

# HIGH CARBON STOCK FOREST STUDY REPORT

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Defining and identifying high carbon stock  
forest areas for possible conservation



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## Foreword

Golden Agri-Resources (GAR), together with subsidiary PT SMART Tbk (SMART), global non-profit The Forest Trust (TFT) and Greenpeace (together, the “Team”), have reached a significant milestone with the publication of this report detailing the methodology and findings from the High Carbon Stock (HCS) forest study, conducted under GAR’s Forest Conservation Policy (FCP). The fieldwork was carried out between the first quarter and last quarter of 2011. Following the launch of the FCP in early 2011, the Team proceeded to test how this policy and the provisional HCS forest definition would be implemented on the ground. GAR’s intention is to take a leadership role in finding a suitable definition for HCS and to act on its commitment to ensure no deforestation footprint in its palm oil operations. Ultimately, the conserved HCS forest area can revert to its natural ecological function as a forest.

The Team is taking a consultative approach and would welcome views from all stakeholders. The company recognises that in order to be successful, it cannot do this alone. The HCS forest conservation should be supported by all palm oil industry stakeholders. As such, this report is the starting point for multi-stakeholders to discuss, debate and improve upon the Team’s findings. GAR hopes that people will come together to work hand-in-hand because we share a common ground in wanting to find solutions for sustainable palm oil production.

The Team would like to take this opportunity to thank the various parties who have been working alongside us for the HCS fieldwork and this report. They include local communities, NGOs, and key government institutions in Indonesia.

The Team hopes that you will review the report carefully and looks forward to working with you. GAR believes that this is a strong platform for multi-stakeholders to find solutions to conserve the forests, create much needed employment and ensure long-term sustainable growth of the palm oil industry which is a vital part of the Indonesian economy.

**Daud Dharsono**

*President Director*

PT SMART Tbk

## Executive Summary

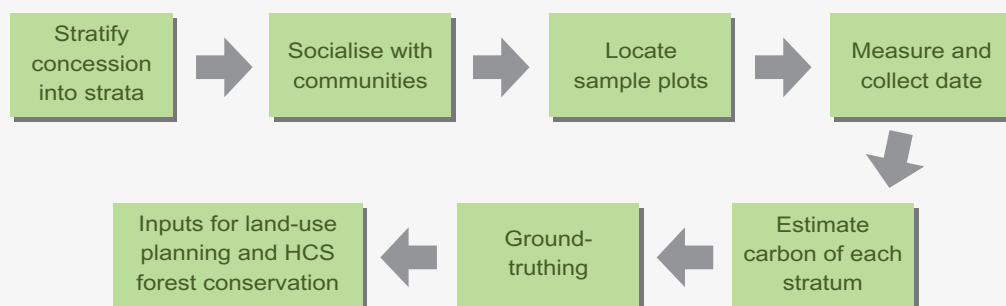
The tropical forests of Indonesia hold large stores of carbon, harbour important biodiversity, and are critical for the livelihoods of thousands of local communities. The conversion of these forests to other uses including agriculture or plantations, in particular those over carbon-rich peat land, has made Indonesia one of the largest emitters of greenhouse gases.

To contribute to a reduction of greenhouse gas emissions and as part of Golden Agri-Resources' (GAR), commitment to sustainable palm oil production, GAR in collaboration with The Forest Trust (TFT), a global non-profit, launched the Forest Conservation Policy (FCP) on 9 February 2011. The FCP focuses on the conservation of forests and ensures that GAR has no deforestation footprint. The company adopts the FCP for all the plantations that it owns, manages or invests in regardless of the stake.

This will be achieved by not developing oil palm plantations on areas that have High Conservation Value (HCV) and areas of peat regardless of depth and not developing forest areas with High Carbon Stock (HCS); obtaining free, prior and informed consent from indigenous and local communities; and complying with all relevant laws and internationally accepted certification principles and criteria.

To implement these commitments, GAR, its subsidiary PT SMART Tbk (SMART), TFT, and Greenpeace (together, the "Team") collaborated in a study to develop a practical, scientifically robust and cost effective methodology to define and identify areas of HCS for conservation. Ultimately, the conserved HCS area can revert to its natural ecological function as a forest. The methodology was based on the premise that there is a correlation between vegetation density and above ground living wood volume in trees greater than or equal to 5 cm DBH (diameter above breast height). This is then converted to tonnes of carbon per hectare (tC/ha). It followed the recommendation of a number of studies that a combination of remote sensing data analysis with ground-based field data is likely to provide an effective approach. For the purpose of this study, a provisional threshold for HCS forest of greater than 35 tC/ha of above ground biomass (AGB) was set.

Using a learning and adaptive approach, the methodology is summarised below.



Steps to identify HCS forest areas within concessions

The methodology stratified vegetation cover into different classes through analysing satellite images combined with data from fieldwork. The fieldwork measured 431 plots in four of GAR's concessions in Central and West Kalimantan from the first quarter to last quarter of 2011. As the study focused on undeveloped areas which local

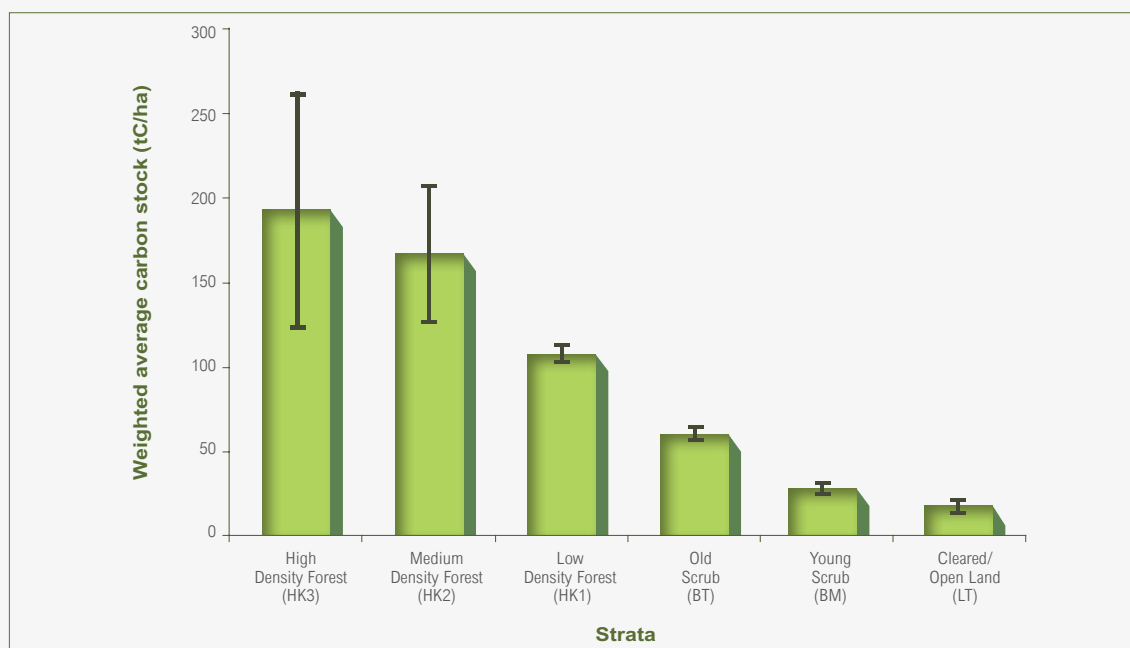
communities depended on, a socialisation programme was carried out to ensure that the communities understood and supported the fieldwork. GAR has also sought to engage broadly with the Government of Indonesia, civil society organisations, local and indigenous communities, key players and others stakeholders in the Indonesian palm oil industry.

The study found that six strata of vegetation cover could be identified; High Density Forest (HK3), Medium Density Forest (HK2), Low Density Forest (HK1), Old Scrub (BT), Young Scrub (BM), and Cleared/Open Land (LT) and these correlated with different average carbon stocks.

Vegetation cover definitions:

- **High Density Forest (HK3)** – Remnant forest or advanced secondary forest close to primary condition. Average 192 tC/ha;
- **Medium Density Forest (HK2)** – Remnant forest but more disturbed than High Density Forest. Average 166 tC/ha;
- **Low Density Forest (HK1)** – Appears to be remnant forest but highly disturbed and recovering (may contain plantation/mixed garden). Average 107 tC/ha;
- **Old Scrub (BT)** – Mostly young re-growth forest, but with occasional patches of older forest within the stratum. Average 60 tC/ha;
- **Young Scrub (BM)** – Recently cleared areas, some woody regrowth and grass-like ground cover. Average 27 tC/ha;
- **Cleared/Open Land (LT)** – Very recently cleared land with mostly grass or crops, few woody plants. Average 17 tC/ha;

Given the similarities in the carbon stock of strata across the different concessions, we plotted the weighted average carbon stock of the various strata and noticed that some of the strata's carbon values overlap.



Weighted average carbon stock of the various strata

The study confirmed that trees with larger diameters (DBH greater than 30 cm) dominated the higher carbon strata (HK1, 2 and 3) and smaller diameters less than 20 cm dominated the lower strata (BT, BM and LT). In addition, the BT stratum has occasional characteristics of older forest (as seen in the presence of trees of bigger DBH), consistent with the observation that BT could be regenerating forest. This supports the provisional HCS threshold falling between BT and BM, and that the lower carbon classes of HCS forest include a potential for regeneration of carbon stock.

The HCS forest study approach is relatively simple, practical, quick, and cost-effective and is technically sound to make carbon stock estimates. However it is not rigorous enough or technically sufficient to be used for carbon accounting, and this was never the intention.

A number of lessons were learnt during the socialisation process with the local communities in the study concessions. More time could have been spent to explain the objectives of the HCS forest study and address issues around compensation and allocation for plasma smallholders for areas that would be marked for HCS conservation.

There were several limitations with the HCS forest study, including the following:

- The methodology did not account for all AGB (e.g. by excluding trees with DBH less than 5 cm, and AGB dead matter such as logs and branches) and below-ground biomass, meaning carbon was underestimated;
- Field surveys were limited only to areas where permission was obtained from the local communities;
- Satellite images were of low to medium resolution and two years old.

Following identification of HCS forest areas, an additional conservation process which analyses the shape, size including “core” size, connectivity and habitat quality would need to occur to ensure that the medium-term objective of regenerating an ecologically functioning natural forest is achieved. Additional aspects to consider are the legal status of the land, free, prior informed consent of the local community, the impact of the HCS areas on plantation design and management, and overall monitoring. The findings of our HCS forest study indicate that:

- Vegetation cover can be used broadly to estimate the level of carbon stocks;
- Vegetation cover can be stratified into different classes to broadly represent different carbon stocks;
- Across some of the different classes of vegetation cover there are significant differences in the carbon stock;
- HK2 and 3 are remnant forests, with some disturbance;
- HK1 is also remnant forest, but highly disturbed and has a larger number of smaller trees;
- BT appears to be largely regenerating forest, with occasional remnants of older forests;
- BM and LT appear to have been cleared recently and are re-growth.

The vegetation stratification indicates that:

- The setting of the provisional HCS threshold as more than 35 tC/ha would result in HK1, 2 and 3 as well as BT being classified as HCS and hence could be considered for conservation;
- BM and LT would be low carbon stock and be considered as non-HCS, and could be developed, subject to the HCS conservation process (outlined above) and further research that considers the regeneration potential of BM.

The HCS forest methodology will facilitate GAR's commitment to ensure no deforestation footprint as outlined in the FCP. The HCS forest study findings indicate that there is a practical and robust method to identify HCS forest in GAR's concessions in Kalimantan. However, for the methodology to be used as a reliable predictive tool for HCS forests across Indonesia, further testing and fieldwork would be required.

Furthermore, the Team will be presenting the findings and holding wider discussions with representatives from the Government of Indonesia, civil society organisations, local and indigenous communities, key players and other stakeholders in the Indonesian palm oil industry, to gather feedback on the study and the outcomes.

More dialogue is also needed to focus on the ways to up-scale this HCS forest study mapping process to regional or national levels, as well as the options on how to conserve, manage and protect areas designated as HCS forests.

Upon gathering the required input and feedback from all stakeholders, GAR intends to develop its action plans for how it will proceed further with this methodology and will announce this in due course.

To be successful in HCS forest conservation, GAR cannot do this alone. It needs to engage with other stakeholders to find solutions to the existing challenges. GAR is focused on playing a leading role in developing a strong multi-stakeholder platform to find solutions to conserve the forests, create much needed employment and ensure long-term sustainable growth of the palm oil industry which is a vital part of the Indonesian economy.

# 1 Introduction

The tropical forests of Indonesia hold large stores of carbon, harbour important biodiversity, and are critical for the livelihoods of thousands of local communities. The conversion of these forests to other uses including agriculture or plantations, in particular those over peat lands, has made Indonesia one of the world's largest emitters of greenhouse gases.

The Indonesian government has acknowledged this through committing to a 26% reduction in emissions by 2020 or a 41% reduction with international financial assistance<sup>1</sup>. This commitment was sealed in a moratorium on any "new concessions converted from natural forests and peat lands into other land-uses including plantations" when the Norwegian government promised to contribute US\$1 billion to a climate partnership with the Indonesian government<sup>2</sup>.

## 1.1 GAR policy commitments

To contribute to a reduction in greenhouse gas emissions and as part of the aim for sustainable palm oil production, on 9 February 2011, GAR announced its Forest Conservation Policy (FCP), which committed to no deforestation footprint in its palm oil operations. This is achieved by not developing oil palm plantations on areas that have High Conservation Value (HCV) and areas of peat regardless of depth, and not developing areas with High Carbon Stock (HCS).

The FCP is part of GAR's holistic approach to sustainability, which includes the launch of a Social and Community Engagement Policy (SCEP) in November 2011, and a Yield Improvement Policy (YIP) in February 2012.

This is in addition to ensuring legality of all operations, implementing the principles of free, prior and informed consent, and obtaining certification by the Roundtable of Sustainable Palm Oil for all its operations by 2015<sup>3</sup>. The FCP applies to all the plantations that GAR owns, manages or invests in regardless of the stake.

<sup>1</sup> Statement by the President of Indonesia at the 2009 G20 meeting in Pittsburgh.

<sup>2</sup> Government of Norway (2010) "Norway and Indonesia in partnership to reduce emissions from deforestation", Government of Norway press release, 26 May.

<sup>3</sup> This is applicable to 433,200 ha of plantation and 42 mills as at 30 June 2010.



## **1.2 Working with partners and stakeholders**

To assist in realising these commitments, GAR has partnered with TFT and has collaborated with Greenpeace in the implementation of the FCP.

Further, since the launch of the FCP, GAR has been actively engaging with the Government of Indonesia, civil society organisations, local and indigenous communities, key players and other stakeholders in the Indonesian palm oil industry. GAR expects that this multi-stakeholder approach will ensure its policy commitments are well understood, there is feedback on and participation in their implementation, and that transparency throughout the whole process will give it credibility.

## **1.3 Development of the HCS forest study approach**

Key to GAR's FCP is developing a practical and cost effective methodology to define and identify areas of HCS for possible conservation. While there are accepted definitions and methodologies for identifying peat and HCV, HCS is a new concept with little agreement on its definition and identification. There was no methodology on how to identify HCS forests in an accurate, consistent and practical manner.

A further objective of the HCS study is to investigate the issues and review the options to estimate carbon stocks, while developing a scientifically robust and practical methodology for identifying HCS forests. These findings can be used by GAR and other businesses with similar requirements to develop land-use planning and other management tools to ensure no deforestation footprint in its operations.

The discussion of the HCS forest concept started in the fourth quarter of 2010 and several different approaches were considered. GAR developed maps for 13 concessions that contain forest areas and with plans for new plantings. The vegetation in these concessions was first stratified (see section 2.3.1 for details) using canopy cover and incorporating information from earlier aerial surveillance conducted by Greenpeace in some concessions. Areas that appear to contain more vegetation were identified for field visits at eight sites.

We began our initial fieldwork in the fourth quarter of 2010 in these eight sites in one test concession to assess AGB.

We found that most of the carbon in these forest areas (not peat land areas) is in larger trees. Measuring small trees less than 5 cm in diameter at breast height (DBH) is laborious and the carbon they contain was viewed as not significant enough to either alter greatly the outcome of the stratification or justify the time and effort that would be required to survey them.

While these initial findings provided a framework for the ongoing discussions, GAR announced its FCP in February 2011. In order to refine the methodology, a provisional definition of HCS forest was set as being greater than 35 tC/ha in living AGB.

Between the first and last quarter of 2011, fieldwork was conducted in four concessions: PT Kartika Prima Cipta (KPC), followed by PT Paramitra Internusa Pratama (PIP) and PT Persada Graha Mandiri (PGM) located in West Kalimantan, and then PT Buana Adhitama (BAT) in Central Kalimantan.

Using a learning and adaptive approach, we improved our stratification process including reducing the number of strata from 16 to 6 (see section 2.3.1 and Appendix 1 for a full discussion). We also adjusted our sampling technique based on the results obtained from the first fieldwork (see section 2.3.2) and also changed the way we selected the plots (see section 2.3.3). The combined data from the four concessions was analysed to assess how practical and robust the methodology is for identifying HCS forests.

## 1.4 Socialisation<sup>4</sup>

The Government of Indonesia grants an *ijin lokasi* (land-use permit) to companies for development activities on land that has been used before and is considered to be degraded land. However, these areas are often occupied by local communities. Before any development can take place it is necessary to engage these communities and where necessary, complete a process of obtaining free, prior and informed consent, as well as compensate them for their direct or indirect loss of use of these areas through an open and transparent process.

As our HCS forest study involved areas that are not yet developed and could still belong to local communities, it is important to ensure that they understood and gave their consent for the fieldwork. We also recognise that as with HCV areas, community support is vital to the successful conservation of HCS areas.

<sup>4</sup> Socialisation involves the interaction and engagement with relevant stakeholders such as government representatives, informal leaders, local communities and landowners. In the case of the HCS fieldwork, it involved face-to-face meetings, generating awareness, receiving feedback and addressing any concerns from this stakeholder group. The objective is to create an understanding and secure support for the HCS fieldwork and conservation of HCS forests.

## 2 The High Carbon Stock Forest Methodology

Quantifying biomass and carbon stocks is one of the key components of addressing emissions reductions from deforestation and forest degradation (Gibbs et al 2007). A number of methodologies have evolved, in particular based on the proportional relationship between AGB and the product of wood density, tree diameter and total height (e.g. Chave et al 2005, Brown 1997, Bryan et al 2010).

This approach of quantifying biomass and carbon stocks has been studied in more detail in Indonesia for *Dipterocarp* forests in Kalimantan (e.g. Yamakura et al 1986, Basuki et al 2009), and mixed secondary forest in Sumatra (Ketterings et al 2001). Given the size of areas to be assessed and limited time and resources, a combination of remote sensing data analysis with ground-based field data is likely to provide an effective approach, as advocated by many groups, e.g. DeFries et al (2007) and Gibbs et al (2007) in a global assessment and Bryan et al (2010) for Papua New Guinea.

### 2.1 The HCS forest study approach

A number of alternative approaches were also considered in the initial stages. These included using canopy cover, the 20/30 rule and estimating AGB.

Canopy cover was considered as a proxy for biomass and carbon stock based on the Food and Agriculture Organization (FAO) definition of forest. The FAO definition of forest is “any area with a minimum size of 0.5 ha and with at least 10% canopy cover” (FAO 2006). However, preliminary studies and fieldwork identified weaknesses of using canopy cover. These included the difficulty of adding up the 10% canopy cover in a degraded mosaic landscape, inability to separate natural forest cover from other tree cover, and not taking into account regenerating areas with substantial biomass that may not yet form a canopy.

We considered the “20/30” rule to define HCS forests. This rule as stipulated by the Indonesian Ministry of Forestry (*Peraturan Menteri Kehutanan no. P. 14/Menhut-II/2011*), requires operators to obtain a licence before timber can be harvested in areas containing more than 20 cubic metres of timber in trees measuring more than 30 cm in diameter at breast height (DBH), at 1.3 m above ground level<sup>5</sup>.

There were concerns that this could result in a significant variation in forest condition within the same area. In other words, the forest condition could be highly degraded with a few large trees that contain high timber volumes. On the other hand, some areas have very few trees above 30 cm DBH but contain dense regeneration giving them high biomass values and potential for conservation. Expert advice was also sought on the “20/30” approach<sup>6</sup>, and the general comment was that other factors such as biodiversity and the landscape need to be considered.

<sup>5</sup> DBH is measured at 1.3 m above ground level.

<sup>6</sup> E.g. David Lamb from University of Queensland, Australia.

Following the recommendations of international studies assessing AGB, using a combination of remote sensing data analysis with ground-based field data was chosen as the best option to pursue in the study to define and identify HCS forest areas. To carry out initial methodology development a number of field sites were selected. In each of these sites, we identified a main plot<sup>7</sup>, measuring 20 m by 20 m, and measured all the trees with DBH that are above 20 cm. Within the main area, a sub plot of 10 m by 10 m was identified to measure all trees taller than 2 m and below 20 cm in DBH.

Next we used these measurements as inputs to calculate the AGB. AGB is calculated using a generic Asia-wide formula, where wood density of 600kg/m<sup>3</sup> is generally accepted as an average density for Asian tropical tree species. AGB is then converted to tonnes of carbon per hectare (tC/ha) using a conversion factor of 0.47 (IPCC 2006).

These initial measurements indicated that we needed:

- Satellite images with higher resolution to identify HCS areas more accurately;
- More focus on the stratification process of the satellite images so as to establish preliminary estimates of the range of carbon values;
- A more structured approach in conducting an AGB inventory using an appropriate allometric<sup>8</sup>.

As discussed in section 1.3, a provisional definition of HCS forest as being greater than 35 tC/ha in living AGB is used. This provisional definition is deliberately conservative as the focus is on a portion of the AGB, meaning that other AGB and below-ground biomass are not measured. Furthermore, other forest values such as biodiversity are not accounted for.

While this provisional definition is somewhat subjective in its origin, it is backed up by expert review<sup>9</sup>, and other research into carbon sequestration by oil palms: “to avoid carbon debt, conversion should be conducted only from shrub and grassland with an aboveground C stock of less than 40 ton C ha” (cited in Dewi et al, 2009 and Van Noordwijk, 2012)<sup>10</sup>.

To help develop the methodology we engaged a specialist in timber and carbon inventories<sup>11</sup>. The methodology includes the plot size to be measured, sampling technique and a Microsoft Access database which performs statistical calculations for the data collected during the fieldwork.

<sup>7</sup> During the initial fieldwork, we marked out a square area of 20 m by 20 m, which we call a main plot. Within this main plot, we then marked out a smaller area measuring 10 m by 10 m; which we call a sub-plot.

<sup>8</sup> Scaling rule or equation that relates tree biomass, carbon or other similar properties to stem diameter and/or tree height. In our study, we use a formula that relates DBH to AGB biomass of the tree.

<sup>9</sup> E.g. “The use of threshold 35 tC/ha should be acceptable for defining HCS concept when the estimation of the biomass only consider from trees with diameter of more than or equal to 5 cm.” (de Boer 2011, pers. Comm). Also, research carried out in Jambi found that “the lower carbon stock estimate of the above ground biomass in secondary forest was about 32 tC/ha and had potential to regenerate naturally”. (Wasrin, U.R., Rohiani, A, Putera, A.E. and Hidayat, A. 2000. Assessment of aboveground C-stock using remote sensing and GIS technique. Final Report, Seameo Biotrop, Bogor, pg28)

<sup>10</sup> Also see the review paper “Greenhouse Gas Emissions from Palm Oil Production” prepared by the RSPO Greenhouse Gas Working Group (2009); it includes citations which calculated that over a 25 year rotation, oil palm plantations have mean carbon stock of 35.3 tC/ha.

<sup>11</sup> George Kuru, President Director of Ata Marie Group Ltd, a specialist provider of professional services to the Forestry, Agri-Business and Natural Resource Management sectors, based in Jakarta, Indonesia.

However, given the carbon content (AGB and Below Ground Biomass) of primary equatorial tropical forest may exceed 200 tC/ha (Gibbs et al 2007), it would therefore follow that 'high carbon' would denote forest with carbon stocks of approximately 150 tC/ha or more. As an objective of the HCS forest study approach is to ensure forest viability through regenerating to an ecologically functioning state in the medium to long term, this includes a major element of potential forest carbon i.e. AGB carbon that will be accumulated through the forest regenerating. For our study, the term High Carbon Stock therefore includes a component of potential carbon stock.

Thus as a provisional threshold, 35 tC/ha can be used to identify actual and potential areas of HCS and, while based on carbon, it is assumed that it also serves as a proxy for biodiversity and other forest values. For our study, only living AGB, defined as biomass in trees with a DBH greater than or equal to 5 cm (Brown 1997), is measured. Plantations and mixed gardens are not part of our study, which is focused on natural forest, but we recognise that such areas can contain high quantities of carbon.

## **2.2 Location of the study sites/concessions**

In total, fieldwork was conducted in four concessions where new plantings are taking place.

These concessions contain large areas that are still covered with vegetation and are subjected to extensive human disturbances, including timber harvesting and swidden agriculture (BSI-CUC 2010). In addition, these concessions are selected for ease of access to study locations and community engagement. As with all our concessions, these four concessions are designated as land for other uses (APL).

Three of the concessions are in West Kalimantan and one is in Central Kalimantan (see Figure 1). They range from 14,000 ha to 20,000 ha.

The dominant vegetation in West Kalimantan where we conducted our fieldwork is forest types commonly subject to water inundation (*Shorea sp.*) as well as dry land forests (*Dipterocarpaceae sp.*) at higher elevations. These sites also contained heath forest, which is dominated by trees with smaller diameters. However, the vegetation in Central Kalimantan is less varied, consisting mainly of dry land forests. In both regions, there are community plantations including rubber, as well as mixed gardens.



Figure 1 – Map of Kalimantan, Indonesia, with the location of the four HCS forest study concessions. Three concessions are in the province of *Kalimantan Barat* (West Kalimantan), and one concession is located in the province of *Kalimantan Tengah* (Central Kalimantan).

## 2.3 Methodology

Our method is based on the assumption that there is a correlation between vegetation cover and carbon stock, and that this correlation is broadly consistent across and within similar conditions (MacDicken 1997, Gibbs et al 2007, Solichin et al 2011).

Since there are no similar studies that can act as a precedent, we refined our methodology as we progressed. Initially, we grouped or stratified vegetation cover by their canopy densities by analysing satellite images. This desktop review is supplemented with fieldwork where we measured the carbon for each of the stratum within sample plots.

In our entire study, carbon is measured indirectly as we are unable to conduct a destructive sampling experiment<sup>12</sup>. Instead, we used the DBH of the trees in the sample plot as a proxy to calculate the carbon in the vegetation within the strata. We extrapolated the results of the sample plots to the rest of the concessions.

Using a learning and adaptive approach, our methodology is summarised in Figure 2.

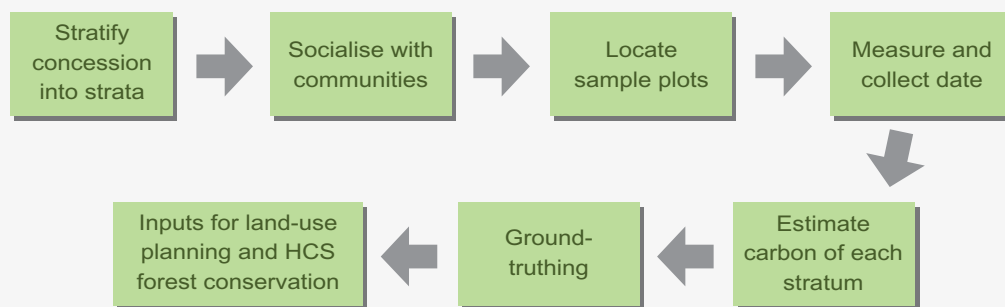


Figure 2 – Steps to identify HCS forest areas within concessions

<sup>12</sup> In a destructive sampling experiment, the vegetation found in a sample plot needs to be cut down, dried, and then burnt. The carbon dioxide released will be weighed to provide a measurement of the amount of carbon stored in the vegetation.

### 2.3.1 Stratification

The objective of stratification is to classify vegetation into distinct groups and in the process minimise intra-stratum variance. This can be achieved by interpreting vegetation cover from satellite images of areas being studied (GOFC-GOLD 2010). Put simply, the colours and textures on the satellite photos approximate different densities of vegetation and can be grouped accordingly. The process of stratification is discussed in full in Appendix 1.

As recent satellite images were not readily available, we used a combination of Landsat images comprising medium-resolution images such as SPOT-4, with a spatial resolution of 20 m, and SPOT-5, with a spatial resolution of 10 m. See Table 1 below.

Table 1 – Information on the satellite images used in this study

No.	Concession	Region	Images		
			Satellite	Path/row	Taken on
1	PT Kartika Prima Cipta	West Kalimantan	Landsat 7 ETM	120/60	18/07/2010
			SPOT 5	292/349	29/07/2009
2	PT Paramitra Internusa Pratama	West Kalimantan	Landsat 7 ETM	120/60	18/07/2010
			SPOT 5	291/349	18/07/2009
3	PT Persada Graha Mandiri	West Kalimantan	Landsat 7 ETM	120/60	18/07/2010
			SPOT 5	291/349	18/07/2009
4	PT Buana Adhitama	Central Kalimantan	Landsat 7 ETM	119/61	01/06/2010
			SPOT 4	294/353	14/05/2010

During our study, we improved the process of stratification as new information and data were collected from the fieldwork (see Appendix 1 for details). We began with 16 strata classified by the Image Processing Software, which were later streamlined to only six strata. Through an iterative process of data analysis and fieldwork, we were able to classify the vegetation into relatively statistically distinct strata.

The six strata are:

- HK3: High Density Forest (*Hutan Lahan Kering 3*)
- HK2: Medium Density Forest (*Hutan Lahan Kering 2*)
- HK1: Low Density Forest (*Hutan Lahan Kering 1*)
- BT: Old Scrub (*Belukar Tua*)
- BM: Young Scrub (*Belukar Muda*)
- LT: Cleared/Open Land (*Lahan Terbuka*)

We also developed an Interpretation Key (see Appendix 3) to help us interpret satellite images into the six strata. When we used this key, we found a strong correlation between the HK (*Hutan Lahan Kering*) strata identified in our study and the HK in the Ministry of Forestry Decree (*Peraturan Menteri Kehutanan*) no. 33/2009 on Guidelines of Periodical Comprehensive Forest Inventory (IHMB - *Inventarisasi Hutan Menyeluruh Berkala*).



### 2.3.2 Sampling

As the fieldwork covered vast areas, we identified sample plots to measure AGB in trees more than or equal to 5 cm DBH. Furthermore, we focused the sample plots on the strata that we expected would overlap the provisional threshold of 35 tC/ha. In these strata we planned to measure about 25 plots. For the other strata, we planned to measure a minimum of 15 plots per stratum.

Using the results from the first fieldwork at PT KPC as a sampling study for the other concessions, the coefficient of variance for the target strata was calculated using the Winrock Terrestrial Sampling Calculator with a 5% sampling error (Pearson 2006).

In our final fieldwork at PT BAT, a coefficient of variance of 45% was used for the strata where we envisaged that the provisional threshold of 35 tC/ha occurs.

### 2.3.3 Design of sample plot

We used a rectangular nested design for our sample plots. This design incorporates a smaller 10 m by 10 m plot, where trees with DBH of greater than or equal to 5 cm and less than 20 cm were measured, within a larger 10 m by 50 m large plot where all trees with DBH greater than or equal to 20 cm were measured (see Figure 3).

We recognise that the smaller plot size is relatively smaller than those used in other studies (e.g. Pearson et al 2005). However, as our study focused on degraded areas with few trees of 20 to 50 cm in DBH, the smaller plot size is justified as we expect the smaller plot to produce more variable results in more heavily forested areas. This sample plot design was used in subsequent fieldwork.

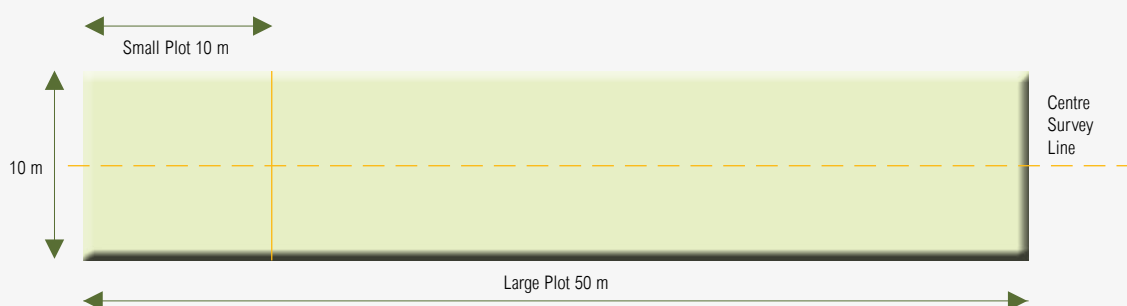


Figure 3 – Schematic of the plot design used during the field inventory

During the fieldwork, each tree was assigned a number, and we recorded its DBH and species type. This information was written on a label that was stapled to the tree for any future quality control checking. In addition to measuring the trees, we recorded a visual assessment of vegetation cover for comparison purposes. We also assessed the soil type visually, and took photographs in five different directions, namely North, South, East, West and skywards.

### 2.3.4 Plot details

Two different techniques were used in designing the 431 plots that were sampled in all the four concessions (see Table 2 below). In PT KPC, given the lack of baseline data, transect lines were used. Subsequently, we refined the technique and identified plots randomly.

a) Transect Plots

Plots are systematically located every 200 m across transect lines drawn across the concession.

b) Random plots

Plots were randomly located across the concessions and within targeted strata, although some random plots were not measured, as they were inaccessible. To navigate to these plots, we used a hand-held Global Positioning System.

Table 2 – Total plots visited in each of the four concessions under each stratum

Strata	Concession				Total
	PT Buana Adhitama	PT Kartika Prima Cipta	PT Persada Graha Mandiri	PT Paramitra Internusa Pratama	
High Density Forest (HK3)	3	9	0	0	12
Medium Density Forest (HK2)	4	5	1	0	10
Low Density Forest (HK1)	29	19	8	13	69
Old Scrub (BT)	39	39	2	13	93
Young Scrub (BM)	20	62	0	9	91
Cleared/Open Land (LT)	10	97	0	24	131
Plantation	0	23	0	2	25
<b>Total</b>	<b>105</b>	<b>254</b>	<b>11</b>	<b>61</b>	<b>431</b>

## 3 Data Analysis

We estimated the carbon stock within each stratum and overlaid these estimates with the provisional HCS threshold of 35 tC/ha. The similarities or differences between each stratum across the four concessions were also investigated.

### 3.1 Allometric

A tree's biomass is estimated from its DBH by using a generic allometric for Tropical Moist Forests (Brown 1997), where

$$\text{Biomass} = 42.69 - 12.800 \cdot \text{DBH} + 1.242 \cdot \text{DBH}^2$$

This equation is developed from multiple sources, using trees with DBH between 5 cm and 148 cm, including trees from East Kalimantan (Brown 1997). This is not a locally developed allometric equation but the data set behind it does include a large number of trees harvested from *Dipteocarp* forests in East Kalimantan and thus we assume it would serve our needs. The use of more general equations developed for tropical moist forests is common practice (e.g. Pearson et al 2005). To develop a local one would be ideal, but this is expensive to develop and not practical for this project given the time available and the diversity of trees found across Kalimantan.

To calculate the amount of carbon per plot, we used a carbon conversion factor of 0.47 (IPCC 2006) and converted kilograms of biomass to tonnes of molecular carbon per tree. After the tree carbon weight was summed for each plot, we calculated the amount of carbon per plot which we then extrapolated to a per hectare figure basis and expressed as tonnes per hectare.

### 3.2 Data checking

A total of 114 anomalous plots were removed from the final analysis because of uncertainty or inconsistency in allocating forest cover vegetation classification to specific plots. These plots are in:

- Areas where there was recent human activity subsequent to the satellite mapping such as timber harvesting (12 plots);
- Areas in transition from forest to open land or vice versa (14 plots);
- Areas with poor visibility of satellite images due to cloud cover (3 plots);
- Areas where there were plantations, rice fields, or mixed gardens (85 plots).

The data checking process is based on notes taken during fieldwork. The number of plots used for the final analysis after the data checking is summarised in Table 3.

Table 3 – Number of plots per stratum included in the final data analysis

Strata	Concession				Total
	PT Buana Adhitama	PT Kartika Prima Cipta	PT Persada Graha Mandiri	PT Paramitra Internusa Pratama	
High Density Forest (HK3)	3	9	0	0	12
Medium Density Forest (HK2)	4	5	1	0	10
Low Density Forest (HK1)	28	15	8	13	64
Old Scrub (BT)	38	24	2	13	77
Young Scrub (BM)	20	34	0	9	63
Cleared/Open Land (LT)	10	70	0	11	91
<b>Total</b>	<b>103</b>	<b>157</b>	<b>11</b>	<b>46</b>	<b>317</b>

### 3.3 Data extrapolation to calculate and estimate carbon stock

Carbon values for each stratum were calculated by averaging plot data to produce a mean carbon value for each stratum. To calculate the confidence level of our mean, we used a 90 percent confidence level to calculate our data.

## 4 Results and Discussion

### 4.1 Results

Our findings support research indicating that carbon stock declines correspondingly to a decline in vegetation canopy density (e.g. Solichin 2011, Dewi 2009). While this is expected, these findings support the use of vegetation canopy cover to estimate the average carbon stock and therefore as a useful way to define and map HCS.

The results as summarised in Table 4 indicate that there are:

- Similarities in the carbon stock of strata across the different concessions;
- Differences in the carbon stock between strata.

Table 4 – Carbon stock of living AGB in trees with DBH greater than or equal to 5 cm

Strata	Average carbon stock by concession (tC/ha) and number of plots (n)				Weighted average carbon stock (tC/ha) and number of plots (n)	Confidence limits (t, 0.90)	
	PT Buana Adhitama	PT Kartika Prima Cipta	PT Persada Graha Mandiri	PT Paramitra Internusa Pratama		Value	%
High Density Forest (HK3)	265 (3)	167 (9)	- (0)	- (0)	192 (12)	81	42%
Medium Density Forest (HK2)	163 (4)	134 (5)	334 (1)	- (0)	166 (10)	51	31%
Low Density Forest (HK1)	97 (28)	96 (15)	134 (8)	125 (13)	107 (64)	11	10%
Old Scrub (BT)	56 (38)	60 (24)	66 (2)	67 (13)	60 (77)	7	12%
Young Scrub (BM)	27 (20)	27 (34)	- (0)	29 (9)	27 (63)	6	21%
Cleared/Open Land (LT)	4 (10)	14 (70)	- (0)	25 (11)	17 (91)	6	33%

Given the similarities in the carbon stock of strata across the different concessions, we plotted the weighted average carbon stock of the various strata and noticed that some of the strata's carbon values overlap.

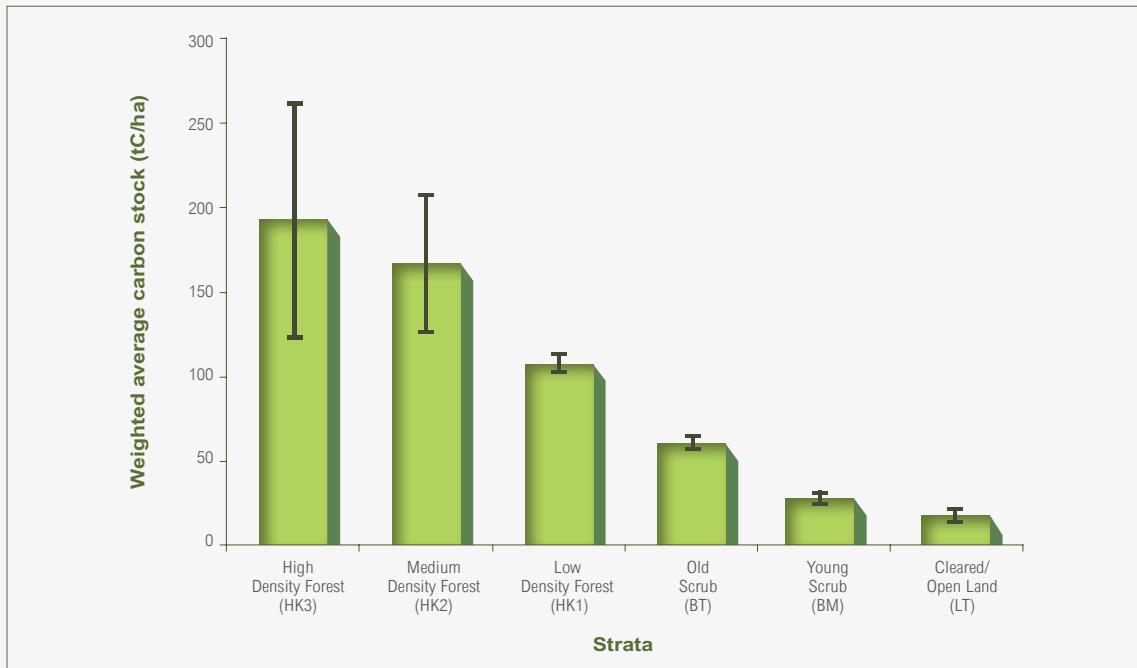


Figure 4 – Weighted average carbon stock of the various strata

To establish if there is any statistical difference between the weighted average carbon stock across the strata, we conducted an analysis of variance (ANOVA) which indicated that there are statistically distinct groups (see Table 5).

Table 5 – ANOVA analysis of the six strata

Source	DF	SS	MS	F	PROB>F
Between	5	701427	140285	54.97	0.000
Within	313	798769	2552		
<b>Total</b>	<b>318</b>	<b>1500196</b>			

As the ANOVA results only indicate that a difference exists among means, not which pair or pairs of means are different, a multiple comparisons test is used to detect where the differences lie.

We chose the Scheffe test as it allows the determination of simultaneous confidence intervals for group only based on the number of groups (strata) and the number of observations (plots).

As summarised in Table 6, we found that:

- There are no significant differences between HK3 and HK2;
- There are no significant differences between BM and LT;
- Other pairs of strata are significantly different from each other.

Table 6 – Scheffe test for difference between the weighted average carbon stock of the six strata

Group 1	Group 2	Difference	Scheffe statistic	Critical value	Significant difference
HK3	HK2	26.1	1.21	3.349	No
	HK1	84.7	5.33		Yes
	BT	132.1	8.42		Yes
	BM	164.6	10.34		Yes
	LT	174.9	11.29		Yes
HK2	HK1	58.7	3.41		Yes
	BT	106.0	6.24		Yes
	BM	138.5	8.05		Yes
	LT	148.8	8.85		Yes
HK1	BT	47.3	5.54		Yes
	BM	79.8	8.90		Yes
	LT	90.1	10.98		Yes
BT	BM	32.5	3.79		Yes
	LT	42.8	5.50		Yes
BM	LT	10.3	1.25	No	

From the observations made during the fieldwork, we could describe the strata according to their general qualitative characteristics (see Appendix 4 for photos):

- **HK3** – Remnant forest or advanced secondary forest close to primary condition;
- **HK2** – Remnant forest but more disturbed than High Density Forest;
- **HK1** – Appears to be remnant forest but highly disturbed and recovering (may contain plantation/mixed garden);
- **BT** – Mostly young re-growth forest, but with occasional patches of older forest within the stratum;
- **BM** – Recently cleared areas, some woody re-growth and grass-like ground cover;
- **LT** – Very recently cleared land with mostly grass or crops, few woody plants.

A further analysis (summarised in Appendix 2) of the diameter of trees found across the different strata indicated a significant dominance of trees with smaller diameters (DBH less than 20 cm) in the lower carbon strata (BT, BM and LT). As expected, trees with larger diameters (DBH greater than 30 cm) dominated the higher carbon strata (HK1, 2 and 3).

In addition, the BT stratum has sporadic presence of trees of larger DBH, consistent with the observation that old scrub could be regenerating forest.

## 4.2 Discussion

The approach described and the study that was carried out are tailored specifically for a rapid assessment of vegetation to determine if there is a difference in the amount of carbon between strata and if they should be classified as HCS forest or not. Thus the methodology adopted is relatively simple, practical, quick and cost-effective while maintaining an overall technical robustness. It is not rigorous enough or technically sufficient to be used for carbon accounting and this was never the intention.

It is significant that three of the strata (HK1, BT and BM) are statistically distinct from each other and the other strata. The correlated carbon content of these different strata thus provides good information for HCS forest identification. It is also of interest that HK2 and HK3 are not statistically distinct from each other, most probably due to the small sample size, so it may be practical for future work to group these two strata into one. BM and LT are also not statistically distinct. Further study is required to ascertain the reasons for this.

However, with BM and LT clearly classified as low carbon, it allows these areas to potentially be converted into plantations.

With the BM stratum containing a high proportion of smaller stems of regenerating trees, it is possible that the decision to exclude stems less than 5 cm in diameter has meant the biomass and carbon could be considerably higher than currently assessed, to a point that it would exceed the upper tC/ha range of BM. It is possible that if the factors that caused the forest degradation ceased, BM could restore itself to forest with much higher carbon values and thus become HCS. Further study on this would be required to determine if this is a realistic scenario and how best to factor this potentially regenerated forest and carbon into the methodology.



To some degree, by setting the provisional threshold at 35 tC/ha there is a collective decision on needing to draw the line on what forest lands are substantially degraded and low carbon that they can effectively be considered non-forest (and therefore can be converted to other uses). This was necessary to be able to be pragmatic in the field and for on-going land management. Furthermore, in the HCS forest conservation process described below, viability and regeneration potential of areas are considered in the final boundary setting, connectivity and rationalisation of blocks for conservation. This will enable some of these areas with high regeneration potential and high ecological viability to be conserved through being part of or connected to larger blocks of HCS forest. The considerations for conserving these areas is discussed further in section 4.3.

There were also some challenges and lessons learnt in the socialisation process with the local communities in the study concessions. More time could have been spent to explain the objectives of the HCS forest study to the local communities.

While conducting fieldwork in the second and third concessions, it was observed that the communities were concerned about compensation for areas that would be marked for HCS forest conservation. The communities were also concerned about the impact of conserving HCS forests on their potential plasma holdings<sup>13</sup>. In the interest of maintaining good community relations, the fieldwork was suspended in these two concessions, reducing the number of plots that could be surveyed.

Learning from this experience, we developed and implemented a comprehensive socialisation programme before commencing fieldwork in the fourth and final concession, PT BAT. This included face to face meetings and using visual aids like posters to explain the objectives of the HCS forest study to the local people and community leaders. During this interactive process, we also obtained feedback from these communities on their attitudes towards HCS forests, how they must be involved in the conservation of HCS forests, how they view forests and how they would like to see them being managed. After this comprehensive and concerted socialisation, the fieldwork in PT BAT was conducted fully.

<sup>13</sup> Between 1978 and 2001, the Government of Indonesia and the World Bank provided policy support and financial support respectively, to nucleus-plasma (Perkebunan Inti Rakyat or PIR) supported grower schemes, in which plantation companies would develop oil palm plots for smallholders in a "plasma" area around their own plantations ("nucleus"). Management of plasma plots, generally 2 ha of oil palm plus 1 ha for other crops, would be transferred to individual smallholders after 3-4 years. The nucleus-plasma schemes were conceived as an integral part of the government's transmigration programme, where people from Java and other densely populated islands were resettled on less populated islands. In a typical scheme, holders of the plasma plots would be supported in the early years before the oil palms reached maturity, through employment and subsistence agriculture. The management of the plasma area would come officially under a cooperative of smallholders, which would generally contract technical functions back to the nucleus plantation company. Hence, plasma smallholders are often engaged as workers on their plots. They receive additional income through the guaranteed sale of fresh fruit bunches at a price set through a government formula. The plasma scheme evolved from the original PIR to KKPA (Koperasi Kredit Primer untuk Anggotanya) in 1986, to the current Revitalisation Programme (Pengembangan Perkebunan Melalui Program Revitalisasi) in 2006. In 2007, the government mandated that nucleus plantations have to set aside minimum 20% of the net cultivated area for plasma plantations.

### 4.2.1 Limitations of the study

As a learning and adaptive approach to our HCS forest study was taken, there were a number of limitations and biases in the study.

The small plot size used is more suited for highly disturbed sites (larger plot sizes should be used for more intact forests). The methodology did not account for all AGB (e.g. by excluding trees with DBH less than 5 cm, and AGB dead matter such as logs and branches) and below-ground biomass. This means that the total carbon stored in the area was underestimated and reinforces a conservative HCS threshold. The carbon estimates generated will thus not be directly applicable for full carbon accounting. We also did not undertake a full biological survey, so other important elements to consider for conservation, such as species and habitat diversity and habitat quality, were not directly taken into account.

As the study was limited to areas where permission was obtained from the local communities, this may have biased our results through not being able to complete a fully statistically valid sampling approach. The study was also limited to using satellite images that were taken up to two years earlier. Hence there could be subsequent disturbance resulting in changes to the vegetation canopy cover. The quality of the findings could have been improved by using more recent satellite images, but there were problems with their availability (especially cloud free images).

However, with medium-resolution satellite images, there is still a potential for human error being introduced in the course of their interpretation. It was found that while the boundaries between two very distinct strata could be differentiated and mapped, such as HK2 and LT, other strata such as HK1 and BT are more difficult to differentiate as the boundaries between these two strata are not distinct. The use of high-resolution satellite or aerial imagery along with semi-automated processing is expected to assist in addressing this limitation.

Likewise, the visual interpretation of satellite images of vegetation canopy cover cannot fully identify land use. Hence, an area mapped as HK1 may well be a timber plantation or mixed garden.

To achieve a scientifically robust method, stratification should be accompanied by extensive ground-truthing, which in turn can be used to refine the stratification process. Ground-truthing is also necessary to improve the demarcation of boundaries between the different strata for land use planning such as conservation and land preparation.

### 4.3 Conservation of HCS areas

Given the degraded nature of the concessions which are mainly ex-logging areas, we found patches of varying size and degree of isolation for the different strata throughout the concessions. Studies in tropical forests elsewhere in the world indicate that the size, shape, connectivity, and quality of these forest patches have a huge influence on their immediate to medium- or long-term viability to regenerate into an ecologically functioning natural forest.

To ensure that the conserved HCS forest areas can regenerate themselves, the following key principles were developed to guide the analysis and patch selection process and to provide on-going monitoring and management. The key principles are to:

- Maximise the overall size of a patch;
- Maximise the “core area” of a patch (area of forests relatively unaffected by “edge” effects);
- Maximise the degree of connectedness between patches and create corridors and linkages between patches.

Based on these principles, landscape level conservation planning tools can be developed to select the HCS forest areas, as well as to facilitate monitoring or research programmes within these areas.

Given the complexity of this issue, a research and monitoring programme needs to be initiated together with HCS forest conservation in order to develop a systematic and effective approach to identify which patches should be conserved versus those that have little conservation value and potentially may be developed.

In addition to the ecological viability considerations, broader social and management issues also need to be addressed to ensure long-term viability of the patches. These include:

- Determining the legal status of HCS conservation areas in the Indonesian context, as there could be threats of conversion of these conserved areas by other parties;
- Obtaining free, prior and informed consent from local communities to conserve HCS forests, bearing in mind that local communities’ support and involvement in forest conservation is vital;
- Managing the impact of the HCS conservation areas on oil palm plantation design and management;
- Using oil palm plantation design to support inter-rotation connectivity between patches of conserved HCS forests to facilitate movement of animals, if any.

As pointed out by Wilcove and Koh (2010), “a mixture of regulations and incentives targeted at all sectors of the oil palm industry will be necessary to protect the region’s rapidly disappearing forests” (pg 1006).

## 5 Conclusion and Recommendations

The findings of HCS forest study indicate that:

- Vegetation cover can be used broadly to estimate the level of carbon stocks;
- Vegetation cover can be stratified into different classes to broadly represent different carbon stocks;
- Across some of the different classes of vegetation cover there are significant differences in the carbon stock;
- HK2 and 3 are remnant forests, with some disturbance;
- HK1 is also remnant forest, but highly disturbed and has a larger number of smaller trees;
- BT appears to be largely regenerating forest, with occasional remnants of older forests;
- BM and LT appear to have been cleared recently and are re-growth.

The vegetation stratification indicates that:

- The setting of the provisional HCS threshold as more than 35 tC/ha would result in HK1, 2 and 3 as well as BT being classified as HCS and hence could be considered for conservation;
- BM and LT would be low carbon stock and considered as non-HCS, and could be developed, subject to the HCS forest conservation process (outlined above) and further research that considers the regeneration potential of BM.

The HCS forest methodology will facilitate GAR's commitment to ensure no deforestation footprint as outlined in the FCP. The HCS forest study findings indicate that there is a practical and robust method to identify HCS forest in GAR's concessions in Kalimantan. However, for the methodology to be used as a reliable predictive tool for HCS forests across Indonesia, further testing and fieldwork would be required.

Furthermore, the Team will be presenting the findings and holding wider discussions with representatives from the Government of Indonesia, civil society organisations, local and indigenous communities, key players and other stakeholders in the Indonesian palm oil industry, to gather feedback on the study and the outcomes.

More dialogue is also needed to focus on the ways to up-scale this HCS forest study mapping process to regional or national levels, as well as the options on how to conserve, manage and protect areas designated as HCS forests.

Upon gathering the required input and feedback from all stakeholders, GAR intends to develop its action plans for how it will proceed further with this methodology and will announce this in due course.

To be successful in HCS forest conservation, GAR cannot do this alone. It needs to engage with other stakeholders to find solutions to the existing challenges. GAR is focused on playing a leading role in developing a strong multi-stakeholder platform to find solutions to conserve the forests, create much needed employment and ensure long-term sustainable growth of the palm oil industry which is a vital part of the Indonesian economy.

## 5.1 Recommendations for future research

Further research needs to be conducted on the stratification methodology if it is to be used in other parts of Indonesia, considering that variations in strata characteristics in these areas that are likely to occur. More study is needed to determine if our methodology is applicable regionally or nationally. This would in particular be useful to determine if the strata BM and LT are distinct or if it is more practical to combine them to simplify the methodology along with combining HK2 and HK3.

Additionally, consideration should be given to updating the methodology to improve the accuracy and reliability of the outcomes including: allometric equations that include species-specific wood densities, carrying out test plots on the carbon stored in saplings less than 5 cm DBH, use of circular plots and distance measuring equipment (DME), or incorporating a Quality Control plan into the standard operating procedure for the methodology.

Given the approach to conduct the study within a limited time frame and resources, existing satellite images were used with its inherent limitations (outdated and of low to medium resolution). Hence future research and study could consider using other technology such as LiDAR<sup>14</sup> or high resolution imagery to provide better quality data. We would also recommend that additional Geographic Information System tools be incorporated into the methodology to allow a semi-automated classification procedure, as well as databases to provide more information on likely land uses, to improve the speed and consistency of mapping the six strata. As a starting point, we have developed an interpretation key to guide this process (see Appendix 3).

<sup>14</sup> LIDAR (Light Detection And Ranging) is an optical remote sensing technology that can measure distance by measuring the time it takes for a light, or more often pulses from a laser, to travel.

One of the key objectives of conserving HCS forest is that the conserved area can revert to its natural ecological function as a forest. While potential regeneration and increase in carbon stocks is inherent in the HCS forest study approach, we need to understand the conditions that are required for nature to take its full course and the impact on human and economic activities to allow this to happen. Further consideration of how this potential carbon is incorporated into the HCS forest study approach is needed.

Also given the legal challenges as well as incentives necessary to achieve HCS forest conservation, there is much to be done to find equitable solutions. We envisage that successful HCS forest conservation needs to involve the Government of Indonesia, civil society organisations, local and indigenous communities, key players and other stakeholders in the Indonesian palm oil industry.

These considerations should be explored further.

## Glossary

**Above ground biomass (AGB):** Biomass above the soil surface, e.g. trees and other vegetation.

**Allometry:** The morphological evolution of species, based on the relation between an organism's size and the size of any part of the organism, i.e. the change in proportion between size and shape as a consequence of growth.

**Allometric equation:** Scaling rule or equation that relates tree biomass, carbon or other similar properties to stem diameter and/or tree height.

**Biomass:** Organic material both above ground and below ground, both living and dead, e.g. trees, crops, grasses, tree litter, roots, etc.

**Carbon stock:** 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.

**Carbon sequestration:** The process of removing carbon from the atmosphere and depositing it in a reservoir. Carbon dioxide is naturally captured from the atmosphere through biological, chemical or physical processes. Some sequestration techniques exploit these natural processes while others use artificial processes.

**Diameter at breast height (DBH):** The standard method of expressing the diameter of the trunk or bole of a standing tree. Tree trunks are measured at the height of an adult's breast, which is defined differently in different countries and situations. In continental Europe, Australia, the UK, and Canada the diameter is measured at 1.3 metres above ground and in the US, New Zealand, Burma, India, Malaysia, and South Africa at 1.4 metres. In many cases the height makes little difference to the measured diameter.

**Landsat:** Satellite-based remote sensing technology for earth observation. Medium-resolution Landsat images are acquired from optical and multi-spectral sensors, which are highly capable of detecting forest and land cover changes. Due to their limitation to penetrate cloud and aerosols, cloud cover is the biggest problem that hinders monitoring in tropical areas.

**SPOT:** Système Pour l'Observation de la Terre (lit. "System for Earth Observation") a high-resolution, optical imaging earth observation satellite system operating from space. Medium-resolution Landsat images are acquired from optical and multi-spectral sensors, which are highly capable of detecting forest and land cover changes. Due to their limitation to penetrate cloud and aerosols, cloud cover is the biggest problem that hinders monitoring in tropical areas.

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# Appendix 1

## Process undertaken in stratification and analysis

### a) Unsupervised classification, post stratification (first fieldwork - PT KPC)

PT KPC was stratified into 16 strata through an unsupervised classification based on the quantile methodology using the Image Processing Software. This pre-stratified map was used to provide information on the diversity of land cover within the concession area. The 16 strata were ranked from dense vegetation to open land. We started with unsupervised classification to test if we could have an automated method, and thus reduce the potential for subjectivity.

After the fieldwork at PT KPC was completed, the data was verified to remove anomalous plots and the carbon content for the different strata was estimated from extrapolated plot data. The results showed a trend where the estimated carbon content decreases as the strata move from dense vegetation to open land, but there was low confidence in the estimates, with no statistical difference between strata.

By grouping the 16 strata into six strata (HK3, HK2, HK1, BT, BM and LT), based on similarity of canopy cover, we found some statistical difference between the strata.

### b) Unsupervised classification, grouping, post stratification (second and third fieldwork – conducted in PT PIP, PT PGM)

We used a similar unsupervised classification to generate the same 16 strata as PT KPC. However as we had a better understanding of how vegetation canopy cover correlated with each of the 16 strata, we then grouped the strata into the six strata listed above through visual interpretation for the maps of PT PIP and PT PGM.

We also ensured that we had more plots in the target strata and avoided measuring too many plots in the non-target strata.

#### **c) Visual Interpretation (fourth fieldwork - PT BAT)**

Prior to conducting the fieldwork at PT BAT, we investigated the strata by doing a fully manual visual interpretation to stratify the concessions, hence minimising the intra-strata variance. This led to the development of an interpretation key (see Appendix 5), using information from the Ministry of Forestry Decree (Peraturan Menteri Kehutanan) no. 33/2009 on Guidelines of Periodical Comprehensive Forest Inventory (IHMB) as the starting reference. More qualitative details were also added to describe the characteristics of the strata.

With this method of fully manual stratification, a SPOT 4 image of PT BAT from 2009 was stratified into the six strata. Following the field visit, we reviewed the classification, and adjusted strata boundaries to more accurately reflect conditions observed during the fieldwork.

#### **d) Final combined analysis**

With the creation of a method to stratify the concessions into six distinct strata through a fully manual visual interpretation, PT KPC, PT PGM and PT PIP were stratified again so that all the plots were classified into strata based on this method. The carbon content of each stratum was then estimated, assuming uniformity of carbon in the vegetation across all concessions. In other words, the carbon of each stratum was estimated using the average of all the plots from all the four concessions that belonged to the stratum.

It is important to emphasise that the results of the fieldwork (the plot data, i.e. the carbon calculated from the diameters of the trees) were retained. What changed is the process of stratification, which we have refined based on observations in the field and information and data collected from the fieldwork.

The carbon value of each stratum, therefore, is the aggregate of all the plots (assigned to each respective stratum using a fully manual visual interpretation).

#### **e) Future research**

In order to be able to use the stratification method as a predictive tool, it is important to conduct more fieldwork to test the validity of our method.

One option is to have fieldwork conducted independently of the stratification by two different teams, that is, to have a team conduct fieldwork at locations stratified by another independent team.

## Appendix 2

### Analysis of tree diameter across strata

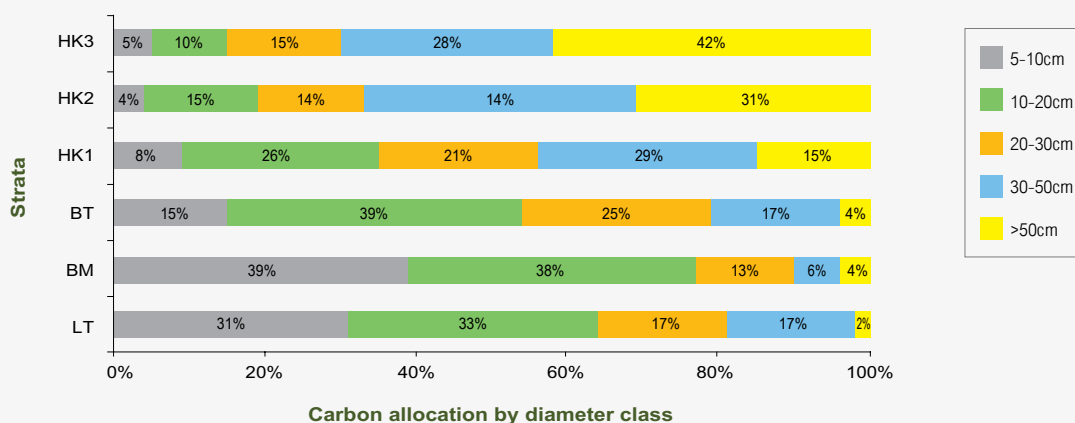
The confidence limits for HK3 and HK2 are very wide. This is likely the result of the few plots being located within these strata, and further compounded by the relatively small plot size, which is known to result in increased variance where more large trees are present (Brown 1992).

Similarly the variation found in BM and LT, as a proportion of the average, is higher than that found in other strata. The occurrences of more dense patches within these strata will have added to this variation. The classification of the concessions identifies patches with a minimum area of 10 ha, and because of this, areas mapped as being LT may in fact have sporadic larger trees that are located within patches less than 10 ha. Furthermore, regenerating areas are reported to have high levels of variation (Lawrence 2005).

Further analysis of the distribution of the carbon by diameter class indicates that in addition to different carbon stocks, there are differences in the structure of the strata, as seen in the graph below. For BM, the results indicate that most of carbon ( $\approx 76\%$ ) is in trees with a DBH less than 20 cm. A similar result was also found for BT, where on average, most of the carbon stock ( $\approx 55\%$ ) was found in trees with a DBH less than 20 cm. Given these findings, it appears that these areas are dominated by younger vegetation, rather than older, remnant vegetation. Notwithstanding this, elements of remnant forest can be found in BT, as seen in the presence of some very large trees (greater than 50 cm).

In contrast to BT and BM, HK1, 2 and 3 appear to be largely remnant forests, as seen in the larger number of trees with DBH of more than 50 cm. These strata also have a larger proportion of carbon in trees with a DBH more than 20 cm, compared to the other strata. However, there is still a high proportion of carbon found in trees of smaller diameter (less than 20 cm) in HK1. This suggests that while these areas have remnant vegetation, they have been highly disturbed with a loss of trees with larger diameters. Given the limited number of plots in HK3 and HK2, findings are considered potentially indicative.

From the figure below, there is a shift in the composition of the different strata, with progressively less carbon being stored in larger trees as we move from the heavily to less forested areas.



## Appendix 3

### Interpretation Key

We developed this classification to help our stratification, using information from the Ministry of Forestry Decree (*Peraturan Menteri Kehutanan*) no. 33/2009 on Guidelines of Periodical Comprehensive Forest Inventory (IHMB) as the starting reference. Qualitative details developed from working knowledge of forest areas in West and Central Kalimantan were also added. The predicted conditions, including estimated carbon values, are based on fieldwork findings.

			Identification/Detection of elements of image interpretation					Predicted condition				
	Cover/Land use	Code	Primary	Secondary	Tertiary	Expert		Description	Dominant diameter by volume (cm)	SPH $\phi > 50$ cm	Canopy (%)	Estimated carbon
			Colour-hue	Texture	Pattern	Situation	Association					(tC/ha)
1	High density forest	HK3	Green-dark	Coarse/dense	Irregular	Far from settlements	No road access	The area has experienced little human activity, is intact with many trees in the area with a DBH >50 cm. Old secondary forest.	>50	>35	>70	192±81
2	Medium density forest	HK2	Green-medium, dark	Coarse-moderate	Irregular	Far from settlements	No road access	The area has experienced human activity, although not severe. Trees with a DBH >50 cm are common.	35-50	25-50	40-70	166±51
3	Low density forest	HK1	Green-medium	Rough-rare	Irregular	Some distance from settlements	A little road access	The area has experienced much human activity largely for timber production, with an increased proportion in mid-range diameter trees compared to HK3 and HK2. Trees with a DBH >50 cm are rarely seen.	20-35	15-25	10-40	107±11
4	Old Scrub	BT	Green-medium, light	Rough-smooth	Irregular	Some distance from settlements, roads	A little road access	There has been substantial human activity in the area, including clearing areas for agriculture. This is expected to have occurred >10 years ago. Possibly occasional larger trees (DBH >50 cm).	10-20	-	<10	60±7
5	Young scrub	BM	Green-light	Smooth-being	Irregular	Near settlements, roads	Many access roads	There has been substantial human activity in the area, including clearing areas for agriculture. This is expected to have occurred <10 years ago. The area is dominated by small trees and scrub.	2-10	-	<10	27±6
6	Cleared/Open Land	LT	Red, green-bright	Smooth	Irregular	Near settlements, roads	Many access roads	Recently cleared areas, or areas used for agriculture. Dominated by grass, non-woody vegetation or seedlings.	<2	-	<10	17±6

## Appendix 4

Cleared/Open Land: LT



Young Scrub: BM





Old Scrub: BT



Low Density Forest: HK1



Medium Density Forest: HK2



High Density Forest: HK3



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