errors b – b'	Mean square errors $((b - b') - \mu)^2$
P01	28.84	28.20	0.63	0.40
P02	24.57	25.16	-0.59	0.35
P03	26.19	23.32	2.88	8.27
P04	24.61	26.84	-2.23	4.99
		Mean error (μ) =	0.17	
			RMSE	± 3.74

Magnitude of errors of the four check plots ranged between 0.63 and 2.88 t ha^{-1} (note: magnitude is modulus, considered as no negative). The huge variations that occurred within the distribution represented the randomness of the check plots. The mean error of 0.17 indicated that the generated carbon stock from the equation had underestimated the carbon stock by about 0.2 t ha^{-1}. Having calculated the RMSE, standard error of the carbon stock within the study area is therefore ± 3.74 t ha^{-1}, with and accuracy of about 86%.

Photos of validation and verification activities on the field

Appendix 2. Plates of the APFP pilot site

Parts of APFP pilot site in outside of forest reserve are planted with oil palm

Fire indication at APFP pilot site

Ex-mining area

Open area of peat swamp forest areas colonized mainly by lalang (*Imperata cylindrical*)

Low peat swamp forest areas occupied by short peat swamp forest vegetation such as Inggir burung (*Euodia* spp.)


Medium peat swamp forest areas occupied by pioneer species such as Mahang (*Macaranga* spp.)


Dense peat swamp forest areas dominated with higher vegetation