

## A tool for assessing ecological status of forest ecosystem

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**Abstract.** Managers and policy makers are beginning to appreciate the value of ecological monitoring of artificially regenerated forest especially in urban areas. With the advent of more advance technology in precision forestry, high resolution remotely sensed data e.g. hyperspectral and LiDAR are becoming available for rapid and precise assessment of the forest condition. An assessment of ecological status of forest ecosystem was developed and tested using FRIM campus forest stand. The forest consisted of three major blocks; the old growth artificially regenerated native species forests, naturally regenerated forest and recent planted forest for commercial timber and other forest products. Our aim is to assess the ecological status and its proximity to the mature old growth artificially regenerated stand. We used airborne LiDAR, orthophoto and thirty field sampling quadrats of 20x20m for ground verification. The parameter assessments were grouped into four broad categories: a. forest community level-composition, structures, function; landscape structures-road network and forest edges. A metric of parameters and rating criteria was introduced as indicators of the forest ecological status. We applied multi-criteria assessment to categorize the ecological status of the forest stand. The paper demonstrates the application of the assessment approach using FRIM campus forest as its first case study. Its potential application to both artificially and naturally regenerated forest in the variety of Malaysian landscape is discussed

### 1. Introduction

Managers and policy makers are beginning to appreciate the value of ecological monitoring of artificially regenerated forest especially in urban areas. With the advent of more advance technology in precision forestry, high resolution remotely sensed data e.g. hyperspectral, airborne light detection and ranging (LiDAR) are becoming available for rapid and precise assessment of the forest condition.

Foresters usually measure the status of the forest based on ground sampling through various scales of forest samplings from stand level, landscape level and national level. The sampling results provide indications of the forest ecological status in terms of its stocking density, structure and composition. For continuous forest inventory plots, the forester may be able to generate the forest dynamics status such as growth and mortality. With the advent of remote sensing technology, more forestry application has now embarked on forest assessment combined with field inventory over large areas. The remote sensing application may include the use of optimal and radar image as well as (LiDAR) to assess forest area. The application of LiDAR can provide detailed three-dimensional structure of forest



canopies and has been widely used to characterize forest cover and structure [6]. In Malaysia, the application of LiDAR is still at research scale [4] and its potential application to support national forest inventories should be explored. Some the most important research areas where the LiDAR can play significant roles are canopy and tree height estimation, forest structure, and biomass and volume estimation [4]. The application of LiDAR may contribute to the assessment of the ecological status of a forest ecosystem. Knowing the ecological status or its integrity provides a useful framework for ecologically based monitoring and valuable information for assessing ecosystem condition and management effectiveness by Geraldine *et. al* [2]. The approach can be based on spatial and non-spatial information. In this presentation, we will demonstrate the application of non-spatial output in terms of tables of metrics and its ratings (see Geraldine *et. al* [2]). We also combine the metrics to generate a single index that describe the ecological status of the stand using Multi-Criteria Analysis Shell for Spatial Decision Support (MCAS-S) [5].

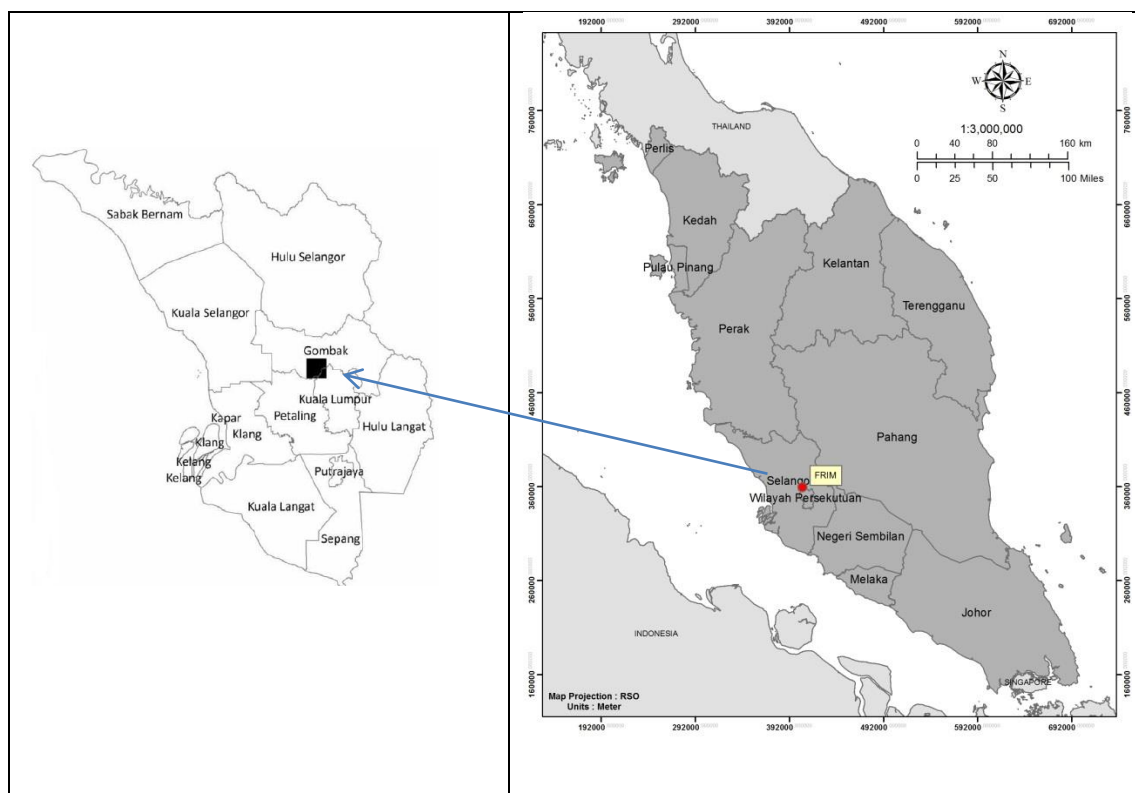
An assessment of the ecological status of forest ecosystem was developed and tested using FRIM campus artificially and naturally regenerated forest stands. The forest consisted of three major blocks; the old growth artificially regenerated native species forests, naturally regenerated forest and more recent planted forest for commercial timber and other forest products. In the past, the assessment of forest carbon had been conducted by Hamdan *et. al* [3] using remotely sensed L-Band SAR data. With the availability of LiDAR data for the year 2007 and 2013, we extended the assessment of FRIM stands in terms of carbon and other metrics of ecosystem structure and function.

Our aim is to demonstrate the assessment of the ecological status and its proximity to the mature old growth artificially regenerated stand using LiDAR data and FRIM's campus forest stands as its first case study. The study site has a long history of artificially regenerated forest stand of various species mixture planting of both native and exotics species. Its potential application to both artificially and naturally regenerated forest in variety of Malaysian landscape is briefly discussed.

## **2. FRIM's Campus Forest Stand as example**

### *2.1. Site description*

Major plantation researches began in the Forest Research Institute Campus in the 1920's and more than 100 species, both natives and exotics, were planted in 1920's and 30's (Watson 1935 cited in Francis Ng [1]). The planting was successful, however no scaling up of efforts towards industrial tree plantation levels were embarked. As a result, these areas serve as demonstration sites rather than production sites. Over the years, since 1970's, several plantation trials of exotic species such as pines, *Eucalyptus spp*, *Araucaria spp* and *Acacia spp* were established to support wood based industry. The establishment of all these plantations trials together with existing native forest within the FRIM campus and its close proximity to the permanent reserve forest makes it a unique setting for natural succession of flora and fauna species into the area. Some of the planted forest stands have grown to a fully stocked stand, perhaps approaching the condition of the pristine climax forest.



**Figure 1.** Location of study site at FRIM Campus forest stand.

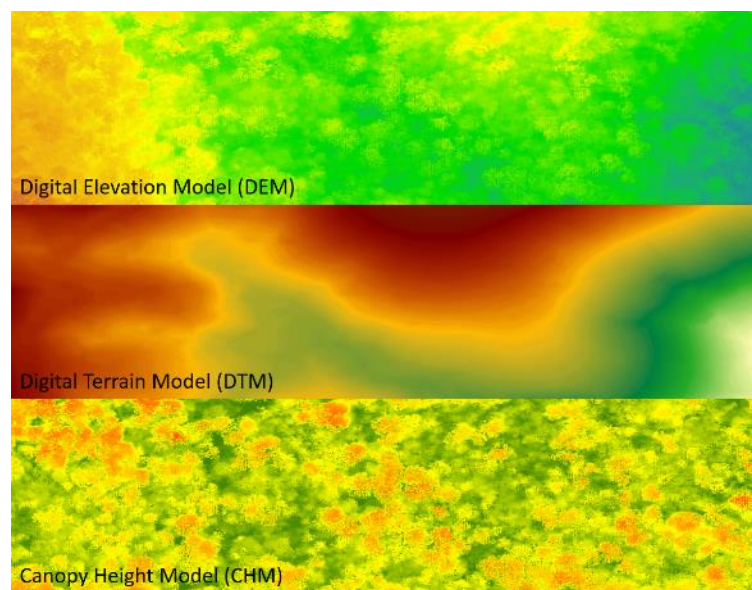
## 2.2. Assessment approach

We used airborne LiDAR data set taken in 2007 and 2013 and 30 field sampling quadrats of 20x20m for ground verification to assess the metrics of ecological status.

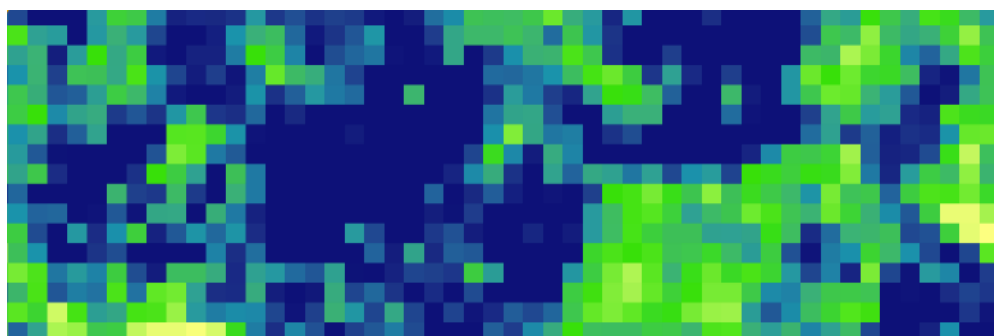
### 2.2.1. LiDAR Processing

LiDAR data was used to produce several layers of ecological information. Generally, canopy height model (CHM) was generated from LiDAR data and this information was used to generate other layers for the assessment of the ecological status. CHM gave the information of the height of canopy trees from the ground. CHM was generated by subtracting digital elevation model (DEM) with the digital terrain model (DTM) as shown in the Figure 2.

CHM was used as one of the layer and several other layers were generated from this information. This includes the estimation of biomass and volume of the forested area. The biomass and volume of the inventory plots established were correlated with the average CHM's values of each plot to get the function of both parameters as shown in Figure 3. Biomass and volume were then estimated using the functions established.



**Figure 2.** Generation of Canopy Height Model (CHM) from Digital Elevation Model (DEM) and Digital Terrain Model (DTM)

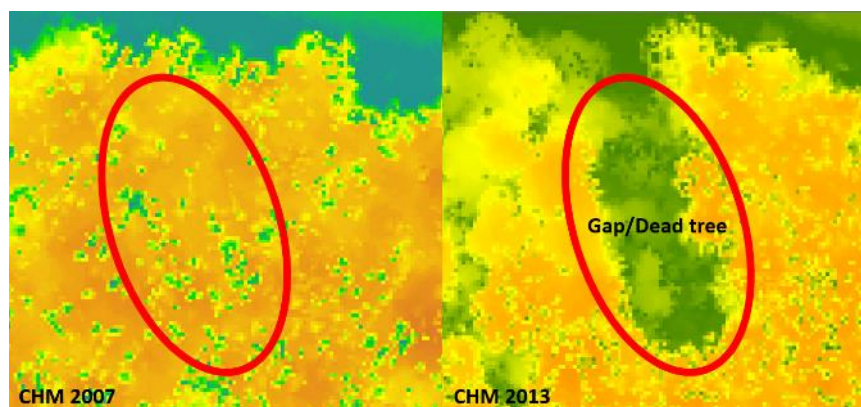


**Figure 3.** Example of biomass estimation using average CHM's values at 20 x 20 m resolution.

Other layers that were generated from CHM are height growth, volume and biomass changes, and mortality. These layers were produced by processing two sets of LiDAR data that were acquired from different dates. Height growth of the canopy tree was produced by calculating the difference of both CHMs. The same method was also applied with the volume and biomass changes layers. As for the mortality layer, it was generated by detecting canopy gaps or dead trees by using CHM's data of both years (Figure 4).

#### 2.2.2. *Developments of metrics and indicators*

We take into account the component of forest ecosystem in describing the ecological status of the stand i.e. composition, structure and function. Beside the three aspects, we also included the landscape structures to indicate the threat to the stand especially in area potentially expose to disturbance due to its proximity to forest edges. Table 1 showed the metric parameter and its rating criteria.



**Figure 4.** Canopy gaps or dead tree detection using two CHM data sets.

We used the “traffic light” color code to indicate the status of the ratings, namely, the status of the forest as good (Green), moderate (Yellow) and poor (Red). The Green color reflects the stand as in good condition and performing as expected; the Yellow color indicates that it is relatively good but can be further improved; while Red color indicate that the stand is in the stage of significant concern and may require human intervention to improve its ecological status

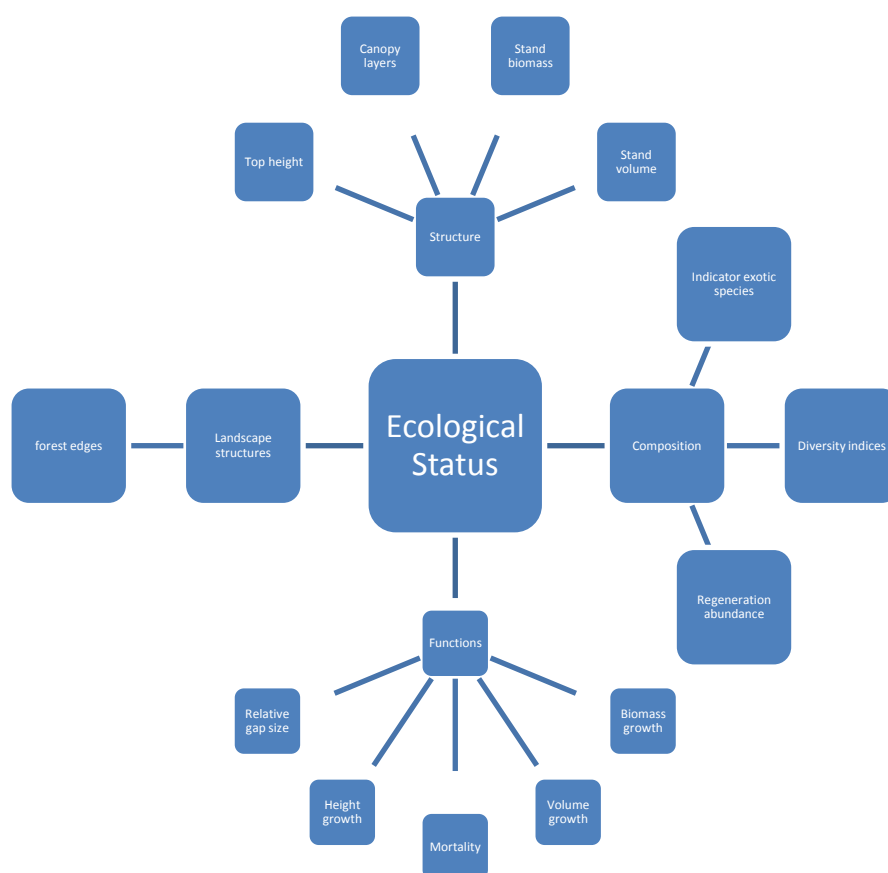
**Table 1.** A metric of structure, composition and function developed for FRIM campus site with its rating value.

Metric type	Metrics	Rating		
		Good	Moderate	Poor
Structures	Volume ( $\text{m}^3\text{ha}^{-1}$ )	>300	100-300	<100
	Biomass ( $\text{Mg}^3\text{ha}^{-1}$ )	>400	200-400	<200
	Canopy layers	Multi-layer	Mono-layer >20m	Mono-layer <20 m
	Top height (m)	>40	20-40	<20
	Height structural indices	TBA	TBA	TBA
	Light intensity (%)	TBA	TBA	TBA
Composition	Regeneration abundance	TBA	TBA	TBA
	Indicator exotic species	TBA	TBA	TBA
	Diversity indices	TBA	TBA	TBA
Function	Volume change ( $\text{m}^3/\text{ha}$ )	>4	1-4	<1
	Biomass change ( $\text{Mg}/\text{ha}$ )	>10	3-10	<3
	Relative gap size	TBA	TBA	TBA
	Height growth (m)	>0.7	0.3-0.7	<0.3
Landscape	Relative disturbance	0	0-30	>30

*Note: TBA means to be arranged*

### 2.2.3. Ecological status based combine metrics

We applied multi-criteria assessment system (MCAS) to combine the ecological status of the forest stand. Using the spatial information of each metric, we combined each metric into clusters based on structure, function and composition of forest ecosystem to define the ecological status of the stand. In addition, we included the landscape structures which examine the edge effects within and at the boundary of FRIM's campus forest stand. MCAS is a technique that allows for the measurement and aggregation of the performance of alternatives or options, involving a variety of both qualitative and quantitative dimensions. The final output will be subjected to consultation with relevant experts.



**Figure 5.** Clusters of forest metrics and indicators combined to assess the ecological status of the stand. Note that we have yet to establish the layers for composition component.

## 3. Results and Discussions

We presented the results in two parts: (a) Metrics and its rating output (b) Ecological status based on combined clusters of metrics and indicators.

### 3.1. Metrics and rating results

Here, we demonstrate the application of the ecological assessment based on the metrics and its indicators performance of three different sites in FRIM campus (a) Field 9a: mature old growth artificially regenerated Kapur Forest (b) Field 12 C: mature old growth of artificially regenerated mixed dipterocarp forest (c) Field 43: naturally regenerated forest. Kapur (*Dryobalanops aromatica*)

is one of the major timber species in Malaysia. The stand consisted of almost pure crop of Kapus trees and form a two layer vertical structure i.e. the main canopy and the understory layer. Field 43 is a natural forest but probably in disturbed condition and remained less productive with stand volume growth is less than  $1 \text{ m}^3\text{ha}^{-1}$ . probably due to its past disturbance. Several actions are being taken by FRIM's Forestry and Environment Division to enrich the forest stand through enrichment planting of high quality timber trees.

**Table 2.** Metrics and its rating based on the traffic light colors for three field in FRIM campus.

Metric type	Metrics	Field 43	Field 9A	Field 12C
Structures	Volume ( $\text{m}^3/\text{ha}$ )			
	Biomass ( $\text{m}^3/\text{ha}$ )			
	Canopy layers			
	Top height (m)			
	Height structural indices	TBA	TBA	TBA
	Light intensity (%)	TBA	TBA	TBA
Composition	Regeneration abundance	TBA	TBA	TBA
	Indicator pioneer species	TBA	TBA	TBA
	Diversity indices	TBA	TBA	TBA
Function	Volume change ( $\text{m}^3/\text{ha}$ )			
	Biomass change ( $\text{Mg}/\text{ha}$ )			
	Relative gap size			
	Height growth (m)			
Landscape	Relative disturbance			

*TBA: to be arranged*

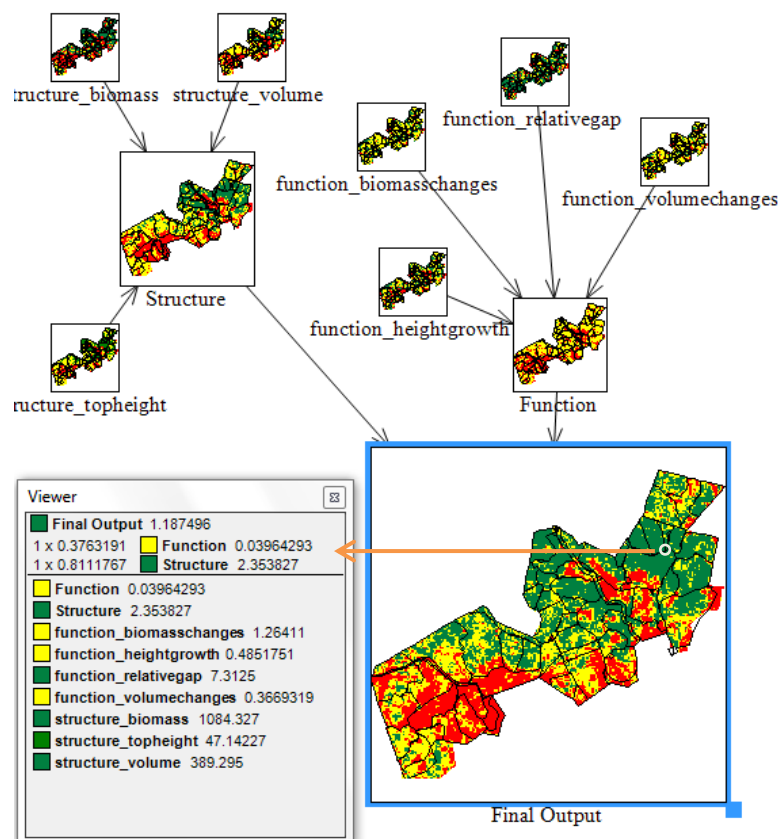
### 3.2. Ecological status based on combined clusters of metrics

The application of MCAS allows us to generate a value based on combination of metrics and its parameters. We assumed that the old growth from multi species artificially regenerated stand can be a good indicator of productive forest resembling the pristine native forest condition. A closeness of the stand to the old growth from multi species artificially regenerated stand would be the stand that has high in volume, biomass, tall height, multi structure, low light intensity, dominance of pioneers or invasive species etc. In the assessment, we included the available structure and function metrics (Table 1 and 2) to produce the expected that reflect variation in ecological status indices within the FRIM campus forest stand. The embedded box in the graph illustrates the ecological status index for the final output, and its respective structure and function cluster metrics.

### 3.3. General remarks

We have demonstrated the assessment of ecological status for 3 stand management units or known as Field within FRIM campus based on the LiDAR data and field ground sampling. We take into considerations the structures and function of the artificially regenerated forest ecosystem of FRIM campus. We are still lacking with the assessment on the composition component.





**Figure 6.** Example of GIS layer output on ecological status of forest stand based on combined metrics.

To address a complete assessment of the stand requires further effort to examine several other parameters: biodiversity indices, structural indices, and light intensity. Currently our assessment is based on LiDAR data and field sampling plot and development of statistical model to predict stand biomass and volume. Although the predictive model is perhaps sufficient for assessment of the parameters mentioned above, predicting biodiversity may requires different approach in sampling of the sites to include the variations across the campus forest. Stratification based on planting species mixture and age of stand may serve as a good criteria to examine the biodiversity variation status of various site. Height generated from LiDAR data may also be used as one criterion to relate with biodiversity variation. In general, a multi-structure forest stand consisting of the several ecological guilds have often been associated with diverse flora and fauna.

Many new forests of native and exotic species in the country are being established as parks especially in urban areas (e.g. Putrajaya) and FRIM's forest stand can therefore be a benchmark for other artificially regenerated forest. However the suitability of the tool application for forested areas of naturally regenerated stand has yet to be established. Effort has been initiated to establish a benchmark for ecological status assessment for primary and disturbed lowland forest in Sg Menyala Forest Reserve, Negeri Sembilan.



#### 4. Conclusions

The forest stand consisted of naturally and artificially regenerated stand of FRIM campus had provide us the opportunity to assess the ecological status of forest stands due to its known long history and background of the stand. The differences in the species mixtures demonstrate its long-term impact on the timber volume and biomass as well as the forest structure and may explained variation in biodiversity. Further research is required to establish the relationship of biodiversity indices from ground sampling and spectral images to upscale the value over the entire FRIM campus.

LiDAR data provides us the opportunity to address metrics and its rating of ecological status of a forest stand. The application of MCAS-S provides us with the opportunity to develop an indices based on combine metrics that may reflect the ecological status of the forest stand. However, care should be taken in assigning the combine metrics so that it will reflect the expected results.

#### 5. Acknowledgement

We would like to thanks all staff of the Geoinformation Programme of FRIM for their contribution in data collection and ground verification. We extend our gratitude to other colleagues of FRIM who have shared their views on the approach to assess ecological status of forest ecosystem at FRIM campus. Thanks to Mrs Rodziah Hashim for preparing location map. Lastly to our Director General of FRIM and other senior management officers who have been supportive of this study. The study is currently funded under the 11<sup>th</sup> Malaysian Plan, Ministry of Natural Resources and Environment entitled “Penyelidikan indeks integriti ekosistem (IIE) untuk pengurusan hutan tropika negara secara mapan”.

#### References

- [1] Francis SP 2010 100 Years of Tropical Forest Research *The Story of the Forest Research Institute Malaysia* FRIM Special Publications.
- [2] Geraldine LT Faber-Langendoen D Brian RM Shriver WG Gibbs JP 2009 Monitoring and evaluating the ecological integrity of forest ecosystems *Frontiers in Ecology and the Environment* 7(6):308–316.
- [3] Hamdan O Aziz KH Abd Rahman K 2011 Remotely sensed L-band SAR data for tropical forest biomass estimation *Journal of Tropical Forest Science* 23(3): 318-327.
- [4] Ismail MH Manaf MS 2011 The potential of LiDAR application in Malaysia *International Journal of Remote Sensing Applications* 1(1):1–5.
- [5] MCAS-S development partnership 2014 *Multi-Criteria Analysis Shell for Spatial Decision Support MCAS-S version 3.1 User guide* ABARES Canberra.
- [6] Zald HSJ Wulder MA White JC Hilker T Hermosilla T Hobart GW Coops NC 2016 Integrating Landsat pixel composites and change metrics with LiDAR plots to predictively map forest structure and aboveground biomass in Saskatchewan, Canada *Remote Sensing of Environment* 176:188–201.