UNIVERSITI PUTRA MALAYSIA

DELINEATING MANGROVE FOREST ZONE USING SPECTRAL REFLECTANCE

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

DELINEATING MANGROVE FOREST ZONE USING SPECTRAL REFLECTANCE

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June 2020

Chair : Assoc. Prof. Norizah Kamarudin, PhD
Faculty : Forestry and Environment

The zonation of mangrove species has to be clearly identified and demarcated using geospatial data. This will help to update the zonation patterns of mangroves species associated with the current anthropogenic threat to mangrove. By using geospatial techniques and remotely sensed imagery data, the distribution of mangrove tree species associating with anthropogenic matrix can clearly be identified and mapped. The objectives of this study were to: (1) examine the variation of electromagnetic spectral reflectance on trees species and colonizing mangrove forest, and (2) demarcate the zonation of tree species in mangrove forests associated with anthropogenic activities. To identify individual mangrove species, in-situ measurement was conducted using handheld optical sensors of spectroradiometer to examine the most effective wave bands and spectral regions for discriminating mangrove tree species. To determine the significant wave bands, one-way ANOVA was applied. Later, linear discriminant analysis (LDA) was used to discriminate mangrove species. Also, laboratory tests for chlorophyll were conducted to determine the total chlorophyll contents using the same leave samples. The relationship between chlorophyll content and spectral reflectance of individual mangrove species was later identified.

In order to determine the anthropogenic effect across the entire range of study area, four temporal satellite imageries Landsat 7 and Landsat 8 were analysed and compared with Boolean algebra. Mangrove loss because of anthropogenic activities was observed across the study area. Later, electromagnetic wave bands derived from the in-situ measurements were used as spectral libraries to classify individual mangrove species. Species identification with spectral library derived from in-situ measurements using SID algorithm and derived from Landsat 8 using SAM algorithm was done. Variation of species distribution associated with anthropogenic matrix was also examined. The significant species having a relationship with distance to anthropogenic activities were tested with one-way ANOVA.

The study successfully discriminated 7 wave bands within visible region (400-700nm), 9 wave bands within NIR region (701-1000nm), 16 wave bands within SWIR-1 region (1001-1830nm), and 19 wave bands within SWIR-2 region (1831-2500nm). The study indicated that the leaf spectral reflectance for mangrove species provided poor reflectance at visible region due to high chlorophyll concentration. By conducting the laboratory measurement of leaf chlorophyll contents at three different observances, viz. 1) A_{662}, 2) A_{663}, and 3) A_{645}, the relationship with the spectral reflectance of individual mangrove species was identified. Overall, the spectral reflectance measurement pairing with leaf chlorophyll measurement provides a sound basis for classifying mangrove tree species (R^2>80%).

Mangrove loss resulting from anthropogenic activities was observed across the study area. The primary driver of anthropogenic mangrove loss was found to be the conversion of mangrove to aquaculture, however logging activity showed continuous decrease of land use and land changes at 53%. Classification accuracy was observed at 84.95% and 85.21% respectively for the in-situ measurements, and Landsat 8 spectral library. The mangrove species distribution was found to be correlated with anthropogenic activities, which were randomly distributed without specific zones (SID classification- Moran index: 0.019; z-score: 0.361; *p*-value: 0.718; SAM classification- Moran index: 0.010014; z-score: 0.731010; *p*-value: 0.464773). Based on the findings, this study has shown the possibilities of discriminating mangrove trees species through chlorophyll content-to spectra linkages. The use of SID and SAM may provide the most promising classification algorithm for improving mangrove species mapping. In addition, the characteristics of mangrove zonation is better to understand the mangrove species appearance and conservation. Therefore, mangrove zonation study will remain as an important challenge for ecologists in the future.

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sebagai memenuhi keperluan untuk ijazah Master Sains

PERINCIAN ZON HUTAN PAYA LAUT MENGGUNAKAN SPEKTRAL PANTULAN

Oleh

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Zonasi spesis paya laut seharusnya dikenalpasti dan dibezakan dengan menggunakan data geospatial. Justeru dapat membantu dalam mengemaskini corak pengzonan bagi spesis paya laut setelah dipengaruhi ataupun diancam oleh aktiviti antropogenik. Dengan menggunakan teknik geospatial dan imej penderiaan jauh, taburan spesis paya laut dan matrik daripada aktiviti antropogenik dapat dikenalpasti dan dipetakan. Tujuan utama kajian ini dilakukan adalah untuk mengenalpasti zon hutan paya laut berdasarkan aktiviti antropogenik dan corak pantulan spektral bagi spesis paya laut di Kawasan kajian. Objektif kajian ini ialah: (1) Untuk mengenalpasti variasi pantulan spektral elektromagnetik bagi spesis dan tumbuhan yang terdapat di hutan paya laut, dan (2) Untuk menentukan zon spesis pokok paya laut yang berkaitan dengan aktiviti antropogenik. Bagi mengenalpasti spesis paya laut secara individu, sensor optik spektroradiometer digunakan untuk mengenalpasti gelombang dan spektral yang berpotensi dalam membezakan spesis paya laut. Untuk mnegenalpasti gelombang yang ketara, ANOVA sehala telah dilakukan. Kemudian, analisis diskriminasi linear (ADL) digunakan untuk membezakan spesis paya laut. Ujian makmal kemudiannya turut dilakukan untuk klorofil bagi mengenalpasti jumlah keseluruhan kandungan dengan menggunakan daun yang sama. Hubungkait diantara kandungan klorofil dan pantulan spektral bagi setiap spesis akan dikenalpasti kemudian.

Untuk menentukan kesan antropogenik di seluruh kawasan kajian, empat gambar satelit Landsat 7 dan Landsat 8 telah dianalisa dan dibandingkan dengan menggunakan Algebra Boolean. Kehilangan hutan paya laut telah dikenalpasti adalah disebabkan aktiviti antropogenik disepanjang kawasan kajian. Kemudian, gelombang elektromagnetik yang diambil daripada bacaan di lapangan digunakan sebagai perpustakaan spektral dimana ianya digunakan untuk mengelaskan spesis paya laut. Identifikasi spesis dengan menggunakan perpustakan spektral yang dihasilkan daripada bacaan di lapangan dengan menggunakan algoritma SID dan perpustakan spektral yang dihasilkan

daripada imej satelit Landsat 8 dengan menggunakan algoritma SAM telah dilakukan. Variasi taburan spesis dengan pengaruh aktiviti antropogenik turut dikenalpasti. Spesis yang mempunyai hubungan yang ketara dengan jarak diantara aktiviti antropogenik kemudiannya diuji dengan menggunakan ANOVA sehala.

Kajian ini berjaya membezakan tujuh gelombang diantara bahagian *Visible* (400-700nm), Sembilan gelombang diantara bahagian *NIR* (701-1000nm), enam belas gelombang diantara bahagian *SWIR-1* (1001-1830nm), dan sembilan belas gelombang di bahagian *SWIR-2* (1831-2500nm). Kajian ini menunjukkan pantulan spektral daun bagi spesis paya laut memberikan pantulan yang kurang baik di bahagian *Visible* berikutan kandungan klorofil yang tinggi. Pengukuran kandungan klorofil daun di makmal dengan menggunakan tiga pemerhatian 1) A_{662}, 2) A_{663}, dan 3) A_{645}, mendapati terdapat hubungan diantara pantulan spektral bagi spesis paya laut. Secara keseluruhannya, pengukuran pantulan spektral dengan pengukuran klorofil daun memberikan asas yang baik untuk mengklasifikasikan spesies pokok bakau (R^2> 80%).

Kehilangan hutan paya laut adalah disebabkan oleh aktiviti antropogenik telah dikenalpasti di kawasan kajian. Faktor utama kehilangan hutan paya laut ini adalah daripada aktiviti penukaran kawasan guna tanah kepada aktiviti akuakultur. Walaubagaimanapun, aktiviti pembalakan menunjukkan penurunan penggunaan tanah secara berterusan dan perubahan tanah pada 53%. Ketepatan pengkelasan menunjukkan pada 84.95% dan 85.21% bagi pengukuran di lapangan, dan perpustakaan spektral Landsat 8. Taburan spesis paya laut didapati berhubungkait dengan aktiviti antropogenik, dimana secara rawaknya dipilih tanpa zon spesifik (Pengkelasan SID- Index Moran 0.019; z-skor: 0.361; *p*-nilai: 0.718; Pengkelasan SAM – Indek Moran: 0.010014; z-skor: 0.731010; *p*-nilai: 0.464773). Berdasarkan hasil dapatan daripada kajian ini menunjukkan kebarangkalian untuk diskriminasikan spesis paya laut dengan kandungan klorofil dan spektral. Pengunaan SID dan SAM dapat membantu memberikan algoritma pengkelasan yang terbaik dimana dapat membantu mengenalpasti spesis paya laut. Dengan mengenalpasti ciri-ciri zon paya laut adalah lebih baik dengan memahami ciri-ciri spesis dan cara pemuliharaan kawasan paya laut. Secara keseluruhannya, pada masa hadapan, kajian mengenai zon hutan paya laut masih menjadi cabaran bagi ahli arkeologi.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

µm	Micrometre
A.S. L	Above sea level
ANOVA	Analysis of Variance
ASD	Analytical Spectral Devices
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
BP ANN	back-propagation artificial-neural-network
EMR	Electromagnetic radiation
FAO	Food and Agriculture Organization of the United Nations
FDPM	Forestry Department Peninsular Malaysia
Ha	Hectare
HRVIR	High resolution visible infra-red
HRG	High resolution geometry
IKONOS	Greek word `eikon' (icon), meaning “image
IRS	Indian Remote Sensing
K_{hat}	Kappa coefficient
Km^2	Kilometre square
LANDSAT	Land Remote-Sensing Satellite (System)
LANDSAT ETM	Enhanced Thematic Mapper
LANDSAT MSS	MultiSpectral Scanner
LANDSAT TM	Thematic Mapper
LDA	Linear discriminant analysis
LIDAR	Light Detection and Ranging
M	Meter
MLC	Maximum Likelihood Classification
MMFR	Matang Mangrove Forest Reserve

NDVI	Normalized difference vegetation index
NIR	Near infrared
nm	Nanometre
PCA	Principal Component Analysis
R	Regression
ROC	receiver operating characteristics
RSME	Residual mean square error
SAM	Spectral angle mapper
SAR	Synthetic Aperture Radar
Sg	Sungai
SID	Spectral Information Divergence
SPOT	Satellite Pour l'Observation de la Terre (satellite to observe Earth)
SPOT HRG	Satellite Pour l'Observation de la Terre high resolution geometrical (satellite to observe Earth)
SPOT HRVIR	High-Resolution Visible and Infrared
SPOT HVR	High Resolution Visible
SPOT XS	Multi Spectral
SVM	Support Vector Machine
UAV	Unman Aerial Vehicle
VHR	High Resolution System
OLI	Operational Land Imager
TIRS	Thermal Infrared Sensor

CHAPTER 1

INTRODUCTION

1.1 General Background

1.1.1 Mangrove

Malaysia is endowed with high mangrove species richness and structures. 70 mangrove species from 28 families have been recorded in Malaysia. For MMFR, dominant species present are *Rhizophora apiculata*, *Rhizophora mucronata*, Avicennia – Sonneratia, *Bruguiera parvifolia,* and *Bruguiera cylindrica* as documented by (Ibharim et al., 2015). Roslan and Nik Mohd (2013) listed 27 mangrove species exclusive in Matang Mangrove Forest Reserve (MMFR) with 76 species that were common to other sites. Exclusive species are referred to species that are endemic or restricted within particular habitat whereas non-exclusive species may be introduced or even commonly found to other sites (Saenger et al., 1983). Appendix 1 lists exclusive and non-exclusive species in MMFR. Some other species found to be indigenous in some part of Malaysian mangroves viz. Sg Merbok and Langkawi Island, Kedah; Selangor; Sg Pulai, Johor; Tioman Island, Pahang; Terengganu, and Sibuti, Sarawak as listed in Appendix 2.

Mangrove species distribution found to be varied nowadays. Record et al., (2013); Alongi, (2008); Thampanya et al., (2006), suggested changes in global climate and periodic sea-level rise is the reason for such variation. Additionally, this might due to anthropogenic effects such as mangrove conversion to agriculture land, aquaculture farming conducted along coastal mangrove areas, mangrove tree harvesting activities, and mechanized transportation system leaving coastal areas with oil spill alters vegetation structure. (Son et al., (2016); Ibrahim et al., 2015; Thu & Populus, 2007) expressed aquaculture activities notably shrimp farming triggers the occasion of mangrove depletion. The aforementioned issues lead to a succession of mangrove vegetation. On top of that, the zonation of mangroves has become uncertain. Tomlinson (1986) describes, within a tide-dominated shore, mangroves were zoned to four parts viz. i) seaward zone, ii) mesozone, iii) landward zone and iv) terrestrial zone. He added mangrove species zonation often appears as a clear sequence of species colonization with *Avicennia* on the seaward zone, followed by *Rhizophora*, *Bruguiera,* and *Ceriops* in the mesozones (Figure 1.1).

Different areas have different influences on a mangrove; thus, zonation patterns may vary at both global and local scales. For example, mangrove zonation in the South America region contradicts with the Asia region. *R. mangle* (red mangrove) is found at seaward zone, *A. germinans* (black mangrove), and *L. racemosa* (white mangrove) are found in the landward zone in South America region (Feller & Sitnik, 1996). On the other hand, Avicennian communities are found in the seaward zone, Rhizophora community adaptable at soft, deep mud zone- middle zone, followed by the Bruguiera community that is more adaptable at landward zone (FAO, 2005). According to (Feller & Sitnik, 1996), differences in species occurrence can be found across an estuary and this may be influenced by the fresh and saltwater source at local scales.

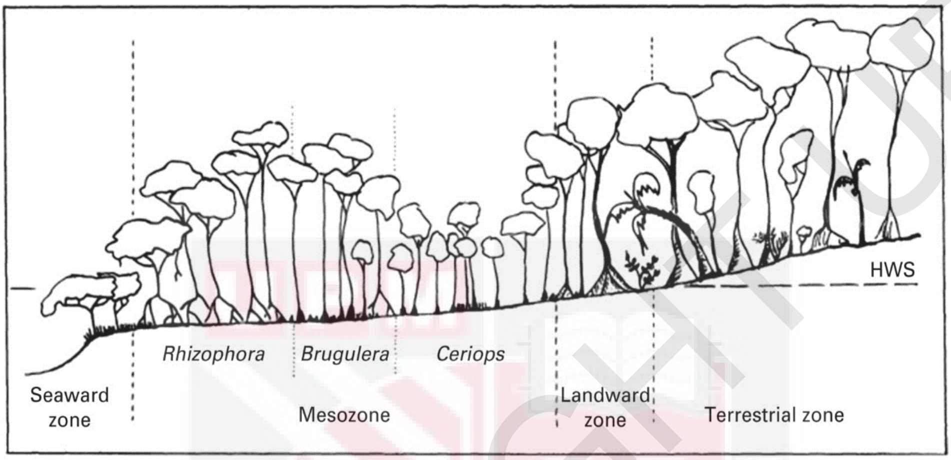

Figure 1.1: Classical mangrove profile (Source: Tomlinson, 1986)

Not entire mangroves exhibit clear zonation patterns. For example, mangrove in Tanzania may be either zoned or unzoned, Mozambique is apparently unzoned, while mangrove in Australia showing classical zonation pattern (Hogart, 2012). Some mangrove species colonized close to shores, fringing islands, and sheltered bays; others are found further inland, or in estuaries influenced by tidal action. Watson (1928) recognized five major types of mangrove forest zones in Peninsular Malaysia viz. i) Avicennia–Sonneratia types, ii) Bruguiera types, iii) Bruguiera parviflora types, iv) Rhizophora types, and v) Bruguiera gymnorrhiza types that are approaching landward margin. This zone was based on the dominant species which form almost pure stands from the seaward into the landward such illustrated by Mubarak & Azian (2012) in Figure 1.2.

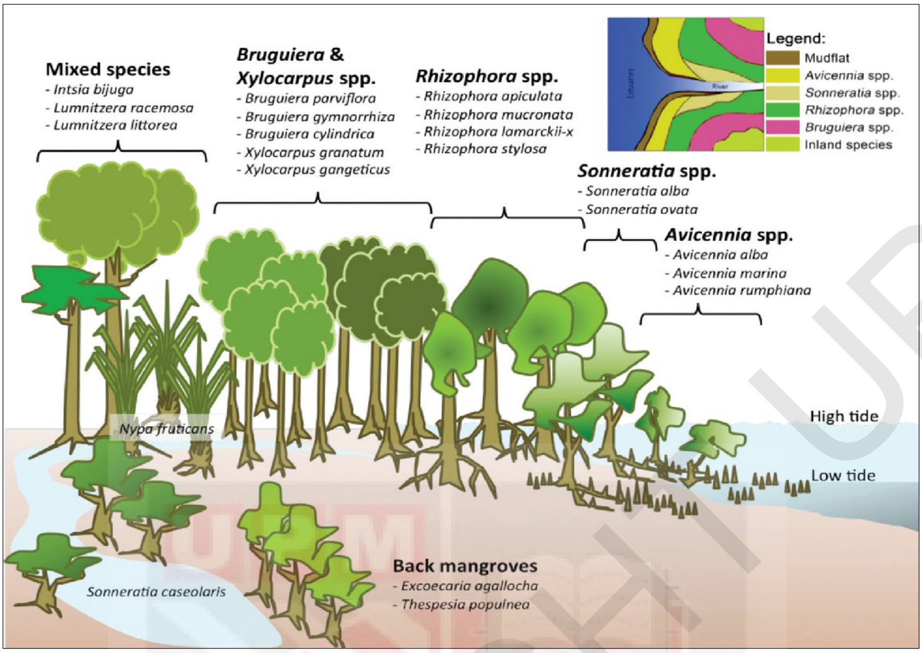

Figure 1.2: Typical zonation of mangrove in Malaysia (Source: Mubarak & Azian, 2012)

1.1.2 Application of Remote Sensing Technology in Mangroves Management

For centuries, the advance application of geospatial technology has been practically analysed with digital image processing algorithms for management, monitoring, and mapping areas that are huge or difficult to access. Time and labour constraints to conduct full scale inventory is the main reason for the emerging of geospatial technology application (Younes et al., 2017; Kovacs et al., 2005; Hirano et al., 2003; Green et al., 1998; Long & Skewes, 1996; Sader et al., 1995). This does not exempt geospatial technology to be applied to mangrove forests (Giri, 2016; Ibrahim et al., 2015; Heenkeda et al., 2014; Rao et al., 2014; Ibrahim et al., 2013; Chun et al., 2011; Wang & Sousa, 2009). Breakthrough in remotely sensed imagery acts as a modification of human eyes because it is beyond human ability especially to observe isolated, huge, and dense vegetated areas.

More than a decade, geospatial technology in Malaysia has been applied in forest management, monitoring, and mapping of mangrove ecosystems by Forest Department of Peninsular Malaysia (FDPM) as well as researcher. A number of researchers related to the mangrove ecosystem have been conducted in mangrove forest with the approach of geospatial technology. For example, Roslani et al. (2014) utilized satellite image; RapidEye 2011 with a combination of Jazz Ocean Optic Spectrometer to get Spectral reflectance reading for 11 mangrove species in Matang Mangrove Forest Reserve (MMFR). The study concludes that it is possible to identify tree species with a higher result of classification from RapidEye 2011 data with integrated NDVI $_{Red\ Edge}$ instead of with NDVI $_{Red}$. According to Cheng and Sustera (2009), the red edge band is suitable for measuring variance in vegetation, monitoring vegetation health, and discriminating between species of an interest area.

A study by Ibharim et al. (2015) uses three different multiSpectral images to detect mangrove changes from pixel-to-pixel comparison of over 18 years span from 1993 to 2011; Landsat TM 1993, Landsat ETM+ 1999, and RapidEye 2011. Their application revealed two main timber species; *Rhizophora apiculata* and *Rhizophora mucronata* are still being preserved about 80% of the total species although these two species are the main species harvested for charcoal production. In different study conducted by Chun et al. (2015); Chun et al. (2011), spectral reflectance of seven mangrove species were recorded; *Acrostichum aureum, Acrostichum speciosum, Acanthus ilicifolius, Ceriop tagal, Sonneratia ovata, Rhizophora apiculata and Rhizophora mucronata* for Matang Mangrove Forest Reserve (MMFR) by employing handheld field portable Analytical Spectral Devices (ASD) spectroradiometer. Their study proved that spectral discrimination of individual leaves is applicable to ascertain mangrove species for mapping purposes.

In principle, an object (vegetation, water, open area, utilities, and etc.) can be identified from the spectral reflectance signature of remote sensing if the sensing system has sufficient spectral resolution to distinguish between the materials spectrum (Shaw & Burke, 2003). Reactions occurred with the object viewed when spectral reflectance also known as electromagnetic radiation (EMR) reaches the earth's surface. Later, the EMR reflected, absorbed, or transmitted to the source of energy that the sensor used. This depends on three components such as the nature of the surface, the wavelength of the energy, as well as the angle of illumination. The reaction between EMR with objects on the earth surface is disparate at different wavelengths. The reflectance of material also varies with the wavelength of the electromagnetic energy. These differences in reflectance make it viable to identify different earth surface features or materials by analysing their Spectral reflectance signatures. Spectral reflectance shown as curves in the graph represents different objects as a function of wavelengths.

In general, healthy vegetation is a very good absorber of electromagnetic energy within the visible region. Chlorophyll strongly absorbs light at wavelengths around 0.45 (blue) and 0.67 µm (red) which in turn reflects strongly in a green light, therefore our eyes perceive healthy vegetation as green. Healthy plants have a high reflectance in the near-infrared between 0.7 to 1.3 µm. This is primarily due to the internal structure of plant leaves. As this internal structure varies amongst plants, the near infrared wavelengths can be used to discriminate between different species. The Spectral reflectance of leaves is the most important factor in understanding the reflectance of the full canopy (Kamaruzaman & Kasawani, 2007). However, the spectral properties and characterization of vegetation canopies are one of the most crucial problems in remote sensing because the signal of the reflectance properties for vegetation canopy detected at the sensor is influenced by many biochemical and biophysical canopy attributes as well as their external factors (Chuvieco and Huete, 2010). According to Adam et al. (2010) there are two major challenges when mapping wetland vegetation. Firstly, the accurate demarcation of vegetation community boundaries is difficult, due to the high spectral and spatial variability of the communities. Secondly, Spectral reflectance values of wetland vegetation are often mixed with what is underlying in wet soil and water that will attenuate the signal of the near-infrared to mid-infrared bands (Lobell & Asner, 2002; Pinty et al., 1998).

1.1.3 History of Land Use Changes in Matang Mangrove Forest Reserve

Despite being realized the importance of mangroves forest in ecosystem, the extents of mangrove have inevitably declined since the last few decades. Unfortunately, the declines have been resulting mainly from human activities such as aquaculture expansion, coastal movement, and over harvesting (Giri et al., 2015). According to Hamdan et al., (2019), distribution of mangrove ecosystem has been threated by various land use activities. Reported by Roslan et al., (2014), in the last decade approximately 580,000 ha of mangrove forest has been lost while Aizpuru et al., (2000) and FAO, (1997) reported that in between 1975 to 2000, the extent of mangrove area in Malaysia especially has been recorded decreasing from 700,000 ha till 572,000 ha due to intensive harvesting and natural wave. Generally, Asia was the region which undergo the largest net loss of mangroves forest since 1980 around 1.9 million ha because conversion activity to urban or to agriculture. However, the mangrove loss has been slow down around 187,000 ha in 1980s to 102,000 ha in between 2000 till 2005 due to increasing to awareness about important of mangrove and management system get improved. There are a few factors which derived the changes of land used in mangrove area due to conversion to urban and industrial areas, aquaculture and agriculture. In additional, natural phenomena also cause the changes of land used such as coastal erosion, storm, lightning strikes and tsunami which driver to mangrove loss.

1.2 Problem Statement

A veritable knowledge and understanding of mangrove species zonation associated with anthropogenic activities across intertidal zones are outlined as the focus of this study. Spectral reflectance related to chlorophyll infiltration with the sensor are occupied in identifying mangrove species. Although remote sensing has been extensively applied in the mangrove forest, the uncertainty between the relationship of spectral reflectance and objects exists in discriminating mangrove forest structures (including vegetation, water, soil, etc.) as supported by Heumann.b (2011); Chuvieco & Huete. (2010); Liu et al. (2008) and Wang et al. (2004). Thus, to fill the gap of such related problems, a new approach is essential to be developed in this study to increase the accuracy of satellite imagery utilization to further define information on mangrove forests. A spectral library of certain mangrove species at Matang Mangrove Forest was developed from this study with an accuracy of classification was carried out via Spectral Information Divergence (SID) and Spectral Angle Mapper classification (SAM). The distribution maps at the species level or zoning in mangrove forests were produced by using the spectral reflectance library as a reference. Changes of mangrove forest mostly due to anthropogenic activities are examined and interpreted with mangrove species distribution as a reference to the cause of species occurrence following to land use changes.

1.3 Objective

The aim of this study is to identify the zonation of mangrove forest structured by anthropogenic activities based on the spectral reflectance pattern of mangrove species at Matang Mangrove Forest Reserve (MMFR), Perak.

The specific objectives are as follow:

1. To examine the variation of electromagnetic spectral reflectance on trees species and colonizing mangrove forest.
2. To demarcate the zonation of tree species in mangrove forests associated with anthropogenic activities.

1.4 Frame Work

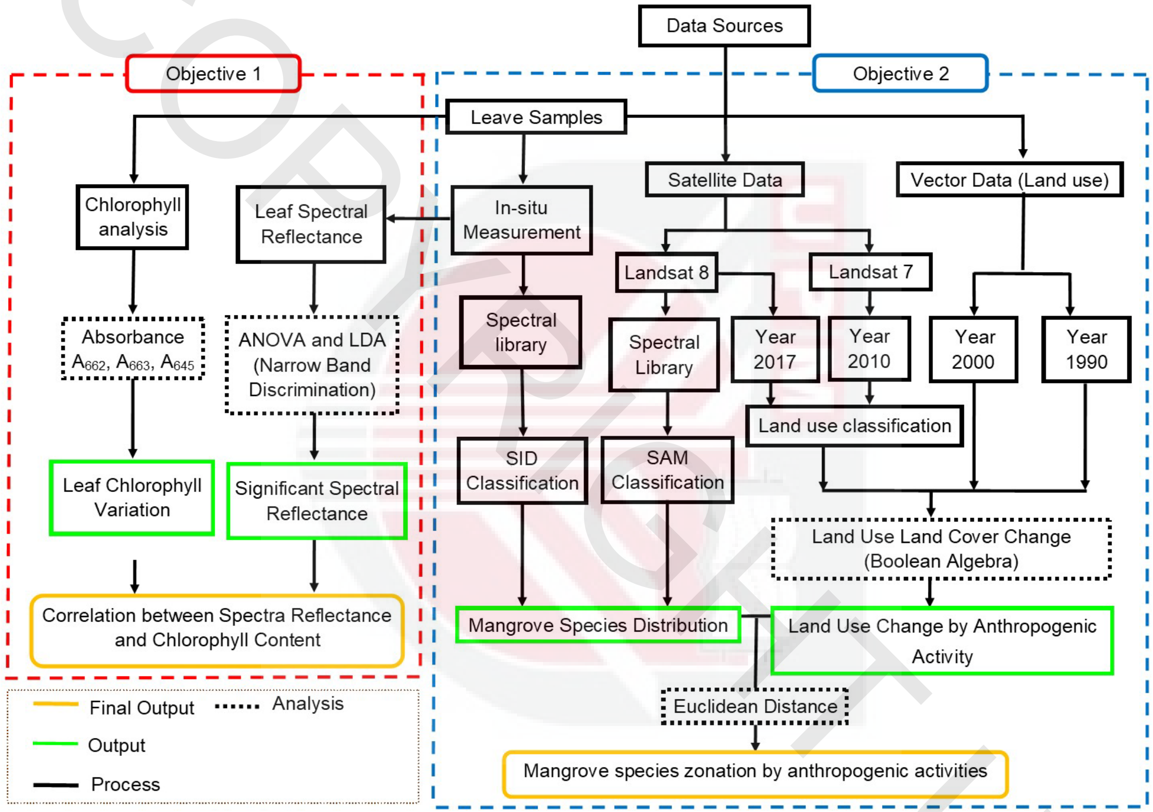

Figure 1.3: Workflow for research study

1.5 Thesis Outline

The thesis was organized as follows in Figure 1.3:

Chapter 1: Presents the general background of the study, problem statement, aim and objectives. This chapter consists of the important spatial technology in mangrove forest specially to discriminate the mangrove species based on the electromagnetic spectral reflectance.

Chapter 2: Reviews and discusses the relevant issues related to the application of remote sensing on mangrove forests and previous research related to mangrove forest mapping.

Chapter 3: Present the relationship between spectral reflectance and chlorophyll contents.

Chapter 4: Present the mangrove species zonation structured by anthropogenic effect.

Chapter 5: Concludes the overall research findings from this study.

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