MANGROVE MIGRATION DUE TO SEA LEVEL RISE

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To my beloved husband,

Thank you for your love, patience and understanding

To my beloved Ayah and Emak,

Thank you for bringing me into this world

To my friends and families,

Thank you for being a part of this journey

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ABSTRACT

The coastal zone of Pulau Kukup is characterized by muddy substrates and is classified as a micro-tidal coast. Potential impacts of sea level rise were studied to relate the effects of tidal inundation regime associated with accelerated SLR and mangrove migration for the next centuries. The primary objective of this research is to simulate and estimate the potential mangroves migration under several conditions of sea level rise scenarios projected for the years 2025, 2050 and 2100. Another goal of this study is to evaluate the Coastal Vulnerability Index (CVI) and develop the supplementary maps for the island. Vegetation map were developed from WorldView-2 data within SPRING 5.2 software. The Digital Terrain Model from IFSAR data, were processed in ArcGIS 9.3 to produce the mangrove migration map. The CVI study showed that the northern and southern sectors are highly vulnerable risk to sea level rise and this accounted for 42% from Pulau Kukup shorelines. From the field survey analyses and mangrove vegetation map, *Rhizophora apiculata* and *Rhizophora mucronata* dominates an outer part of the mangrove belts, accounting for 89% from the total sampled trees. The study concluded that, mangrove plant will tolerate to the inundation change in order of *Sonneratia alba, Rhizophora mucronata, Rhizophora apiculata, Bruguiera parviflora, Brugueira cylindrica* and *Xylocarpus moluccensis.* A series of mangrove migration map for 2025, 2050 and 2100 sea level rise scenarios shows an adjustment to tidal inundation class due to increase of seawater level. Mangroves from the lower zones (Z2 and Z3) migrate into the higher zone (Z4) as a response to sea level rise. In the worst case scenario, more than 25% of the mangrove forest will be converted to the open water due to a 1.3 metre sea level rise. The total land loss in the year 2100 was estimated at 69.75 hectare (Case study 1), 73.52 hectare (Case study 2) and 148.92 hectare (Case study 3). The worst case scenarios will possibly lead to the extinction of *Xylocarpus moluccensis* at Pulau Kukup when zone Z4 was begin to disappear from the year 2050 SLR projection. In conclusion, the findings showed that the mangrove migrations will occur if the tidal inundation were modified by future sea water level. It is a strategic response developed by mangrove species to maintain the preferable condition for their optimal growth and species colonisation. This research approach can be applied to other mangrove forest at regional scale to identify the potential mangrove response in a simple way for basic information of future development and planning for scientist, engineer, researchers and decision makers.

ABSTRAK

Zon pesisir pantai Pulau Kukup mempunyai ciri-ciri substrat berlumpur dan diklasifikasikan sebagai pesisir pantai mikro-pasang surut. Potensi impak Kenaikan Aras Laut telah dikaji untuk mengaitkan kesan inundasi pasang surut yang berkaitan dengan kepantasan kenaikan aras laut dan migrasi pokok bakau untuk abad seterusnya. Objektif utama kajian ini adalah meramal dan menganggar migrasi berpotensi bakau dalam pelbagai senario kenaikan aras laut yang diunjurkan bagi tahun 2025, 2050 dan 2100. Matlamat lain kajian ini adalah menilai 'Coastal Vulnerability Index (CVI)' dan menghasilkan peta-peta sokongan pulau tersebut. Peta tumbuhan telah di bangunkan menggunakan data WorldView-2 melalui perisian SPRING 5.2. Peta migrasi bakau seterusnya di hasilkan menggunakan Model Paramuka Berdigit dari data IFSAR, melalui aplikasi ArcGIS 9.3. Hasil kajian 'CVI', menunjukkan sektor-sektor yang terletak di kawasan utara dan selatan mengalami risiko keterancaman yang tinggi akibat kenaikan aras laut dan ini mewakili 42% dari jumlah keseluruhan pesisir pantai Pulau Kukup. Analisis dari tinjauan tapak dan peta tumbuhan bakau mendapati *Rhizophora apiculata* dan *Rhizophora mucronata* mendominasi bahagian luar lilitan bakau sebanyak 89% dari jumlah keseluruhan sampel pokok-pokok. Kajian ini menyimpulkan bahawa tahap toleransi pokok bakau terhadap perubahan inundasi adalah seperti berikut iaitu *Sonneratia alba, Rhizophora mucronata, Rhizophora apiculata, Bruguiera parviflora, Brugueira cylindrica* dan *Xylocarpus moluccensis.* Satu siri peta migrasi bakau bagi senario kenaikan aras laut di hasilkan untuk tahun 2025, 2050 dan 2100 menunjukkan pelarasan kepada kelas inundasi pasang surut di sebabkan oleh kenaikan aras air laut. Bakau daripada zon yang lebih rendah (Z2 & Z3) akan mengalami migrasi ke zon yang lebih tinggi (Z4) akibat kenaikan aras air laut. Senario terburuk menunjukkan lebih dari 25% hutan bakau akan hilang akibat kenaikan 1.3 meter aras air laut. Jumlah penyusutan kawasan bakau pada tahun 2100 dianggarkan sebanyak 69.75 hektar (Kajian kes 1), 73.52 hektar (Kajian kes 2) dan 148.92 hektar (Kajian kes 3). Senario kes terburuk mungkin akan membawa kepada kepupusan *Xylocarpus moluccensis* di Pulau Kukup apabila zon Z4 mula mengalami penyusutan melalui unjuran peningkatan aras air laut pada tahun 2050. Kesimpulanya, hasil kajian menunjukkan migrasi bakau dijangka berlaku apabila terdapat perubahan inundasi pasang surut disebabkan kenaikan aras laut di masa hadapan. Ia merupakan satu tindakbalas strategik spesis bakau bagi mengekalkan keadaan yang sesuai untuk pertumbuhan yang optimum dan pengkolonian spesis. Pendekatan yang di bangunkan melalui kajian ini boleh diguna pakai di kawasan hutan bakau lain pada skala serantau untuk mengenalpasti potensi tindakbalas bakau dengan cara yang mudah untuk maklumat asas pembangunan dan perancangan masa hadapan oleh ahli-ahli saintis, jurutera, penyelidik dan pembuat keputusan.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

CD	-	Chart Datum
CVI	-	Coastal Vulnerability Index
DBH	-	Diameter at Breast Height
DEM	-	Digital Elevation Model
DID	-	Department of Irrigation and Drainage
DSAS	-	Digital Shoreline Analysis System
DSM	-	Digital Surface Model
DSMM	-	Department of Survey and Mapping Malaysia
DTM	-	Digital Terrain Model
EGM	-	Earth Gravitational Model
ENVI	-	Environment for Visualizing Image
EPR	-	End Point Rate
EVI	-	Environmental Vulnerability Index
GIS	-	Geographic Information System
IFSAR	-	Interferometric Synthetic Aperture Radar
IPCC	-	Intergovernmental Panel on Climate Change
LIDAR	-	Light Detection and Ranging
LMSL	-	Local Mean Sea Level
MRSA	-	Malaysian Remote Sensing Agency
MSMD	-	Malaysia Survey and Mapping Department
NAHRIM	-	National Hydraulic Research Institute Malaysia
NCVI	-	National Coastal Vulnerability Index
NHC	-	National Hydrographic Center
NIMA	-	National Imagery and Mapping Agency
ORI	-	Ortho-Rectified Image
PAN	-	Panchromatic Image
PCQM	-	Point-Centre-Quarter Method

PVI	-	Physical Vulnerability Index
SAR	-	Synthetic Aperture Radar
SCR	-	Shoreline Changes Rate
SLR	-	Sea Level Rise
TIN	-	Triangulated Irregular Network
USGS	-	United State of Geological Survey

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Research Background

Natural threats originating from the ocean waters have become a major concern to coastal communities. Sea-Level-Rise (SLR) phenomenon was identified by IPCC, (2001) as an expected problem faced by intertidal communities resulting from global climate change. Projection of global sea level rise by several models indicated an increase from 12-22cm in seawater surface during the 20^{th} century (Thomas et al., 2004). Solomon et al., (2007) projected an increase of 0.19-0.59 m in 21st century based on data projection of 1999-2099. The long term effects of SLR will reduce the quality of intertidal ecosystems due to habitat deterioration (Gilman et al., 2007). SLR may combine with other coastal hazard (e.g: tsunami) and maximize the impacts to the coastal ecosystem.

Some major physical impacts of SLR have been listed by Titus, (1991) such as increase in inundation, coastal erosion, exacerbated coastal flooding and increase in the salinity intrusion to estuaries and aquifers. Marfai and King, (2008) conducted a research on the impacts of SLR to the Semarang coast in Indonesia and found that the tidal inundation and land subsidence were increased by the impact of SLR.

Inundation is the most obvious physical impact of sea level rise (Cooper et al., 2008). The conversion of dryland to wetland or the wetland to open sea is anticipated, resulting from the changes of normal inundation processes due to SLR. The inundation risk to coastal communities had been extensively studied by many authors from all over the world, such as Marfai and King, (2008a) in Indonesia, Kuhn and Tuladhar, (2011) at Australia, Tian et al., (2010) in China, and later Di Nitto et al., (2014) in Kenya. As the sea level rises, the inundation level and distances, period of submergence and frequencies will change accordingly. These modifications will affect the intertidal ecosystem, especially the low-lying wetland ecosystem such as the mangroves. Mangrove chains will face mass fatality, while the survivability rate of mangrove trees would be reduced.

Mangroves grow widely all over the world between Indo-Pacific Region, South and Central America to Africa. Majority of mangrove populations are distributed between equatorial line to latitudes 30 degree north and south. According to Tomlinson, (1986) mangrove species variability will decrease with increasing latitudes, therefore more than 40 species of mangrove are found in the Eastern group (Australia, South East Asia, Western Pacific, India and East Africa), compared to 8 species found in the Western Group (South America, Florida, Atlantic South America, Pacific North, Western Africa and Caribbean). Mangroves comprise less than 2% of the total land area in Malaysia. There are 641,886 ha of mangrove forests in Malaysia, of which 57% is found in Sabah and 26% in Sarawak while remaining 17% in Peninsular Malaysia (Kamaruzzaman, 2013).

In recent years, mangroves are declining at an alarming rate. A global reduction of approximately 25% has been observed since 1980, and the mangrove area today is less than 15million ha (Valiela et al., 2001). Kathiresan and Rajendran, (2005) conducted a study after the December 2004 tsunami event, and listed certain places in India, Bangladesh, Malaysia, Thailand and Indonesia as not severely impacted by the lethal power of the tsunami waves, because a chain of coastal mangrove vegetation helped to dissipate the wave energy and lowered the impacts to the coastal areas.

Despite the capability in coastal defense mechanism, mangrove is a long-living and slow growing plant (Woodroffe, 1990). Mangroves cannot keep pace to sea level rise when the intensity of changes is drastic. Mangroves will respond to the impacts of SLR as their adaptation strategies. Gilman et al., (2008) described that the mangrove response in term of the mangrove position to sea level rise can be classified under four categories (Figure 1.1). They are ‘stable (no migration), ‘seaward migration, ‘landward migration' and 'landward migration' (obstructed).

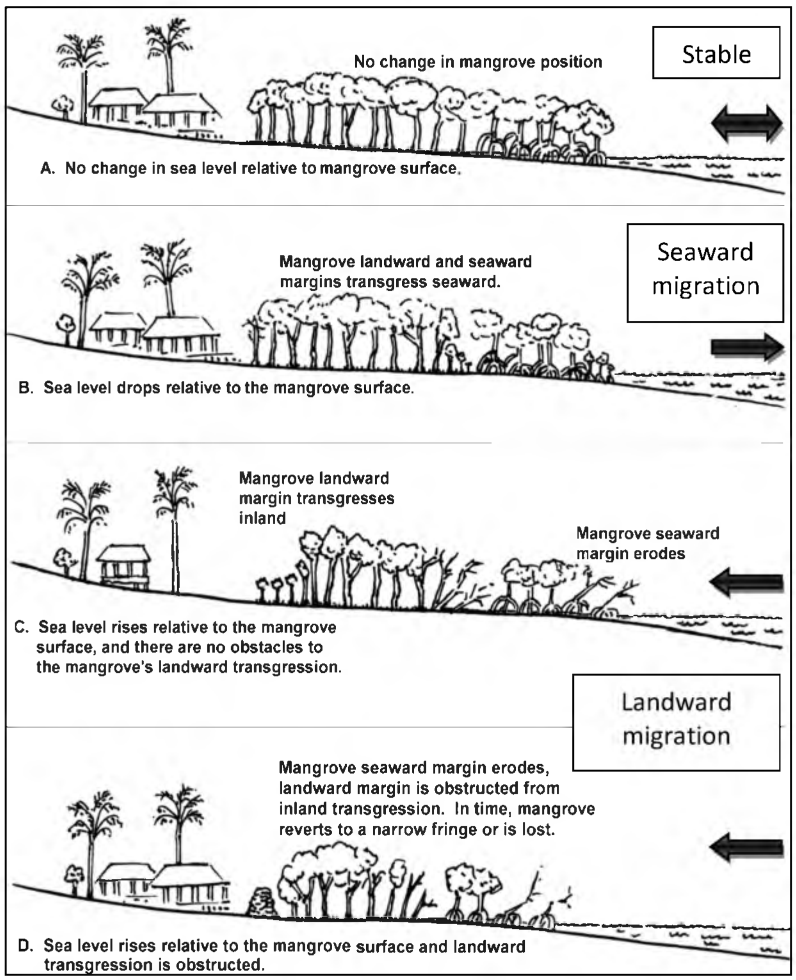

Figure 1.1 Mangrove response to relative sea level rise (Gilman et al., 2008)

Landward migration is a natural response of mangrove species to the anticipated effects of SLR. Mangroves will migrate via seedling recruitment and vegetative reproduction to new habitat and form a new zonation pattern (Gilman et al., 2008). This response is crucial for mangrove species to maintain the preferable zones for their growth and expansion. Basic information and predictions of local mangrove response to the long term effect of SLR are therefore significant. In the end, the prediction of mangrove migration will provide useful information for site planning and conservation strategies to offset the anticipated losses.

1.2 Problem Statement

The loss of mangrove can be disastrous as evidenced by past events. The Tsunami event on 26th December 2004 triggered by a magnitude 9.15 earthquake in the Indian Oceans released a series of devastating tsunami waves and caused enormous environmental damage to northwestern Peninsular Malaysia (Kamaruzzaman, 2013). The post-tsunami assessment in affected areas showed that healthy mangroves communities not only broke the impacts of the waves, but also trapped debris and prevented people from being washed out to sea, which was a major cause of death in other countries. In normal situation, when waves are small, mangroves also contribute to dissipating the wave energy and reduce the coastal erosion. It is reported that the height of wind and swell waves is reduced by 13-66 percent within the first 100m of mangroves belt (Dahdouh-Guebas and Koedam, 2006). To perform these functions effectively, the mangrove green belt should be wide enough and contain high diversity of species and age groups.

In Malaysia, mangroves comprise less than 2% of the total land area. 40% of mangrove area had been reduced since 1980 due to shrimp pond farming, woodchip industry and natural phenomenon (Sujahangir et al., 2014). Sea Level Rise (SLR) is one of the long term natural hazards that potentially contribute to the mangrove losses (Alongi, 2002).

A sea level rise study conducted by Azura and Hadibah, (2013) in the west coast Peninsular Malaysia based on tidal gauge data showed an increasing trend of mean sea level at all study areas. The affected places were Langkawi, Penang, Lumut, Port Klang, Tanjung Keling and Kukup. Meanwhile, a national finding by Malaysia government agency was stated in National Coastal Vulnerability Index report (DID, 2007). The report identified that the mean sea level at the southern region of Peninsular Malaysia had risen at an average of 1.25mm/yr over 1986 to 2006. These findings showed a strong indication of sea level rise issues and the long term impacts to coastal ecosystem. Marfai and King, (2008) suggested that the long term impacts of untreated SLR problems can combine with other coastal hazards and maximize the damaging effect to coastal communities. Therefore, the mangrove restoration effort should be intensified but not limited to the replanting programme only. The basic understanding on mangrove habitat and its response towards the threat is equally important to ensure the success of the whole conservation strategies. However, according to Ong, (1995) the availability of basic information on local mangrove response to the natural hazards (e.g: SLR) is still poor. Lack of basic information on potential mangrove migration will definitely influence the efficiency of mangroves conservation plan. Hence, through this study, the basic information on local mangrove response to the future SLR is investigated and will provide useful information to strengthen mangrove conservation plans and strategies.

1.3 Study Area

In this study, Pulau Kukup, which is located in Pontian district, Johor, was selected as the site study. Pulau Kukup is an uninhabited mangrove island located 1km offshore from the south – western tip of the state of Johor, Malaysia. It is a small mangrove island surrounded by mudflats with mature mangrove in the interior. Pulau Kukup is a natural mangrove island with six small creeks dissecting the islands in various places. In January 2003, Pulau Kukup was designated as a RAMSAR site by Geneva-Based Ramsar Bureau. The hydrological value of Pulau Kukup is important for flood control and land protection as it shelters the mainland town from severe storm events. It reduces the wave energy reaching Kukup town and helps in stabilizing the shoreline by trapping sediments. The location of the study area was selected based on the physical and ecological features and the importance of Pulau Kukup to local communities.

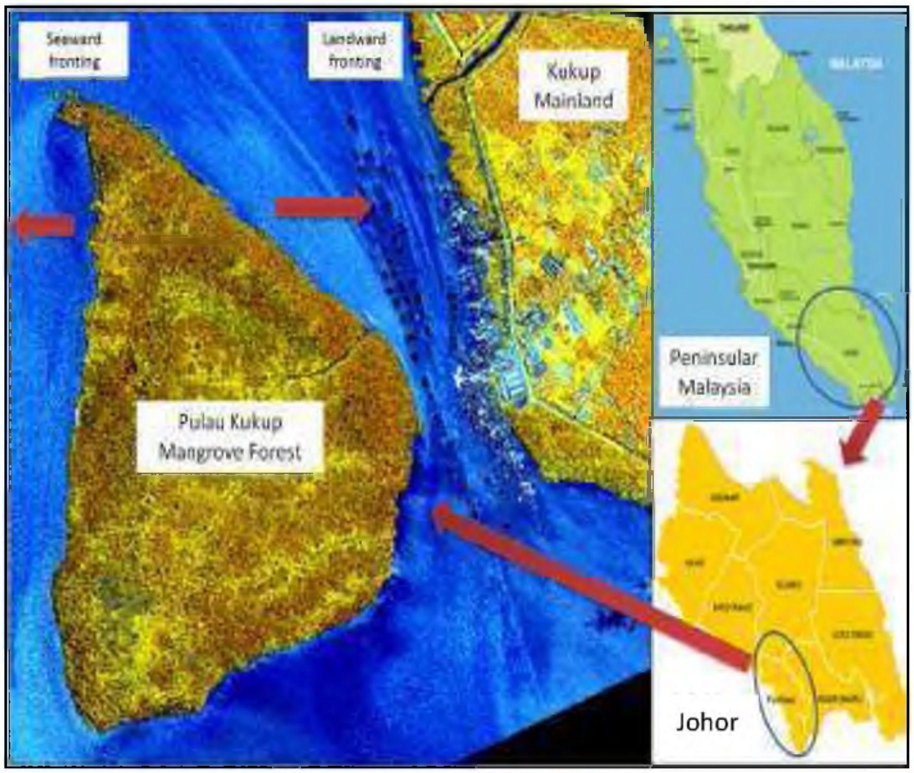

Figure 1.2 Location of the study area

1.4 Objectives of Study

I. To determine the Coastal Vulnerability Index (CVI) of Pulau Kukup due to Sea Level Rise

II. To develop the mangrove vegetation map for Pulau Kukup using World View-2 image

III. To predict the mangrove migration under different Sea Level Rise scenarios for the year 2025, 2050 and 2100

1.5 Scope of Study

The scope of this study can best be described as follows:

I. A review of literatures related to mangrove response to sea level rise, sea level rise scenarios, mangrove characteristics and inundation processes and frequency.

II. Data collection is based on the field survey data and archive records of Pulau Kukup to perform the analysis.

III. Collected data is analyzed through several methodologies. The vegetation map is developed in SPRING 5.2 software based on collected data at the field. The Coastal Vulnerability Index (CVI) is determined based on the methodology adopted in National Coastal Vulnerability Index studies (DID, 2007). The simulation of inundation impacts due to sea level rise is performed in GIS environment (ArcGIS 9.3). In the end, the potential mangrove migration was calculated to represent the effect to the study area.

IV. The determination of mangrove migration in this study is limited to the relationship of tidal inundation changes due to sea level rise with the mangrove zones classification based on Watson, (1928). The final output of this study is in the form of predicted mangrove loss due to SLR, and the mangrove migration map for 2025, 2050 and 2100.

1.6 Significance of Study

The research findings are expected to provide:-

I. The coastal vulnerability index of Pulau Kukup due to Sea Level Rise

II. A vegetation map with mangrove species distribution for Pulau Kukup

III. The migration maps for mangrove zones in 2025, 2050 and 2100 due to selected SLR scenarios (relative, average and worst SLR scenarios)

1.7 Organization of the Thesis

The structure of this thesis as follows:-

I. Chapter 1 will introduce the background of the study, scopes, significance and the objectives of the study.

II. Chapter 2 will be focused on the compilation of general concepts, definition and related issues associated with Sea Level Rise, mangrove response and coastal inundation. This chapter reviews past research on coastal inundation model, physical impacts of Sea Level Rise and the mangrove response to Sea Level Rise.

III. Chapter 3 will explain the methodologies involved for the data analysis. It will give the description of the softwares use (SPRING 5.2, ENVI 4.8 and ArcGIS 9.3), the types of data collections and procedures undertaken to conduct the Coastal Vulnerability Index (CVI) study, the development of vegetation map at the study area using the WorldView-2 image and the strategy to extract the elevation data from IFSAR package. Finally the procedures and calculation method for mangrove migration analysis will also be explained.

IV. Chapter 4 describes the data handling and the manipulation of the raw data for data analysis. The analysis for the CVI study, vegetation map development and mangrove migration analysis will be presented in the chapter.

V. Chapter 5 will discuss the findings from the data analysis. The description will be divided into three parts. They are the discussion on CVI findings, the vegetation map for Pulau Kukup and the discussions on mangrove migration investigation.

VI. Chapter 6 describes the final findings from the research and suggestion for further works.

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