Quantifying rate of deforestation and CO$_2$ emission in Peninsular Malaysia using Palsar imageries

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Abstract. Increasing human population and the rapid grows of Malaysia’s economy are often associated with various environmental disturbances which have been contributing to depletion of natural resources and climate change. The need for more spaces for numerous land development activities has made the existing forests suffer deforestation. The study was carried out in Peninsular Malaysia, which currently has about 5.9 million ha of forests. Phased array type L-band SAR (Palsar) and Palsar-2 images over the years 2010 and 2015, respectively were used to identify forest cover and deforestation occurrences resulted from various conversion of forests to other land uses. Forests have been identified from horizontal-vertical (HV) polarization and then classified into three major categories, which are inland, peat swamp and mangrove. Pixel subtraction technique was used to determine areas that have been changing from forests to other land uses. Forest areas have been found declined from about 6.1 million ha in year 2010 to some 5.9 million ha in 2015 due to conversion of forests to other land uses. Causes of deforestation have been identified and the amount of carbon dioxide (CO$_2$) that has been emitted due to the deforestation activity has been determined in this study. Oil palm and rubber plantations expansion has been found the most prominent factor that caused deforestation in Peninsular Malaysia, especially in the states of Pahang, Terengganu, Johor and Kelantan. The rate of deforestation in the period was at 0.66 % yr$^{-1}$, which amounted a total of about 200,225 ha over the five years. Carbon loss was estimated at about 30.2 million Mg C, which has resulted in CO$_2$ emission accounted at about 110.6 million Mg CO$_2$. The rate of CO$_2$ emission that has been resulted from deforestation was estimated at 22.1 million Mg CO$_2$ yr$^{-1}$. The study found that the use of a series of Palsar and Palsar-2 images are the most appropriate sensors to be used for monitoring of deforestation over the Peninsular Malaysia region.

1. Introduction
In Malaysia, forest is defined as land spanning more than 0.5 ha with trees higher than 5 m and a canopy cover of more than 30 %, or trees able to reach these thresholds in situ. It does not include land that is predominantly under agricultural or urban land use [1]. Major forest types in Malaysia are lowland dipterocarp, hill dipterocarp, upper hill dipterocarp, montane, ericaceous, peat swamp and mangrove forests. In addition, there also smaller areas of freshwater swamp forest, heath forest, forest on limestone and forest on quartz ridges. Currently there are about 5.89 million ha of forest occur in Peninsular Malaysia, which covers about 44.7% of its land area. Out of this, 4.92 million ha falls under Permanent Reserved Forest (PRF), 0.58 million ha is Totally Protected Area (TPA) and the remaining 0.39 million ha belongs to state/alienated land [2].

Forests play an important role as a substantial coastal carbon sink. It is interesting to note that plant biomass in the ocean and coastal areas comprise of only 0.05% of the total plant biomass on land, get it cycles a comparable amount of carbon each year. Forests account for a large percentage of carbon fixing of about 80% of plant biomass carbon and 40% of the soil carbon [3]. Carbon sequestration results from
the difference between photosynthetic carbon fixation and ecosystem respiration in the forest ecosystem [4] and overall it results in the determination of the net ecosystem carbon exchange [5].

The largest single source of greenhouse gases (GHG) emission in recorded history is from conversion of forest to other land use types [6]. This conversion has direct on-site effects resulting in degradation of vegetation, loss of biodiversity, destruction of property and occasional loss of life, while off-site impacts include carbon emissions and thus global warming and climate change. Deforestation in tropical region is considered as the second largest source of anthropogenic greenhouse gas emissions [7] and is expected to remain a major emission source for the foreseeable future. Deforestation is defined as the felling of trees without subsequent replanting or regeneration, i.e. the conversion of previously forested land to agricultural, urban or other land uses, which do not have a substantial tree canopy cover <10% [1]. Statistically, about 1 to 2 billion Mg of carbon per year which is equivalent to 15 - 25% of annual global greenhouse gases (GHG) emissions arises from tropical deforestation and forest degradation [8,9].

In Malaysia the conversion of existing forest to non-forest areas has increased the GHG emissions and contributed to the global climate change. Loss of forests have resulted from rapid clearing and conversion of land for agricultural purposes, and the forest had decreased by 1.2 million hectare by 1990 [1]. Half of the forests in the Peninsular Malaysia was cleared in the late 1980s [10], which decreased the total forest area to 57% of the original area by 2002 [11]. This has resulted in a serious land cover challenge in the Peninsular Malaysia [12]. The rapid expansion of oil palm over the two decades has led to the transformation of large areas of forest and plantation landscapes throughout Southeast Asia and is believed to be one of the major sources of greenhouse gas (GHG) emissions linked to land use in the region [13].

Malaysia is now committed to the program 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 program is to stabilize the GHG concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. However the amount and rate of deforestation, and to some extent emission resulted from the deforestation are yet to account. Identifying the drivers of deforestation is therefore essential as the first step to provide information for the decision-making processes and to establish land use policies in a way to combat land use change and be able to control any potential drivers that might contribute the carbon emission [7].

Given the current gap in knowledge and understanding of emission at national level, the research presented in this paper aims at providing methodology for estimating emission from deforestation with special reference to the use of synthetic aperture radar (SAR) satellite data. While national data on carbon emission have commonly not been available in the past, this research will generate new information for the country in-line with the REDD+ requirements.

2. Materials and methods

2.1. The study area
The study area covers entire region of Peninsular Malaysia, which encompasses an area of about 131,598 km². Peninsular Malaysia is located between latitudes 1°20' and 6°45' N and about longitudes 100' and 104°30' E. Practically the entire region is in the tropical moist forest life zone with annual rainfall in excess of 2000 mm fairly evenly distributed throughout the year. A mountain range runs along most of the peninsula with peaks >2000 m. More than 60% of the area is undulating lowland <300 m above sea level, about 35% is hilly with elevations of 300 to 1300 m, and the remainder is very mountainous. Forests in this region comprises mainly inland dipterocarps, which consist of lowland, hill and upper hill, which are categorised based on land altitude, i.e. <300, 300–750 and 750–1200 m respectively. Trees from the family Dipterocarpaceae are dominant in these forests. Other types of forests montane, peat swamp, and mangrove.
2.2. Satellite data
Satellite data that was used in data came from two satellites, which are Advanced Land Observing Satellite (Alos) and Alos-2. Alos-2 is the successor of the Alos, but the structure of the new satellite is quite different from its predecessor. Alos was launched in January 2006 and brought Phased Array type L-band Synthetic Aperture Rader (Palsar) on-board. After 5 years of observations it stopped transmitting in April 2011. Alos-2 was then launched on 24 May 2014 and bringing Palsar-2 sensor. Palsar-2 is currently operating and producing L-band SAR data, that has similar (with some advancements) characteristics with Palsar.

Both Palsar and Palsar-2 images datasets used in this study consisted of 1x1 degree mosaic tiles. A tile product consisted of two bands in horizontal-vertical (HV) and horizontal-horizontal (HH) polarisations at 25 m spatial spacing, geometrically and radiometrically corrected and normalised for topography. It also contains additional ancillary image data layers with information about acquisition dates, local incidence angle and a water- and no-data mask. The mosaic images were acquired from a number of individual scenes acquired in year 2010 from Palsar, and in year 2015 from Palsar-2. This 5-year interval data over Peninsular Malaysia is shown in Figure 1.

![Figure 1](image.png)

Figure 1. Mosaic images of Alos Palsar (a) and Alos-2 Palsar-2 (b) over the years 2010 and 2015, respectively.

2.3. Forest–non-forest classification
Forest–non-forest classification was performed on both mosaic images to delineate forests from other land uses. This process is critical to define the boundary of forests and to ensure that the estimated forest cover does not include other types of vegetation. The reason is that forests are often confused with rubber, teak and other timber tree plantations, which are common in Peninsular Malaysia and they appear almost identical on both HH and HV polarisations images. To minimise error associated with misclassification, image enhancement was applied to the images. Detailed explanation on the image enhancement technique can be found in [14]. The process was then finally produced a classified image that contained only forest areas for year 2010. This images were converted to vector format to be used for forest cover changes analysis.
2.4. Forest cover changes analysis
Changes of forest area is referred to as deforestation, which is 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 other purposes. Temporary change in forests, like one rotation tree crop (up to 25 years) within forest reserves are not considered as deforestation and it falls under sustainable management of forests. Forest cover changes analysis has been conducted to determine the areas that have been converted from forest to other land uses.

Deforested areas were detected based on pixel differencing method. Mosaic images from both years were subtracted by using the following function;

\[ \text{Change} = \text{DN}_{2010} - \text{DN}_{2015} \]  

where \( \text{DN} \) denotes digital number of pixel from images over the years 2010 and year 2015, respectively.

This process produced another image that represent changes that have occurred between year 2010 and 2015. The vector layer of forest cover in 2010 was used as the base for changes analysis. Areas that have been changing from 2010 were detected and classified as deforestation. The vector layer was edited manually to produce another vector layer that represent forest areas of year 2015.

Land use categories that have been classified as deforestation were identified and were generalized into 6 major classes that consisted of oil palm plantation, rubber plantation, urban area, agriculture (other than oil palm and rubber plantations), water body and others (comprised mine and quarry, aquaculture, animal husbandry areas and cleared land) for the purpose of simplification. A ground truthing activity has been conducted at several locations to conform the current land use on the ground.

2.5. Carbon stock assessment
Carbon stock in the remaining forests have been assessed before carbon emission due to deforestation can be estimated. To complete this exercise, carbon stock in all forest types (i.e. inland, peat swamp and mangrove forests) in Peninsular Malaysia have been surveyed on the ground at a number of sample sites. The sampling design in this study was a modified sampling design according to the standard operating procedure (SOP) that has been developed by Winrock International [15], which follows the IPCC standards [16]. A cluster comprises four (4) subplots and the design is shown in Figure 2. The subplot was designed in circular with smaller nests inside. The biggest nest measures 20 m in radius, followed by the smaller nests measuring 12 and 4 m. The sizes of trees were measured according to the nest sizes, which is summarized in Table 1. Depending on the nest size, it indicates that not all stands were measured in a single subplot. In additional to these nests, there is another small nest measuring 2 m in radius, which is used to count saplings (i.e. trees measuring < 10 cm in diameter at breast height (dbh) and > 1.3 m in height). Clustering of subplots at each sampling unit is recommended for natural forest areas and areas that have been selectively logged. The sampling system is design in a way to make the data collection processes easier, faster but reliable and representative for a particular forest stratum.

A forest ecosystem normally has five terrestrial carbon pools, which are; (i) aboveground living biomass, (ii) belowground living biomass, (iii) deadwood, (iv) non-tree vegetation and litters, and (v) soil. However, one of the most significant carbon pools is aboveground biomass as it the easiest and the most practical pool to assess, while representative to an ecosystem. Aboveground biomass (AGB) comprises all the living aboveground vegetation, including stems, branches, twigs and leaves, deadwood, non-tree vegetation and litters. Allometric functions is the best way that above ground biomass can be estimated. In this study, regional allometric functions that are found in the literature (Table 2) were used to estimate the biomass of living trees in the inland, peat swamp and mangrove forests. A default factor of 0.47 was used to convert the biomass into carbon.
Table 1. Summary living trees measurement in a subplot.

| Nest radius (m) | Size   | Tree size, dbh (cm) |
|----------------|--------|---------------------|
| 4              | Small  | ≥ 10                |
| 12             | Medium | ≥ 20                |
| 20             | Large  | ≥ 40                |

Table 2. Allometric functions that have been used for AGB estimations.

| Forest type     | Allometric function                                                                 | Source |
|-----------------|-------------------------------------------------------------------------------------|--------|
| Inland forest   | AGB = \[\exp(-1.803 - 0.976E + 0.976 \ln(\rho) + 2.673 \ln(D) - 0.0299 [\ln(D)]^2)\] | [17]   |
| Peat swamp forest| AGB = 0.65*\exp(-1.239 + 1.98*\ln(D)+ 0.207* \ln(D)^2 - 0.0281*ln(D)^2)          | [18]   |
| Mangrove forest | AGB = 0.251\rho D^{2.46}                                                       | [19]   |

AGB denotes aboveground biomass (kg/tree), \(E\) represents bioclimatic variable, \(\rho\) is wood specific gravity/ wood density, and \(D\) is dbh.

2.6. Estimation of carbon emission

There are two methods that can be used to estimate emission, which are the stock-difference method and the gain-loss method. Stock-difference requires two measurements in two different time periods. The estimated carbon stocks between the two periods divided by the time difference between the two time periods is the estimated carbon stock change per unit area. This method is better suited for deforestation. The gain-loss method, on the other hands, does not require two measurements; instead it simply measures the rate of carbon change in a given period, i.e. mean annual increment of carbon. Hence, this method is better suited for forest degradation where the stock change can be measured in two time periods through the expected change in carbon stock. Once the areal extents of deforestation is known, emission factor (EF) is then required. Emission factor is a measure of carbon loss that is caused by conversion of forest to other land uses. The carbon stock in forested areas was measured on the ground while carbon stock in the other landuse categories were adopted from literature to obtain the EF, as summarized in Table 3. Net emission from land use and land use changes can be estimated based on equations provided by [16], which can be expressed as

\[
\Delta C = \frac{(Ct2-Ct1)}{(t2-t1)}
\]
where $\Delta C$ is annual carbon stock change (Mg C yr$^{-1}$), $C_{t_1}$ and $C_{t_2}$ is carbon stock at time $t_1$ and $t_2$ (Mg C) respectively. However, whenever activity data (i.e. deforestation information) is available from changes analysis that has been conducted prior to the estimation of carbon emission, the following equation can be used,

$$C_{t} = \sum (AD \times EF)$$  \hspace{1cm} (3)

where $C_{t}$ is the carbon stock in time $t$, $AD$ is the activity data or the area undergoing a specific type of land use change that emits carbon (measured in ha), and $EF$ is emission factor, which is the total loss of the carbon stock per unit land area during the specific type of land use change (measured in Mg C ha$^{-1}$). Carbon emission can be expressed in terms of C loss or can be converted to CO$_2$ by multiplying with a factor of 3.67 which is the molecular weight of CO$_2$ per unit atomic weight of C.

Table 3. Emission factor for different types of land conversion. (Summarized from [6])

| Land use categories     | Carbon stock (Mg C ha$^{-1}$) | Conversion of forest to | Emission factor (Mg C ha$^{-1}$) |
|-------------------------|-------------------------------|-------------------------|----------------------------------|
| Forest                  | 186                           | Forest                  | 0                                |
| Oil palm                | 36                            | Oil palm                | 150                              |
| Rubber                  | 58                            | Rubber                  | 128                              |
| Urban area              | 7                             | Urban area              | 179                              |
| Agriculture             | 54                            | Agriculture             | 132                              |
| Water body              | 0                             | Water body              | 186                              |
| Others                  | 0                             | Others                  | 186                              |

3. Results and discussion

3.1. Forest distribution and extent

The study has classified the forests into three major types, which are inland, peat swamp and mangroves as indicated in Table 4. Inland dipterocarp forest is the major type of forest in Peninsular Malaysia, which accounted over 90% of the total forest cover. In addition to the identified major forest types, ‘gelam’ was also found within the study area. Gelam ($Melaleuca cajuputi$) is a monospecific trees which occurs in swamp forest behind beaches and mangroves. This forest – although in a small proportion – is found dominant, fringing behind the mangroves in the north eastern part of Terengganu, a state that resides in the East Coast of Peninsular Malaysia. However, due to difficulty in delineating this forest from inland forest, it was grouped into inland forest.

3.2. Deforestation in Peninsular Malaysia

The total land area in Peninsular Malaysia is estimated at about 131,598 km$^2$ with an overall forest area at 58.96 km$^2$ in the year 2015. Changes of forest cover in Peninsular Malaysia between 2010 and 2015, as resulted from deforestation are reported in Table 4. Factors of deforestation are generalized into six categories as summarized in Table 5. The total deforested area was found at 200,225 ha between years 2010 and 2015, which was accounted for deforestation at the rate of 40,045 ha yr$^{-1}$. Large piece of forest area in Peninsular Malaysia have been converted to oil palm and rubber at commercial scales, which occupied about 61% and 14%, respectively. 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, and highways. Similarly, agricultural land was the share of the forests area that is converted to arable under permanent crops. The forest area were also converted to quarry and mine sites from which dimension stone, rock, construction aggregate, riprap, sand, gravel, or slate have been excavated from the ground. These activities resulted to open-pit mine from which minerals were extracted. Certain area of the forest were left idle that is they are not cut, burned, cropped, heavily grazed, cultivated, or
otherwise disturbed. Other parts of the forest were converted to animal husbandry and farms for domestic supplies. Small patches of the clear land were also identified as scars of forest fires that occurred in the year 2014. A spatially distributed map indicating the deforestation that occurred between 2010 and 2015 was produced and depicted in Figure 3.

### Table 4. Deforestation in Peninsular Malaysia between years 2010 and 2015.

| Forest type | Forest cover 2010 (ha) | Forest cover 2015 (ha) | Deforestation (ha) | Rate of deforestation (ha yr⁻¹) | Rate of deforestation (% yr⁻¹) |
|-------------|------------------------|------------------------|--------------------|-------------------------------|-------------------------------|
| Inland      | 5,690,816              | 5,525,034              | 165,782            | 33,156                        | 0.58                          |
| Peat swamp  | 290,038                | 264,578                | 25,460             | 5,092                         | 1.76                          |
| Mangrove    | 115,181                | 106,198                | 8,982              | 1,796                         | 1.56                          |
| Total       | 6,096,035              | 5,895,810              | 200,225            | 40,045                        | 0.66                          |

### Table 5. Categories of land uses that have been converted from forested areas.

| No. | Land use category | Area (ha) | Percentage area (%) |
|-----|-------------------|-----------|---------------------|
| 1.  | Water body        | 7,506     | 4                   |
| 2.  | Oil palm          | 122,137   | 61                  |
| 3.  | Rubber            | 28,031    | 14                  |
| 4.  | Agriculture       | 18,020    | 9                   |
| 5.  | Urban             | 12,013    | 6                   |
| 6.  | Others            | 12,516    | 6                   |
| Total|                  | 200,225   | 100                 |

#### 3.3. The assessed carbon stock

The assessment of carbon stock have been done in all major forest types found in Peninsular Malaysia. However, the calculation of EF used an average value of carbon stock from inland and peat swamp forests only. Mangrove forest was excluded from the estimation because its extent was found too small and if included in the estimation, will produce serious underestimate of carbon stock for all forests in entire study area. The average carbon stock of these forests was estimated at 186.46 Mg C ha⁻¹. Table 6 summarizes the assessed carbon stock for all forest types in different pools of aboveground carbon. Table 3 that was shown earlier used these values as a basis to calculate the EF.

### Table 6. The estimated aboveground carbon stock at different forest types.

| Forest type | Average carbon stock (Mg C ha⁻¹) |
|-------------|----------------------------------|
|             | Aboveground living | Deadwood | Non-tree vegetation and litters | Total carbon stock |
| Inland      | 174.49               | 4.92     | 1.29                           | 180.70             |
| Peat swamp  | 168.63               | 21.40    | 2.19                           | 192.22             |
| Mangrove    | 135.45               | 22.12    | 3.88                           | 161.45             |

#### 3.4. The estimated carbon emission

The loss of carbon was estimated by multiplying the extents of deforested areas (Table 5) with the emission factors for each corresponding land use category. Normally the rate of net emission is reported in yearly basis between two periods. The study found that the net CO₂ emission from deforestation in Peninsular Malaysia was at 110.6 million Mg CO₂ from year 2010 to 2015, with the rate of CO₂ emission at about 22.1 million Mg CO₂ yr⁻¹. Table 7 shows the estimated loss of carbon and CO₂ emission for the entire Peninsular Malaysia. It is obvious that the major contribution to the loss of carbon in the study
area was from the expansion of oil palm and rubber plantations as compared to the other land uses, as shown in Figure 4.

**Figure 3.** Map showing extents of changed forest cover in Peninsular Malaysia between years 2010 and 2015.
Table 7. Summary of carbon loss and emission of CO$_2$ resulted from deforestation between 2010 and 2015.

| Land use categories | Area (ha) | Carbon loss (Mg C) | Emission (Mg CO$_2$) |
|---------------------|-----------|--------------------|----------------------|
| Water body          | 7,506     | 1,396,116          | 5,119,092            |
| Oil palm            | 122,137   | 18,320,555         | 67,175,367           |
| Rubber              | 28,031    | 3,588,026          | 13,156,094           |
| Agriculture         | 18,020    | 2,378,669          | 8,721,785            |
| Urban               | 12,013    | 2,150,413          | 7,884,846            |
| Others              | 12,516    | 2,328,062          | 8,536,228            |
| Total               | 200,225   | 30,161,840         | 110,593,412          |

4. Conclusion
The study has provided methodology for estimating emission from deforestation with special reference to the use of Palsar data. The rate of deforestation was at 0.66 % yr$^{-1}$, which amounted a total of about 200,225 ha over the five years between 2010 and 2015. Carbon loss was estimated at 30,161,840 Mg C, which has resulted in CO$_2$ emission accounted at about 110,593,412 Mg CO$_2$. The rate of CO$_2$ emission that has been resulted from deforestation was estimated at 22,118,682 Mg CO$_2$ yr$^{-1}$.

Expansions of the palm oil and rubber plantations were found the common factor of deforestation in Peninsular Malaysia. The findings of this study will be an important indicator in assessing forest status and the trend of agricultural crops expansions in the country. It is also essential in providing activity data for carbon emission studies to make the REDD+ a reality. The information produced from this study is valuable for the policy makers to balance between development and environmental amenity. Although agricultural expansion has been determined as the key factor of deforestation in Peninsular Malaysia, the factors are actually vary regionally and change over time. The study also found that the use of a series of Palsar and Palsar-2 images are the most appropriate sensors to be used for monitoring of deforestation over the region.

The sampling design adapted for assessing carbon pools was appropriate to represent forests in Peninsular Malaysia. While national data on carbon assessment have commonly not been available in the past, this research has generated new information for the country in-line with the REDD+ requirements. However, some limitations have been identified from the study, which can be summarized as (i) generalization of net CO$_2$ emission from conversion, regardless the CO$_2$ intake during the growth
of the agriculture crops, and (ii) the forest ecosystem was considered as one single stratum, regardless the variations of the status and management practices. Above all, to identify cost effective policies that will effectively reduce emission from agriculture expansions in Malaysia, REDD+ mechanism should depends on capacity to implement measures for effectively controlling deforestation and practicing good agriculture practices.

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References
[1] Food and Agriculture Organization of the United Nation – FAO. (2010). Global Forest Resources Assessment 2010. FAO Rome.
[2] Forestry Department Peninsular Malaysia – FDPM. (2015). Annual Report 2014. Kuala Lumpur.
[3] Dixon, R.K. (1994). Carbon pools and flux of global forest ecosystems. Science, 263: 185–190.
[4] Gong, J., Ge, Z., An, R., Duan, Q., You, X. & Huang, Y. (2012). Soil respiration in poplar plantations in northern China at different forest ages. Plant Soil, 360: 109–122.
[5] Valentini, R., Matteucci, G., Dolman, A.J., Schulze, E.D., Rebbmann, C., Moors, E.J., Granier, A., Gross, P., Jensen, N.O, Pilegaard, K., Lindroth, A., Grelle, A., Bernhofer, C., Grünwald, T., Aubinet, M., Ceulemans, R., Kowalski, A.S. & Vesala, T. (2000). Respiration as the main determinant of European forests carbon balance. Nature, 404: 861-865.
[6] Agus, F., Henson, E.I., Sahardjo, H.B., Harris, N., Noordwijk, V.M., & Killeen, J.T. (2014). Review of emission factors for assessment of CO2 emission from land use change to oil palm in Southeast Asia. Report from the technical panels of the 2nd Greenhouse Gas Working Group of the Roundtable on Sustainable Palm Oil (RSPO).
[7] IPCC (Intergovernmental Panel on Climate Change). (2007). Climate Change 2007. Cambridge University Press.
[8] Houghton, R., (2005). Tropical deforestation as a source of greenhouse gas emissions. Eds. Mutinho & Schwartzman, Tropical deforestation and climate change. Belém.
[9] Gibbs, H., Brown, K., Niles, S.J. & Foley, J.A. (2007). Monitoring and Estimating Tropical Forest Carbon Stocks: Making REDD a Reality. Environ Res Lett, 2: No. 045023.
[10] Gillis, M. & Repetto, R. (1988). Public Policies, the misuse of Forest Resource. Cambridge University Press, Cambridge.
[11] Langner, A., Miettinen, J. & Siegert, F. (2007). Land cover change 2002–2005 in Borneo and the role of fire derived from MODIS imagery. Glob Change Biol, 13: 2329–2340.
[12] Brookfield, H. & Byron, Y. (1990). Deforestation and Timber extraction in Borneo and the Malaysia Peninsular. Glob environ Chang, 1: 42-56.
[13] Wicke, B., Sikkema, R., Dornbury, V. & Faaij, A. (2011). Exploring land use changes and the role of fire derived from MODIS imagery. Glob Change Biol, 13: 42-56.
[14] Hamdan, O., Mohd Hasmadi, L., Khalil Aziz, H., Norizah, K. & Helmi Zulhaidi M.S. (2015). Determining L-Band Saturation Level for Aboveground Biomass Assessment of Dipterocarp Forests in Peninsula Malaysia. J Trop For Sci, 27(3): 388 – 399.
[15] Walker, S.M., Pearson, T.R.H., Casarim, F.M., Harris, N., Petrova, S., Grais, A., Swailes, E., Netzer, M., Goslee, K.M. & Brown, S. (2014). Standard Operating Procedures for Terrestrial Carbon Measurement: Version 2014. Winrock International.
[16] IPCC (Intergovernmental Panel on Climate Change). (2006) Guidelines for National Greenhouse Gas Inventories, Geneva, Switzerland.
[17] Chave, J. and co-authors. (2014). Improved allometric models to estimate the aboveground biomass of tropical trees. *Glob Change Biol.* geb.12629: 14p.

[18] Chave, J. and co-authors. (2005). Tree allometry and improved estimation of carbon stocks and balance in tropical forests. *Oecologia*, **145**: 87–99.

[19] Komiyama, A., Ong, J.E. & Poungpam, S. (2007). Allometry, biomass, and productivity of mangrove forests: A review. *Aquat Bot*, **89**:128–137.