HIGH SPATIAL RESOLUTION AND HYPERSPECTRAL REMOTE SENSING FOR MAPPING VEGETATION SPECIES IN TROPICAL RAINFOREST

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For my wife and my family.

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ABSTRACT

The focus of this study is on vegetation species mapping using high spatial resolution IKONOS-2 and digital Color Infrared (CIR) Aerial Photos (spatial resolution 4 m for IKONOS-2 and 20 cm for CIR) and Hyperion Hyperspectral data (spectral resolution 10 nm) in Pasoh Forest Reserve, Negeri Sembilan. Spatial and spectral separability in distinguishing vegetation species were investigated prior to vegetation species mapping to provide optimal vegetation species discrimination. A total of 88 selected vegetation species and common timber groups of the dominant family Dipterocarpaceae with diameter at breast height more than 30 cm were used in this study, where trees spectra were collected by both in situ and laboratory measurements of foliar samples. The trees spectra were analysed using first and second order derivative analysis together with scatter matrix plot based on multi-objective optimization algorithm to identify the best separability and sensitive wavelength portions for vegetation species mapping. In high spatial resolution data mapping, both IKONOS-2 and CIR data were classified by supervised classification approach using maximum likelihood and neural network classifiers, while the Hyperion data was classified by spectral angle mapper and linear mixture modeling. Results of this study indicate that only a total of ten common timber group of dominant Dipterocarpaceae genus were able to be recognized at significant divergence. Both high spatial resolution data (IKONOS-2 and CIR) gave very good classification accuracy of more than 83%. The classified hyperspectral data at 30 m spatial resolution gave a classification accuracy of 65%, hence confirming that spatial resolution is more sensitive in identification of tree genus. However, for species mapping, both high spatial and spectral remotely sensed data used are marginally less sensitive than at genus level.

ABSTRAK

Kajian ini memfokuskan pemetaan spesies tumbuhan dengan menggunakan data resolusi spatial yang tinggi IKONOS-2 dan foto udara berdigit inframerah berwarna (CIR) (resolusi spatial 4 m bagi data IKONOS-2 dan 20 cm untuk CIR) dan data *Hyperion Hyperspectral* (resolusi spektral 10 nm) di Hutan Simpanan Pasoh, Negeri Sembilan. Untuk memberi perbezaan spesies tumbuhan yang optimum, keupayaan pemisahan spatial dan spektral dikaji terlebih dahulu sebelum pemetaan spesies tumbuhan dijalankan. Sejumlah 88 jenis spesies tumbuhan terpilih dan tumbuhan dalam kumpulan balak umum untuk keluarga dominan *Dipterocarpaceae* yang mempunyai diameter pada ketinggian paras dada lebih daripada 30 cm telah digunakan di mana spektra pokok dikumpulkan dengan penyampelan folia lapangan dan makmal. Untuk mengenalpasti pemisahan bahagian panjang gelombang yang baik dan sensitif dalam pemetaan spesies tumbuhan, spektra pokok dianalisis dengan analisa derivatif pertama dan kedua bersama dengan plot matrik serakan berasaskan algoritma optimikasi multi-objektif. Dalam pemetaan data resolusi spatial tinggi, data IKONOS-2 dan CIR dikelaskan dengan pendekatan pengkelasan berpenyelia menggunakan pengkelas kemungkinan maksimum dan rangkaian saraf manakala data *Hyperion* dikelaskan dengan pemeta spektra bersudut dan model campuran berkadar langsung. Keputusan kajian ini menunjukkan bahawa hanya sejumlah sepuluh jenis kumpulan balak umum dalam keluarga dominan *Dipterocarpaceae* dapat dikenali dengan nyata perbezaannya pada peringkat genus. Kedua-dua data resolusi spatial yang tinggi (IKONOS-2 dan CIR) memberi ketepatan pengkelasan yang sangat baik, iaitu melebihi 83%. Data *hyperspectal* yang telah dikelaskan pada resolusi spatial 30 m memberi ketepatan pengkelasan 65%, maka disahkan bahawa resolusi spatial adalah lebih sensitif dalam mengenalpasti genus pokok. Walau bagaimanapun, bagi pemetaan spesies, kedua-dua data remote sensing yang mempunyai resolusi spatial dan spektral yang tinggi adalah kurang sensitif jika berbanding dengan pemetaan tumbuhan pada peringkat genus.

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LIST OF ABBREVIATIONS

APAR	-	Absorbed Photosynthetically Active Radiation
ASMS	-	Airborne Sensor Management System
BRDF	-	Bidirectional Reflectance Distribution Function
CASI	-	Compact Airborne Spectrographic Imager
CCD	-	Charge-Coupled Device
CIR	-	Colour Infrared
DBH	-	Diameter at Breast Height
DC	-	Dark Current
DMC	-	Digital Mapping Camera
DN	-	Digital Number
ETM+	-	Enhanced Thematic Mapper Plus
FOV	-	Field-of-View
FRIM	-	Forest Research Institute Malaysia
GCP	-	Ground Control Point
GMT	-	Greenwich Mean Time
GPS	-	Global Positioning System
GRABS	-	Greenness Above Bare Soil
HRV	-	High Resolution Visible
II	-	Infrared Index
IFOV	-	Instantaneous Field-of-View
IR	-	Infrared
JERS	-	Japanese Earth Resources Satellite
JPL	-	Jet Propulsion Lab
LAI	-	Leaf Area Index
LDA	-	Linear Discriminant Analysis
LMM	-	Linear Mixture Modelling
MESSR	-	Multispectral Electronic Self-Scanning Radiometer

MIR	-	Middle Infrared
MNF	-	Minimum Noise Fraction
MOS	-	Marine Observation Satellite
MSI	-	Moisture Stress Index
MSS	-	Multispectral Scanner
NASA	-	National Aeronautics and Space Administration
NIES	-	National Institute of Environmental Study
NIR	-	Near Infrared
NNC	-	Neural Network Classifier
OIF	-	Optimum Index Factor
PCA	-	Principal Components Analysis
PPI	-	Pixel Purity Index
PFR	-	Pasoh Forest Reserve
RMSE	-	Root Mean Square Error
ROI	-	Region of Interest
RWC	-	Relative Water Content
SAM	-	Spectral Angle Mapper
S/N	-	Signal-to-Noise
SAIL	-	Scattering by Arbitrarily Inclined Leaves
SAR	-	Synthetic Aperture Radar
SPOT	-	Satellite Pour l'Observation de la Terre
SWIR	-	Short-wave Infrared
TM	-	Thematic Mapper
USGS	-	United States Geological Survey
UTM	-	Universal Transverse Mercator
VNIR	-	Visible Near Infrared

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Vegetation can be defined as plant life of a region (i.e. plant community), which refers to land cover provided by plants without specific reference to any structure, spatial extent, or any other specific botanical or geographical characteristics (Jensen, 2000; Austin and Heyligers, 1991). Vegetation is broader than the term flora which refers exclusively to species composition (Laubenfels, 1975). Vegetation is known to have a strong influence on land-atmosphere interactions, and major changes in land cover, associated primarily with deforestation, have been shown to have significant impacts on the local climate (Fuentes et al., 2006). Vegetation is critical in local and global energy balances which helps in regulating the flow of numerous biogeochemical cycles, including water, carbon, and nitrogen.

Most people have an understanding that vegetation refers to forest, plantation and grassland in which these terms conjure up an image of what such vegetation looks like. However, ecologists discriminate vegetation structure at a much more detailed level, whereby the vegetation structure is determined by an interacting combination of environmental and historical factors, as well as species composition (Kabat et al., 2004). In this study, the term vegetation is thus confined to the forest vegetation that exists in the study area.

Vegetation studies over the forested area have become a great interest of ecologists and scientists due to its importance in maintaining a sustainable biological diversity in this complex ecosystem (Clark et al., 2005). Over 30 percent of the Earth's surface is covered with forests, a community of plants, animals, and many other micro-organisms with vegetation dominating the largest organism found on this planet. Out of this 30 percent, 6.4 percent is covered by tropical rainforest. The existing of tropical rainforest may not be so significant by looking at the percentage of total forests exist on Earth but it maintain a large proportion of the world's biological diversity (Thomas et al., 2004; Whitmore, 1990). Tropical rainforest has become the most notable storehouses of biological diversity on land, accumulating two-thirds of known terrestrial species and protects the largest share of threatened species. The type of forest in a given area depends on many elements, including the climate, soil, water source, rainfall patterns, seed sources and human influence. Forest can also be defined as a biological system with distinctively big numbers of interrelationships of the living part of the environment (such as plants, animals and micro-organisms) to each other and to the non-living, inorganic or abiotic parts (e.g. soil, climate, water, organic debris, rocks) (Maarel, 2004).

The tropical rain forest of Malaysia is a highly complex ecosystem which is rich and varied in plant and animal life. The forest maintains the environment stability of the country and is a store house of plant and animal species in such a way that their richness and diversity are considered as the centre of origin and diversity of many present-day as well as future crop plants (Chin and Lai, 1993).

Vegetation studies, particularly the forests inventory and management, including species richness mapping have always remained as an issue of concern by all parties over the world (Revilla, 1994). It plays an important role in the economic development of a country, generating much government revenues, especially in terms of foreign exchange earnings, such as the development of local wood-based and related industries and employment. The complex ecological relationships involving forests could allow humans to benefit from them in a variety of ways (e.g. processing the wood from trees, adopting nutrition from animals, making the forest into a recreation park, as a medicinal source and so on) (WWF, 2005). The importance of vegetation studies are further discussed in next section.

1.2 Importance of Vegetation Studies

Vegetation is one of the most important components in the biosphere. Vegetation being the primary producer and capable of photosynthesis, its growth, maintenance and development are sensitive to the environment. Therefore, it provides evidence or clues for us to understand other processes of the ecosystem, such as climate changes, carbon cycling, ecosystem evolution, and human-nature interaction. Understanding the vegetation community (including its species richness and evenness), alternations in vegetation phenological (growth) cycles, and modifications in plant physiology and morphology also provide us with valuable insight into the changing of climatic, geologic, and physiographic characteristics of an area (Jensen, 2000).

The importance of vegetation study is getting more significant with the establishment of the Kyoto Protocol. The Kyoto Protocol is a protocol to the United Nations Framework Convention on Climate Change (UNFCCC or FCCC) and an international environmental treaty produced at the United Nations Conference on Environment and Development (UNCED) which is informally known as the Earth Summit held in Rio de Janeiro, Brazil from 3–14 June 1992. During the convention, the member countries (and Malaysia is one of the member countries) who signed the treaty agreed and intended to achieve the "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system" (UNFCC, 2005). The Kyoto Protocol establishes legally binding commitments for the reduction of four greenhouse gases (carbon dioxide, methane, nitrous oxide, sulfur hexafluoride). Vegetation plays an important role in reducing the emission of greenhouse gases and the circulation of carbon (Smith, 2003). Warmer global temperatures which linked directly to greenhouse gas emission may alter tree growth rates, recruitment and mortality, thereby creating new assemblages of tree as global temperature increase and extinction of some vegetation species (Laurance et al., 2004).

Some observations made have concluded that 80 percent of the nutrients in the tropical ecosystem are in the vegetation and this should always be carefully weighed in the design/formulation of forest management system in the tropics (McGinley and Finegan, 2003; Mendoza et al., 1999; Prabhu et al., 1996). This situation is more serious in cases where there is a danger of accelerated soil erosion resulting in the loss of most nutrients in the soil, or, in the event where the original vegetation has to give way to plantations (Zhang et al., 2003 and Revilla, 1994). Tropical rainforest biodiversity is endangered by large scale (e.g., 10-500 ha) deforestation and logging activities (Achard et al., 2002). Some vegetation species are very sensitive to environmental changes. For example, wetland vegetation species can be a good indicator of the environmental changes once the anticipated biophysical parameters are determined. The importance of vegetation in biodiversity has led to the concerns for forest inventories that include type of forest inventories involving precision of estimates, accuracy of estimates, control of re-enumeration, systematic sampling and monitoring of forest change.

Malaysia is fully aware of the need for effective forest management and conservation, not only to ensure a sustained supply of timber but also to maintain environmental stability, providing sanctuary for wildlife and to serve as an invaluable storehouse of genetic resources useful for the improvement of its indigenous tree species, agricultural crops and live stocks (Razak et al., 2002; Appanah, 1999; Salleh and Musa, 1994). From individual crown to landscape scales, vegetation in tropical rainforest has a dominant role in maintaining its rich environment sustainability. Furthermore, vegetation of the tropical rainforest represents a major pool of terrestrial carbon. In this instance, remote sensing can be used as an effective tool to monitor, perform inventory mapping and detecting the sustainable environment.

The growing needs to conserve and provide accurate information on forest biophysical parameters implies the relative importance of different vegetation species, their occurrence and distribution to be studied. Knowledge of vegetation species composition and diversity is therefore the most useful tool in evaluating overall species diversity and endemism in tropical forest, and it is critical for conservation planning. Subsequently, there is a need to formulate sound management policies and guidelines for the conservation of these species (Ashton, 1990). In order to meet this need, remote sensing technology has been widely used in vegetation and its related studies due to its advantages in wide coverage, cost effective and availability of multi temporal archived data.

1.3 The Use of Remote Sensing Analysis in Vegetation Studies

According to Yamada (1997), the obstacles faced by foresters and ecologists in studying the tropical rain forest can be categorized into three broad categories, namely: 1) human factors, 2) natural factors and 3) biological factors. Among these factors, one of the main problems in studying the tropical rain forest is accessibility. This can be further explained as the understanding, monitoring and inventory mapping of tropical rain forests are being influenced by a lack of spatially and temporally extensive information on vegetation composition, species richness and structure. Due to expensive costs and inaccessibility (as mentioned earlier), most available data only comes from relatively small field plots with infrequent re-sampling intervals. With the existing plots, it is difficult to scale-up the field data to the landscape, regional or global scales needed in sustainability analysis of ecosystem in tropical rainforest (Tuomisto et al., 2003).

Since the launching of Landsat in 1972, remote sensing has become a powerful means in providing data from which updated forest cover and related information can be obtained. Passive remote sensing sensors provide multi-scale, good spatial and temporal measurement of radiance from tropical rainforest canopies which can be linked to species composition and richness mapping (Foody et al., 2006; Nagendra, 2001). However, remote sensing studies in tropical rainforest have only focused on the mapping of general forest cover classes for calculating the rate and extent of regional deforestation and forest fragmentation relied upon medium spatial resolution imagery from multispectral spaceborne sensors due to the reasonable costs and acceptable accuracy (Roberts et al., 2002; Steininger et al., 2001). Remote sensing technology helps to resolve the accessibility problem as mentioned earlier in mapping the forest vegetation species and its related studies with reasonable costs.

In vegetation studies that employ remote sensing techniques, two widely used data are satellite and airborne colour infrared (CIR) images (Gould, 2000; Madden et al., 1999; Welch, 1996). The first and second generation satellite data (i.e. the first generation of satellite data refer to Landsat MSS and second generation of satellite data refer to Landsat TM, SPOT HRV and other multispectral sensors with broad bands spectral resolution) mostly do not have adequate spatial resolution to differentiate between detailed ground information. The airborne CIR images were then used to complement the satellite data. Both of these data complement each other when studying large areas where airborne data can be very costly to acquire, and are mostly used when detailed studies involving smaller areas are of interest. However, the complexity of the vegetation species composition in a tropical rainforest due to high tree diversity and both natural and human disturbances results in complex radiance signals that are difficult to discriminate using broad spectral and spatial resolution sensors. In order to delineate vegetation properly, the recent high spatial and hyperspectral remote sensing data therefore meet the needs in terms of both spatial and spectral resolution.

A new generation of high spatial resolution multispectral sensor (less than 4 meters) permitted the mapping of individual tree crown at species level as a group of image pixels (Gougeon & Leckie, 2003). Such advancement in remote sensing technology could greatly improve multi-scale forest classifications of vegetation species richness, habitat and disturbance history mapping. With the temporal data, individual tree crown analyses may also provide a means to systematically monitor changes in some special valuable species (e.g. common timber species) due to logging and climate change. (Clark et al., 2004; Read et al., 2003 and Nagendra, 2001).

With the advancement in remote sensing technology, the development of sensor has a great achievement in developing hand-held, airborne and spaceborne hyperspectral optical sensors which allow the spectral measurement over 50 narrow, continuous bands spanning the visible (400 nm to 700 nm), near infrared (700-1327) and two short wave infrared (1467-1771 nm and 1994-2435 nm respectively) regions of electromagnetic spectrum (Asner, 1998). The automated vegetation classification and species identification from tropical rainforest are now possible with hyperspectral imagery which is fine enough in terms of spectral wise. However, the accuracy may vary from different spatial resolution hyperspectral data and feature extraction techniques used, which will be discussed in later chapters.

In Malaysia, the use of remote sensing techniques in mapping the tropical rain forest has been explored since 1990s (Nuraznin and Hashim, 2007; Okuda et al., 2004; Okuda et al., 2003; Hashim et al., 2002; Hashim et al, 1999; Khali et al., 1993, Radzali, et al., 1992, Sawada et al., 1991). Series of researches had been carried out by Forest Research Institute Malaysia (FRIM) with the aid of remote sensing technology to extract forest and vegetation information. Khali et al. (1993) had started a research at the North Selangor peat swamp forest to assess the forest condition after logging by using remote sensing techniques. Landsat-TM data were used and results showed that the peat swamp forest could be mapped using remote sensing analysis and the area was differentiated into different classes of damage severity and the area extent was calculated. (Khali et al, 1994). Because of the high demand for assessing and monitoring vegetation change, vegetation observation has long been an important application of remote sensing.

1.4 Problem Statement

Remote sensing is an important tool for measuring global biodiversity in forest ecosystems. Remote sensing techniques offer to deliver structural information about forest stands such as the nature of the canopy surface, the layering within the canopy and even individual tree identification (Innes and Koch, 1998). In this study, this information is being linked with ecological species information derived from ground sampling to give estimates of species richness and distribution over much larger scales than previously available.

Moderate spatial resolution systems such as Landsat TM are able to provide valuable information on macro-level deforestation and fragmentation. It is used to make measurements of ecosystem properties and correlate these properties with ‘invisible’ properties such as biodiversity and species distribution that serve as key indicator of forest sustainable management. Since eight years ago, high resolution remote sensing system with a spatial resolution finer than 4 m and spectral resolution better than 10 nm are available commercially in the market. It provides detailed information and shows great potential in providing information for many applications especially in vegetation and its related studies. With the existence of the new system, the ability to detect every single tree species, canopy structure and even soil properties is now possible (Johnson, 2002; Newman et al. 1998).

However, the increase in spatial and spectral resolutions raises two common issues for effective extraction of information in either high spatial or spectral resolutions data respectively. In the case of high spatial resolution, the inherent effectiveness of spatial information have somehow ensured ‘busyness’ or variation in a ‘class of target’ hence preprocessing such as texture analysis need to be carried out prior to information extraction (Schowengerdt, 2007). On the other hand, the high spectral resolution such as found in hyperspectral data often face “Rayleigh phenomenon” and problem in selecting optimum bands from the voluminous data set. “Rayleigh phenomenon” refers to the fraction of light scattered are sensitive with the narrow bands and sometimes give false information in interpreting the target object (Borengasser et al., 2007). In selecting the optimum band for selected application, the voluminous spectral resolution data will have a lot of redundancy. A total of about 200 narrow bands may be available in hyperspectral data but only small portion of narrow wavebands are useful (for example in case of vegetation species recognition).

It appears that the advancement of high resolution system which provides high spatial and hyperspectral data is having a dilemma - as the imagery is so detailed that individual pixels often lose their representation of the landscape. Consequently, a traditional pixel-based process becomes incapable due to insufficient consideration of the rich amount of information on spatial and spectral association. Vegetation information extraction, especially species mapping from high spatial resolution imagery and hyperspectral remote sensing analysis is one of the most important research topics in the field but not much effort has gone into this topic so far, especially in tropical rainforest of this region.

Identification of individual crown species was traditionally performed by using visual interpretation method from high spatial resolution aerial photographs which are taken from film camera. New digital forms of high spatial resolution imagery from airborne and spaceborne multispectral sensors (i.e. Digital Color Infrared Aerial photo and IKONOS-2 in this study) have stimulated the development of automated techniques for individual crown species detection, delineation and subsequent measurement of related information (Chubey et al. 2006). Automated individual crown species identification from micro to macro (which can be further explained as leaf to crown scale) algorithms have been optimized for species mapping in some tropical forests, and it is not clear how these algorithms will perform in tropical rainforest in Malaysia with high species diversity and complex canopies. Consequently, this study is undertaken to further examine the algorithms and techniques available for micro to macro level vegetation species mapping and to suggest the algorithm and processing flow which would be suitable for use in tropical rainforest region with some modifications of algorithm by selecting the suitable spectral regions which were identified and tested in this study for the purpose of species richness and forest health mapping. With all the selected algorithms and techniques examined and tested using high spatial and hyperspectral remote sensing analysis at micro level vegetation mapping, the challenge lies on how to implement the best algorithm chosen for the macro-level analysis in order to enable large scale biodiversity mapping so as to make full use of the algorithm for vegetation species mapping and its related analysis.

There are some pre-processing requirements that should be first addressed when applying the hyperspectral remote sensing analysis in vegetation species mapping. These include the creation of a spectral library and the calibration of hyperspectral data. A spectral library is needed to compare the spectra recorded by the sensor to the spectra collected in the field work as a reference to find out the endmember (known as class in multispectral analysis). Most of the spectral libraries available created by Jet Propulsion Lab, (JPL) and United States Geological Survey, (USGS) are more focused on geological study such as mineral exploration. Recently, USGS has started developing spectral libraries for common vegetation types. In Malaysia, a complete set of hyperspectral libraries has yet to be developed. Therefore, to study Malaysian vegetations using hyperspectral data, a new set of spectral libraries is needed. These libraries should be complete because different regions of study may need a different spectral library to increase the accuracy of the study. From the spectral library created, series of analysis need to be carried out to study the separability of different species available in study area to make sure the species identification at micro level (leaf scale) is possible and further scale-up the species mapping to macro level (entire study area of this study).

With the doubts and problems discussed, it is worthwhile to carry out the study and the detailed objectives and scope of this study are defined in the next two sections.

1.5 Objectives of the Study

The overall aim of this study is to perform vegetation species mapping in tropical rainforest using high spatial resolution and hyperspectral remote sensing analysis. In order to achieve the overall aim, the following sets of specific objectives are formulated:

1 To create a spectral library for tropical rainforest and investigate the spectral variation among tropical rainforest vegetation species, thereby permitting spectral-based species discrimination;

2 To identify the spectral regions and spatial scale which provide optimal vegetation species discrimination by the analysis of spatial and spectral separability and variability in distinguishing vegetation species using high spatial and hyperspectral remote sensing analysis;

3 To examine and identify the existing techniques in vegetation species mapping of tropical rainforest and develop an analytical procedure to perform species mapping of tropical rainforest using high spatial resolution and hyperspectral remote sensing analysis;

4 To perform accuracy assessment on results obtained in objectives (1), (2) and (3) as compared to baseline information by using statistical approaches.

1.6 Scopes of the Study

The scopes of the study are as follows:

1. Vegetation species mapping in this study is confined to the identification of different types of vegetation, which means counting of the number of different type of plants in the study area by mapping the vegetation community in species, genus or family. The vegetation species mapping in this study is further confined to big families (at least 100 trees in each genus that existed in the study area with diameter at breast height, DBH > 30 cm). Trees with DBH larger than 30 cm were used so as to ensure that the top layer of the canopy can be analysed by using remotely sensed data. In addition to this, common timber species available in the study area will also be identified.

2. The high spatial resolution remotely sensed data used in the study is confined to multispectral IKONOS-2 data with 4 m spatial resolution and digital color infrared aerial photo by Z/I Imaging's Digital Mapping Camera with 20 cm spatial resolution. Hyperspectral remotely sensed data used in this study are confined to Hyperion (provides 220 continuous spectral bands ranging in wavelength from 0.4 µm to 2.4 µm with spatial resolution of 30 m). More details will be given in Chapter 3 on Data Acquisition, Preprocessing and Data Enhancement.

3. The study area is confined to tropical rainforest located in Pasoh Forest Reserve (PFR) 50 ha plot which contains 335,240 trees in 814 species, 290 genus and 78 families. On a per hectare basis, the species diversity of trees at Pasoh is comparable with those recorded anywhere in the world species-rich tropical rain forest similar to many seasonal forests of Malaysia. The availability and continuous census used as ground truth is the important selection factor apart from the scientific documents on tree species mapping undertaken.

1.7 Significance of Research

The monitoring, conservation and management of tropical rainforests has become a great challenge due to lack of spatially and temporally extensive information on tree floristic composition and vegetation species mapping (Foody et al., 2006 and Tuomisto et al., 2003). The vegetation species distribution map can be an important tool for understanding the extent and pattern of old growth forests, predicting rare plant habitat, modelling the spread of invasive species, and modelling how vegetation might change under various climate change scenarios (Clark et al., 2005). The introducing of high spatial resolution and hyperspectral remote sensing provided a good solution in vegetation species mapping which was done earlier in relatively small field plots with infrequent re-sampling intervals but involved prohibitive costs and inaccessibility problems. Thus, this study is carried out to perform vegetation species mapping of tropical rainforest using high spatial and hyperspectral remotely sensed data. Furthermore such a study have not being reported for tropical rainforest species or even at genus level due to the remoteness, dense, complex multi-storey canopies.

Spectral library of tropical rainforest species even for common timber species have not been reported to be available. Lack of this basic information, have cause major set-back for not enabling hyperspectral data to be classified optimally at full capacity to derive absolute forest information. Worst still, even the fine resolution hyperspectral airborne data is only being relatively classified due to lack of the spectral library. This study have successfully created spectral library which consists of common timber species of the dominant family Dipterocarpaceae; thereby would serve as baseline information for vegetation species identification in any tropical rainforest of this region by using hyperspectral remote sensing analysis.

This study has also placed contribution to the assessment of the spatial and spectral sensitivity of high spatial resolution and hyperspectral remotely sensed data in mapping the vegetation species in tropical rainforest. In particular whole electromagnetic spectrum from 400-1200 nm have been explored and had successfully identified the wavelengths as well as spectral band for identification of all common timber groups of the dominant family Dipterocarpaceae. This information is very vital for any mission and design of future sensing systems including satellite for forestry and related vegetation studies in tropical rainforest.

Apart from the above, this thesis has also significantly contribute to new knowledge on understanding of the vegetation species mapping and determine the advantages and limitations of high spatial and hyperspectral remote sensing analysis in vegetation species mapping in tropical rainforest environment. This research thus, produces a series of accurate vegetation distribution maps of vegetation in genus and species level for Pasoh Forest Reserve.

1.8 Study Area

The area of this study is confined to Pasoh Forest Reserve which located at 2° 55' N latitude and 102° 18' E longitude, about 8 km from the town of Simpang Pertang, Negeri Sembilan, approximately 70 km southeast of Kuala Lumpur (Figure 1.1). The Pasoh Forest Reserve comprises of low hills and alluvium rising to a granite ridge along its eastern border. A buffer zone of 700 ha within the western and southern margins was logged in the 1950s. The study area was further confined to 50-ha plot 1 km long by 0.5 km wide of Pasoh Forest Reserve. The plot was established between 1985 and 1988 for research purposes. The first detailed descriptions of the forest botany and stand structure were published in 1990 (Kochummen et al., 1990; Manokaran and LaFrankie 1990). The enumeration included all free standing trees and shrubs > 30 cm diameter-at-breast-height (DBH) excluding climbers. According to the details by which the plot was first surveyed, the 50-ha plot contains 335 240 trees in 814 species, 290 genus and 78 families. In 2000, another detailed survey was carried out and there were 338 924 trees in 818 species in 295 genus and 81 families. The number of trees has increased and the variety of the vegetation community in the 50-ha plot of Pasoh Forest Reserve is enough to represent any other tropical rain forest available within this region (Okuda et al., 2003).

The 30 species of Dipterocarpaceae family dominated the 50-ha plot, accounting for 27.3% of the total basal area (Manokaran and LaFrankie, 1990). The Euphorbiaceae with 85 species was the richest family in the plot and had the highest number of trees in the plot with 13.4% of total tree numbers. Shorea was the most important genus in the 5-ha research plot in terms of tree number (20 960 trees, 6.2 % of all trees). Shorea was the fifth most diverse genus in the plot with 14 species (1.7% of all species). As for the common timber groups, the family Dipterocarpaceae once again dominated the plot with 10 common genus. Red Meranti was the biggest genus under Shorea with a total of 13 401 trees (43.36% of total basal area) follow by Balau under same genus (shorea) with 6842 trees (22.13%) (Davies et al., 2003). More details can be obtained in Table 1.1.

The selection of the study area was based on: (1) the variety of vegetation types and (2) the availability of airborne and spaceborne high spatial and hyperspectral data over the study area. As mentioned earlier, the variety of the vegetation species that exist in the 50-ha plot of Pasoh Forest Reserve is enough to represent any other tropical rain forest available within this region and suitable to be selected as study area due to its completeness of secondary data, for example the complete census plot of the 50-ha plot of Pasoh Forest Reserve. It is not easy to acquire both high spatial resolution and hyperspectral remote sensing data for same tropical rainforest with ready and complete set of secondary data. Large number of biological researches had been carried out at Pasoh Forest Reserve since 1970s which also helps when performing the literature search.

Table 1.1: The most important families for 50-ha plot of Pasoh Forest Reserve.

Family	Basal Area (m^2)	Family	Total number of Trees	Family	Species number
Dipterocarpaceae	453.21	Euphorbiaceae	45436	Euphorbiaceae	85
Fabaceae	141.47	Dipterocarpaceae	31178	Lauraceae	49
Euphorbiaceae	120.46	Annoaceae	24752	Myrtaceae	48
Burseraceae	100.91	Rubiaceae	20506	Rubiaceae	47
Myrtaceae	56.96	Burseraceae	17701	Annoaceae	42

Source: Davies et al., (2003)

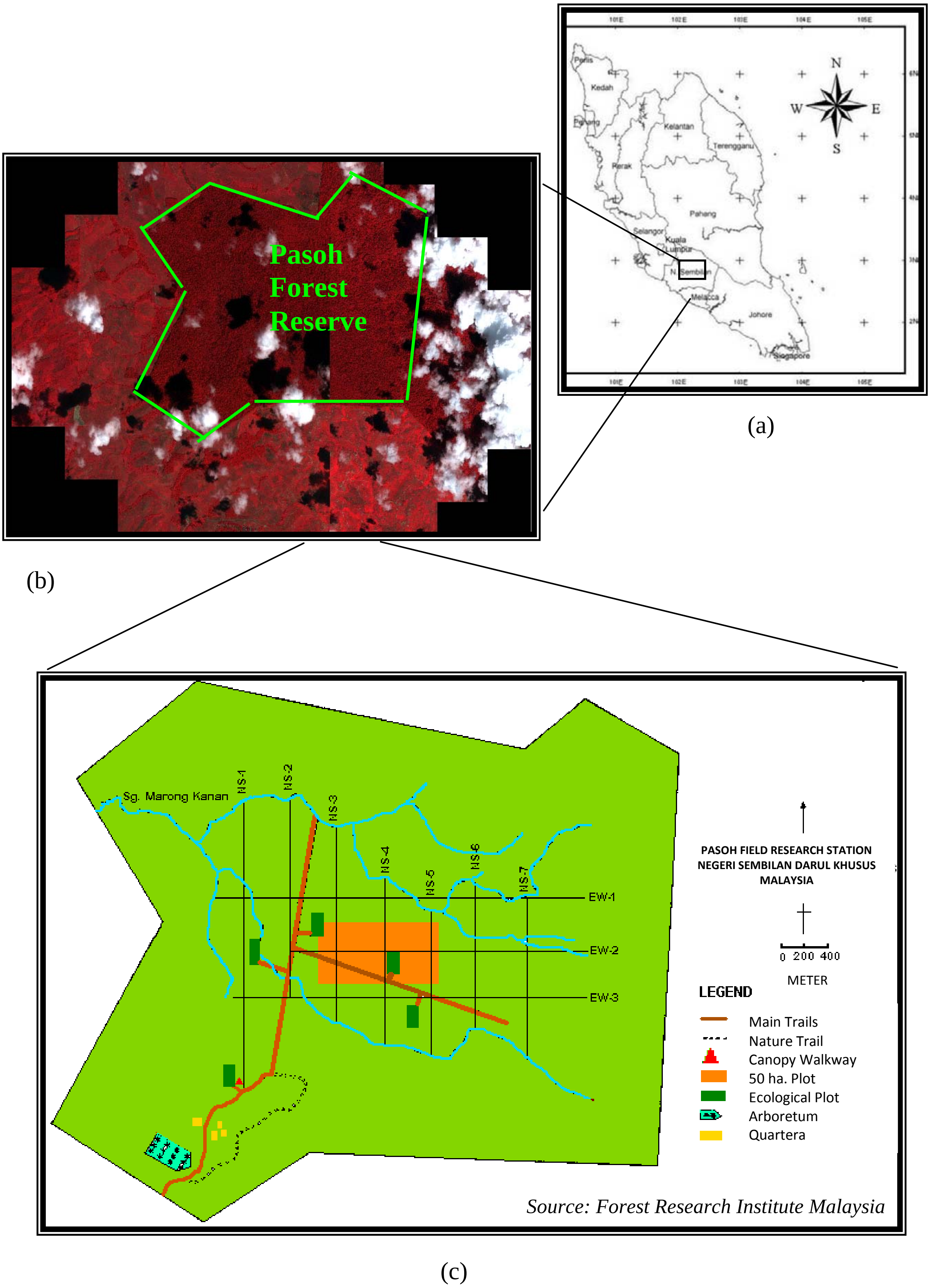

Figure 1.1: Study area; (a) location map, (b) the raw IKONOS satellite image of the study area and (c) the detailed plan of Pasoh Forest Reserve.

1.9 Thesis Outline

This thesis comprises of six chapters. Chapter 1 explains the research background of the study and gives the problem statement, objectives and scope of the study. The review of the high spatial and hyperspectral remote sensing techniques, together with its applications and works previously done using remote sensing techniques for vegetation and its related studies are addressed in Chapter 2. The literature review on vegetation mapping, especially on vegetation health mapping and species richness mapping (identification of different vegetation species), are also addressed in this chapter. In Chapter 3, preparation of two sets of high spatial and hyperspectral remote sensing data and pre-processing employed in the study are discussed. Data preparation includes the collection of field and image spectra for spectral library. All the pre-processing works including radiometric calibration, geometric correction and data mosaic, data masking, and image enhancements (Minimum Noise Fraction and Pixel Purity Index), which need to be done prior to feature extraction and data classification of vegetation species mapping, are also presented in this chapter. Chapter 4 presents the flow for creating a spectral library for different vegetation species available in the study area, which will be used later in the hyperspectral data processing. The sensitivity of high spatial resolution data and hyperspectral remote sensing data used in this study were also analysed in the same chapter. The feature extraction process and data classification, which are carried out using different approaches (i.e. Band Selection Feature Extraction, Spectral Angle Mapper, and Linear Mixture Modelling for hyperspectral data) on hyperspectral data (neural network classifier and maximum likelihood for high spatial data) are discussed in Chapter 5. Results and analyses of the feature extraction and classification of the vegetation are also presented and discussed in this chapter. Conclusions of the research and recommendations for future work are given in Chapter 6.

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