KEY DRIVERS OF DEFORESTATION IN PEHANG PENINSULAR MALAYSIA: A THREAT TO CLIMATE CHANGE

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Abstract

Increasing human population and the growing economy is often associated with various environmental disturbances which have been altering the natural earth ecosystem. The need for more spaces for numerous land development activities has made the existing forests suffer deforestations. The aim of the research is to ascertain the drivers of deforestation and to stabilize the GHG concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate. Pahang currently has only about 1,562,902 ha of forests, which cover the inland forest, peat swamp forest and mangrove forest. These forests have declined in terms of forest cover between 2002 and 2010 due to conversion of forests to other land uses. Identifying drivers of deforestation as a major cause of carbon emission into the atmosphere as carbon dioxide (CO\(_2\)) is crucial to combat climate change issue, maneuvers future development and sustainable environment. Pahang, which is the largest state in Peninsular Malaysia has the largest forest cover and was selected as the study area. The period of the research was between 1990 and 2010, where variations of drivers of deforestation were quantified spatially and temporal. In this study, Landsat-TM and SPOT-5 satellite images between years 1990 and 2010, with 5-year interval, land use map and ground truthing were used to estimate forest cover and forest cover changes. The images from the satellite and the information on land use map were assessed to determine the rate of deforestation based on permanent land use changes that occurred within the periods. Magnitude of land use changes has been quantified and drivers of deforestation were identified indicating commercial agricultural such as palm oil plantation and rubber plantation was the main proximate drivers for the deforestation in Pahang.

Keywords: Deforestation, landsat, landuse, Forest, Drivers

Introduction

Forest play an important role as a substantial coastal carbon sink. It is interesting to note that plant biomass in the ocean and coastal areas comprises only 0.05% of the total plant biomass on land, it cycles a comparable amount of carbon each year. A recent study revealed that mangroves have higher levels of primary productivity than most other forests.
Their standing biomass is considered high as such mangroves are among the most carbon-rich forests in the tropics. It was reported that a hectare of mangrove forest stores up to four times more carbon (C) than most other tropical forests around the world (Daniel et al., 2011). Daniel et al. (2011) also found that the C storage of dense mangrove has a typical mean of 1,023 t C ha-1, which is exceptionally high compared to the mean C storage values of the world’s major forest domains. Above-ground C pools were sizeable (mean 159 t C ha-1, maximum 435 t C ha-1), but below-ground storage in soils dominated, accounting for about 50–98% of total storages. Forests account for a large percentage of carbon fixing of about 80% of global plant carbon and 40% of the soil carbon (Dixon, 1994). Carbon sequestration results from the difference between photosynthetic carbon fixation and ecosystem respiration in the forest ecosystem (Gong et al. 2012) and overall it results in the determination of the net ecosystem carbon exchange (Valentini et al., 2000). Total carbon deposits per square kilometer in the coastal systems may be up to five times the carbon stored in tropical forests, due to their ability to absorb or sequester carbon at rates up to 50 times those of the same area of tropical forest. CO₂ stored in these ecosystems is found not only in the plants, but in layer upon layer of soil underneath (IUCN 2011). Hence, mangroves may have an important role to play in global carbon budgets and in mitigating climate change.

Malaysia is now committed to the programme of Reducing Emissions from Deforestation and Degradation, and forest conservation (REDD+) under the United Nations Framework Convention on Climate Change (UNFCCC). The main aim of the programme is to stabilize the GHG concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Forest Research Institute Malaysia (FRIM) in collaboration with Pahang State Forestry Department is currently engaged in a research project hosted by International Timber Trade Organization (ITTO) to address the issues related to the deforestation and forest degradation. Through this project, the drivers of deforestation and forest degradation are identified.

Remote sensing has been recognized as one of the primary spatial inputs for this process (Angelsen et al., 2009; Goetz et al., 2009). Multi temporal optical remote sensing system has been used for identifying landuse change since the last few decades. The system offers specific advantages, challenges and limitations for producing reliable estimate at a given scale (Lu 2006). Given the current gap in knowledge and understanding of drivers at national level, the research presented in this documents aims at providing methodology for identifying drivers of deforestation by using multi temporal satellite images and developing reference level for emission (RL). While national data on drivers have commonly not been available in the past, these researches have generated new information provided for countries in-line with the REDD+ requirements. The study was conducted in Pahang, Peninsular Malaysia. The period covered was between 1990 and 2010, where variations of drivers of deforestation were quantified spatially and temporally. Benefits from the study not only help the country to reduce carbon emissions but potentially gain credits from carbon stocks from the current REDD+ initiative. It is also to ensure that activities under the REDD+ will be able to provide advantages to the communities as well as government.

**Study area**
Pahang is the largest state in Peninsular Malaysia with a total area of 36,137 km² and is situated in the eastern coastal region. The state is bordering Kelantan in the North, to the West by Perak, Selangor, Negeri Sembila, to the South by Johor and to the east by Terengganu and the South China Sea. This study was conducted in the Pahang of 1,562,902 ha of forest cover at a latitude of (-----) and longitude (---------).

**Forests in Pahang**

A forest must have at least with 30% crown cover, with the minimum area spanning 0.5 ha and the minimum stands height of 5 m at maturity (NRE??). Despite the forest being a crucial component in the global carbon cycle and having potentially profound influence on climate change, the areal extent of forests has declined significantly as a result of coastal development, aquaculture expansion and over-harvesting. Pahang, which is the largest state in Peninsular Malaysia was selected as the study area. Despite the largest state, currently Pahang has only about 1,562,902 ha of permanent forest. Other forests area involve; (1) The Inland forest which has a landmass of about 1,395,613 ha and it cover all types of dry inland forests which are lowland, hill and upper hill dipterocarp, and montane. It covers entire extent of Inland forest, regardless land status (Protection/Production/STATeland/alianted and logging history) (Table 1.1). (2) The Peat swamp forest which fall under the Permanent Reserve Forest, State land forest and production forest which regardless the logging history with a landmass of 140,830 ha. It also includes alienated lands i.e. forested areas that owned by individuals and private alliances under this category (Table 1.1). (3) The 9,000 ha of mangrove forest regardless status and logging history. It includes protection, production, state land and alienated lands under this category. Out of which about 2,416 ha is under reserve. Despite a small extent of mangrove forest, it is also inevitable from being threatened by these landuse activities. (4) The Permanent Reserve Forest Permanent Reserve Forest is designated for protection purposes such as Virgin Jungle Reserve (VJR), land protection areas, water catchments, flood control areas, wildlife protection, education, research and amenity forests. It cover an area of about 24,043 ha (Table 1.1). A summary of total area covered by each forest type is depicted in Table 2.2 while the forest types in Pahang is show in figure 1.2.

<table>
<thead>
<tr>
<th>State</th>
<th>Inland Forest (ha)</th>
<th>Peat Swamp Forest (ha)</th>
<th>Mangrove Forest (ha)</th>
<th>Forest Plantation (ha)</th>
<th>Total Area (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pahang</td>
<td>1,395,613</td>
<td>140,830</td>
<td>2,416</td>
<td>24,043</td>
<td>1,562,902</td>
</tr>
<tr>
<td></td>
<td>1,506,443</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Production</td>
<td>714,182 (45.4%)</td>
<td>Protection</td>
<td>822,261 (54.6%)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1.1 Permanent Reserved Forest (Pahang) - 2012
Table 1.2 Total Land Cover by Each Forest Type in Pahang

<table>
<thead>
<tr>
<th>Category</th>
<th>Area (ha)</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inland forest</td>
<td>2,070,495.24</td>
<td>90.6</td>
</tr>
<tr>
<td>Peatswamp forest</td>
<td>206,832.65</td>
<td>9</td>
</tr>
<tr>
<td>Mangrove forest</td>
<td>9,039.26</td>
<td>0.4</td>
</tr>
<tr>
<td>Permanent reserve Forest</td>
<td>1,562,902.20</td>
<td>68.4</td>
</tr>
<tr>
<td>State Parks and National Parks</td>
<td>399,740.00</td>
<td>11.1</td>
</tr>
<tr>
<td>Non forest</td>
<td>1,310,132.85</td>
<td></td>
</tr>
</tbody>
</table>
Land use

Land use can be defined as a total of all arrangements of human activities such as agriculture, forestry and building construction that alter land surface processes including biogeochemistry, hydrology and biodiversity. Meanwhile land cover refers to the physical and biological cover over the surface of land, including water, vegetation, bare soil, and/or artificial structures (Ellis, 2010). Land use and land cover information are important for several planning and management activities concerned with the surface of the earth (Lillesand & Kiefer 1994). There is a fact that humans and natures are connected and have an effect upon each other. The unlimited and unplanned development could contribute high impact on
the nature geological changes. For example increment of deforestation is mainly due to the high demand in the agricultural sector in concurrent with rising standards of living and economy to meet the needs of daily life. According to Lambin & Geist (2006) forest area has reduced from 30% to 50% globally due to human activities. Environmental impact of land cover loss due to rapid development in Malaysia has raised great concerns especially towards the quality of natural forest.

**Land Use Category**

In spite the six land use category by IPCC 2006, Malaysia land use classes has been categorized into ten different category namely; Forest area, oil palm plantation, rubber plantation, urban area, agriculture area, water body, mine and quarry, idle grassland, animal husbandry areas and cleared land (Fig 2.1). The forest area is land under natural or planted stands of trees of at least 5 meters in situ, whether productive or not. Whereas the large piece of forest land in Pahang have been intentionally converted to oil palm and rubber for widespread commercial sale. Furthermore, the forest area has been replaced by urban area in terms of development, high density of human structures such as houses, commercial buildings, roads, bridges, and railways. Likewise, agricultural land is the share of the forests area that is converted to arable, under permanent crops, and under permanent pastures. This arable land includes land defined by the FAO (2006) as land under temporary crops (double-cropped areas are counted once), temporary meadows for mowing or for pasture, land under market or kitchen gardens, and land temporarily fallow. The significant accumulation of water, generally on a planet’s surface form the water body areas as this has occurred in Pahang forest. The Pahang forest area are also converted to quarry and mine sites from which dimension stone, rock, construction aggregate, riprap, sand, gravel, or slate are been excavated from the ground. This activity result to open-pit mine from which minerals are extracted. Certain area of the forest are left idle that is they are not cut, burned, cropped, heavily grazed, cultivated, or otherwise disturbed. Other part of the forest are converted for the management and care of farm animals by humans for profit and likewise the forest are clear by removal of a forest or stand of trees where the land is thereafter converted to a non-forest use (Fig 2.1).
Activity Data
The activities involved in determination of deforestation drivers are the assessment of forest cover, forest cover change and land use change analysis (Fig 2.2). Forest cover was carried out to ascertain the present status of forest cover areas and likewise cover changes was determine to estimate the rate of changes that occurred resulted from deforestation. Furthermore, land use change analysis was conducted to establish the various deforestation drivers in order to develop reference level of emissions.

Methodology for Determination of Deforestation and Drivers of deforestation

Satellite Images Method
Pahang is the largest state in Peninsular Malaysia, which covers areal extents of about 35,965 km², was selected as the study area. It also consists of all major forest types found in Malaysia, which are i) inland dipterocarp, ii) peat swamp, and iii) mangrove forests. Two types of satellite data which is Landsat-TM and SPOT-5 satellites images that were acquired in years 1990, 1995, 2000, 2005, and 2010 were used for forest cover change analysis (Fig 2.4). These images were the major inputs for mapping of forest cover and identification of changes over time. Landsat data over the year 1990 – 2005 were downloaded from US Geological Survey National Center for Earth Resources Observation and Science via the GLOVIS data portal (http://glovis.usgs.gov/) with relatively cloud cover less than 30%. At least four individual scene of Landsat images are required to cover the entire Pahang for a year and the path/row numbers for the scenes are 126/057, 126/058, 127/057, and 127/058. Therefore, 20 were acquired to complete the years of 1990 – 2005, whereas for year 2010, SPOT-5 satellite images was used.
The digital landuse map and topographic maps was used to estimate the changes in forests cover area between 2000 and 2010. This was follow by verification using ground truthing.

### Deforestation and Forest Cover Changes in Pahang

Deforestation refer to as human induced permanent conversion of forest land to non-forest, as all of the forest is cut and the land is cleared and used for another purpose. Temporary change in land use, like one rotation tree crop (up to 25 years) within forest reserves are not considered as deforestation (NRE??). Pahang total land area has being estimated to be about 3.6 million ha with an overall forest cover stood at 2.5 million ha in the year 2000 (Fig 2.4). There were great changes in forests area in Pahang between 2000 and 2010 (Table 2.1), as the forests were replaced with various land uses.

### Table 2.1 Forest Change in Pahang

<table>
<thead>
<tr>
<th>Forest changes (2000-2002)</th>
<th>Oil palm</th>
<th>Rubber</th>
<th>Urban area</th>
<th>Agriculture</th>
<th>Water Body</th>
<th>Mine &amp; quarry</th>
<th>Animal Husbandry</th>
<th>Cleared Land</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest changes (2000-2002)</td>
<td>23870</td>
<td>1292</td>
<td>3015</td>
<td>4102</td>
<td>818</td>
<td>670</td>
<td>5467</td>
<td>5</td>
</tr>
<tr>
<td>Forest changes (2000-2002)</td>
<td>42118</td>
<td>20287</td>
<td>5455</td>
<td>11674</td>
<td>586</td>
<td>1811</td>
<td>10574</td>
<td>531</td>
</tr>
<tr>
<td>Forest changes (2000-2002)</td>
<td>2069</td>
<td>182</td>
<td>12723</td>
<td>4101</td>
<td>644</td>
<td>5824</td>
<td>2290</td>
<td>172</td>
</tr>
<tr>
<td>Total</td>
<td>8069</td>
<td>2143</td>
<td>32481</td>
<td>23196</td>
<td>25701</td>
<td>2512</td>
<td>8843</td>
<td>0</td>
</tr>
</tbody>
</table>
Forest Cover and Forest Cover Change Using Satellite Images

Figure 2.5 images were obtained from Remote Sensing Agency Malaysia. SPOT-5 satellite data were also obtained with relatively cloud cover of less than 30% (Fig 2.6). A total of 24 scenes were used with the path/row members of 268/341, 269/341, 269/342, 269/343, 270/341, 270/342, 270/343, 270/344, 271/341, 271/342, 271/343, 271/344, 272/341, 272/342, 272/343, 272/344, 272/345, 273/342, 273/343, 273/344, 273/345, 274/343, and 274/345.

The methodology was based on two main approaches; (i) images classification for landuse and (ii) post-classification changes detection. Images for each year were classified to determine landuse classes that have been existed in the study area. Forest cover was definitely the single class that was extracted first from the classification (Fig 2.7). Other landuses such as agriculture crops, urban areas, water bodies, and open lands were also classified. The classification accuracy was done by cross-checking with landuse maps that were obtained from the Department of Agriculture. The classification results were then converted to vector format (.shp) to perform post-classification change detection. Changes have been determined from this process for each pairing interval of 1990-1995, 1995-2000, 2000-2005, and 2005-2010. Rate of deforestation as well as drivers that caused the forest changes were identified and quantified within each interval. Furthermore, the location of the changes occurred were also mapped spatially.

Figure 4  Landsat Images
Forest Cover and Forest Cover Change using Land Use Map

The land use map indicated changes in forest cover area between 2000 and 2010 due to various land use activity (Fig 2.8) and the rate of deforestation was indicated using the land use map to occurred between 2000 and 2010 (Fig 2.9). The composition of land use categories involved oil palm plantation, rubber plantation, urban area, agriculture area, water body, mine and quarry, idle grassland, animal husbandry areas and cleared land (Fig 2.10). The changes in land use in Pahang using land use map show a clear trend of deforestation from 2000 to 2010 (Fig 2.10 & appendix 1).

The land use map showed a decline in forest cover between 2000 and 2004 and sharply decline from 2004 to 2010. The forest covers depict a clear change between the year 2000 and 2002 as land use was responsible for the changes (Fig 11). Land use such as oil palm and rubber plantation were found to occurred in over 12644 and 10720 ha of the land cover (Fig 2.11) subsequently follow by agricultural activity, idle grassland, clear land, urban area (Fig 2.11). Between the periods of 2002 to 2004 there were few changes as oil palm increases to about 23870 ha while rubber deceased by 1292 ha with changes in other land uses (Fig 2.12). Based on FAO 2006 statistics which was similar to the land use map analysis, it was been estimated that the land use rate in Pahang for the period 2004 to 2008 has increased and the changes involve the increases in oil palm, rubber, agricultural activity, land clearing, urban area and mining and quarry activity with the rapid changes recorded in land clearing (Fig 2.13). Between 2008 and 2010 total oil palm and rubber cover is estimated to have stood at 17212 and 7361 ha higher compare to previous years (Fig 2.14). There was slightly increased in urban area, agriculture while animals husbandry and mining activities reduces (Fig 2.14).

Cumulative forest changes resulted from drivers of deforestation recorded between 2002 to
2010 (Fig 15), with a total cumulative recorded between 2000 to 2010 indicated high increase in oil palm, rubber plantation, land clearing, agricultural activity, urban area and subsequently follow by idle grass land, mine and quarry, water body and animal husbandry (Fig 2.16).

Figure 7 Forest cover changes from Land Use Map
Results
The studies showed that commercial agricultural such as palm oil plantation and rubber plantation was the main proximate drivers for the deforestation in Pahang (Fig 22). The drivers of deforestation were found to spread across various locations in Pahang area with each area indicating changes in land cover (Fig 2.23). It was demonstrated that the integration of multi temporal datasets from Landsat-TM and SPOT-5 satellite images with landuse maps was capable in identifying direct drivers of deforestation. The study suggests more detailed changes analysis should be carried out to define the drivers accurately. Integration of satellite imagery with a comprehensive ground truth information will be able to improve the accuracy. Nevertheless, the findings of this study will be an important indicator in assessing forest status in the country. It is also essential in providing activity data for carbon emission studies to make the REDD+ a reality. Although agricultural expansion has been determined as the key driver of deforestation in the tropics, the drivers are actually vary regionally and change over time.

Figure Summary of Deforestation Drivers in Pahang
Verification of Drivers of Deforestation using Ground Truthing

Ground truth set of measurements is known to be much more accurate than measurements from the system a testing is conducted. Without groundtruthing verification, our data from space is hypothetical at best. The Ground truthing was carried out to gather data in the field to complements or disputes airborne remote sensing data collected by aerial photography, satellite images and land use maps. The team of ground truthing FIRM scientists collected detailed calibrations, measurements, observations, and samples of predetermined sites (Fig 2.24). From this data, FIRM was able to identify land use from forest cover of Pahang (Fig 2.25) and it was compare to the satellite images and land use map. Subsequently data were verify and updated with the corresponding data from both satellite images and land use maps.

![Figure 18 Ground trothing sampling points using the GPS](image)

Definitions

**Carbon pools** is a system with capacity to accumulate or release carbon in mass unit, tonnes C (ref here). This involved (1) above ground biomass (sapling and understory), (2)
dead wood (standing and lying), (3) litter, soil (soil organic matter 30 cm depth) and (5) below ground living.

**Forest Stratification** simply refers to the different layers of plants in a forest. In a mature forest, one can typically see several distinct layers of vegetation rising from the forest floor to the tree canopy. Young forests may not show clear separations between layers. It is only as forests age and trees grow to create a tall canopy that layering becomes most visible.

**Forest Stratification**

Land classes are seldom homogenous with respect to forest carbon stocks because forest carbon stocks will vary by forest type and ecological regions. This depend on physical factors such as soil type, vegetation type, precipitation, elevation, slope and aspect, drainage, disturbance history, rural population density, distance to transportation networks or settlements, distance to deforested land or forest edge, and other factors. Based on this, the associating a given area of deforestation or degradation with a specific carbon stock that is relevant to the location where deforestation or degradation will most likely occur will result in more accurate and precise estimates of carbon.

Structurally, the tropical rain forest is considered to have five strata; three tree layers, a layer of shrubs and a ground layer of herbaceous plants. This contrasts with most temperate forests where, at most, three strata are recognised; tree, shrub and ground. The uppermost layer of very tall trees (overstory), in the Pahang tropical rain forest is often discontinuous and the individual trees are referred to as emergent. The Pahang overstory is filled by leaves deployed from large mature trees. During the growing season, canopy leaves intercept much of the sunlight available to a forest. This overstory might be taken to imply that the 'emergents' grow through and above the canopy formed by the second tree layer; but studies indicate that many of them are light-demanding species which establish themselves early in a forest’s history, grow rapidly, and initially form a continuous layer. As the lower forest layers close up, the forest floor becomes more shaded, many emergents cease to regenerate, and in time the highest tree stratums becomes discontinuous as old emergents die and are replaced only sporadically in canopy gaps. The understory layer in Pahang forest which are just beneath the canopy and above the shrub layer, the sapling can claim enough nutrients and sunlight to reach the understory. So many saplings slow their growth and wait in the Understory until a mature canopy tree dies. The lower lying layer of vegetation is typically between 3' and 7' from the ground surface. Mostly bushy shrubs occupy this position in the forest. Furthermore, the forest in Pahang was stratified on the basis of protection forest of 21-30, 11-20, 1-10 years logged forest, greater than 30 years, state land and protection PRF.

**Stratification for Carbon Pool Assessment**

It might be convenient to stratify the forest to make carbon stock estimation easier and more efficient. Hence, if data is available, a carbon map that stratifies the forest into carbon classes (i.e., forest sub-divided into classes such as carbon density). ASEAN (2013) describes the two approaches for stratifying forests as follows: Approach A which requires wall-to-wall mapping, and Approach B which does not require Wall-to-Wall mapping but stratify forests only hot-spot areas. In Approach A, once the forest is stratified based on carbon (i.e., a carbon map is created showing different carbon densities), then the carbon
within each stratum is measured providing an estimate of the amount of carbon per unit area. This needs to be done only once, unless the forest itself undergoes substantial change. In Approach B, there is no need for wall-to-wall mapping before stratification. Only specific areas such as those areas that are currently ‘disturbed’ or most likely to be disturbed due to deforestation or degradation need to be looked at. Areas, such as those forests near roads (existing or planned), population centers (e.g., towns or villages that are most likely to increase in population), or development sites, are most likely to undergo change in the future; hence most likely to experience cover change. In Approach B, adjoining or neighboring cells (areas) can be used to represent the carbon density of the stratum.

**Carbon Stock Calculations**

Estimation of Carbon Stock using Allometric equations

One of the most significant carbon pool is above ground biomass. In fact, for most Asian member state (AMS), this is probably one carbon pool that must be included in the reference emission level (RL) setting. This must be ultimately or sometime after the commitment period (e.g., succeeding monitoring and verification), by using country-specific data. Allometric equations will be one of the ways that above ground biomass can be estimated. Countries will need to develop allometric equations possibly for different forest types. As allometric equations are being developed, AMS may also use regional allometric equations as described by Chave et al. (2005).

a. Aboveground biomass (AGB): Comprises all the living aboveground vegetation, including stems, branches, twigs and leaves. It is the most important pool of carbon of all types of forests. In this study, allometric equations from Kato et al. (1978) (Eq. 1) and Chave et al. (2005) (Eq. 2) were used to calculate AGB for Inland and Peat swamp forest respectively. Both equations have been calibrated based on trees sampled in lowland and hill forest in west Peninsular Malaysia. Wood densities were obtained from the Global wood density database (Chave et al., 2005). Both equations were used to compare the estimated AGB and thus to suggest the most appropriate allometric equation for the forests in Peninsular Malaysia. A default factor of 0.47 was used to convert the biomass into carbon.

\[
\frac{1}{H} = \frac{1}{(2.0* D)} + \frac{1}{61} \quad \text{Inland ABG, Kato et al. (1978)}
\]

\[
\begin{align*}
2 & = 0.9733 \\
M_s &= 0.0313*(D2 H) \\
1.070 & = Mb=0.136*M_s \\
0.794 & = 1/M_l=1/(0.124M_s)+1/125 \quad \text{Inland ABG, Chaves et al (2005)}
\end{align*}
\]

\[
\text{Biomass} = 0.65* \exp(-1.562+(2.148*\ln(D)+(0.207*\ln(D)^2)-(0.281*\ln(D)^3)) \quad (2)
\]

**Peak Swamp ABG Chaves et al (2005)**

\[
\text{Biomass} = 0.65* \exp (-1.239 + 1.98*\ln(D)+0.207*\ln(D)^2-0.0281*\ln(D)^2)
\]
D is the stem diameter at breast height; Ms, Mb, and Ml denote the dry mass of stem, branches and leaves respectively; Wt is the aboveground biomass of standing trees; ρ is the wood density.

b  Biomass of each tree was calculated by using allometric equation that was developed by Komiyama et al. (2007) for common species in the mangroves of Peninsular Malaysia. The allometry can be expressed as

\[ W_t = 0.251 \rho D^{2.46} \]  \hspace{2cm} (3)

\[ W_r = 0.199 \rho^{0.899} D^{2.22} \]  \hspace{2cm} (4)

where  \( W_t \) is the dry weight of aboveground component and  \( W_r \) is the root biomass, which can be referred to as belowground biomass. \( \rho \) and D is wood density and diameter at breast height (dbh), respectively. The calculated biomass was converted into C by using a constant factor of 0.47.

c  Belowground biomass (BGB): Comprises the living coarse and fine roots of trees. The BGB are an important part of total forest biomass after AGB, representing 25% of the total biomass. Equations 3 and 4 from Niiyama et al (2010) Mokany et al. (2006) were used to estimate the BGB in this study.

A combined size parameter (dbhH) was used for the allometry of above-ground woody parts (Msb; stem plus branch mass), and Msbw was used for the allometry of leaf mass (Ml), as follows:

\[ 1M = 1a \text{dbh} + 1H_{\text{max}} \]  \hspace{2cm} (5)

\[ \text{Msb} = \text{adbhH} \]  \hspace{2cm} (6)

\[ 1M1 = 1a \text{Msbb} + 1H_{\text{max}} \]  \hspace{2cm} (7)
In these equations, $H_{\text{max}}$ in Eq. (5) and $M_{l\text{max}}$ in Eq. (6) indicate asymptotic values (or upper limits) of tree height and leaf mass, respectively.

c. Deadwood: Coarse woody debris (CDW) involves large pieces of standing and lying dead wood. Depending on the forest type, stage of succession, land use history and management practices, CDW can be a significant contributor to the total AGB.

Calculation of carbon for this category is based on the equation 7.

\[
\text{Carbon stock} = (\text{Volume} \times \text{wood density}) \times 0.47 \quad (7)
\]

d. Understory and litter: the oven-dry mass per area of this category was obtained from the samples that have been collected in the field. The carbon stock calculation was based on the following equations:

\[
\text{Carbon} = \text{Dry mass} \times 0.4 \quad \text{(IPCC default for understory vegetation and litter)}
\]

e. Soils: Samples were oven-dry at a constant temperature of 115°C for about 24 hours and the dry mass was used to obtain the bulk density. Samples were then analyzed at the soil laboratory for OC by using combustion method, after pre-treatment to remove carbonate. Soil OC (%) was then multiplied by soil bulk density and soil depth to obtain total soil carbon stock per unit area.

**Result and Discussion for carbon Pool in Inland Forest**

Results indicated that the biggest portion of biomass carbon is in the living trees, which comprised about 79% of the total carbon pools in the forest. It was followed by belowground living biomass carbon, which consisted of about 19%. Deadwood and litter share the same percentage, which is about 1%. Understory vegetation and soil organic carbon contributes less than 1% (Appendix 2). The analysis found the organic carbon stored in the soil consisted only about 1% of the total mass, for all soil types that were collected in the field. It means that for every 1 kg of dry soil, 10 g is carbon. It was estimated that soil organic carbon in the study area ranged from 32 to 49 kg ha-1 with an average of 42 kg ha-1. Figure 3.7 shows the proportion of carbon stored in a carbon pool of the forest in the study area. Figure 3.8 shows a comparison of carbon pools that were calculated based on Kato’s and Chave’s allometric equations and the results demonstrated there are high variations of carbon stocks between both equations for each forest strata. The study found that Chave’s equation estimated more reasonable result because the application of wood density parameter produced more accurate prediction. The study also found that there were significant differences of carbon stock among forest strata, as the protection forest has the highest carbon stock as compared to the other forest strata (Figure 3.8). The carbon stock in this area was found to be influenced by large trees composition and coarse woody debris in the forest floor in protection forest. The lowest carbon stock occurred in logged <10 years stratum. It was not surprise that this forest has the lowest carbon stock because most of the large trees have been removed, recently, during logging. The remaining forest strata indicated almost similar carbon stock as the forests grow over time and increased the tree size of the trees and thus biomass.
Figure 3.7. Proportion of carbon pools in the forest.

Comparison of estimated carbon stock in the forest strata.
By using the results obtained from Chave’s equation, carbon stock for the entire dipterocarp forests in Pahang was then estimated. It was estimated that in year 2010, Pahang has about 1.94 million ha of inland dipterocarp forests, which is dominated by production areas. The total carbon stock was estimated at about 0.5 billion Mg with an average of 238.16 Mg ha\(^{-1}\) throughout all strata. Table 3.5 and appendix 2 shows an estimated and spatial distribution of the carbon stock in Pahang forest.

<table>
<thead>
<tr>
<th>Strata</th>
<th>Extent (ha)</th>
<th>Carbon stock (Mg ha(^{-1}))</th>
<th>Total C stock (Mg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protection</td>
<td>727,333.82</td>
<td>257.5</td>
<td>187,287,004.03</td>
</tr>
<tr>
<td>Logged &gt; 30 years</td>
<td>528,402.76</td>
<td>230.17</td>
<td>121,623,520.07</td>
</tr>
<tr>
<td>Logged 21 - 30 years</td>
<td>311,917.06</td>
<td>219.83</td>
<td>68,568,726.20</td>
</tr>
<tr>
<td>Logged 11 - 20 years</td>
<td>265,834.27</td>
<td>232.14</td>
<td>61,711,565.64</td>
</tr>
<tr>
<td>Logged 1 - 10 years</td>
<td>7,566.03</td>
<td>165.34</td>
<td>1,250,997.50</td>
</tr>
<tr>
<td>Stateland</td>
<td>99,461.06</td>
<td>218.23</td>
<td>21,704,890.43</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1,940,515.00</strong></td>
<td></td>
<td><strong>462,146,703.87</strong></td>
</tr>
</tbody>
</table>

Result and Discussion for carbon Pool in Peat Swamp Forest

For above-ground biomass components, several size–mass allometric equations were established as stated previously. The allometric relationships, based on data from the original set of sample trees of each plots area, the biomasses of woody parts (stems plus branches) and leaves were estimated separately using corresponding allometric equations which they are the same as those derived in the International Biological Programme (IBP) studies. The estimated of above-ground total biomass (AGB) for H. S Pekan (001A) plot area are; total (tan) 7.41, 185.32 t/ha and 87.10tC/ha (Table 3.5), H. S Pekan (001B) plot area total (tan) 10.71, 267.71.32 t/ha and 125.83tC/ha, H. S Pekan (001C) plot area total (tan) 14.26, 356.61 t/ha and 167.60tC/ha and H. S Pekan (001D) plot area total (tan) 7.45, t/ha 185.25 t/ha and 87.54 tC/ha (Table 3.6).

The total above-ground biomass (AGB) differ greatly among the four plots and having an average of 117.0179 tC/ha (Table 3.5). The above-ground total biomass (AGB) in the Peat swamp forest estimated was found to be larger as reported from other seasonal rain forests (<300 Mg ha\(^{-1}\)) in South-East Asia or South America (Hozumi et al. 1969, Kira 1978; Clark et al. 2001b, Houghton et al. 2001, Yamakura et al. 1986). AGB from the various plots in the Peat swamp forests have been estimated using the generated data and the average values have been estimated to be 117.0179 tC/ha. The carbon stock calculated based on Niyiima et al. 2010 equation demonstrated variations of carbon stock among the different locations as it was observed to influence by the variation in trees sizes composition. The lowest carbon stock occurred in plot 001A indicating few number of trees concentration due to logging. The largest carbon stock was found to occur in plot 001C due to the increase in trees sizes and concentration (Table 3.6).

The estimated carbon stock in the Peat swamp forest is very similar to the various Asia forest mean values. Furthermore, these result obtained from the studies indicate that the AGB ratio varies depending on the absolute biomass value. Likewise thedbh-based
allometric equations AGB gave a good fit to the data that was acquired, even including data for some emergent trees and a wide range of species. From a practical view point, The equation maybe useful for evaluating Above and below-ground carbon stocks in other stands of dipterocarp forests in Malaysia.

Table 3.6 Total Carbon Stock in Peat Swamp Forest of Pahang

<table>
<thead>
<tr>
<th>Plot</th>
<th>Total tan t/ha</th>
<th>tc/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>001A</td>
<td>7.412859</td>
<td>185.3215</td>
</tr>
<tr>
<td>001B</td>
<td>10.70853</td>
<td>267.7131</td>
</tr>
<tr>
<td>001C</td>
<td>14.26449</td>
<td>356.6122</td>
</tr>
<tr>
<td>001D</td>
<td>7.45002</td>
<td>186.2505</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td></td>
<td><strong>117.0178</strong></td>
</tr>
</tbody>
</table>

**Materials**

Emissions factors have long been the fundamental tool in developing national, regional, state, and local emissions inventories for air quality management decisions and in developing emissions control strategies. The materials involved in carry out emission factor in respect of this study are digital compartment /NFI shape file, and sampling plots. The materials are based on specification in line with UNFCC.

**Activity Data**

The activities for emission factors involved forest stratification as earlier discussed in previous chapter and establishment of emission factor by calculation and projection based on land use changes and carbon pool.

**Methodology for Setting Emission Factor**

Forest strata was based on protection forest, that is reserved forest in natural condition without logging activities while other strata involved logged area between the ages of 1-10 years, 11-20, 21-30 and > 30 years and state land which fall outside the Forest Reserve. The strata were previously discussed chapter 3.

**Conclusion**

The studies showed that commercial agricultural such as palm oil plantation and rubber plantation was the main proximate drivers for the deforestation in Pahang. It was demonstrated that the integration of multi temporal datasets from Landsat-TM and SPOT-5 satellite images with landuse maps was capable in identifying direct drivers of deforestation. The study suggests more detailed changes analysis should be carried out to define the drivers accurately. Integration of satellite imagery with a comprehensive ground truth information will be able to improve the accuracy. Nevertheless, the findings of this study will be an important indicator in assessing forest status in the country. It is also essential in providing activity data for carbon emission studies to make the REDD+ a reality. Although agricultural expansion has been determined as the key driver of deforestation in the tropics, the drivers are actually vary regionally and change over time.

The sampling design adapted for assessing carbon pools was appropriate to represent dipterocarp forests in Pahang Peninsular Malaysia. It is also suite to the current logging
practice in which the design has been able to estimate the carbon pools representatively. While national data on carbon assessment have commonly not been available in the past, these researches have generated new information for the country in-line with the REDD+ requirements. The introduced approach is also practical where the forest practitioners can apply the sampling design for more accurate estimates. Likewise in determining the rate of deforestation in Pahang, quantification of the changes C stock in this ecosystem since 1990 until 2014 was ascertain. The study found that the combination of field inventory and remote sensing data can produce a reliable estimate of C stock in mangroves and can be used to monitor changes over times. The study suggests that an action should be taken by the State Government to protect the priceless mangrove ecosystem in Pahang. One way to conserve the mangrove in the state is to gazette the remaining stateland forest as Forest Reserve. This Forest Reserve should be maintained intact for amenity for current and future generations, in the mean times contribute to the mitigation of climate change impacts at local level. Any development on this area should be implemented with caution or prohibited totally.

**Based on carbon stocks for different land cover types in Pahang; these values can be used to calculate CO$_2$ emission factors due to land use change (Agus et al, 2013).** In addition the dimensions of the recurrent CO$_2$ emissions caused by fires at the time of plantation establishment. There is high degree of variation in all of these sources of emission which will contribute to uncertainties in any CO$_2$ emission analysis. The values for plant biomass carbon stock reflect the inherent variation in natural habitats and disturbance intensities caused by human intervention. The recommended values for calculating emission factors from land use change between any two land cover categories are the differences between the mean carbon stock values for the two categories. In the case of natural or quasi-natural land cover types, these are not time-averaged values, but are assumed to reflect the carbon stocks at the time of conversion. This is done to avoid confounding CO$_2$ emissions from degradation due to logging and wildfire with the emissions specifically due to the clearing of land for agriculture. In contrast, the carbon stock values for human modified land cover types are the time averaged values that reflect the cyclical harvest or renovation period characteristics of each production system, which in the case of oil palm is based on the 25 year cycle typical for oil palm plantations. The methodological approaches vary widely and the emission factor recommended as a default value (43 Mg CO$_2$ ha$^{-1}$ yr$^{-1}$) is based on evaluation of the various published studies and the assumption that water tables in oil plantations are at approximately 60 cm from the soil surface. Unlike the emissions factors from land use change and fires, which are one-time events, This is not only true for human managed land cover types, such as oil palm and tree plantations, but also for disturbed swamp forests and shrub lands that have been impacted by logging canals.

**References**


APPENDIX 1: Deforestation Rate in Pahang Forest
<table>
<thead>
<tr>
<th>Category</th>
<th>Area (ha)</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deforestation between 2008-2010</td>
<td>26,625.66</td>
<td>1.2</td>
</tr>
<tr>
<td>Deforestation between 2004-2008</td>
<td>63,437.35</td>
<td>2.7</td>
</tr>
<tr>
<td>Deforestation between 2002-2004</td>
<td>16,410.46</td>
<td>0.7</td>
</tr>
<tr>
<td>Deforestation between 2000-2002</td>
<td>13,426.98</td>
<td>0.6</td>
</tr>
<tr>
<td>Inland forest</td>
<td>2,070,495.24</td>
<td>90.6</td>
</tr>
<tr>
<td>Peatswamp forest</td>
<td>206,832.65</td>
<td>9.0</td>
</tr>
<tr>
<td>Mangrove forest</td>
<td>9,039.26</td>
<td>0.4</td>
</tr>
<tr>
<td>Permanent Reserve Forest</td>
<td>1,562,902.20</td>
<td>68.4</td>
</tr>
<tr>
<td>State parks and National parks</td>
<td>399,780.00</td>
<td>11.1</td>
</tr>
<tr>
<td>Non forest</td>
<td>1,310,132.85</td>
<td>36.4</td>
</tr>
<tr>
<td>Forest</td>
<td>2,285,367.15</td>
<td>63.6</td>
</tr>
<tr>
<td><strong>Total Pahang Land area</strong></td>
<td><strong>3,596,500.00</strong></td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX 2: Spatial Distribution of Carbon Stock in the Dipterocarp Forests of Pahang