National Forest Monitoring System

Background

Forest monitoring has been conducted in Malaysia since many decades with a variety of objectives and methods. It consists of both ground and spatial monitoring and has since evolved to meet current needs. Due to the geographical composition of Malaysia, different forest monitoring efforts have taken places in Peninsular Malaysia and in the state of Sabah and Sarawak however, methodologies and objectives have often overlapped.

Aerial photographs in forestry were first made in 1961. Aerial photographs with scales ranging from 1:10,000 to 1:90,000 were investigated and it was determined that the best results for consistency in stratification and forest typing could be obtained from photos with a scale ranging from 1:25:000 to 1:40:000 then. The use of Remote Sensing in Malaysian NFI started with the first inventory in 1971, using panchromatic aerial photographs of scale 1:25,000. The aerial photographs were used to stratify the mixed tropical forests into eleven broad forest types (excluding mangrove forests).

The first documentation of forest inventory methods implemented in Peninsular Malaysia is the “Manual of Malayan Silviculture for Inland Lowland Forest” published in 1954. Since then, various forest inventory methods have been formulated and documented. Forest Management inventories have been conducted to obtain information on stands of forest districts to provide information for management decisions. National Forest inventories were aimed at providing data for large scale planning.

The National Forest Monitoring System is organised in such a way respecting the constitutional arrangements within the country. It consists of two components:

- short term – use of geospatial images assessment
- long term monitoring – national forest inventory

Short term monitoring

The use of Remote Sensing in Malaysian NFI started with the first inventory in 1971, using panchromatic aerial photographs of scale 1:25,000. The aerial photographs were used to stratify the mixed tropical forests into eleven broad forest types (excluding mangrove forests). The same approach was also used for the second NFI in 1981 to assess forest

changes in peninsular Malaysia since the first inventory. For the third NFI (1991-93), space-borne remote sensing data were utilized in recognition of the usefulness of remote sensing for forest monitoring. Therefore, the third NFI was carried out using Landsat Thematic Mapper (TM) data instead of aerial photographs. THE 4TH AND 5TH NFI used SPOT5.

Malaysian Remote Sensing Agency (MRSA) and Forestry Departments has developed the forest monitoring system following the needs of the respective Forestry Departments. The objective of the system is to enhance the effectiveness of monitoring of forest resource including logging activities.

The system developed has changed the monitoring program to be more focused, improve the efficiency and effectiveness. It was developed in phases, starting in 2008, where it was first tested in Peninsular Malaysia and is being expanded to Sabah and Sarawak.

For the period, 2000 -2014, SPOT 5 was used with a spatial resolution of 10mx10m. Biennial assessment of images are the year 2000 was defined as the reference year for identifying changes and mapping, in the following periods: 2000-2002; 2002-2004; 2004-2006; 2006-2008; 2008-2010; 2010-2012 and 2012-2014.

Several analysis steps is required before a map is produced. They are image pre-processing, image enhancement and image classification as known in **Figure 1**.

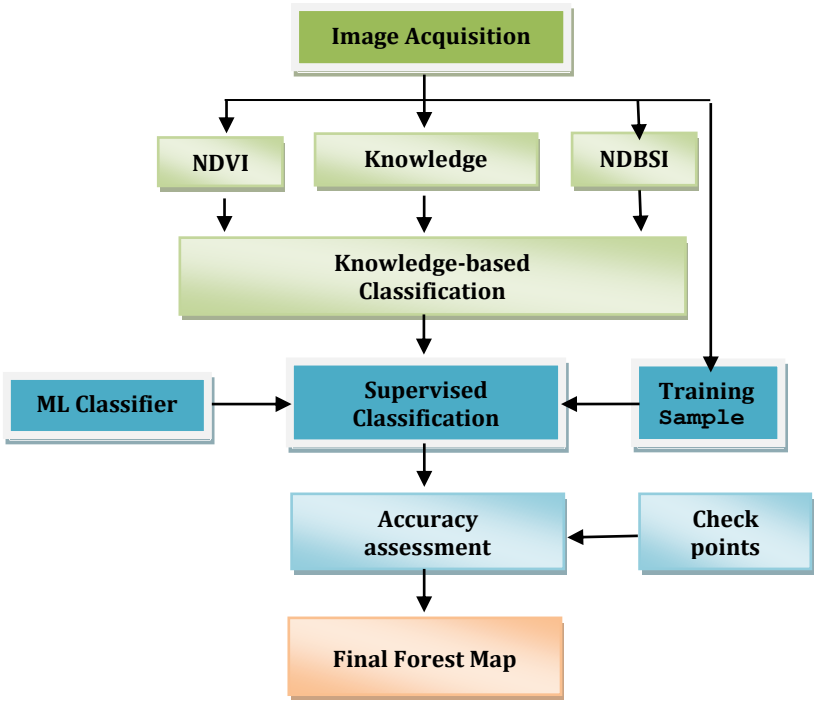


Figure 1: Generalised work flow of the analysis

Image Pre-processing and Enhancement

When image data is recorded by sensors on satellites, its can contain errors in geometry and radiometry. Pre-processing involves any operations undertaken on the imagery prior to the primary analysis. Geometry and radiometry correction and adjustment are made. The enhancement procedures are applied to image data in order to effectively display the data for subsequent visual interpretation or digital classification. The intent of classification process is to categorize all pixels in a digital image into one of several land cover classes or themes. This classified data may be used to produce thematic maps of the land cover present in an image.

CLASSIFICATION

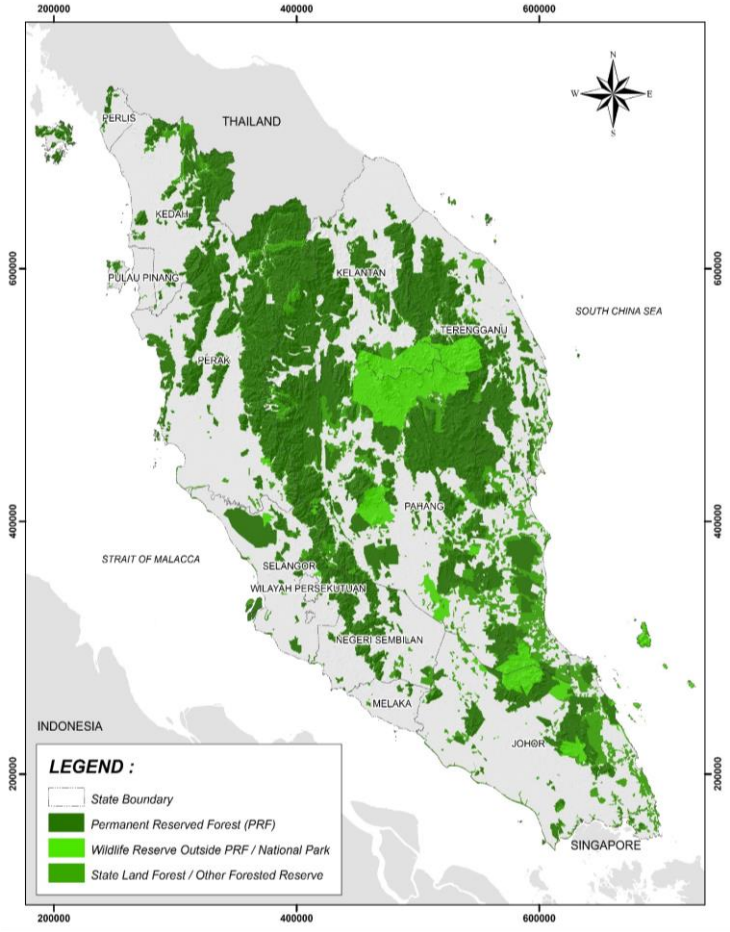
The methods of classification mainly used here are computed a linear combinations of elementary spectral bands or ratios between spectral data primitives acquired in different (in general, adjacent) portions of the electromagnetic spectrum. Normalized difference vegetation index (NDVI), which is aimed to exploit the differences in the reflectance patterns of green vegetation from other objects' spectral signatures. This vegetation indexes are based on ratios or linear combinations of spectral responses in specific portions of the electromagnetic spectrum. As well used Normalized difference bare soil index (NDBSI), which is aimed at enhancing bare soil areas, fallow lands, and vegetation with marked background response. This single value should be useful for predicting and assessing bare soil characteristics such as roughness, moisture content, amount of organic matter, and relative percentages of clay, silt, and sand. Similar to the concept of NDVI.

ACCURACY ASSESSMENT OF FOREST MAP

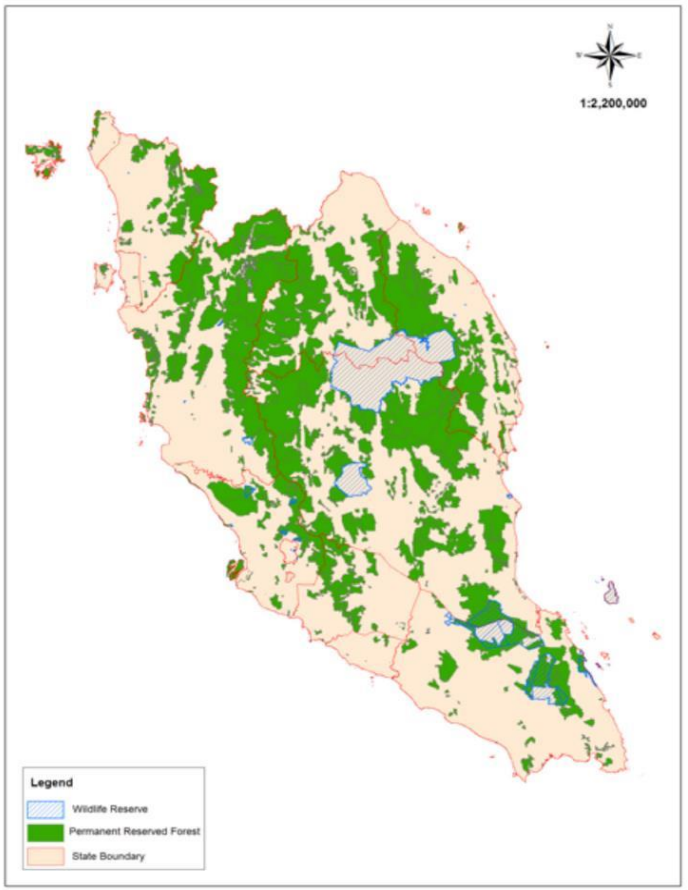
When the image has been classified, checking on some test areas is imperative to ensure that the classes mapped do effectively correspond to the thematic classes they are supposed to belong to. Estimate of this mapping accuracy will be made through a confusion matrix, which will show for each class the respective proportion of omitted, committed, and well-classified pixels. These results can create base map, which provides an approach that is proportionate to the forest types involved.

Changes in forest Areas in Malaysia

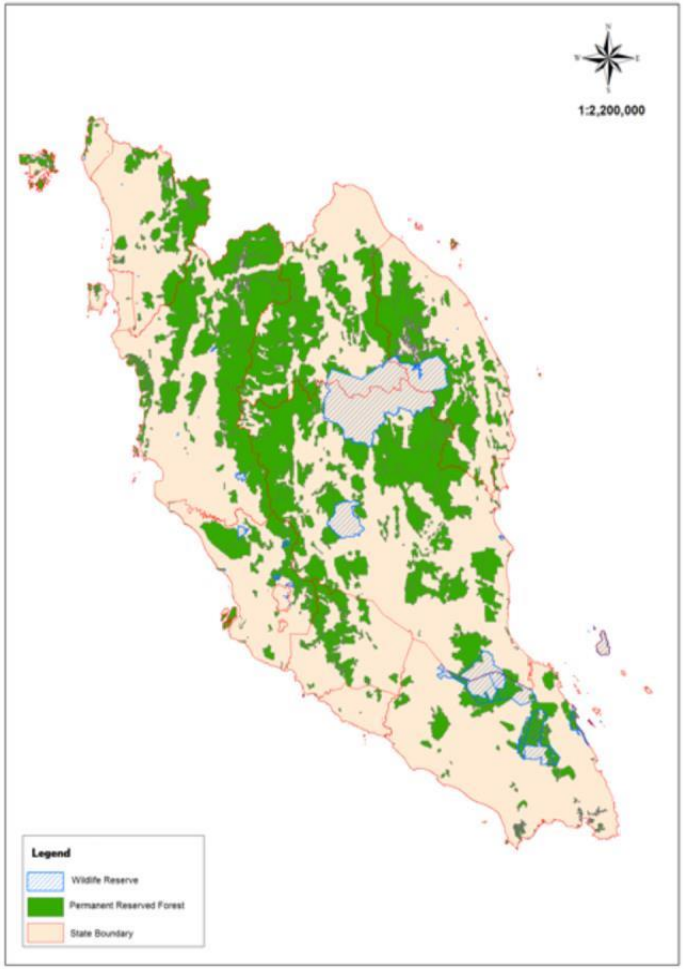
MAP OF PERMANENT RESERVED FOREST, NATIONAL P A R K AND WILDLIFE RESERVE FOR YEAR 2000



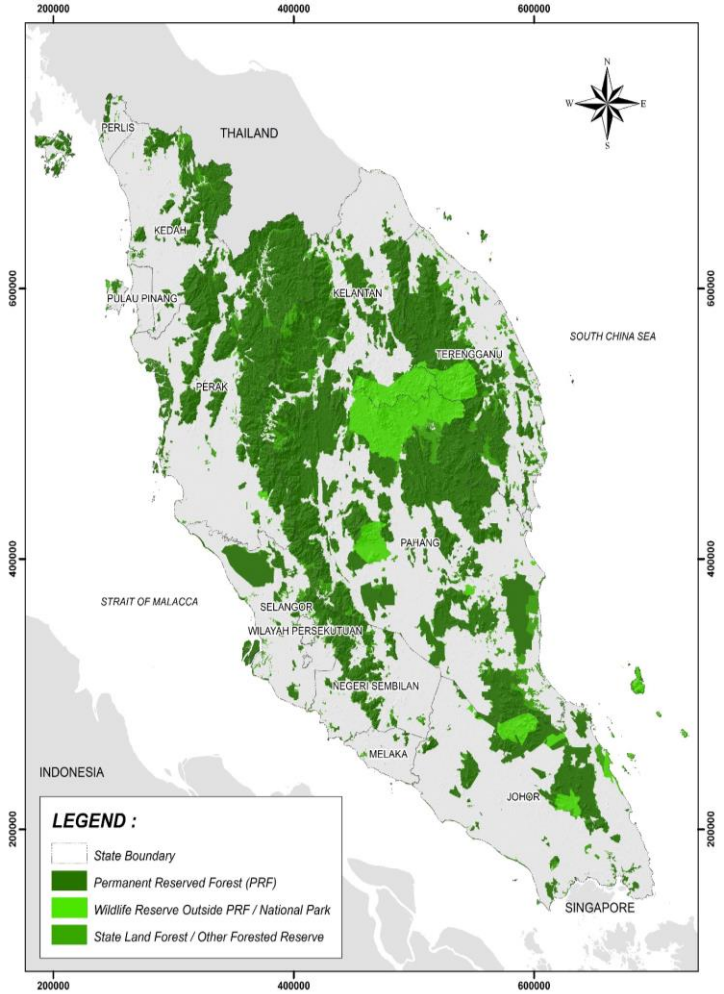
MAP OF PERMANENT RESERVED FOREST NATIONAL P A R K AND WILDLIFE RESERVE FOR YEAR 2005



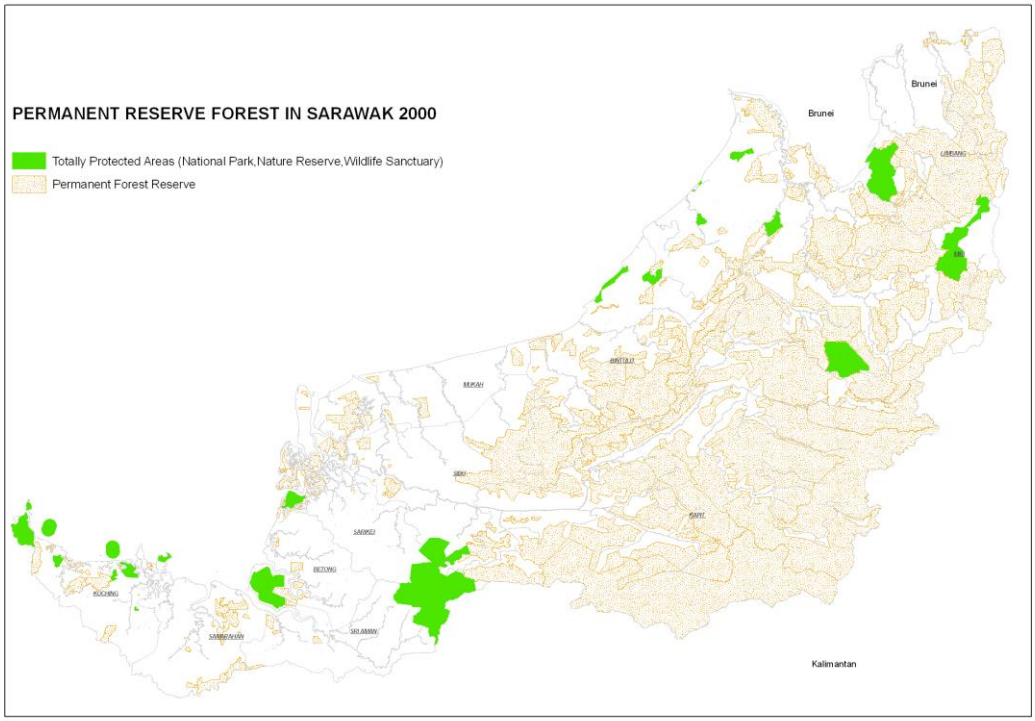
MAP OF PERMANENT RESERVED FOREST NATIONAL P A R K AND WILDLIFE RESERVE FOR YEAR 2010



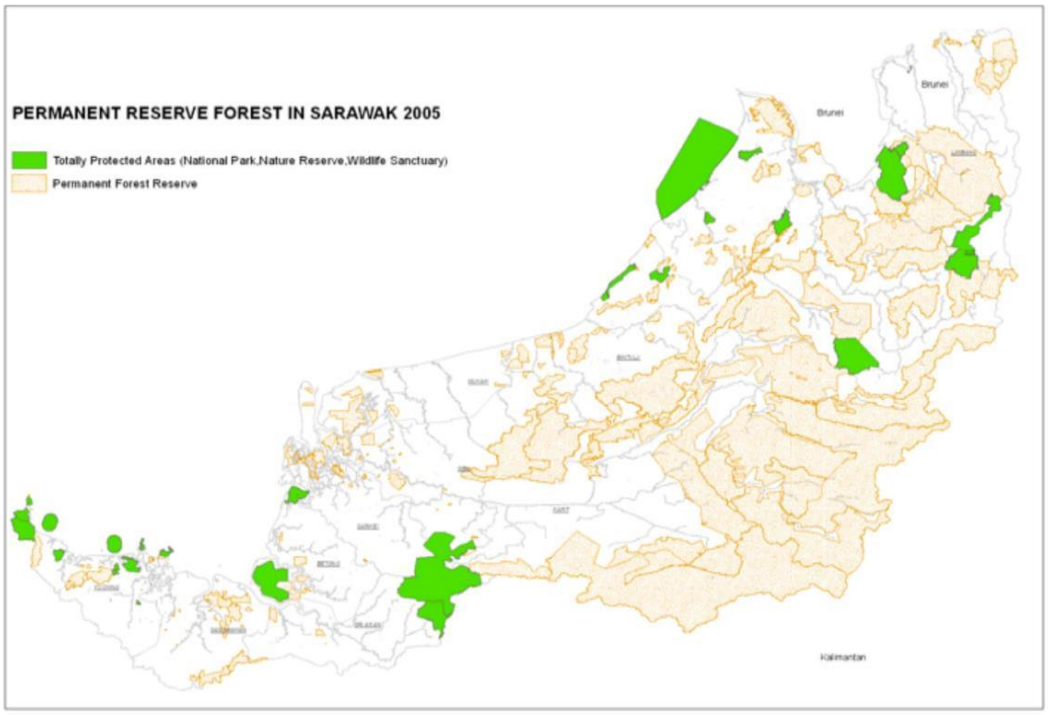
MAP OF PERMANENT RESERVED FOREST, NATIONAL P A R K AND WILDLIFE RESERVE FOR YEAR 2014



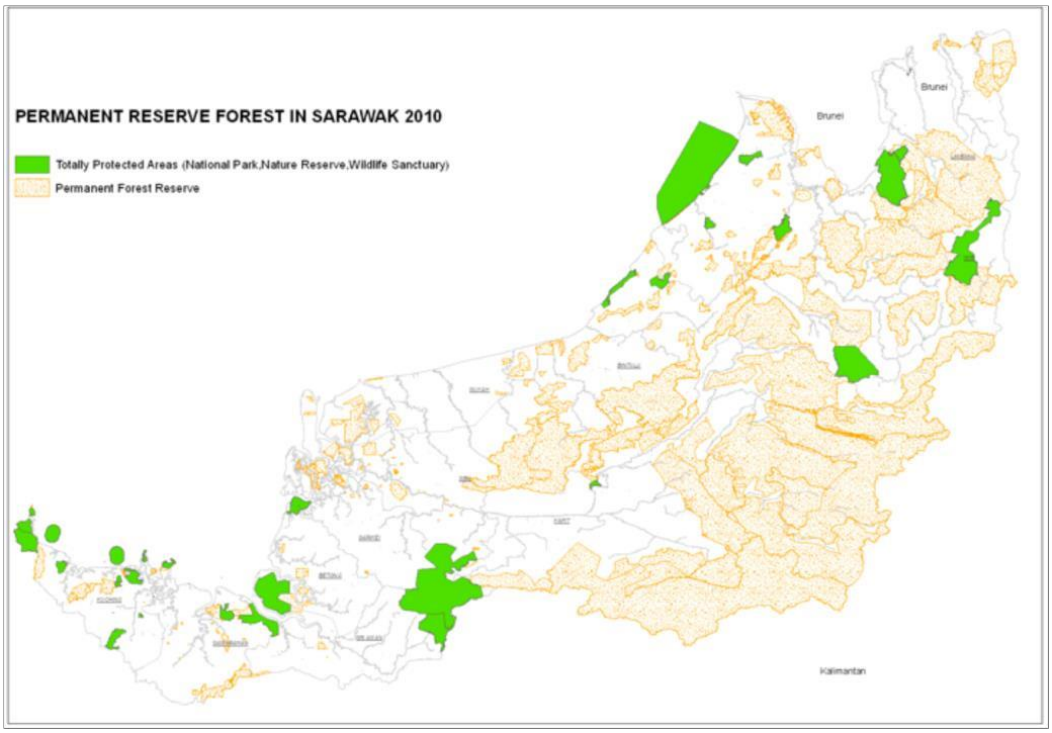
Permanent Reserve Forest in Sarawak 2000



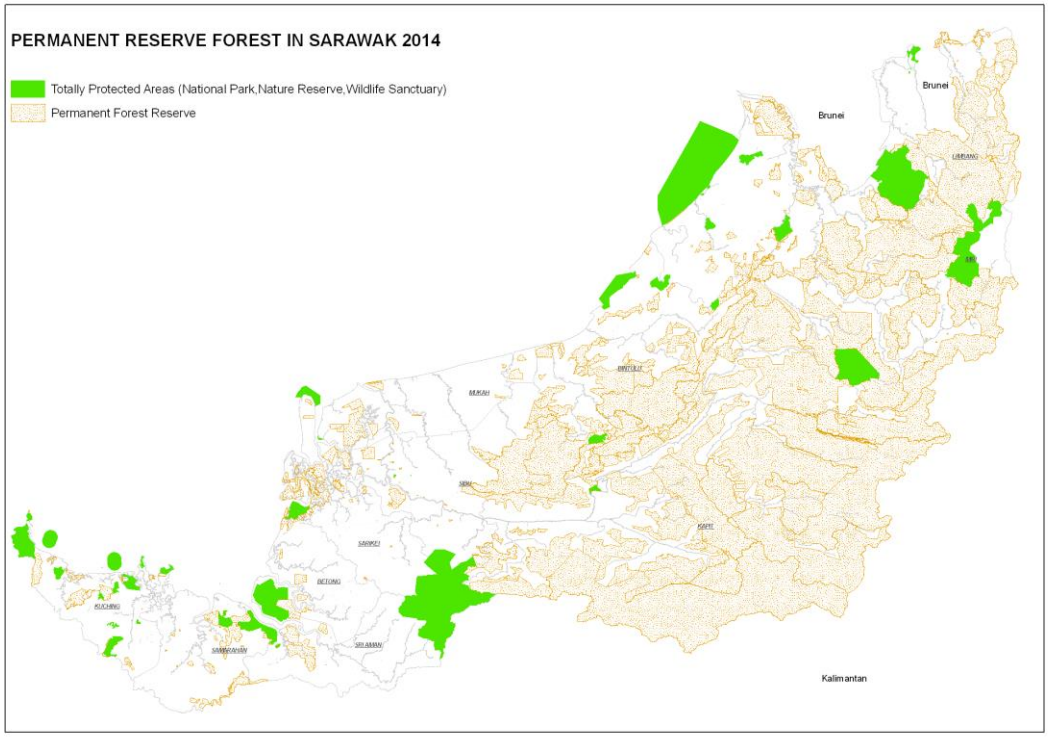
Permanent Reserve Forest in Sarawak 2005



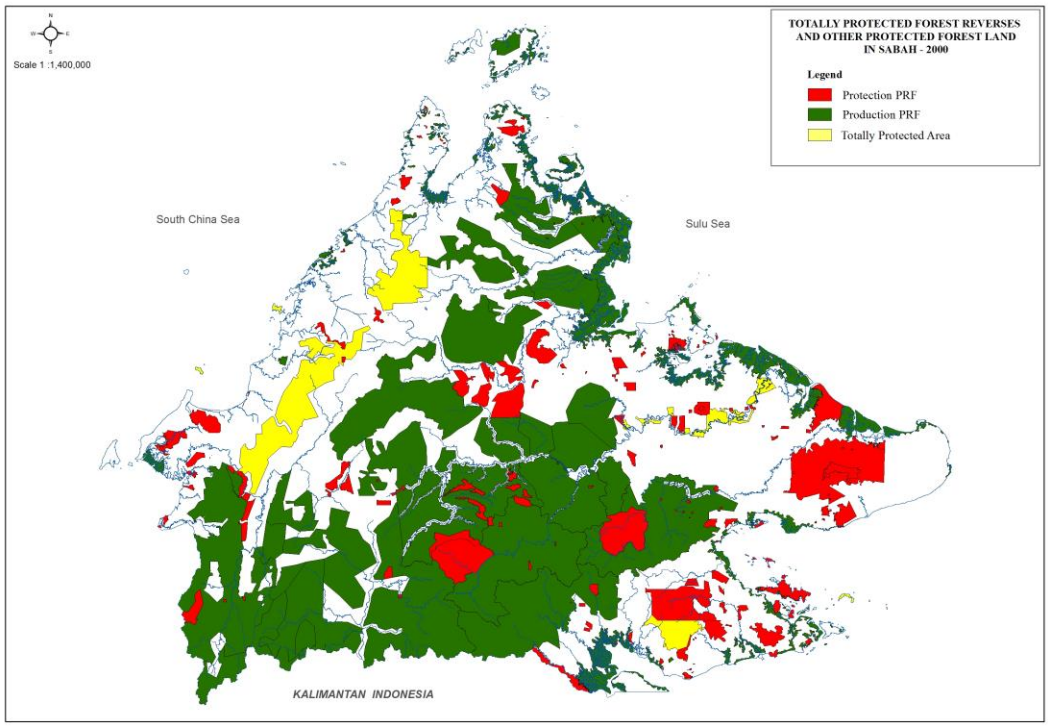
Permanent Reserve Forest in Sarawak 2010



Permanent Reserve Forest in Sarawak 2014



Totally Protected Forest Reserves and Other Protected Forest Land in Sabah – Year 2000



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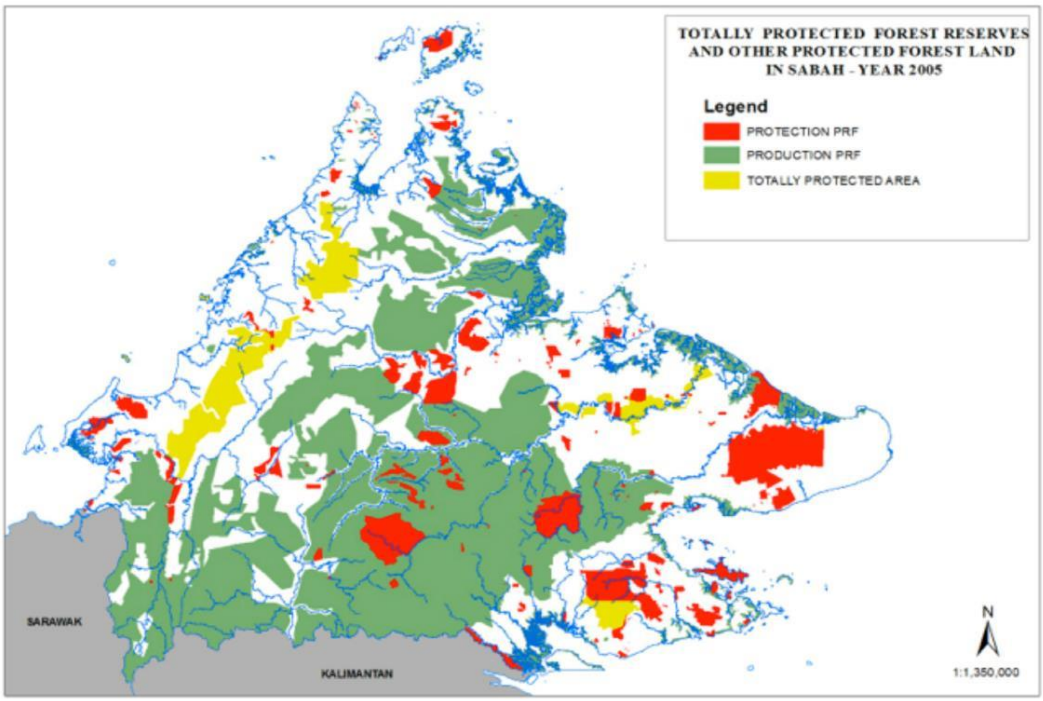
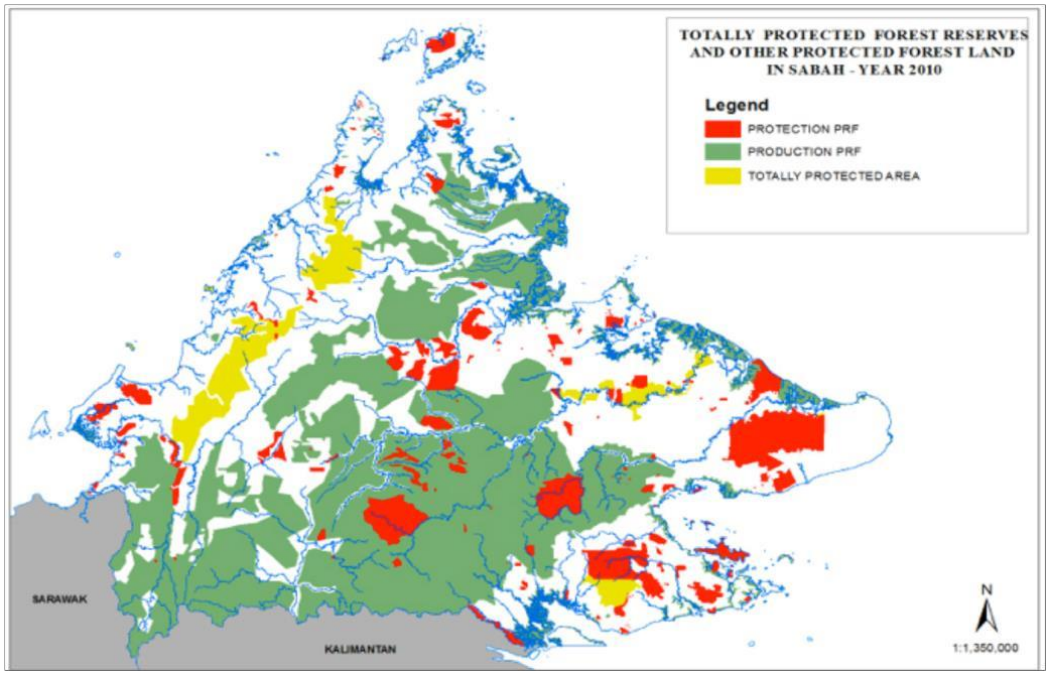
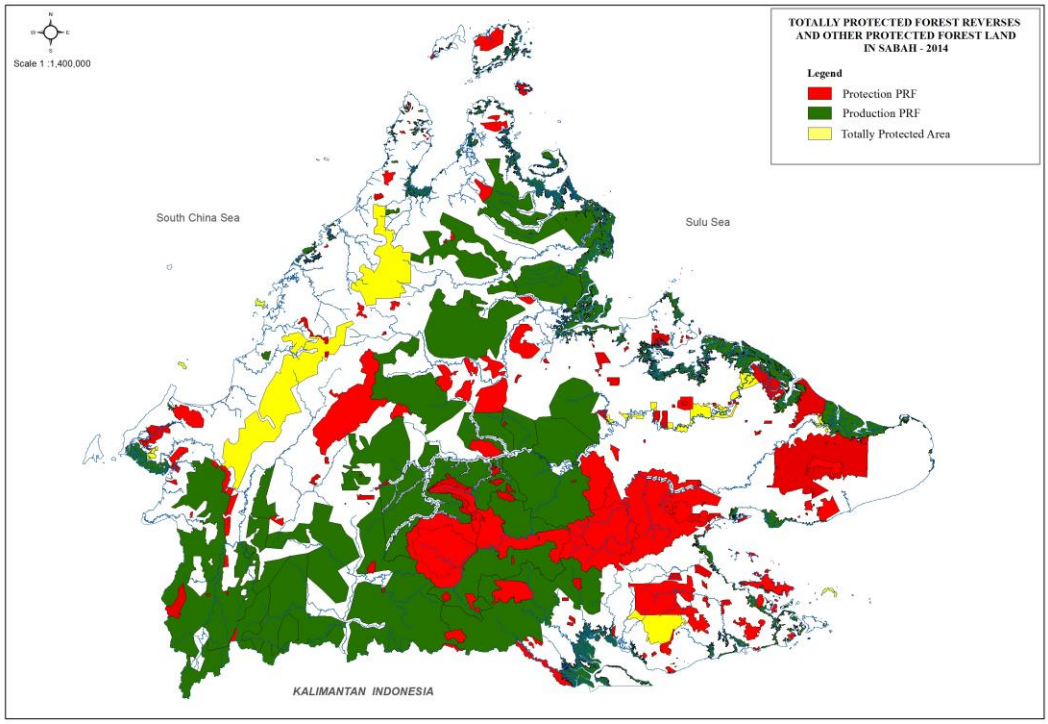


Total Protected Forest Reserves and Other Protected Forest Land in Sabah – Year 2010



Total Protected Forest Reserves and Other Protected Forest Land in Sabah – Year 2014



Total forest covered under the FRL construction

Year	TPA (ha)		PRF (ha)					State Land Forest (ha)				Excluded from FRL(ha)
	PA	Protection Forest	Inland Forest	PSF	Mangrove	Fallow	Unmanaged	Natural Forest	Drained PSF	Fallow	Unmanaged	Plantation Forest
2000	1,206,855	586,000	9,504,274	780,000	440,000	450,639	605,391	2,816,756	200,000	1,056,030	394,609	155,000
2001	1,206,855	586,000	9,504,667	690,000	440,000	449,802	606,272	2,808,220	200,000	1,056,074	393,728	154,000
2002	1,213,465	588,000	10,290,607	700,000	440,000	354,236	789,165	1,943,125	200,000	1,143,401	210,835	163,000
2003	1,213,465	588,000	10,270,820	700,000	430,000	355,366	785,837	1,951,290	200,000	1,141,202	214,163	169,000
2004	1,273,282	588,000	10,258,124	670,000	420,000	348,704	791,087	1,884,338	200,000	1,139,792	208,913	183,500
2005	1,348,880	588,000	10,243,886	660,000	440,000	325,974	812,236	1,669,762	200,000	1,138,210	187,764	200,000
2006	1,348,880	589,000	10,243,680	660,000	440,000	321,594	816,593	1,621,347	200,000	1,138,187	183,407	232,000
2007	1,350,290	594,000	10,096,169	670,000	440,000	325,171	796,626	1,613,557	200,000	1,121,797	203,374	301,910
2008	1,350,290	611,000	10,064,485	660,000	440,000	323,627	794,649	1,594,168	200,000	1,118,276	205,351	318,662
2009	1,363,281	611,000	9,951,418	480,000	430,000	353,901	751,812	1,863,109	200,000	1,105,713	248,188	348,399
2010	1,387,879	723,000	9,812,456	490,000	430,000	374,553	715,720	2,050,588	200,000	1,090,273	284,280	368,215
2011	1,427,217	723,000	9,814,366	500,000	430,000	360,953	729,533	1,922,721	200,000	1,090,485	270,468	462,682
2012	1,429,954	1,029,000	10,198,850	510,000	440,000	194,327	105,458	2,035,621	200,000	1,000,000	374,327	495,714
2013	1,461,378	1,092,000	10,066,078	500,000	450,000	197,569	105,872	1,986,519	200,000	1,000,000	367,569	629,170
2014	1,461,362	1,296,000	9,975,221	510,000	460,000	84,839	59,785	2,702,786	200,000	600,000	374,327	495,714

Source: http://www.nre.gov.my/sites/climatechange/Initiatives-and-Programmes/redd/Pages/default.aspx

Long term monitoring

At the macro level, The First National Forest Inventory of Peninsular Malaysia (hereafter known as NFI-1) was carried out between 1970-1972 by Forestry Department Peninsular Malaysia with assistance from the Food and Agriculture Organization of the United Nations (FAO) with aid from the United Nations Development Programme (UNDP) through the "Forestry and Forest Industries Development Project (FO: DP/MAL/72/009)" (Anon 1973).

The cluster sampling design was adopted for use during the NFI-1 to compensate for the major fluctuations in the stand structure of the Peninsular Malaysia's rainforests, and to balance the volume estimates at the microsite level, which become increasingly homogenous over expanding areas of the forest. These would therefore negate the use of simple random sampling for NFI-1.

The Second National Forest Inventory (NFI-2) of Peninsular Malaysia undertaken solely by the FDPM during the 1980-1982, was largely to update the existing forest resources information collected previously during the First National Forest Inventory. During the NFI- 2, some of the sampling units measured during the NFI-1 in 1970 - 1972 were re-measured, in addition to establishing new sampling units, thereby ensuring the continuity of the system. As such, these NFIs were considered as, Inventories on Successive Occasions with Partial Replacement.

NFI-2 followed the same design as NFI-1, with primary sampling points being fixed at the intersection of the 5 minute grid and within each primary sampling point were the 12 fixed secondary sampling points, each being a rectangular plot measuring 20x50 meters and covering an area of 36 hectares (Anon 1987). All trees having diameters of 30 cm and above were enumerated (Anon 1987). However, NFI-2 differed from NF-1, as it included an added dimension, in that all trees of between 15-30 cm diameter classes were measured, during the sub-sampling of 3 of the 12 secondary sampling points, as well as sampling of rattan and bamboo species.

The sampling design for the Third National Forest Inventory (NFI-3) was formulated through a joint project between the Government of Malaysia (GOM) and the Food and Agriculture Organization (FAO) of the United Nations, with aid from the United Nations Development Programme (UNDP).

The NFI-3, a follow-up to the previous NFI (NFI-1 and NFI-2), was undertaken during 1990- 1992 to collect the most recent and up-to-date data on the forest

resources in Peninsular Malaysia, for use in the planning, management and development of the present and future forest resources. The NFI-3 was planned in such a way to be carried out continuously and to fit into the framework of the Continuous Forest Resources Monitoring System (CONFORMS), using forest inventory data and satellite imagery to formulate and develop suitable methodologies for classifying the natural forest into appropriate management and productivity classes under sustained yield management. The fieldwork of CONFORMS was planned to coincide with that of the NFI-3.

The NFI 4 inventory design is described as a stratified satellite based on randomly distributed permanent sample units.

Sabah

In Sabah, the first statewide forest inventory was conducted from 1969 to 1972 under the Canadian Bilateral Aid Programme (Colombo Plan). Another statewide forest inventory of the disturbed forests has also been carried out during the period 1986-87 by the State Forest Department of Sabah with the assistance of UNDP/FAO.

Sarawak

A forest resource inventory was carried out by FAO during the period 1969-72 under the Forestry and Forest Industries Development Project. Eight industrial units of Mixed Dipterocarp forest covering a total area of 1.2 million hectares were inventoried. Following FAO's forest resources inventory, the State Forest Department of Sarawak has been carrying out forest inventories on different forested areas annually.

National Forest Inventory Design

Field Inventory

The sampling design consists of permanent sample units (satellites) of square shape with one sample plot in each corner. Each sample plot consists of a sample circle for small size trees and a point sample. Each sample unit consists of four (4) sample plots and three (3) sample strips. Each sample plot is a combination of a fixed sample circle of 4 m in radius and a point reference. The distance between the sample plot is 100 m. The total sample area is 0.12 hectare. Within the sample circle only commercial trees <10 cm

Dbh and >1.5 m in height and some key medicinal plants are assessed. The strip sample area is about 0.02 hectare resulting in total sample area at 0.14 hectare.

Management Level Forest Inventory

At the management level, the forest inventory is carried out with sample plots laid along sampling lines 100 m. apart and 200 m. between plot centers. However, this type of inventory is seldom carried out due to shortage of funds and manpower. Hence, in order to quantify the forest resources at the management level, a systematic sequential sampling (SSS) is carried out in the logged over forest types. The inventory design then consists of principal plots of 60m x 20m and four sub-plots of 20 x 20m, 10 x 10m, 5 x 5m and 2 x 2m with the principal plots being 120 m apart along the sampling line or 180 m from one plot center to the next while the distance between sampling lines is of 200 m. The different sampling plots sizes are designed for collecting different size class trees.

Operational Level Forest Inventory

At the operational level, three types of forest inventory are being carried out as follows: (i) linear enumeration of big trees, (ii) pre-felling forest inventory and (iii) post-felling forest inventory. The linear enumeration of big trees is usually carried out to estimate the volume of timber present in a given area prior to logging. The sample or enumerate area consists of 20 m wide, straight, serially numbered strips, 10 m on both sides of the sampling line.

The pre-felling forest inventory is carried out to determine the stand structure of the forest before harvesting starts and to determine the appropriate felling regime which will be equitable to both logger and forest owner and to ensure ecological balance and environmental quality. The inventory is carried out using systematic line plots of 50 x 20 m. with four sub plots of 25 x 20m, 10 x 10m, 5 x 5m and 2 x 2m. Different size trees are enumerated in each size subplot. The presence of bamboos, *Eugeissona triste* (bertam), palms and ferns is also recorded in the principal plot of 50 x 20m along with other features such as slope, aspect, elevation, soil and forest type.

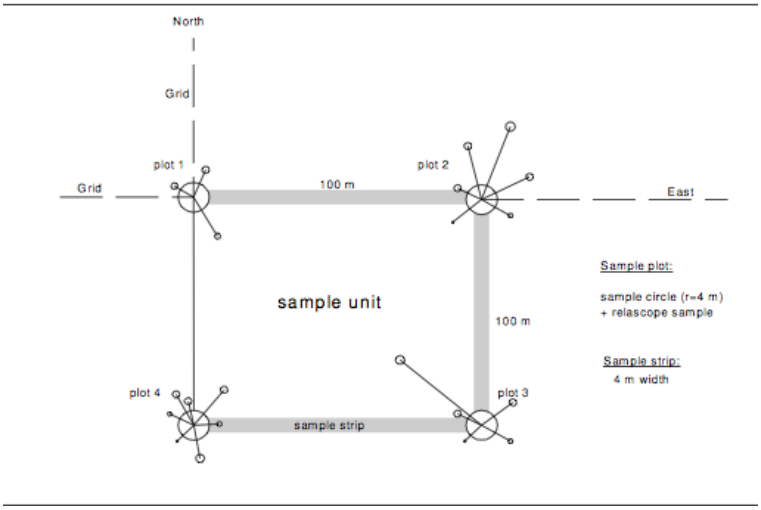
The objective of post-felling forest inventory is to determine the regeneration status of the harvested forest in terms of stocking, composition, size and distribution in order to consider appropriate silvicultural treatments. Two sampling designs are used for post felling forest inventory. The first sampling

design uses strip sampling which is also known as Linear Regeneration Sampling I (LRS I). The strip consists of two quadrants of size 10 x 10 m and 2 x 2 m. along sampling lines laid out 200 m. apart. The second sampling design consists of systematic line plots of 50 x 20 m with four sub plots of 25 x 20m, 10 x 10m, 5 x 5m and 2 x 2m, similarly to the pre-felling forest inventory.

Besides inland forests, the mangrove forests in peninsular Malaysia are enumerated using systematic line plots of 5 m. radius (0.008 ha) laid along sampling lines at 100 m intervals with distance between plot centers of 20m.

The 4th and 5th NFI inventory design is described as a stratified satellite based on randomly distributed permanent sample units. The sampling design consists of permanent sample units (satellites) of square shape with one sample plot in each corner. Each sample plot consists of a sample circle for small size trees and a point sample. Each sample unit consists of four (4) sample plots and three (3) sample strips. Each sample plot is a combination of a fixed sample circle of 4 m in radius and a point reference. The distance between the sample plot is 100 m. The total sample area is 0.12 hectare. Within the sample circle only commercial trees <10 cm Dbh and >1.5 m in height and some key medicinal plants are assessed. The strip sample area is about 0.02 hectare resulting in total sample area at 0.14 hectare. For growth and yield plots, the diameter of all free-standing trees ≥ 10 cm diameter at breast height (dbh) was measured at least twice, using standard protocols.

Figure 1: Layout of sampling unit



Tree diameter growth was checked for all stems, and outliers were treated. Tree diameter and height was measured for all trees per hectare, using a standardized stratified-random sampling approach whereby trees were randomly selected from four size classes (10– 20, 20–30, 30–40 and > 40 cm diameter). The stratification are based on forest type and post logging years.

Based on the National Forest Inventory, the biomass increment for forest logged between 1-10 years, 11-20 years and 20-30 years is between 9.2 – 12t/ha/yr. However, a significant decline is noted after 30 years to 4.3 t/ha/yr. Hence, Malaysia's set its logging cycle of 25-30 years, based on these figures.

Above-ground biomass (AGB) increments cannot be directly measured but estimated by applying allometric relationships relating stem diameter, height and wood density to AGB. The increment was calculated by comparing the growth difference in ABG. The increment was determined for each diameter class and forest stratification between 2002 and 2012 Inventory cycle. For means of comparison, biomass increment was also calculated using the equation presented by Brown (1997), as follows:

$$Y = 42.69 - 12.8 \times (D) + 1.242(D^2) \text{ – Brown 1997}$$

Y= biomass tonne

Biomass density of a strata is estimated using the equation above. Number of trees/ha is obtained from the Forest inventories and the mid point of biomass class is determined. Biomass of tree at mid point is determined using the equation above and biomass of all trees is determined by multiplying the number of trees with the biomass of tree at mid point.

For the analyses of individual trees, both diameter growth and above ground biomass were calculated using the census interval that was > 5 year to reduce noise associated with inter-annual differences and that minimized the difference from the median date for all censuses.

Activity	**Methodology**
Forest land area	Map, Remote Sensing Survey
Area of forest canopy/crown cover	Map, Remote Sensing Survey
Area under formal forest management plan	Map, Remote Sensing Survey
Area under sustainable forest management	Map, Remote Sensing Survey
Forest area with certification	Map, Remote Sensing Survey
Forest fires	Field survey and records
Forest Characteristics	
Distribution of forests	Map, Remote Sensing Survey

For mangrove, Ong and Gong (1993) were used. Allometric techniques, were also used to estimate the mean annual increment based on age of the forest. National studies were undertaken between 2011-15 to assess the growth of mangroves and the reports are being finalised. The initial reports indicated that the growth rates for mangrove forest are between 10- 17 t/ha/yr. The equation is as follows: $Y = 0.0277DBH^{2.1668}$