Testing the impact of RSPO HCV areas in retaining biodiversity and carbon stocks in the oil palm landscape: Initial results from the first phase of field sampling

A technical report by the SEnSOR programme

**Lead author:**
Dr Aritta Suwargo, Wageningen University

**Contributing authors:**
- Dr Peter J. van der Meer, Van Hall Larenstein University of Applied Sciences
- Nils Beaujon, Van Hall Larenstein University of Applied Sciences
- Dr Yeong Kok Loong, University of Sheffield
- Prof Yudi Firmanul Arifin, University Lambung Mankurat, Banjarbaru
- Dr Dony Rachmanadi, Banjarbaru Environment & Forestry Research Development Agency
- Prof Jane K. Hill, University of York
- Dr Glen Reynolds, South East Asia Rainforest Research Partnership
- Dr Jennifer M. Lucey, University of Oxford

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Executive summary
The RSPO Principles and Criteria address the conservation of biodiversity and habitats through the High Conservation Values Approach (https://www.hcvnetwork.org/). Accordingly, all RSPO-certified growers conduct HCV assessment prior to new plantings, and manage and monitor designated HCV areas to maintain or enhance the HCVs identified.

Ensuring that the HCV approach is effective usually requires that the forest area set aside is of sufficient quality to maintain the conservation values identified. This research aims to understand the impact of the HCV approach in retaining high-quality forest in oil palm plantations. In this phase of the project we measured biodiversity and above-ground carbon in the HCV areas of RSPO-certified oil palm plantations in Central Kalimantan, Indonesian Borneo. We established 36 field survey sites in three forest types typical of areas where oil palm is cultivated in the region: lowland dipterocarp forest, peat forest, and heath forest. We selected ants, trees and birds as indicators for biodiversity and ecosystem functioning, and measured living tree biomass to determine the above ground carbon stock, which is an indicator of forest structural quality as well as a direct ecosystem service. We combined these results with data from previous studies of HCV areas in Sabah, Malaysian Borneo. We also compared the data with continuous forest control sites of the same forest types, in order to examine the quality of HCV areas relative to unfragmented forest.

Carbon stocks and biodiversity levels were lower in HCV areas compared to continuous forest control sites. Carbon stocks did not differ significantly among HCV areas in the three different forest types, although there was a trend for higher carbon in lowland dipterocarp forest, as expected from the scientific literature. Carbon stocks in HCV areas were not significantly related to proximity to edges, or the amount of forest in the surrounding landscape. Some IUCN red-listed species of birds were identified in the HCV areas suggesting that HCV areas are potentially important refugia for threatened species in oil palm landscapes.

Carbon stocks are often used as an indicator of high quality forest and of biodiversity levels. We found that carbon stocks were positively related to bird and tree diversity when continuous forest sites were included in the analysis, indicating that carbon stocks and biodiversity respond in similar ways to disturbance and fragmentation. Within HCV areas alone, tree diversity was significantly correlated with carbon suggesting that carbon may be a useful indicator for some aspects of biodiversity in HCV areas. However, birds diversity was not closely related to carbon stocks within HCVs alone implying that other factors such as forest area, connectivity, human activity (e.g. poaching) and food resources may have more influence on birds than vegetation structure in HCV areas. Ant diversity was not found to be related to carbon stocks, but this may be due to the small sample size and coarse level of taxonomic identification in this preliminary study, which led to low levels of differentiation among sites.

Preliminary results indicate that HCV areas in RSPO-certified plantations have lower carbon stocks and biodiversity than the same area of continuous forest, regardless of forest type. Fire and other human disturbance (e.g. poaching and illegal felling) are major factors reducing both carbon stocks and biodiversity in HCV areas and there is substantial opportunity for management of HCV areas to improve forest quality and thus increase the impact of RSPO certification. Carbon stocks may be an indicator of some aspects of biodiversity, such as trees and possibly birds. In the next phase of research we will roll out these protocols to a wider range of HCV areas to capture more variation in forest quality, biodiversity and carbon stocks. This will allow us to understand the impact of the HCV approach, the factors that support high levels of carbon stocks and biodiversity in HCV areas, and to develop management recommendations.
Key terms

HCV- High Conservation Value- a specified conservation value identified within, or affected by the plantation operational area, as defined by the High Conservation Value Approach (www.hcnetwork.org)

HCV area- the area set aside in order to conserve the identified HCV(s). For the purposes of this study this is always a natural forest area.

Biomass- the total weight of organic matter in a given area.

Carbon stock- approximately half the amount of biomass

Ecosystem functioning- the biological and physical processes that occur in a “healthy” ecosystem, such as soil and nutrient cycling, seed dispersal, predator-prey interactions etc.

Ecosystem services- ecosystem processes that benefit people, such as carbon storage, pest control, water protection etc

Connectivity- the extent to which natural habitat is joined-up and located to facilitate the movement of species across the landscape.

Introduction

RSPO principle 5.2 requires that “the status of rare threatened or endangered species and other High Conservation Values, if any, that exist in plantations or that could be affected by plantation or mill management, shall be identified and operations managed to best ensure that they are maintained and/or enhanced”. Many HCVs that are identified in oil palm concessions in SE Asia rely on high-quality natural forest habitat to persist. These HCVs include high levels of biodiversity, rare threatened or endangered species or habitats, protection of soil and water, and some social HCVs. Biodiversity levels are an important indicator of good quality functioning forest, because different species perform different functional roles in the ecosystem. The more similar the biodiversity levels of HCV areas are to those found in continuous forest, the better quality the HCV areas are likely to be. Carbon stocks are a useful indicator of vegetation structural quality because most carbon is stored in tall, slow-growing tree species. Habitat complexity provided by the tree flora is closely linked to levels of animal biodiversity (Tews et al. 2004), and so carbon stocks are a good indicator of forest quality and ecosystem functioning, as well as being a direct ecosystem service in terms of reducing carbon emissions which lead to climate change. This study aims to measure the effectiveness of the HCV approach in retaining good quality forest by assessing the levels of biodiversity and carbon stocks within HCV areas.

Principle 5.6 states that “Plans to reduce pollution and emissions, including greenhouse gases, are developed, implemented and monitored”. Natural forest has potential to store large amounts of carbon (Asner et al. 2018), and thus reduce the net emissions of the management area, therefore forest contained in HCV areas has a key role in achieving this RSPO criterion. The ability of HCV forest areas to perform this role depends on these areas supporting large numbers of big trees. Fragmentation increases the vulnerability of forests to natural and human disturbances, which in turn reduce the carbon storage capacity of the forest (Laurance et al. 1997; Chaplin-Kramer et al. 2015), therefore it is especially important that fragmented HCV areas are managed carefully to maximise their carbon storage potential.
Previous work by the SEnSOR Programme investigated how the size of HCV areas affects carbon and biodiversity (van der Meer et al. 2016; Lucey et al. 2017; Scriven et al. 2017), and tested whether HCV areas were located in the landscape in a way that facilitates connectivity (Scriven et al. 2017). This previous work allowed us to test whether HCV areas were being identified and located appropriately in the landscape during the HCV assessment process. This new study builds on previous findings by field sampling biodiversity and carbon levels. This will allow us to test the impact of RSPO certification on the effectiveness of HCV areas to continue to retain forests that are important for conserving biodiversity, endangered species and ecosystem services. In future, these studies will also allow us to quantify the levels of disturbance experienced in HCV areas, and to provide recommendations for management that could improve the resilience of forest and associated High Conservation Values in oil palm landscapes.

In this phase of field sampling we focused on four HCV areas in RSPO-certified Wilmar International plantations in Central Kalimantan, which encompass three forest types that typically occur in SE Asia. We combined new data with data from previous studies in HCV areas in Sabah, and compared them to data sets from continuous forest sites. Here we present the initial findings from the study which will continue into the next phase of the SEnSOR programme in 2018.

Objectives:
1) Quantify the levels of biodiversity in HCV areas in three different forest types (lowland dipterocarp, peat, heath) compared with baseline information from continuous forest control sites;
2) Quantify the level of above ground carbon storage in HCV areas in three different forest types compared with continuous forest control sites;
3) Understand the level of congruence between biodiversity and carbon stocks in HCV areas to determine whether carbon stocks can be used as an indicator of biodiversity within HCV areas;
4) To determine the impact of RSPO certification in retaining high-quality natural forest areas in the oil palm landscape.

Methods
2.1. Study area

Field work was conducted in HCV areas of four Wilmar International RSPO certified estates in Sampit District, Central Kalimantan, Indonesia (see Figure 1, table 1). A total of 36 plots (yellow circles in figure 1) was established in HCV areas within three forest types: lowland dipterocarp forest, heath forest and peat forest. All HCV areas contained heavily disturbed secondary forest, with some parts severely damaged by fires during the 2015-2016 ENSO event.
Figure 1. (A) The Central Kalimantan study site with plot locations (yellow circles) (B) Map of Borneo showing Central Kalimantan study sites and locations of additional data sets used in the analysis (blue circles), overlaid on forest cover data from Gaveau et al. (2016).

Table 1: Information on study sites

<table>
<thead>
<tr>
<th>Estate name</th>
<th>Number of plots</th>
<th>Forest types</th>
</tr>
</thead>
<tbody>
<tr>
<td>PT Rimba Harapan Sakti 1</td>
<td>10</td>
<td>• lowland dipterocarp forest (6 plots),</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• heath forest (4 plots), (2 plots affected by fires 2015-2016)</td>
</tr>
<tr>
<td>PT Rimba Harapan Sakti 2</td>
<td>13</td>
<td>• peat swamp forest (9 plots),</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• lowland dipterocarp forest (2 plots),</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• heath forest (1 plots),</td>
</tr>
<tr>
<td>PT Sarana Titian Permata</td>
<td>10</td>
<td>• peat swamp forest (4 plots) (all plots affected by fires in 2015-2016)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• lowland dipterocarp forest (2),</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• heath forest (4), (2 plots affected by fire in 2016)</td>
</tr>
</tbody>
</table>
2.2. Plot design
The plots in this research were established in 2017 based on a transect system. Each transect contained plots that were located at least 100 meters from the edge of the HCV areas to avoid the influence of edge effects, such as wind effects (Laurance et al. 2002). The size of the main plots were 20 by 50 meters (0.1 hectare), and the distance between individual main plots was a minimum of 300 m. The main plots included sub-plots that were used to measure small trees, saplings and ant and bird biodiversity (figure 2):

Figure 2. Plot design. A) Main plot- trees with DBH ≥ 30 cm: 20x50 m B) subplot- trees with DBH ≥ 10 cm 2x10x20 m C) Saplings- trees with DBH between 2 – 10 cm: 2x5x5 m D) Ants- pit fall traps: 4x1x1m E) Bird survey point (unlimited radius)

Vegetation and carbon assessment
To determine above ground carbon stocks a tree inventory was undertaken (figure 3), in which trees within three size classes (large trees, small trees, saplings) were counted, identified to genus, or species where possible, and measured (figure 2). Biomass was calculated using wood densities from ICRAF and Dryland Global Wood Density database (Chave et al., 2014; ICRAF, 2017; Zanne et al., 2009). Carbon stocks were calculated by multiplying biomass estimates by 0.471. See appendix 1 for detailed methods.
Biodiversity assessment
Ants were sampled using unbaited pitfall traps and identified to genus (figure 4 a). Ants were chosen as an indicator of biodiversity because they have many different ecological functions, such as nutrient cycling, decomposition of organic matter, soil aeration, suppression of soil-borne disease and pests, and the direct and indirect alteration of soil properties (Folgarait, 1998). Birds were surveyed twice a day, in the morning and afternoon by recording visual and auditory observations at each plot (figure 4 b). Birds are also commonly used as biodiversity indicators, because they include many species listed on the IUCN red-list, and perform different functions within the forest. (For details of ant and bird surveys see Appendix 2). Trees were identified to genus during the tree inventory (see above and appendix 1 for details). Trees provide the physical habitat structure and their diversity in the forest will therefore have important effects on wider biodiversity levels.

Statistical analysis
To examine the quality of HCV areas, we compared the results of our field surveys with existing data from control sites in continuous forest (see appendix 3 for data sources). We also included data from
HCV areas in Wilmar estates in Sabah in these analyses, in order to increase our sample size (Lucey et al. 2014; Van der Meer et al. 2016, see figure 1 for locations of additional sampling sites).

Generalized linear mixed models (GLMMs) were performed to investigate fragmentation effects on carbon stocks. The first GLMM examined the effects of distance of plots from forest edge on above ground carbon stocks and the second examined the effects of the amount of forest within the landscape (within 10 km of plots) on carbon stocks. Above ground carbon stock (Mg/ha) was fitted as the dependent variable, distance from forest edge (m) or amount of forest within a radius of 10 km fitted as fixed factors, forest type (i.e. lowland dipterocarp, peat swamp and heath forests) was also fitted as a fixed factor. Site location as a random factor (to take account of any spatial autocorrelation of plots along transects). All GLMMs used ‘lmer’ function with ‘gaussian error distribution using the lme4 package for R3.3.1 (R Core Team, 2016). All variables were checked for homogeneity of variances and normality of residuals, and standardized where appropriate, before analysis (Faraway 2006; Grueber et al. 2011).

We looked for correlations between plot-level above ground carbon stocks and biodiversity (ant genus richness, tree genus richness and bird species richness; N = 36 plots) using Spearman’s rank correlation in R (R Core Team 2016).

Results

Levels of carbon stocks in HCVs
We measured a total of 1252 trees at the four HCV sites comprising lowland dipterocarp forest (3 plots), peat forest (23 plots) and heath forest (10 plots). We combined these data with data from five lowland dipterocarp forest HCV study sites in Sabah (13 plots) which were collected using the same protocol (van der Meer et al. 2016). Above ground carbon stocks of living trees in HCV areas ranged from 0 Mg C/ha (in several plots which had been severely affected by fire in 2015-2016) to 147 Mg C/ha at one lowland dipterocarp plot in Central Kalimantan. Most areas that were unaffected by fire contained carbon stocks of ~50-70Mg C/ha: higher than the time-averaged carbon stock of oil palm plantations (~36Mg C/ha, Lucey et al 2015) indicating that HCV areas do contribute to higher carbon stocks in the landscape compared with oil palm only. Overall, average carbon stocks per ha were lower in HCV areas than in continuous forest control sites of the same forest type (Figure 5), even when only plots that were not fire damaged were considered. This indicates that there is significant potential to improve levels of carbon stocks within HCV areas to maximise carbon storage and to improve the forest structure for supporting animal biodiversity.

Effect of forest type and fragmentation on Carbon stocks
We found no significant difference in carbon stocks among HCV areas of the three forest types, although lowland dipterocarp forest tended to contain higher levels overall (figure 5). Any differences in carbon among forest types are likely to have been confounded by the varying levels of disturbance caused by logging and fires, within the HCV areas. Carbon stocks of HCV areas were not related to the amount of forest within the landscape, or to the proximity of the plot to the edge of the HCV (figure 6), but again these findings are likely to be confounded by disturbance from fire and logging.
Figure 5. Average above ground carbon stocks in HCV areas of three forest types (lowland dipterocarp forest, heath forest, peat forest; including fire affected and unaffected sites), and indicative potential carbon stocks of these HCV sites after restoration/rehabilitation, based on measures from continuous forest sites (X symbols). Error bars: standard error around the mean.

Levels of Biodiversity in HCV areas
We recorded at total 1252 individuals of 53 tree genera, 430 individuals of 101 bird species and 1955 individuals of 23 ant genera across the four sites and 3 forest types.

Trees: The community of species present differed greatly among forest types, but average diversity was similar across the three forest types.
**Ants:** Ant genus richness was highest in the lowland dipterocarp forest. In several of the Central Kalimantan HCV areas, the ant community was dominated by *Anoplolepis gracilipes*, an invasive species common in oil palm plantations (Konopik et al. 2014), but usually absent from high quality undisturbed forest and its presence in HCVs is therefore indicative of highly degraded habitat (Mezger & Pfeiffer 2011).

**Birds:** Bird diversity tended to be highest in lowland dipterocarp forest, although the three IUCN red listed species recorded in the study (*Centropus rectunguis/ Chloropsis sonnerati / Setornis criniger*, listed as vulnerable; www.iucnredlist.org) were found in peat forest.

*Figure 7. IUCN red-listed bird species identified in the study from left to right: A) Centropus rectunguis, B) Chloropsis sonnerati, C) Setornis criniger*

We combined tree and ant data with data from lowland dipterocarp forest sites in Sabah (van der Meer et al. 2016; Lucey et al. 2017). There were no data available for birds in HCV areas from Sabah. For all forest types there were large reductions in biodiversity across all taxa sampled in HCV areas, compared to continuous forest control sites (figure 8).
Carbon stocks as an indicator of biodiversity

Carbon stocks were significantly correlated with the number of tree genera both within HCV areas (table 3), and when control sites were used in the analysis (table 3, figure 9A). Carbon stocks were significantly correlated with the number of bird species across the full suite of sites including control sites (figure 9B, table 3), but there was no relationship within HCV areas only (table 3). There was no relationship between the number of ant genera and carbon stocks (table 3, figure 9C).

Table 3. Summary statistics examining Spearman’s rank correlation between tree carbon and ant genera, tree genera and bird richness in Borneo. R = correlation coefficient, L = lower confidence bound, U = upper confidence bound. Values in bold signify significant correlation between the two variables (i.e. 95% CIs of correlation coefficient exclude zero).

<table>
<thead>
<tr>
<th>Variables</th>
<th>R</th>
<th>CI</th>
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<tr>
<td></td>
<td></td>
<td>L</td>
</tr>
<tr>
<td><strong>(A) Including control sites</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1) Spearman’s correlation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ant genera</td>
<td>0.24</td>
<td>0.00</td>
</tr>
<tr>
<td>Tree genera</td>
<td><strong>0.56</strong></td>
<td>0.35</td>
</tr>
<tr>
<td>Bird richness</td>
<td><strong>0.40</strong></td>
<td>0.05</td>
</tr>
<tr>
<td><strong>(B) Without control sites</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1) Spearman’s correlation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ant genera</td>
<td>-0.01</td>
<td>-0.32</td>
</tr>
<tr>
<td>Tree genera</td>
<td><strong>0.54</strong></td>
<td>0.30</td>
</tr>
<tr>
<td>Bird richness</td>
<td>0.14</td>
<td>-0.21</td>
</tr>
</tbody>
</table>

Figure 8. Comparison of biodiversity in HCV areas (Bars) compared with continuous forest control sites of the same forest type (X symbols). Average number of tree genera (A), average number of ant genera (B), average number of bird species (C).
Discussion

The initial findings from the first phase of field sampling indicate that HCV areas support lower biodiversity and carbon stocks than sites in continuous tracts of forest of the same forest type. There is wide variation in the natural forest types that comprise HCV areas on Borneo, indicating the need to design experiments carefully to account for this variation, and thus the variation in biodiversity and ecosystem services supported by lowland dipterocarp forest, heath forest and peat forest. However, we found that levels of disturbance were very high among the HCV areas we surveyed, and that this disturbance had more impact on biodiversity and carbon stocks than any differences among the three forest types.

HCV areas contained higher carbon stocks per hectare than the time-averaged carbon stocks of oil palm plantations (Lucey et al. 2015; Ziegler et al. 2012), except in HCV areas that had been badly burned and where above ground carbon stocks could be close to zero. However, overall, carbon
stocks in HCV areas were around half the amount found in continuous forest control sites. Even when burned areas were excluded from analysis, carbon stocks of HCV areas were substantially lower than control sites, indicating that there is significant scope to implement forest restoration to maximise the carbon storage and ecosystem service provision of HCV areas. We did not find a relationship between forest fragmentation (indicated by the amount of forest in the surrounding landscape) or distance to forest edge on carbon stocks (Paula et al. 2011; van der Meer et al. 2016; Chaplin-Kramer et al. 2015), however, these mechanisms are likely to be contributing to the reduced carbon stocks we observed in HCV areas compared to continuous forest control sites (Magnago et al. 2014; Melito et al. 2018). The sample size of HCVs sampled in our first fieldwork season was relatively small (36 plots from four estates), with disturbance from fire confounding any finer scale effects of fragmentation and edge effects.

We identified several IUCN red-listed bird species within HCV areas, indicating that these areas are providing potentially important refugia for endangered species within oil palm landscapes. Despite this, biodiversity was lower in HCV areas compared to continuous forest control sites, although the extent of the reduction differed among taxa and forest types. This suggests that the types of disturbance that can occur in HCV areas affect species differently and this will be important when HCV areas are managed for specific species or groups of species. Some of the HCV areas in Central Kalimantan were not completely isolated from larger tracts of forest, suggesting the potential for recolonization of species if the forest quality of HCV areas could be improved and other pressures such as poaching, felling and fires could be reduced.

Carbon stocks and forest quality (indicated by forest structure) have been shown to correlate with biodiversity levels in the SE Asian forest context (Lucey et al. 2017; Deere et al. 2017) and within fragmented landscapes globally (Magnago et al. 2014). We found broad relationships between carbon stocks and the diversity of birds and trees in our analysis supporting this theory, however, within HCV areas, variation in biodiversity and carbon stocks were only evident for tree species. A close relationship between carbon stocks and tree biodiversity is intuitive because tree species which store the highest amounts of carbon are large climax species with high wood density, and this group is often missing from areas which have been logged or heavily disturbed. The subset of remaining tree species tend to be fast-growing pioneer species with low wood density that are tolerant of disturbance, resulting in lower carbon stocks in these sites with lower tree diversity (Laurance et al. 1997). The lack of a relationship between bird diversity and carbon stocks could be due to the small sample size in our study, and further surveys will help to clarify this. It could also indicate that factors other than forest structure are important for bird diversity, such as forest connectivity, poaching, or availability of bird food resources (e.g. prey, fruit). We found no relationship between carbon stocks and ant diversity even though other studies have found that ants are sensitive to vegetation structure changes (e.g. Tawatao et al. 2014), and so this may be due to the coarse level of taxonomic identification and small sample sizes.

**Conclusion**

The initial survey results from the first sampling phase have provided important insights into the variation in forest types, carbon stocks and biodiversity in HCV areas on Borneo. These results indicate that HCV areas provide important refugia for biodiversity and ecosystem services to persist in RSPO-certified plantations. However, HCV areas are not currently functioning optimally to provide maximum benefits, due to high levels of past disturbance from which forest areas are recovering (fire and commercial logging), as well as ongoing disturbances (e.g. illegal felling, poaching). As we expand our field surveys in the next phase we will survey a wider variety of HCVs and quantify their biodiversity and forest quality in order to understand which factors cause the effectiveness of HCV
areas to decline, and how HCV areas may be managed better to maintain and enhance conservation values over the long term.

References


Appendix 1 Vegetation measurement
The vegetation measurement includes tree inventory that measures the three DBH, the tree height and the identification of tree species for each diameter class. General plot characteristics, such as the soil type (peat/non-peat), date, GPS coordinates and the name of the assessor, are recorded at each plot as the first step of the measurement process.

Biomass inventory

The biomass content of the forest was calculated to obtain above ground carbon stock. In this research, the above ground carbon stock was calculated based on standing biomass and dead tree biomass.

a. Measurement on standing trees and biomass

The measurement on standing trees and or biomass was conducted to obtain the data on trees’ DBH, height and species. These variables were measured according to widely used standards for forest inventories. The diameter at breast height (DBH) was measured at 1.30 m with a diameter tape. A tree was considered inside of the plot or sub-plot if at least half of the stem is located inside the plot boundary. Considering the difference on tree shapes, the DBH was measured followed the guideline presented in Figure 4.
The tree height of the tallest tree in each plot was measured with a clinometer. The height of this tallest tree was then used as the reference to estimate the height of remaining trees in the plot. The estimation of the trees height in this research was conducted by 2 – 4 experienced foresters.

The species identification, for the trees, in this research was conducted by involving local tree spotter and 2 experts from BP2LHK (Banjarbaru Environment & Forestry Research Development Institute) in Banjarbaru. The identification was conducted until species level, and if not possible to genus level, in local species name. Considering the difficulties in identifying some species or genus, some herbarium samples were also taken and analysed in the laboratory of BP2LHK in Banjarbaru. The scientific names of genera and species that were obtained in the field (using local name) were also checked in the laboratory by looking up lists of local and scientific names of species occurring in Kalimantan found in books and online sources (Argent, 1997; ICRAF, 2017a; Sidiyasa et al., 1990; Thomas, 2014).

b. Measurement on dead biomass

The measurement of dead biomass is important to support the calculation of aboveground biomass and carbon stock. In this research, the measurement on dead biomass was conducted for the coarse woody debris (dead trunks on the forest floor with a diameter ≥ 10 cm) and standing dead wood that died within one year. Similarly with the living trees, the dead wood with a DBH ≥ 30 cm was also sampled in the main plot and those with a DBH ≥ 10 cm was sampled in the sub-plots. A tree was excluded from the survey if it was standing outside the plot while still alive, prior to falling inside the plot. Wherever possible, the dead trees have been identified to genus level.

c. Biomass density and above ground biomass

The analysis on species density was then conducted in this research to obtain density value of the wood. This analysis was conducted by involving ICRAF and Dryland Global Wood Density database (Chave et al., 2014; ICRAF, 2017b; Zanne et al., 2009).
Following the wood density analysis, the calculation on the aboveground biomass was conducted by combining the values found for the wood density and the measured tree diameter and height in a location specific allometric equation. We used the allometric equation developed by Manuri et al (2014) that specifically captured dipterocarp species in Kalimantan. The calculation on the aboveground biomass in this research was conducted based on three species categories: dipterocarp trees, hardwood trees and softwood trees. The formulas used in this research for aboveground biomass calculation are presented as follows:

\[
\text{Dipt.} = 0.068 \times \text{DBH}^{1.662} \times \text{WD}^{0.352} \times \text{H}^{1.230} \quad \text{.........(1)}
\]

\[
\text{Non-dipt-hard} = 0.077 \times \text{DBH}^{1.871} \times \text{WD}^{0.669} \times \text{H}^{1.008} \quad \text{.........(2)}
\]

\[
\text{Non-dipt-soft} = 0.187 \times \text{DBH}^{2.190} \times \text{WD}^{0.474} \times \text{H}^{0.287} \quad \text{.........(3)}
\]

Where:
- DBH = Diameter at Breast Height (cm)
- WD = Wood Density (g/cm\(^3\))
- H = tree Height (m)
- Dipt = Dipterocarp
- Non-dipt-hard = Non-Dipterocarps hardwood
- Non-dipt-soft = Non-Dipterocarps softwood

The calculation on carbon content was conducted by multiplying the aboveground biomass with the average carbon percentage found for tropical angiosperm trees, in which 47.1% (Thomas & Martin, 2012), following the formula below:

\[
C_t = \text{AGB} \times 0.471 \quad \text{.........(4)}
\]

where:
- \(C_t\) = total carbon content (kg C)
- \(\text{AGB}\) = above ground biomass (kg)

The calculated biomass and carbon above were converted to megagrams per hectare (Mg/ha).

**Canopy cover measurement**

The canopy cover (%) was measured with the GLAMA (Gap Light Analysis Mobile App) canopy app for mobile phones. Five canopy photos were taken in three segments of the plot, resulting in an average canopy cover based on 15 photos per plot. The GLAMA app provided an easy way to get estimates in the field and allowed photos to be captured without the need of a hemispherical lens. The mobile phones were calibrated for the differences in pixel width. The location of the sampling points for the canopy photos within the plot is presented in Figure 5. The canopy cover is measured in each of the ordinal directions at three different points along the 50m baseline of the main plot (20x50m).
Appendix 2 Faunal biodiversity assessment

Ant sampling and identification

Ant sampling was included in this research to understand the diversity of ants in different forest types in HCV areas. Ants are an important group that has an influence on the vegetation structure and is an overall indicator of biodiversity. The ant samples were collected using passive traps (no bait) of plastic tubes (PVC) that were placed in the soil and filled with 15 ml of a 70% alcohol solution. The dimensions of the PVC tubes were 10 cm in height with a diameter of 1 inch. These pipes were glued together with PVC caps at the bottom side.
The traps were placed in dry soil with the soil tightly pressed to the rim. Iron wire was used to hold a plastic cup above the trap to function as rain cover, avoiding precipitation to enter the ant trap.

Five ant traps were placed in each of the four corners (1x1 m area) of the plot (in total 20 traps per plot). If the corners of the plot were not suitable for ant trap placement (for example flooded areas), the traps were then placed at the closest suitable location inside the plot. The plots were revisited after three days to check on the traps and any ants present inside the trap were collected for identification in the lab.

Ant identification was conducted in the laboratory of BP2LKH in Banjarbaru, following the guides and identification keys below:

Figure 5. Collection of ant samples
• Identification guide to the ant genera of Borneo – (Hashimoto, 2000)
• Key to the ant genera of Borneo – (Fayle & Hashimoto, 2010)
• A guide to the ants of Sabangau – (Schreven et al., 2014)
• Additional info from websites with extensive information on ant identification (AntWeb, 2017; Pfeiffer et al., 2017)

The ant identification was done by using DinoLite microscopes and DinoCapture 2.0 software to capture microscope pictures of the ants. An insect expert from BP2LHK Banjarbaru was the person in charge for the coordination of the ant protocol and identification prior to data analysis.

Figure 6. Ant identification with a DinoLite microscope.

Bird survey and identification

Bird surveys were carried out at point transects, in the centre of the vegetation plots. The survey was conducted twice a day, once in the morning (between sunrise and 10:30) and once in the afternoon (between 14:30 and sunset). Visual sightings and sounds were recorded during two 10 minute intervals at each point. The data recorded from this survey includes the species names and amount of individuals recognised. The scientific species names were then identified with help of birding books for Bornean bird species and assistance of skilled HCV staff from Wilmar (MacKinnon et al., 1993; Myers, 2016). The species names were checked with online databases (Avibase, 2006).

The bird survey in this research was conducted by involving a bird expert from BP2LKH Banjarbaru and resource persons from the estates with experience and knowledge on the birds species in this area.
Appendix 3- Continuous forest control site data sources

<table>
<thead>
<tr>
<th>Data type</th>
<th>Region</th>
<th>Site location</th>
<th>Forest type</th>
<th>GPS coordinates</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bird</td>
<td>Central Kalimantan</td>
<td>Block A NW (MRP)</td>
<td>Degraded peat forest</td>
<td>114.523056</td>
<td>As above</td>
</tr>
<tr>
<td>-----</td>
<td>-------------------</td>
<td>----------</td>
<td>------------------------</td>
<td>-------------</td>
<td>-----------</td>
</tr>
<tr>
<td>Carbon</td>
<td>South-East Asia</td>
<td>Multiple locations within Indonesia and Malaysia</td>
<td>Oil palm, peat forest, dipterocarp forest</td>
<td>no specific coordinates</td>
<td>Agus, F et al. (2013). Historical CO2 emissions from land use and land use change from the oil palm industry in Indonesia, Malaysia and Papua New Guinea. <em>Roundtable on Sustainable Palm Oil, Kuala Lumpur</em>.</td>
</tr>
<tr>
<td>carbon</td>
<td>Sabah</td>
<td>Malua forest reserve</td>
<td>Lowland dipterocarp</td>
<td>117.666567</td>
<td>5.095300</td>
</tr>
</tbody>
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