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# GEOSPATIAL INFORMATION TECHNOLOGY FOR SUSTAINABLE FOREST DEVELOPMENT IN MALAYSIA

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***Abstract***

Growing Malaysian population density lead to scarcity of forest land and widespread changes in forestry land use leading to widespread environmental problems. To solve these problems and to make sure that future generations can enjoy the benefits of the Malaysia's forest resources, better and more careful sustainable development of our forest resources is needed. In the establishment of sustainable development of this forest resources, planners, managers, policy makers and researchers alike need to understand the complexity of factors involved. They must collect and interpret the required data and work together with professionals from other disciplinary fields. Geospatial information technology and especially remote sensing, plays an important role in these tasks. The objective of this paper is therefore to illustrate the usefulness of remote sensing technology in providing a synoptic view and spatial geo-information for sustainable forest development in Malaysia. Specific attention is given to some selected successful case studies involving mapping deforestation in permanent forest reserves (PFR's), forest type and forest land use classifications, forest inventory, forest recreation planning, water turbidity in dams, forest road and timber harvesting. Modern remote sensing (RS) techniques including airborne hyperspectral sensing were digitally analysed and integrated with geographic information system (GIS) and global positioning system (GPS) to collect, quantify and map in a statistically acceptable and sound way, geo-referenced information to support sustainable forest development. The paper also presented a spectrum of recent developments in spatial data capture and analysis techniques in the RS of forest condition. Results indicated that optical data sets such as LANDSAT TM and SPOT imagery provide macro level forest information such as forest fire planning and inventory, airborne radar AIRSAR-TOPSAR data provides the opportunity to penetrate the forest canopy and assess attributes to forest type/land cover mapping, high-resolution imagery such of IKONOS-1 data provides mapping of precise wetland forest, hyperspectral scanners can map individual forest trees/species and change detection which provides efficient, statistically based means of quantifying trends in forest condition. Some interesting and innovative developments in RS such as those presented in this paper show considerable promise in this area.

***Keyword***: Geospatial information, sustainable, forestry, development

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## INTRODUCTION

Interest in monitoring the condition of forest resources is growing worldwide. This reflects increasing community awareness and concern for sustainability of natural resource use. Sustainability is commonly defined as meeting the needs of the current generation without comprising the ability of the environment to meet the needs of future generation. As for Malaysia, the greatest challenge facing her forest resources is to sustainably improve its carrying capacity on a sustainable basis to meet the basic minimal requirements of the future generations (Mohd Hasmadi and Kamaruzaman, 1999). The only hope to ensure habitality of future Malaysian generations with a reasonable quality of life is through initiation of sustainable integrated development on a national basis, to provide minimal food and water, without impairing ecological and environmental integrity.

To meet the requirements of state-of-the-sustainable forest resources reporting, criteria and indicators need to be easily quantified, identified, interpretable and assessable (Kamaruzaman and Haszuliana, 1998). This requires a geospatial data-capture information technology program to efficiently and effectively assess the attributes relevant to the criteria and indicators of sustainability. The term "geospatial information technology (GIT)" refers to the information technology (IT) that identifies the geographic location and the characteristics of natural or constructed features and boundaries on the earth. This IT may be derived from, amongst others, remote sensing, Geographic Information System (GIS) and Global Positioning System (GPS).

The importance of GIT, especially remote sensing to sustainable forestry development in Malaysia has markedly increased during the last few years (Kamaruzaman, 2000). In this paper, I will "paint a canvas" of how remote sensing from the vantage point in space and airborne can provide a vast array of information on spatial and temporal formats to initiate a new Malaysian green revolution for sustainable forestry development.

## MATERIALS AND METHODS

### Location of Study Area

A total of seven study sites were selected for this study. The study areas include Sipitang Forest Reserve (F.R) and Kalabakan/Gunong Rara F.R., Sabah, Ulu Langat F.R., Selangor, Gunong Stong F.R., Kelantan, Larut Matang Mangrove F.R, Perak, Mersing, Johor, Langkawi Island, Kedah and Tioman Island, Pahang.

### Satellite/Airborne Data and Image Selection

A multi-temporal SPOT HRV(XS) 20 m resolution quick look data dated 6 February, 24 February and 4 March 1998 were acquired over Sipitang F.R. in a 60 x 60 km scene (Mohd Hasmadi and Kamaruzaman, 2000). These quick look images were sub-sampled from the full resolution scenes at 100 m interval while preserving the radiometric characteristics of the original values.

Landsat TM data over Gunong Stong F.R and Tioman Island were purchased from The Malaysian Center for Remote Sensing (MACRES). For Tioman Island, a 1991 Landsat TM digital spectral data with spatial resolution of 30 m for path/row 125/58 and less than 30% cloud cover in Computer Compatibe Tape (CCT) was acquired (Azian and Kamaruzaman, 2000). Meanwhile, a Landsat TM scene 127/58 (path/row) of date 25 May 1996 was used for the turbidity mapping in Semenyih and Ulu Langat district (Mohd Hasmadi and Kamaruzaman, 2000). In the case of recreation planning, a Landsat TM taken on 30 January 1992 over Langkawi Island was acquired for path 128 and row 56 with less than 5% cloud cover.

IKONOS-1 Caterra Geo Product data ( 1 m panchromatic- sharperned) purchased from Juru Ukur Perunding came with four CD Roms and was stored in GeoTIFF format. The data which covered the coast of Mersing was stored in 11 bit with 20% cloud cover. The data came with multiple source images which were not mosaicked, where tonal variations between scenes were be evident.

AirSAR data in the cross-track interferometry (XT1) or topographic SAR (TOPSAR), covering the entire island of Tioman comprised of two strips, taken on a 3rd. December 1996 flight. The data constitute the C – band single baseline cross-track interferometry in VV polarization only. The data also contain the polarimetric L-and P-bands. All three bands, C-VV, L-and P-band polarimetry were acquired using the 40 Mhz mode, giving the image an approximate 10 km cross track swath and DEM posting at 10 x 10 m. All data were stored separately in CD-ROMs with file headers as *Tioman* 1 and *Tioman* 2.

CASI (Compact Airborne Spectrographic Imager) Hyperspectral is a compact and programmable pushbroom scanner built in Canada by ITRES Research. This instrument operates over 545 nm spectral range within 400 to 1,000 nm (visible to NIR wavelength), 2.2 nm spectral resolution (1.9 nm spectral sampling), 512 pixels swath width and 288 maximum bands. It utilizes the forward motion platform to form a two-dimensional image of the scene below and was operated in a hyperspectral mode which combined the spatial and spectral modes. The CASI data was acquired using a Cessna aircraft flown from Darwin, Australia to Sabah collecting imageries over Kalabakan/Gunong Rara F.R. The mission was started on January 11 and completed on January 18, 1998.

**Digital Image Pre-Processing/Processing**

All data were subjected to pre-processing involving radiometric and geometric correction. The optical datasets image processing was performed using the ER Mapper/PCI EASi/PACE image analysis ver.6.1 and 6.2 computer software package available at The Forest Geospatial Information and Survey Lab, Lebuh Silikon, Faculty of Forestry, Universiti Putra Malaysia, Serdang. Meanwhile the AIRSAR TOPSAR and CASI data in CD format were processed using Environment for Visualization Images (ENVI) ver. 3.1 and Erdas Imagine ,respectively also available at similar lab. ENVI 3.1 and Arc View 3.2 were also used to process the image for SPOT XS image and IKONOS data for the Matang Mangrove F.R, Kuala Trong and Mersing, respectively. Due to the speckly nature of the optical and radar imagery, enhancements, band combination, contrast stretching and filtering were required before supervised and unsupervised classification and other analysis can take place.

**Field Work/Ground Verification**

Using ARC VIEW (a GIS software package), on a notebook computer linked to a GPS, the classified and enhanced images were taken to the field for ground truthing together with other data sets. In the case of forest inventory mapping and timber volume estimation, field verification involved sampling plots and measurements of standing tree volume at diameter breast height (dbh) and DGPS for precise tree marking. For water turbidity mapping in the Langat Basin, manual water sampling was conducted and analysed with the aid of a GPS to measure the position at the sampling station.

**Assessment of Mapping Accuracy**

The classification accuracy assessment depends on the collection of ground truth. Accuracy assessment needs to ensure that the classification done was precise as to the real condition on the ground. The original references data were obtained from ground visits, topographic map and secondary data from the Forestry and relevant departments.. For digital mapping, the accuracy assessment sites were represented by grouping of pixels and compared them with the references data for the sites and categorized data for similar sites. The reference data was simply done by calculating percentage of the truly classified pixels over total number of pixels that were presented in the confusion matrix. The accuracy was calculated using the following formulae:

$$\% \text{ Accuracy} = \frac{\text{Total Accurate Number of Independent Samples After Training}}{\text{Total Number of Samples}} \times 100$$

## RESULTS AND DISCUSSIONS

### Mapping Deforestation in Permanent F.R

By integrating remote sensing and GIS, the extent of the Permanent F.R that had been converted into non-forestry purpose within eight years was estimated to be 73,236 ha with a 2.3% rate of deforestation per year (Iwan and Kamaruzaman, 2001). The PFR's area extent declined from 402,585 ha in 1989 to 329,349 ha in 1997. The change from forest into mixed crop or rubber within eight years (1989—1997) was estimated to be 19,252 ha. About 53,984 ha of forest was deforested into shrubs, while approximately 1,178 ha of forest were converted into grassland/open areas. Deforestation was mostly located close to transportational features like roads, logging roads and rivers (Figure 1).

Generally, the deforested areas were located in radius of 1km from the roads, rivers or both. Although the Landsat TM image was not capable to differentiate between rubber and secondary forest or shrub, the deforested areas were detected easily using Landsat TM image.

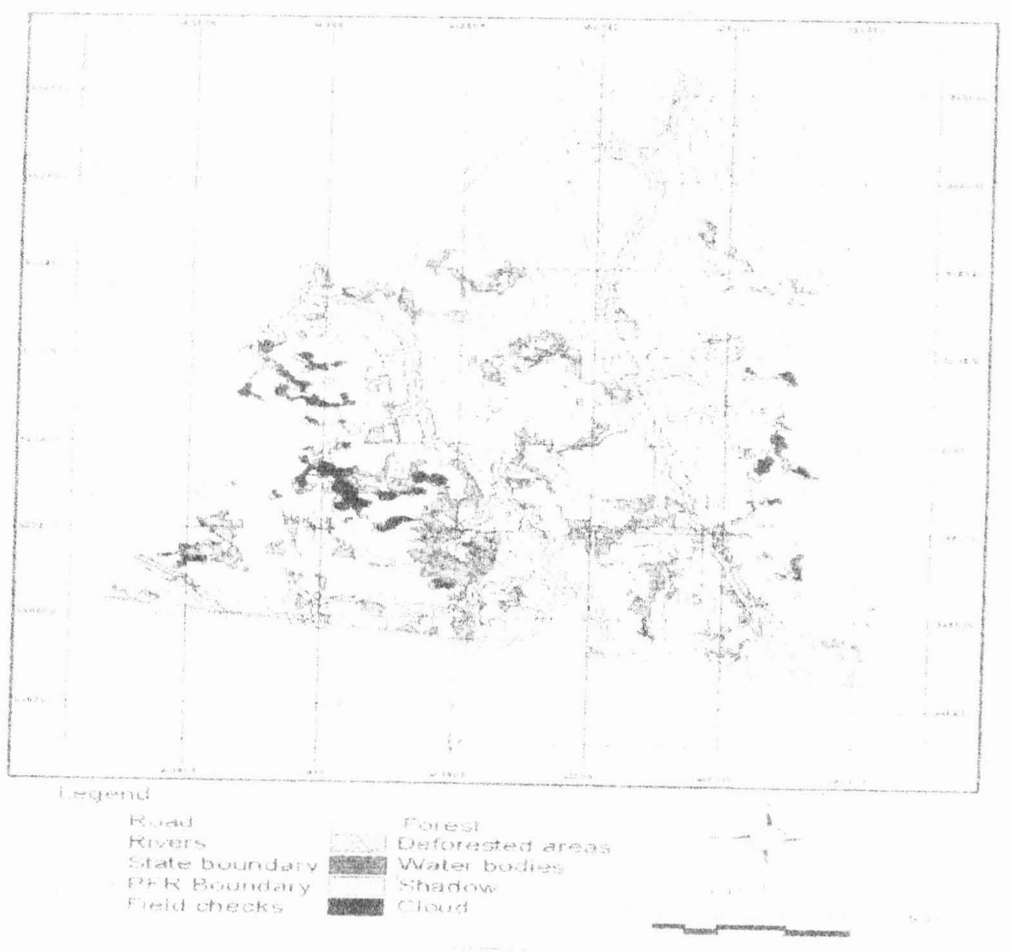


Figure 1: GIS analysis of deforestation in relation to rivers and roads in Northern

**Forest Recreation Planning**

Based on a Potential Surface Analysis (PSA) model with six parameters for potential recreation identification, a spatial map showing the most potential and moderate potential recreation sites were established with a mean overall accuracy of 82% (Figure 2). The quantitative approach on supervised classifications with the combination of Landsat TM bands 452 (FCC) gave satisfactory results in classifying a total of nine land use types namely inland forest, mixed horticulture, prawn breeding site, rubber estate, urban area, mangrove forest, natural bare land, paddy field, and water bodies. It was found out that the most undeveloped forested areas showed the highest potential for recreational development if sustainably managed.

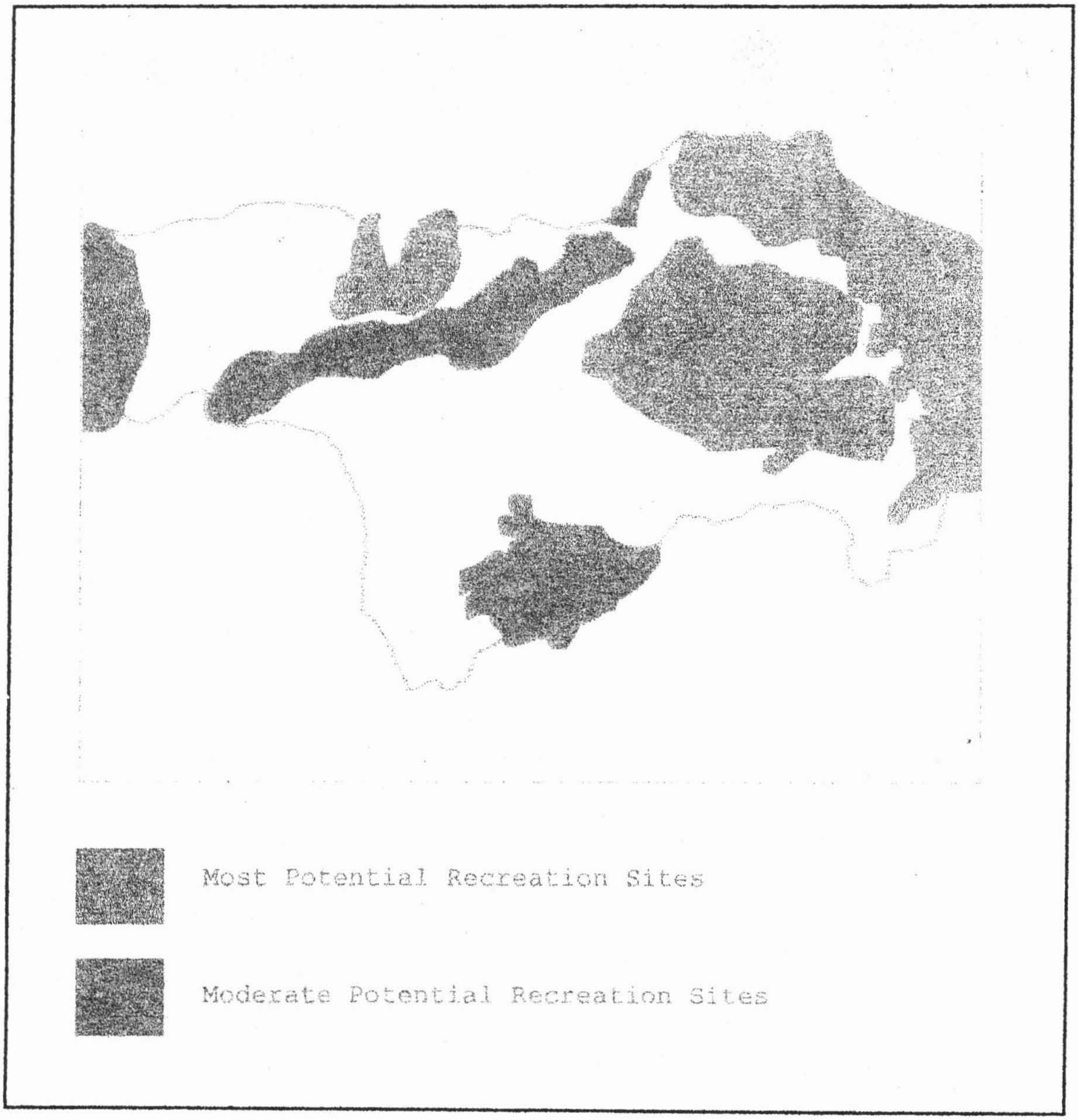


Figure 2: Location of Potential Recreation Sites in Pulau Langkawi based on Landsat TM Imagery

**Water Turbidity Mapping**

Using the density slicing-contrast stretching technique and ground data collection, the distribution of water turbidity level in Semenyih Dam, Ulu Langat F.R was successfully estimated (Mohd Hasmadi and Kamaruzaman, 2000). The spectral ranges of TM1, 2 and 3 were able to map three classes of water turbidity (Figure 4) 1in the dam using digital numbers ranging from DNs 9-11 (7.1-9.0 FTU), DNs 4-8 (5.1-7.0 FTU) and DNs 1-3 (<5.0 FTU). From the satellite imagery, the forest land use surrounding the dam seems to decline due to agriculture conversion and this resulted in water turbidity in the dam.

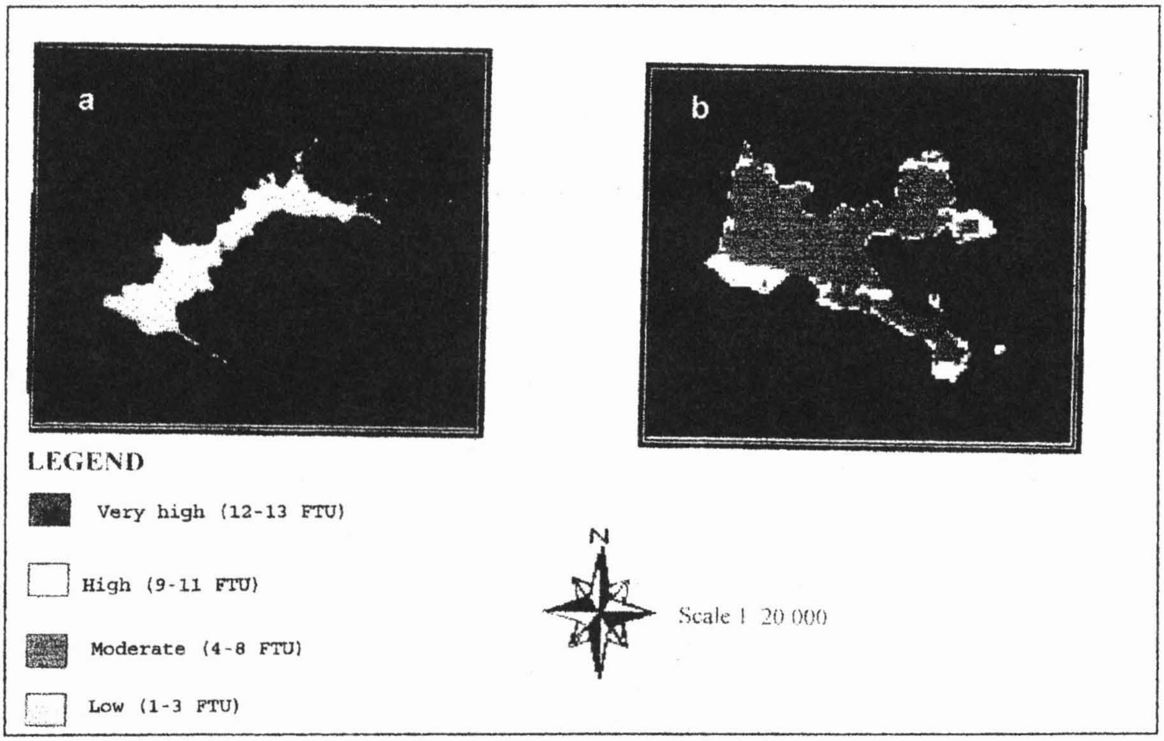


Figure 3: A spatial turbidity map of (a) Semenyih and (b) Langat Dam

**Forest Road and Timber Harvesting**

The prototype (MERANTI) developed in this study could assist planners and managers by providing geo-referenced and temporal-referenced information through evaluating timber volume, slopes, ground conditions and existing forest roads in order to select blocks to be harvested and to layout a preliminary road network.

The developed access road location procedure was designed to locate non-served harvest blocks by constructing access roads along existing secondary forest roads. In the non-served areas, new roads were located to serve the selected harvest blocks at a minimum construction cost. The integration of the developed road location procedure with ARC/INFO was facilitated because ARC/INFO was also designed to be used for network analysis purposes by scanning, intersecting and overlay procedures. With the GIS it was possible to overlay and intersect various types of information, such as slope and ground conditions to obtain a more complete description of the area of interest.

This method provided the advantages of using human expertise to plan, preliminary forest road locations, while using detailed mathematical calculations to compare and select alternatives routes. From extensive testing of the developed procedure, it could be concluded that the solutions were very close to the optimal. However, like all computer-based systems, the quality of the model was only as good as the information that it contained. The major problems encountered in the development of the access road location was the size of harvest blocks that in most cases contained varying slopes and ground conditions which required the development of criterion selection based on its respective area. While, it was possible to determine ground conditions and slope ratings from each harvest block with this procedure, additional input parameters such as of soil series, elevation, surface roughness and cover types would provide a more accurate information and consequently more accurate harvest block terrain classification. Additionally, the resolution provided by the DEM (i.e. 30 meters by 30 meters) might not be adequate for some harvest planning purposes.

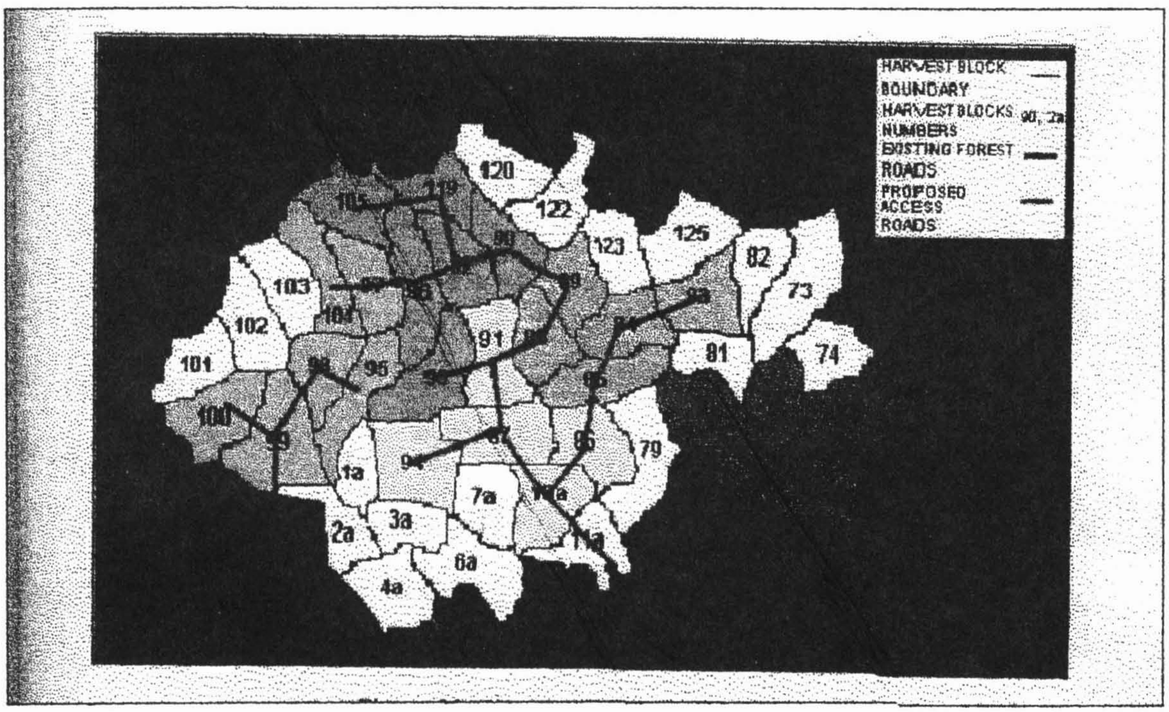


Figure 4: Tactical harvest block plan

**Forest Fire Detection, Mapping and Planning in Sipitang F.R., Sabah Using SPOT-HRV**

The temporal SPOT-HRV images of February and March 1998 clearly showed the chronology event for a three dates of Sipitang forest fires in Sabah. A reduced resolution SPOT quick look image covered about 60 km x 60 km over the scene. Figure 5a was taken on 6 February 1998 and this was an early stage of fire. On 20 February (Figure 5b), which was two weeks later, the same area was covered by scattered and emerging smokes plumes. Figure 5c taken on 4 March (one month later) indicated that several large smoke plumes which can be seen originated to the east of Sipitang. The smokes can also be seen near the town of Lawas in the southern portion of the image. These images were covered with healthy vegetation (red/pink), the white patches were cumulus clouds and smoke. Otherwise, light blue/grey reprieved and revealed the extent of damages (scar).

On major forest fire issues to be faced by forest managers is forest fire management in terms of prevention, mitigation and planning (Kamaruzaman, 2000; and Kamaruzaman and Aswati, 1999). Remote sensing data and GIS/GPS can be used as an alternative tools in order to assess the burnt intensity and in otherwise, the initial maps can be digitized and made part of the local GIS planning database for long term recovery planning and subsequent environment analysis (Kamaruzaman, 2000)

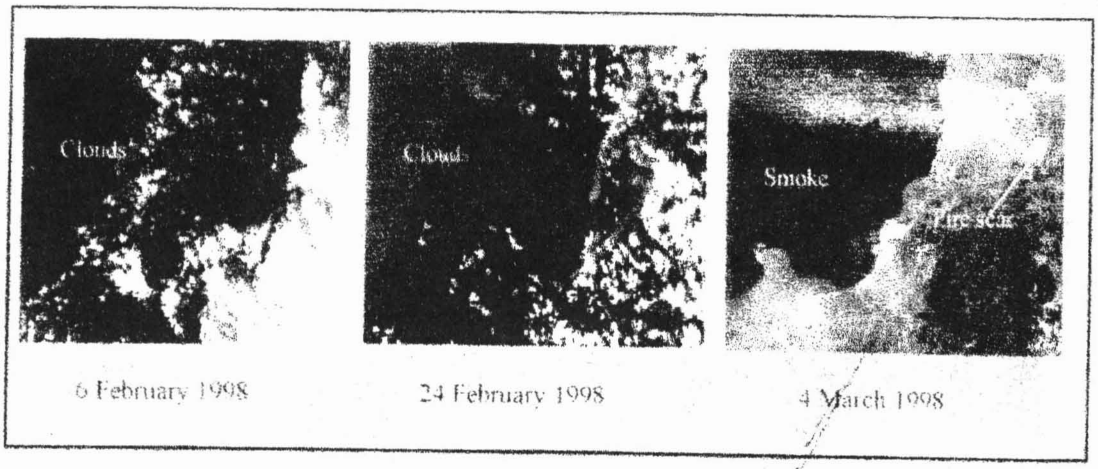


Figure 5a,b,c: Chronology fire in Sipitang Sabah acquired from SPOT Satellite

**Forest Inventory and Timber Volume Estimation Using Landsat TM**

By using a Landsat TM imagery, three forest types namely Primary Forest, Logged-Over Forest, and Degraded Forest can be mapped, quantified and separated (Zailani and Kamaruzaman, 2000). Using the Maximum Likelihood Classification and Forest Canopy Density techniques, the areal extent of the three classified forests can be further categorized as High, Medium and Low density were 34,019, 23,848 and 10,384 ha, respectively. The estimated timber volume for Primary Forest, Logged-Over Forest and Degraded Forest are 58.9, 26.4 and 15.3 m3/ha, respectively (Figure 6). The average timber volume for the study area is 33.5 m3/ha with an overall mean accuracy of 90%.

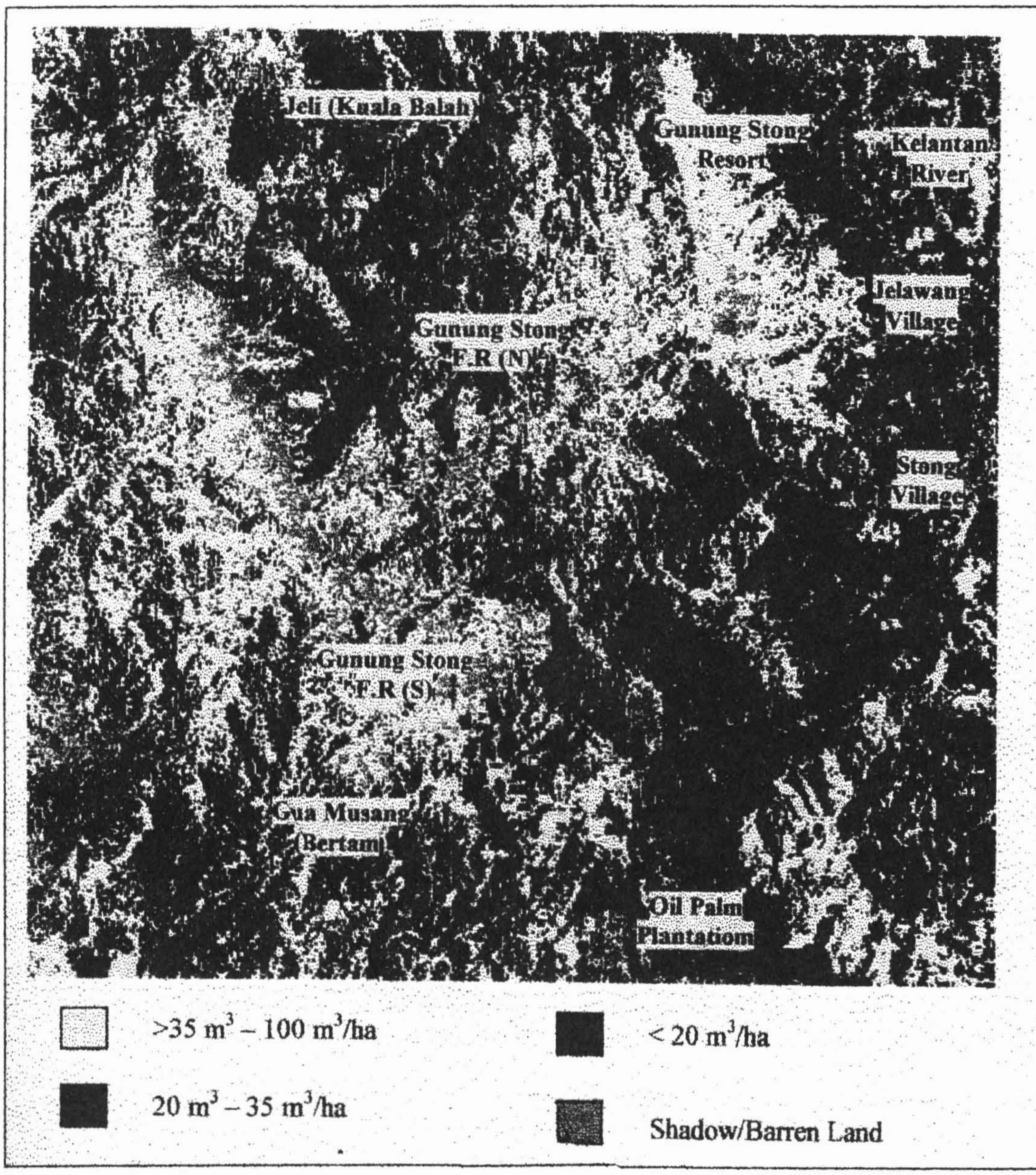


Figure 6: Timber Volume Estimation of Gunung Stong Forest Reserve using Landsat TM image

**Forest Type/Cover Classification and Mapping Using Landsat 5 TM and AIRSAR TOPSAR Data**

Figure 7a shows the forest type/cover map, respectively over Tioman Island (Azian and Kamaruzaman, 2000). From the image, the forest can easily be recognized since the whole of Tioman Island is covered by vegetation and only a few areas are urbanized. A total of five classes of forest type/cover were identified and mapped by supervised classification techniques with a mean overall classification accuracy of 84% as follows: Lowland Dipterocarp Forest (8,033 ha), Hill Dipterocarp Forest (2,138 ha), Urban Area, Disturbed Forest (568 ha) and Mangrove Swamp Forest (2,100 ha). Although it is difficult to reduce the cloud cover of less than 30% using the masking technique, Landsat 5 TM band 453 (RGB) has the capability to classify the different forest cover types in Tioman Island.

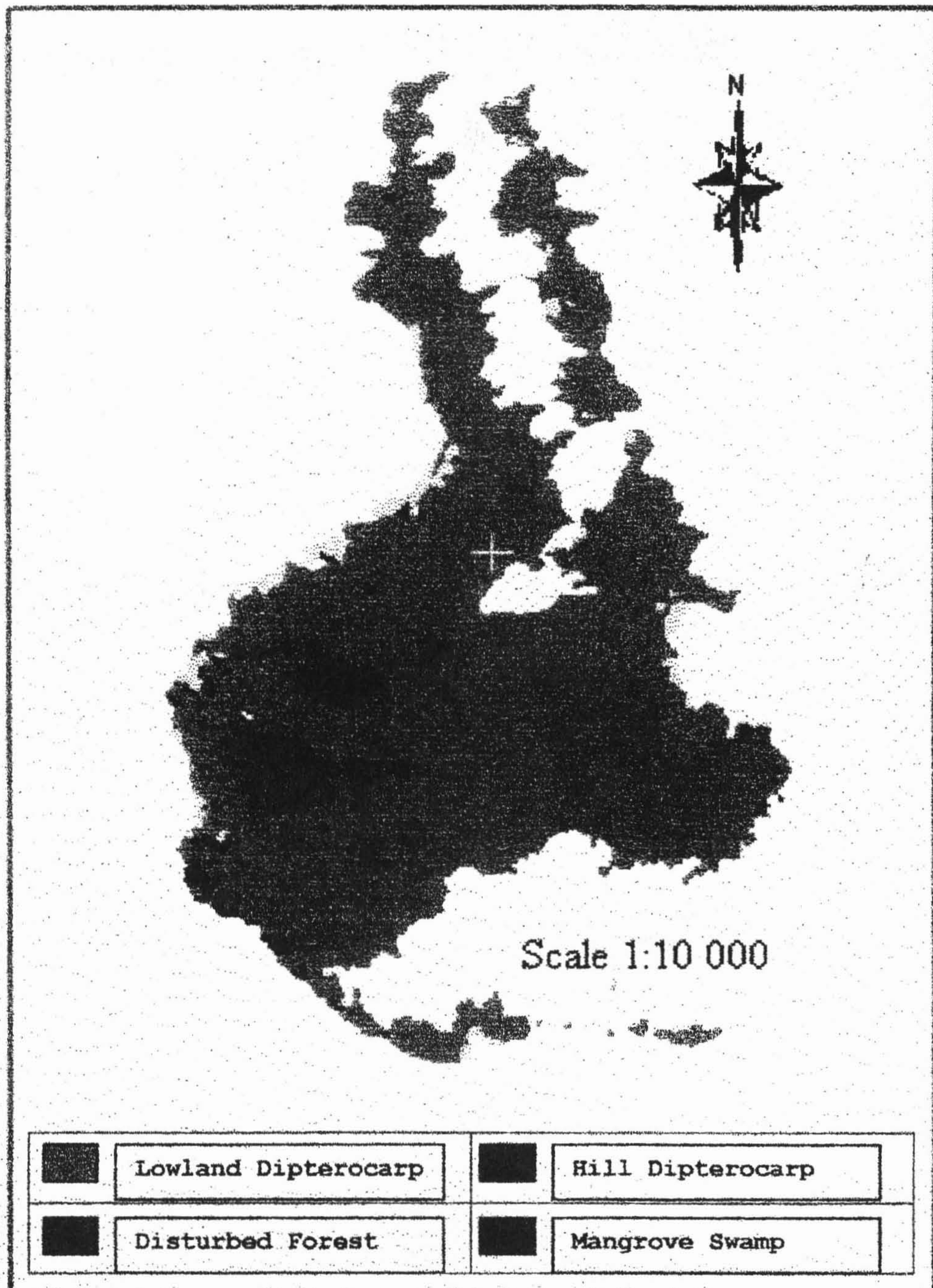


Figure 7a: Four Different Types of Forest Classified in Pulau Tioman

Unlike the optical sensor, NASA's airborne AIRSAR TOPSAR data can only distinguished primary and secondary forests from the cleared/developed land using polarization signatures (Figures 7band 7c). The classification and interpretation results suggest that data acquired using NASA/JPL's TOPSAR sensor is not adequate in forest type mapping when the standard image processing procedures was applied.

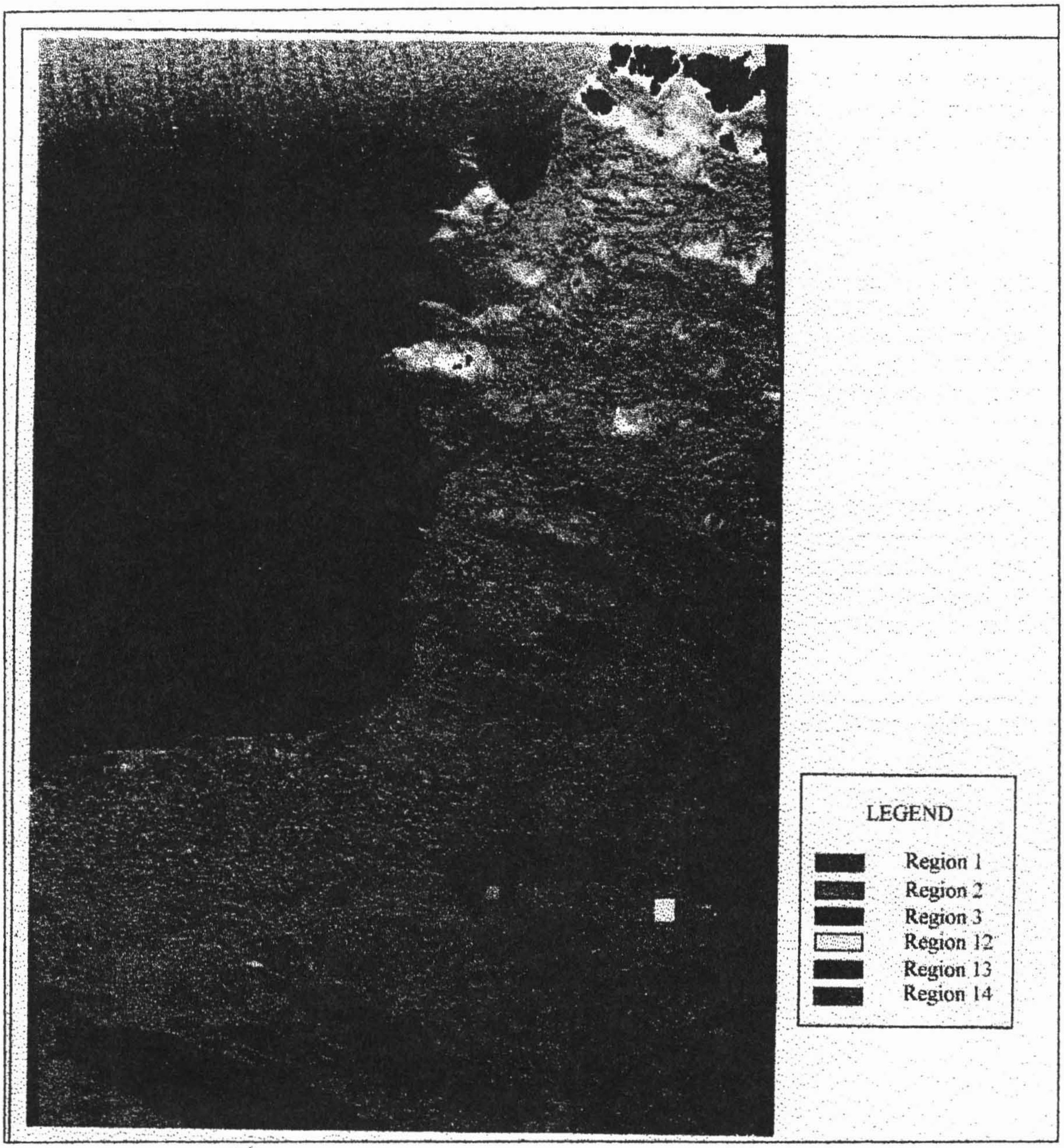


**Figure 7b: An AIRSAR-TOPSAR image over the northern part of Pulau Tioman**

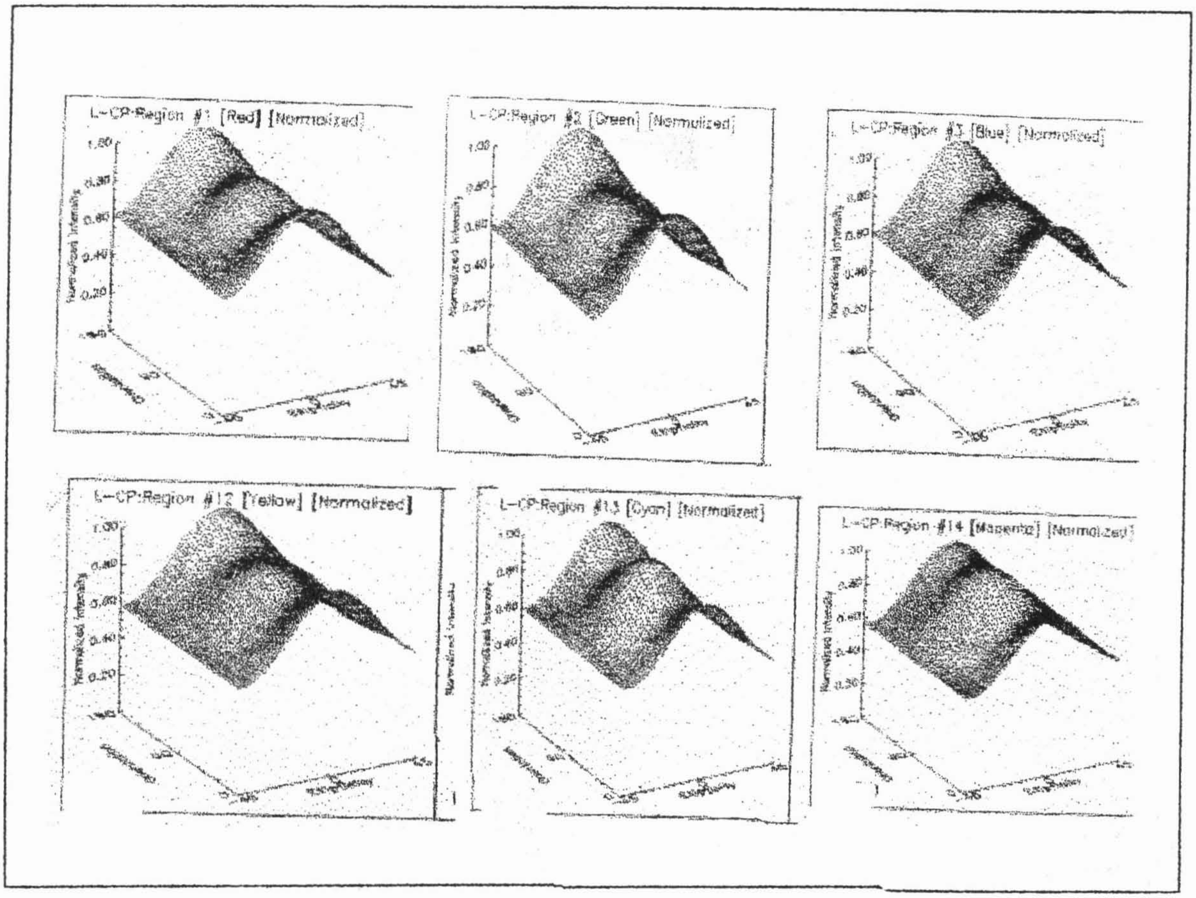


Figure 7c: Polarization signatures of the secondary and primary forest types for ROI's in P. Tioman

**Wetland Forest Mapping Using SPOT XS and IKONOS-1 Data**

The combination of SPOT HRV XS bands 321 (RGB) using linear enhancement generally provides the best contrast and effective separation of wetland forest especially mangroves. A total of seven clusters of mangrove were mapped with an overall accuracy of 78% as follows: Production Forest, Excellent Forest, Dryland Forest, Poor Forest, Seed Stand, Damaged Forest and Good Forest (Azian and Kamaruzaman, 2000). Areas which have been attacked by *Acrostichum aureum* and *A. speciosm* can be easily mapped and categorized as Damaged Forest. The timber production areas comprising of *Rhizopura apiculata, R. mucronata, Avicennia* spp constitute the Production Forest. The other timber production forest classified as Excellent, Good and Poor Forest were dominated by *Bruguiera* spp. With timber densities of above 310 m3/ha, 250-310 m3/ha and below 250 m3/ha, respectively. The Dryland Forest contains the largest single concentration of mangrove species as compared to other mangrove forest types. Seed stand is characterized by regenerating forest, which contain a mixture of seedlings. Figure 8 shows the supervised classification using MLC of mangroves in Kuala Trong MMFR while Figure 9 shows the mangoves (nypa and swamp) that were easily mapped using IKONOS-1 data over Mersing.

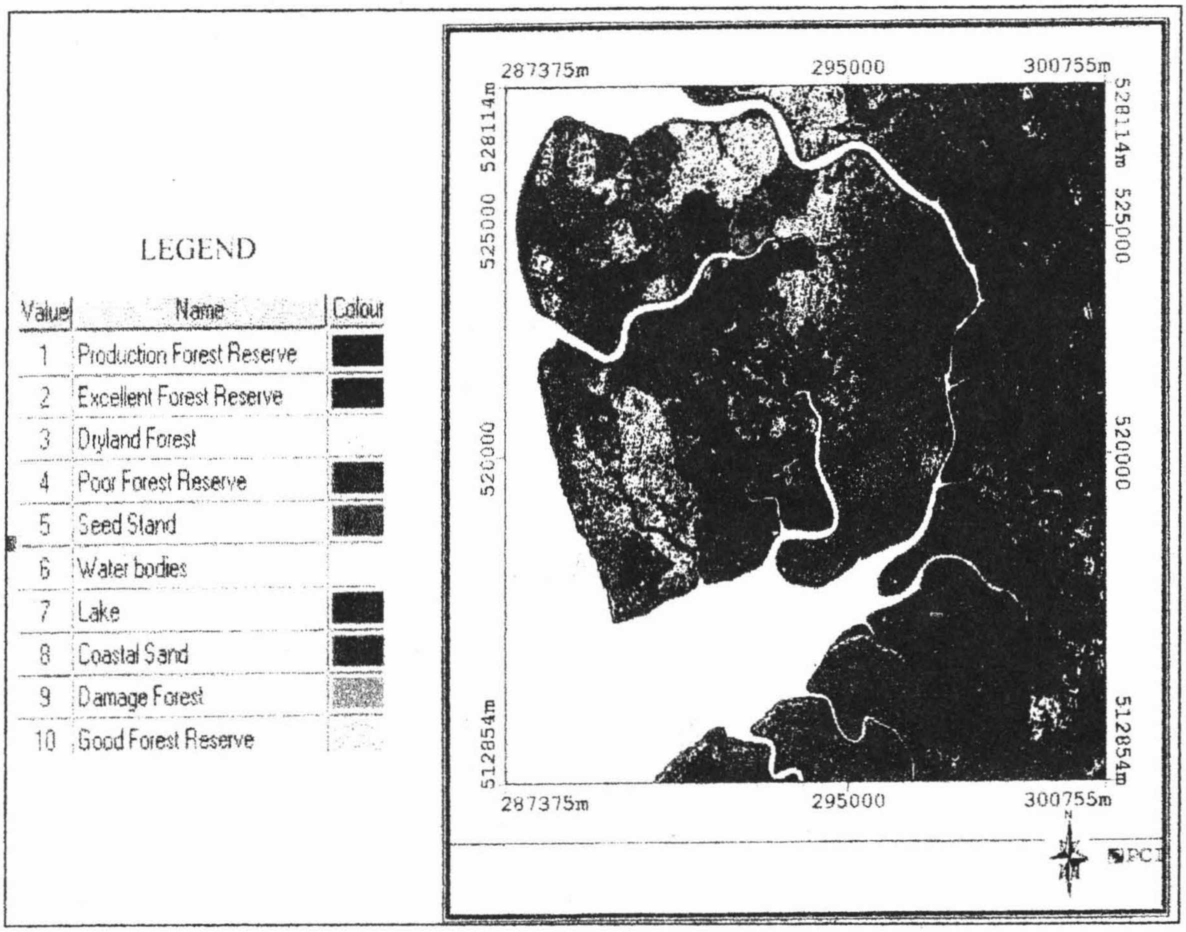


**Figure 8: Vectorizing of Supervised Classified SPOT Image over K. Trong, Matang Mangrove F.R**

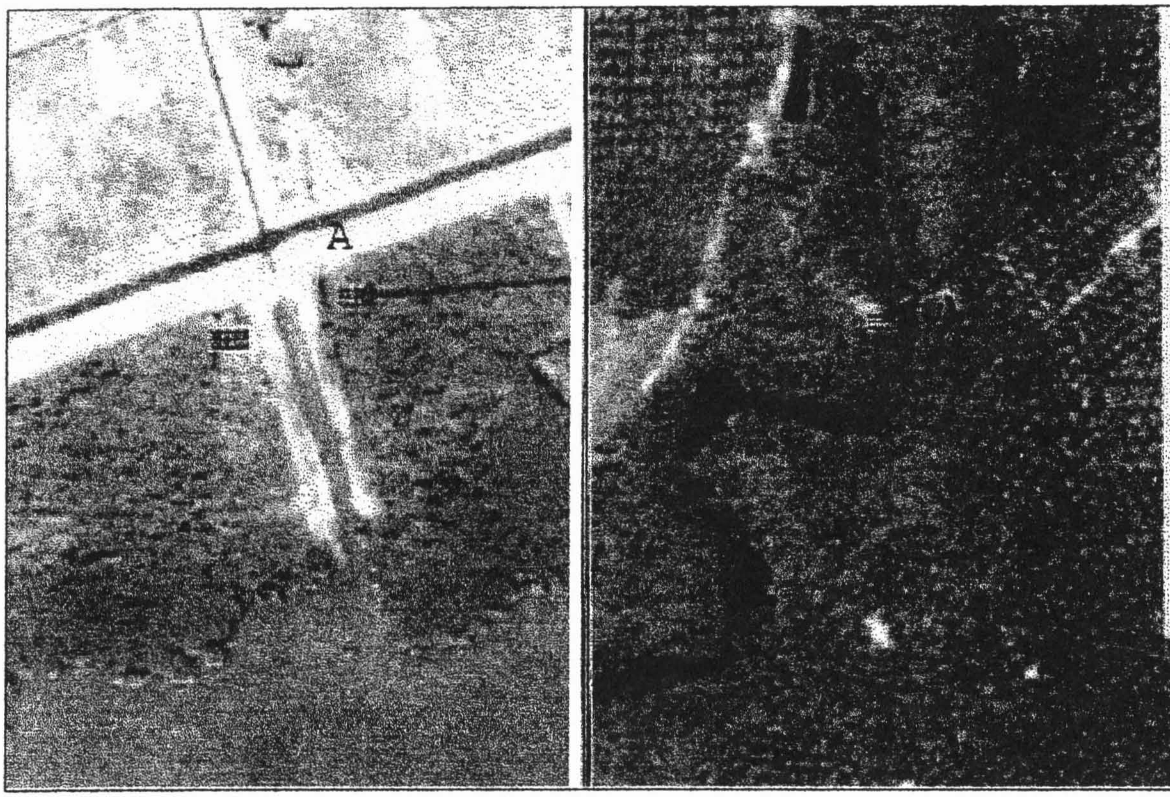


Figure 9: (A)Mangrove Swamp and (B) Nypa Swamp Wetland Forests as seen from IKONOS-1 Image

**Individual Tree Mapping Using Hyperspectral Imaging (CASI)**

From the image processing and analysis and field stratified sampling check, tree stocking by individual tree crowns delineation for a block can be divided into four classes as follows: light yellow (>250 m2), yellow (100-250 m2), light green (50-100 m2) and green (<50 m2), respectively (Kamaruzaman, 1998). The total number of crowns counted is 3,043 trees with the mean volume for each tree is 3.57 m3 (Figure 10).

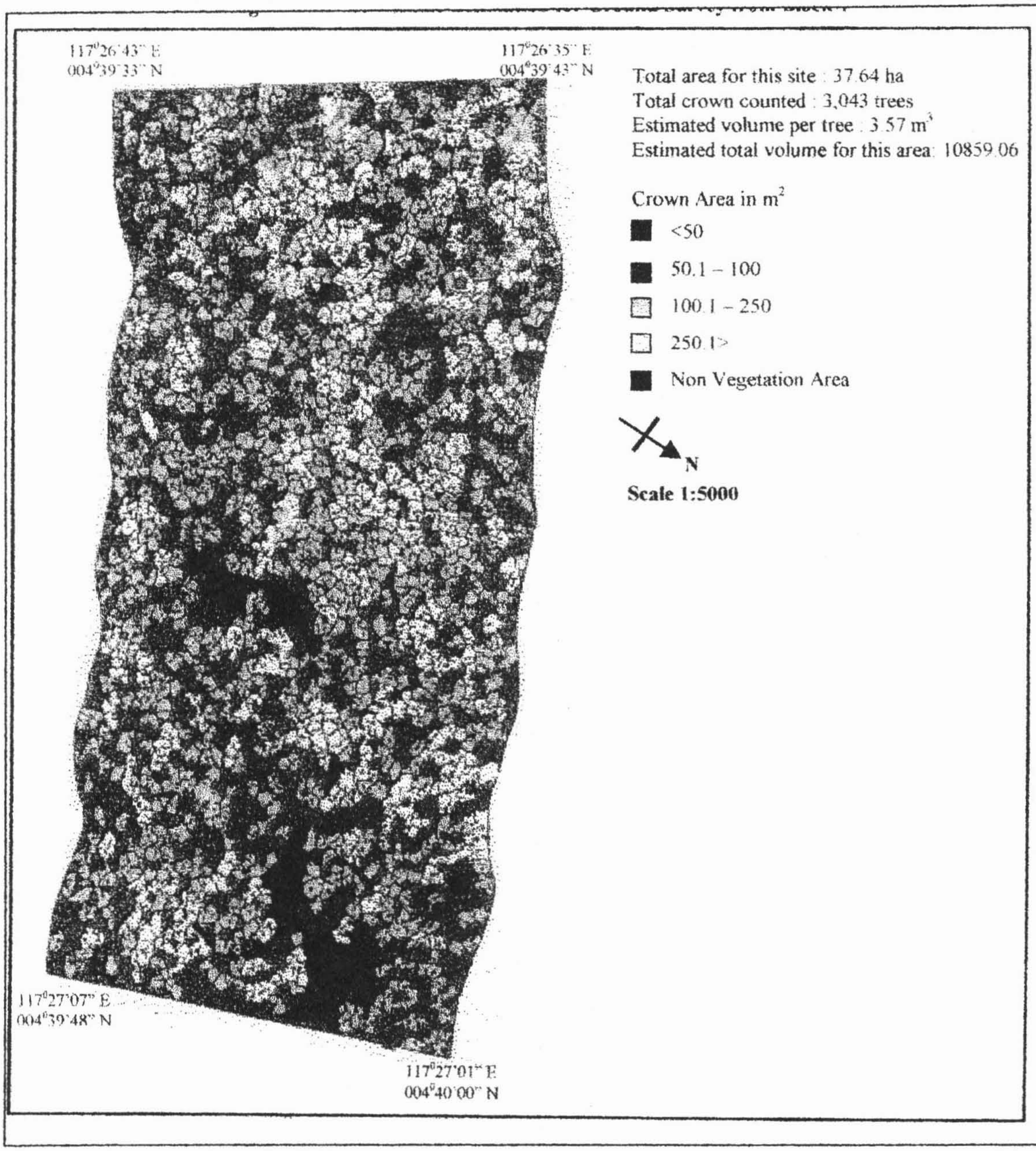


**Figure 10: Tree Volume Estimation for Ground Survey from Block 4, Gunung Rara-Kalabakan F.R**

## CONCLUSIONS

Timely availability of resource thematic maps is essential for initiating, monitoring and optimal management and sustainable development of the Malaysian forest resources. GIT has become an invaluable source of geospatial data on sustainable forest development which can provide timely information on their present status as well as their dynamical changes needed for preparation of thematic forest information maps. The availability of a number of space and airborne remote sensing sensors coupled with GIS and GPS providing continuous data have facilitated timely mapping and change detection in a variety of sustainable forest development application areas-mapping deforestation, individual forest trees, forest fire, water turbidity in dams and land use, forest recreation planning, forest road and timber harvest planning.

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