MAPPING OF SEA BOTTOM FEATURES USING HIGH RESOLUTION SATELLITE DATA

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requirements for the award of the degree of
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This work is dedicated with love and passion to

my mother, Puan Hajah Tupiah Binti Robin

my father, Tuan Haji Yahya Bin Atan

my brother and sisters

and not forgotten

Muhammad Nazri Bin Samat

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ABSTRACT

Satellite remote sensing techniques have been found to be useful in many areas of applications. This thesis reports on a study using high resolution satellite imageries for mapping of different sea bottom features in tropical waters of Sibu Island and Merambong, Malaysia. The satellite data used for Sibu Island are ALOS AVNIR-2, Quickbird and Landsat-5 TM data, while the satellite data for Merambong is ALOS AVNIR-2 data. Two techniques, namely the depth invariant index and bottom reflectance index were applied in order to map different types of sea bottom features. The depth invariant index technique was derived from the measured radiance, deep water radiance and ratio of attenuation coefficients. However, the bottom reflectance index technique used the measured radiance together with water depths and attenuation coefficients. The sea truth data were used to verify the existence of particular sea bottom features. A direct comparison of overall accuracy, kappa coefficient and Tau coefficient between both techniques revealed that depth invariant index technique using Quickbird satellite data provides accurate mapping for Sibu Island which are 85%, 0.78 and 0.79 respectively while bottom reflectance index technique using ALOS AVNIR-2 data gives better results for Merambong which are 85%, 0.30 and 0.30 respectively. Based on the accuracy of both techniques, it can be concluded that different technique is suitable for different water conditions. The waters in Merambong can be classified as moderately clear and the sea bottom cannot be seen directly from the boat unless it is low tide since the sea bottom is covered by mud and dark sand. The waters in Sibu Island can be classified as clear and the sea bottom can directly be seen from the boat for shallow waters. It can be concluded that depth invariant index technique is suitable for clear waters while bottom reflectance index is suitable for areas with moderate clear waters.

ABSTRAK

Teknik satelit remote sensing didapati berguna dalam pelbagai aplikasi. Tesis ini melaporkan kajian menggunakan imej satelit beresolusi tinggi untuk memetakan pelbagai butiran dasar laut di perairan tropika, Pulau Sibu dan Merambong, Malaysia. Data satelit yang digunakan di Pulau Sibu ialah ALOS AVNIR-2, Quickbird dan Landsat-5 TM, manakala data satelit untuk Merambong ialah data ALOS AVNIR-2. Dua teknik iaitu *depth invariant index* dan *bottom reflectance index* telah digunakan untuk memetakan pelbagai jenis butiran dasar laut. Teknik *depth invariant index* menggunakan hubungan antara nilai *measured radiance*, nilai *radiance* laut dalam dan nisbah *attenuation coefficient*. Walau bagaimanapun, teknik *bottom reflectance index* menggunakan nilai *measured radiance* bersama-sama dengan kedalaman air dan *attenuation coefficient*. Data lapangan telah digunakan untuk mengesahkan kewujudan butiran dasar laut. Perbandingan langsung melalui *overall accuracy*, *kappa coefficient* dan *Tau coefficient* di antara kedua-dua teknik mendapati teknik *depth invariant index* menggunakan imej Quickbird di Pulau Sibu menunjukkan hasil pemetaan yang agak tepat iaitu masing-masing 85%, 0.78 dan 0.79 manakala teknik *bottom reflectance index* menunjukkan hasil pemetaan yang baik di Merambong iaitu masing-masing 85%, 0.30 dan 0.30. Berdasarkan ketepatan kedua-dua teknik ini, dapat disimpulkan bahawa teknik yang berbeza sesuai untuk keadaan air yang berbeza. Keadaan air di Merambong adalah dikelaskan sebagai sederhana jernih dan dasar laut tidak boleh dilihat secara langsung dari bot kerana dasar laut dilitupi lumpur dan pasir gelap. Keadaan air di Pulau Sibu adalah dikelaskan sebagai jernih dan dasar laut boleh di lihat secara langsung dari bot bagi kawasan cetek. Kesimpulannya, teknik *depth invariant index* adalah sesuai untuk air yang jernih manakala teknik *bottom reflectance index* sesuai untuk keadaan air yang sederhana jernih.

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LIST OF SYMBOLS

absCalFactorBand	-	Absolute Radiometric Calibration Factor
c	-	y-intercept
Dn, DN_i	-	Digital Number
FOV	-	Field of View
g	-	Geometric Factor Accounting for Path Length Through Water
h	-	Satellite Height
i	-	i-th Habitat
M	-	Number of Habitats
m	-	Slope of Graph
N	-	Total Number of Sites
qPixel,Band	-	Radiometrically Corrected Image Pixels
R	-	Earth Radius
-RB	-	Index Substrate Reflectance
SX	-	Swath Width
T	-	Tau Coefficient
X, Y	-	Coordinates on Map
x, y	-	Coordinates on Image
Z	-	Depth
ΔλBand	-	Effective Bandwidth for a Given Band
Ø	-	Satellite Zenith Angle
α	-	y-intercept
β	-	Horizontal Asymptote
δ	-	Regression Value
R_i’	-	Deglinted Image
Ø’$_s$	-	Sun Zenith Angle Below Water
Ø’	-	Satellite Zenith Angle Below Water

$Ø_s$	-	Sun Zenith Angle
a_i	-	Wavelength Dependent Constant Accounting for Atmospheric Effects and Water Surface Reflection
a_1-a_6	-	Coefficients
$B_{rescale}$	-	$LMIN_\lambda$
b_1-b_6	-	Coefficients
b_i	-	Regression Slope
$CalCoef_i$	-	In-band Radiance Calibration Coefficient
K_i, K_j	-	Attenuation Coefficient for Bands i and j
L_i, L_j	-	Measured Radiance in Bands i and j
L_{si}, L_{sj}	-	Deep Water Radiance in Bands i and j
$LMAX_\lambda$	-	Spectral Radiance that is Scaled to $Q_{cal\ max}$
$LMIN_\lambda$	-	Spectral Radiance that is Scaled to $Q_{cal\ min}$
L_λ	-	Spectral Radiance at the Sensors Aperture
$L_{\lambda Pixel,Band}$	-	Top-of-atmosphere (TOA) Band Integrated Radiance Image Pixels
Min_{NIR}	-	Minimum Pixel Value in NIR Band
n_a	-	Air Refraction Index
n_i	-	Total Row for Habitat i
n_w	-	Water Refraction Index
P_0	-	Overall Accuracy
Q_{cal}	-	Digital Number
$Q_{cal\ max}$	-	Maximum Quantized Calibrated Pixel Value (DN) Corresponding to LMAX
Q_{calmin}	-	Minimum Quantized Calibrated Pixel Value (DN) Corresponding to LMIN
R_{bi}	-	Bottom Reflectance
R_i	-	Pixel Value in Band i
R_{NIR}	-	Pixel Value in NIR Band
r_i, r_j	-	Bottom Reflectance in Bands i and j
X_i, X_j	-	Transformed Measured Radiance in Bands i and j
X_1	-	Transformed Measured Radiance for Band 1
X_3	-	Transformed Measured Radiance for Band 3
x_i	-	Diagonal Value for Habitat i
Y_i	-	Depth Invariant Index

Y_{io}	-	Constant for Fixed Illumination and Atmospheric Conditions

LIST OF ABBREVIATIONS

ALOS	:	Advanced Land Observing Satellite
AVIRIS	:	Airborne Visible Infrared Imaging Spectrometer
AVNIR-2	:	Advanced Visible and Near Infrared Radiometer Type 2
CASI	:	Compact Airborne Spectrographic Imager
DIB	:	Depth-invariant Bottom Index
DGPS	:	Differential Global Positioning System
DN	:	Digital Numbers
EMR	:	Electromagnetic Radiation
ETM+	:	Enhanced Thematic Mapper Plus
GCP	:	Ground Control Points
GIS	:	Geographic Information System
GPS	:	Global Positioning System
IRS	:	Indian Remote Sensing
JAXA	:	Japan Aerospace Exploration Agency
LISS III	:	1C and 1D Linear Imaging Self-scanning Sensor III
MSS	:	Multispectral Scanner
NIR	:	Near Infrared
NRE	:	Ministry of Natural Resources and Environment
ROV	:	Remotely Operated Vehicle
SOS	:	Save Our Seahorses
SPOT	:	Systeme Probatoire de I'Observation de la Terre
TM	:	Thematic Mapper
TOA	:	Top-of-Atmosphere

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CHAPTER 1

INTRODUCTION

1.1 Background

Sea bottom features are very significant to the ecosystem of the marine environment. Seaweed and seagrass are both marine plants that live in the seawater. Coral reefs are complex, important, beautiful, ancient and striking features of the marine environment. These marine life are strongly affected by modification of land changes. They need sunlight for photosynthesis which requires light and carbon dioxide. Photosynthesis process is the major factor for the exchange of gases among seawater, and marine plants system (Hermand et al. 2006).

Seagrass are flowering plants with true roots, adapted to live and reproduce in seawater (Community Environment Network, 2005). Seagrass can be found in tropical, temperate and at the edge of the artic regions (McKenzie, 2008). It is located in calm seawaters, shallow waters, bay, protected sea shorelines and on off-shore islands among coral reef borders where they populate the outer area between coral reef and semi-open sea. Seaweed which are also referred as *macroalgae* are visible to the eyes along most coastal areas. They attach themselves to rocks and their structures are more complex and appear in a variety of colours and forms.

Usually, seagrass are confused with seaweed, but there are many significant differences between these two different marine species. They also differ in reproduction, structure, and the methods by which they transport nutrients and dissolved gases. Figure 1.1 and Table 1.1 show the differences between them.

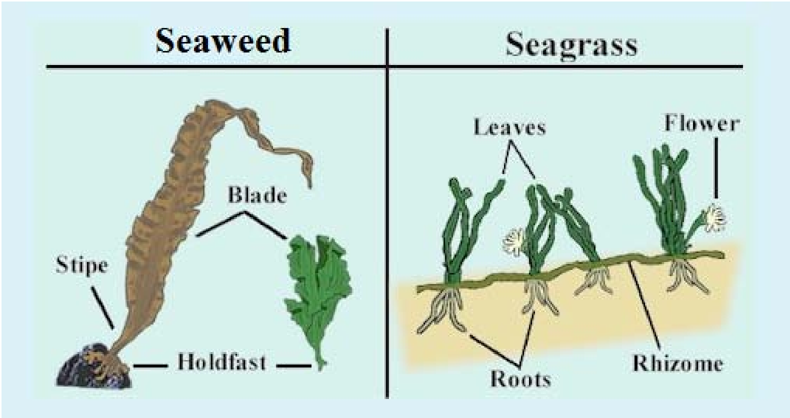

Figure 1.1: Morphological differences between seaweed and seagrass

(Source: Florida Fish and Wildlife Research Institute, 2009)

Table 1.1: Comparison between seaweed and seagrass

	Seaweed	Seagrass
Number of Species Worldwide	• 5000 - 6000	• 60
Reproduction	• Produce spores	• Split sexes
Structure	• Attach to hard surfaces such as rocks using holdfasts • Does not possess roots extending below the surface	• The roots and rhizomes are buried in sand or mud • Produce flowers, fruits and seeds

(Source: McKenzie, 2008 and Florida Fish and Wildlife Research Institute, 2009)

Meanwhile, coral reefs are submarine structures that are made from calcium carbonate unseen by colonies of small animals found in seawaters containing few nutrients. Coral reefs can be found in tropical regions where they require a water temperature of 18°C or more (Buddemeier et al., 2004). Also, they are limited to grow in not deeper than 50 m water as they need clear and warm water and high intensity of sunlight to survive (Nim and Skirving, 2010). Coral reefs eat plankton, zooplankton and small fishes to survive. Generally, coral reefs can be found close to land in shallow water since they require sunlight to stay alive. They exist on the outer edge of the coastal zone with seagrass habitats located between them and mangrove, from low-tide level to the coral reefs fringe. Fringing, barrier and atoll are types of coral reefs. Figure 1.2 shows each type of coral reefs.

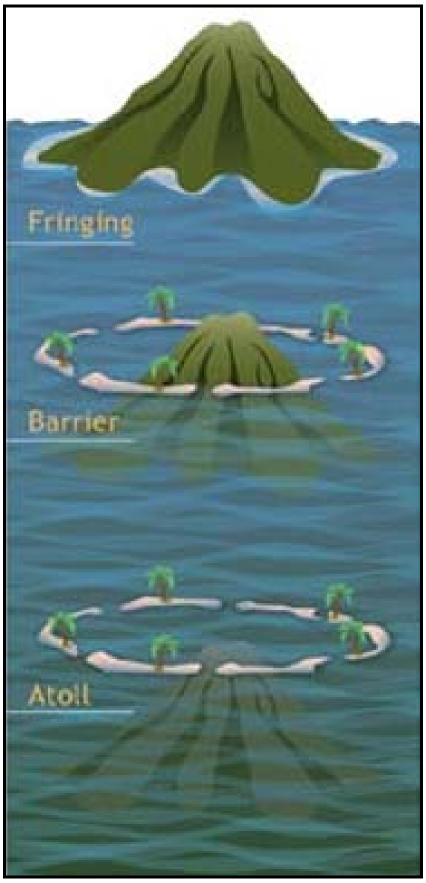

Figure 1.2: Types of coral reefs

(Source: Coral reefs Facts, 2010)

Fringing reef is a type of reef which is located at edge shorelines of islands and continents in tropical ocean water while barrier reef can be found far from shoreline. Finally, atoll reefs are rounded or elliptical shape reefs that surround a middle lagoon which are created when a small volcanic island vanish under the ocean surface. A variety of colourful coral reefs offers protection for marine life such as crabs, fishes, shrimps and other small animals.

Seagrass, seaweed and coral reefs are particularly important ecologically and commercially. Nowadays, seagrass and seaweed are crucial and primary producers in oceanic food webs. Seagrass supply food and habitats for the vulnerable animals like dugongs, seahorses and green turtles. Meanwhile, seaweed are also valuable sources of food, micronutrients, and raw materials for the pharmaceutical industry. They are rich in minerals and vitamins, therefore, they are called medical food of millennium century. However, seaweed and seagrass had been threatened and the population decreases yearly. Construction works in the coastal zone, degrading of water quality, pollution of untreated sewage from accommodation facilities and oil pollution from motorized boats are several factors that contribute to the decreasing number of seaweed and seagrass population. In fact, natural threat activities like wave reactions and soil erosion are also factors of the degradation of these two marine plants.

Human activities are causing the loss of coral reefs through direct and indirect methods. Over fishing by human is among the factors that contribute to loss of coral reefs as fishes are among the major food for coral reefs. Pollution such as garbage, pesticides, oil slicks and other forms of ocean pollution poison coral reefs too. Physical damage is also one of the major threats to coral reefs. Tourists who damage the reefs, anchors dropped in coral beds and ships that collide with coral reefs are examples of physical damage to coral reefs. When mangroves and tropical forests are cut down to clear the land for cultivation purposes, top soil will be washed by rivers into coastal ecosystems. Soil which falls on the coral reefs will block the sunlight needed for coral reefs to live. Harvesting coral reefs itself for food, traditional medicine and aquaria are also threats to coral reefs loss. These activities will definitely destroy the reefs as well as their habitats. The characteristics of seaweed, seagrass and coral reefs habitat are summarised in Table 1.2.

Table 1.2: Habitat requirement for seaweed, seagrass and coral reefs

	Seaweed	Seagrass	Coral reefs
Habitat	Grow around the shore and attach themselves one another	Grow on soft sand or mud	Grow on hard substrate
Depth limit	0 m to 50 m Depends on the sunlight penetration	< 70 m Depends on the sunlight penetration	0 m to 50 m Depends on the sunlight penetration
Water temperature	20°C – 30°C	25°C – 38°C	23°C - 29°C

(Source: Campbell et al., 2006, McKenzie, 2008, Florida Fish and Wildlife Research Institute, 2009 and National Ocean Service, 2012)

A lot of research activities had been made to preserve these sea bottom features (Lotze et al., 2006, Malnar et al., 2008, Kakuta et al., 2010). Continuous monitoring will help to preserve sea bottom features from becoming extinct. In fact, Malaysia also has a group of researchers who specialize in this field (Japar Sidik et al., 2006 and Phang, 2006). The first checklist of the marine benthic algae in Malaysia was published by Phang and Wee (1991). Presently 375 taxa of seaweed (Phang, 2006) and 14 seagrass species (Japar Sidik et al., 2006) have been recorded. Meanwhile, 323 coral reefs species have been identified during status information on the coral reefs of the east coast of Peninsular Malaysia (Harbone et al., 2000). Many researchers have carried out research to map sea bottom features. As regards of sea bottom features mapping, a number of studies can be found in the literature combining in situ observations and remote sensing techniques. Remote sensing provides the most flexible and accurate techniques for sea bottom assessments at differential scale (up to 0.5 meters), while ground techniques are not suitable to complete the mission by a certain time (Dekker et al., 2006). The conventional sensors that are widely used in sea bottom features mapping are medium and high resolution images that are capable of detecting these features. However, hyperspectral airborne sensor data offer more biological information regarding the sea bottom species compared to the usual spaceborne sensors (Dekker et al., 2006). But in Malaysia, there is a limitation to obtain these data because they are expensive.

Besides satellite data, fieldwork also needs to be done to recognize the characteristic of substratum types which shows in the image as well as benthic plant species and other cover types. However, sea truth is frequently performed a few days to weeks earlier or later than collection of the satellite data (Dekker et al., 2006). Some of the instrument that had been used by researchers were side scan sonar measurement (Lucieer, 2008, Sagawa et al., 2008), underwater camera (Sagawa et al., 2010) and remotely operated vehicle (ROV) (Yamamuro et al., 2002) whereby they gave accurate sea truth data.

A study was carried out in Sibu Island and Merambong shoal, Johor to classify different sea bottom features (i.e. seagrass, seaweed and coral reefs). The Landsat-5 TM, ALOS AVNIR-2 and Quickbird satellite data were used in Sibu Island while ALOS AVNIR-2 was used in Merambong shoal. Two different techniques, namely depth invariant index and bottom reflectance index were applied in order to extract different types of sea bottom features. Sea-truth measurements were made to verify the results obtained by direct observations using underwater camera, side scan sonar and handheld Garmin GPS.

1.2 Problem Statement

Seaweed, seagrass and coral reefs features have decreased due to human activities and natural causes. These factors are dominant and existing threats to biological and ecological aspects especially to marine life. Sibu Island is already known as a location of seaweed, seagrass and coral reefs beds, while Merambong shoal is famous for seagrass beds. These two areas are important because they are fish breeding areas and supply food especially for the dugongs, turtles and birds. Sibu Island is a famous place for tourism and it is under the jurisdiction of Johor

Marine Park. Pollution, boating activities and construction works are some of the threats from human activities. Merambong shoal supports nine types of species of seagrass (Japar Sidik et al., 2006) and supports large tract of intact riverine mangroves and endangered species such as the seahorse, pipefish, dugong and sea turtles. However, construction development in the surrounding area has resulted in the habitat and species loss. In addition, land reclamation for port facilities near Tanjung Pelepas Port causes sedimentation and burial of seagrass beds (Japar Sidik et al., 2006). This study investigates the distribution of seaweed, seagrass and coral reefs in Sibu Island and Merambong shoal.

The existing map of sea bottom features over Sibu Island is not up-to-date. The map was published in the year 1997 by Jabatan Perancangan Bandar dan Desa. The map only showed the location of coral reef and sand features. The existing map of Merambong shoal had just been illustrated by an organization called Save Our Seahorses in 2009. Although the illustration appears detailed, it was not mapped according to standards i.e. it lacks projection and scale.

So far, mapping marine plants remains a challenge to researchers. Several techniques and methods had been proposed, however certain sea bottom features tends to overlap with other sea bottom features (Edwards et al., 1999, Andrefouet et al., 2003, Boggs et al., 2009). Therefore, knowledge about the satellite signal and light interference within atmosphere to marine algae features is very important.

1.3 Objectives

This research will focus on sea bottom features mapping over Sibu Island and Merambong shoal areas. The specific objectives of the research are as below,

a) To analyse the suitability of depth invariant index and bottom reflectance index techniques for sea bottom features mapping in tropical waters.

b) To identify the most suitable satellite data for sea bottom features mapping between Quickbird, ALOS AVNIR-2 and Landsat-5 TM satellite data.

c) To produce a new digital map showing the distribution of sea bottom features for Sibu Island and Merambong shoal using Advanced Land Observing Satellite (ALOS) Advanced Visible and Near Infrared Radiometer type 2 (AVNIR-2), Landsat-5 TM data and Quickbird satellite data.

1.4 Scope of Study

The scope of the study is as follows:

a) The satellite data used in this study are ALOS AVNIR-2, Landsat-5 TM and Quickbird data. For Sibu Island, the data used are ALOS AVNIR-2, Quickbird and Landsat-5 TM data while ALOS AVNIR-2 was used for Merambong shoal.

b) Equation of depth invariant index (Lyzenga, 1981) and bottom reflectance index (Sagawa et al. 2010) were used to extract sea bottom features. The depth invariant index technique is independent of the water depth, while the bottom reflectance index is dependent of water depth. From these two techniques, the most suitable algorithm for sea bottom features mapping was determined by comparing the results with sea truth data. In order to achieve this, the overall, producer and user accuracy, kappa coefficient and Tau coefficient were calculated.

c) The sea truth data was obtained by using an underwater camera and side scan sonar to determine the types of sea bottom features and the locations of these features were determined by handheld GPS. Hydrographic charts were also used in the study to obtain depth information.

1.5 Significance of Research

This study can contribute to the preservation of endangered marine species especially seaweeds, seagrass and coral reefs which are the richest and most productive features of the coastal systems of the world. They shield and improve water quality, supply shoreline stabilization, essential habitats for fishes, birds, and other marine life which and now referred to as ecosystem services, that act in several ways as listed below:

- They are important primary producers, that convert sunlight and carbon dioxide efficiently into organic form
- They supply organic food to a variety of dependent food webs
- They stabilize the seabed in which they grow
- They structure the seabed on which they grow into a complex environment which provides places for many organisms to exist
- They act as a nursery ground for many commercially-caught species

(Source: Costanza et al., 1997)

The suitability of the algorithms in 1.3 (a) for determination of seagrass, seaweed and coral reefs in Sibu Island and Merambong shoal area was examined to accurately map their distribution. Hence, the changes of distribution of seaweed, seagrass and coral reefs can be monitored precisely. These sea bottom features can also promote the tourism industry in Malaysia. For fishing industry, the information of sea bottom features location is essential to identify the possible places of higher fish concentrations and also to determine other commercially target species.

1.6 Study Area

The study was carried out in Johor waters i.e. Sibu Island and Merambong shoal (Figure 1.3). Sibu Island which is located at latitude of 2^{o} 12’ North and 104^{o} 5’ East has many resorts and chalets surrounded by white sandy beaches. This area is under the jurisdiction of the Johor Marine Park, a federal agency of the Ministry of Natural Resources and Environment (NRE). Merambong shoal which is located at latitude of 1^{o} 20’ North and 103^{o} 36’ East has the largest seagrass beds in Malaysia which covers Tanjung Adang, Tanjung Kupang, Merambong and Merambong Island.

Sibu Island was selected due to the obvious annihilation of the seaweed, seagrass and coral reefs distribution. This island has clear water almost all around the island. It has shallow water that provide high probability of seaweed, seagrass and coral reefs distribution. This island which is located in a wide coastal area has low pollution effects. Furthermore, it is a sandy island which is very suitable for seaweed, seagrass and coral reefs habitat. The Merambong shoal boasts the most extensive intertidal seagrass meadows in Malaysia and supports large tract of intact riverine mangroves and endangered species such as the seahorse, pipefish, dugong and sea turtles. It contains nine species of seagrass at depths of 2 to 2.7 meter, which is the maximum number of species in Malaysia (Japar Sidik et al., 2006).

However, developments in the surrounding area during the last decade have resulted in the marine habitat loss. Threats from human activities such as sand mining, oil pollution, transportation avenues and land reclamation for port facilities have destroyed most of these habitats (Japar Sidik et al., 2006).

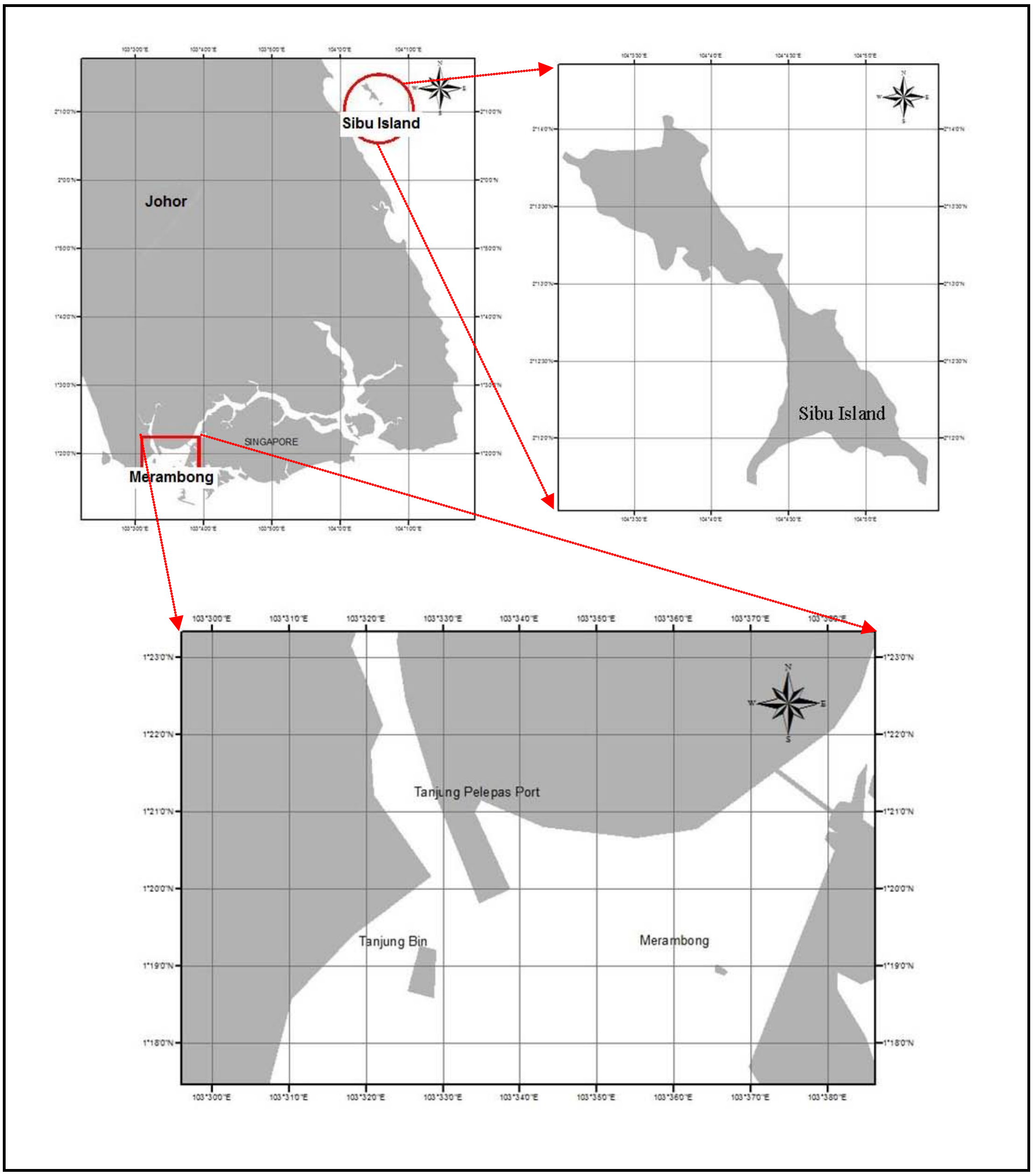

Figure 1.3: Location map of Sibu Island and Merambong shoal in Johor

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