QUANTIFICATION OF SUBMERGED SEAGRASS TOTAL ABOVEGROUND BIOMASS FOR MALAYSIAN COASTAL WATERS USING REMOTE SENSING DATA

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ABSTRACT

Multi-species of seagrass forms dense benthic communities in the coastal clear (Case 1) and less clear water (Case 2) in Malaysia. There are two types of seagrass, i.e. intertidal and submerged, which can easily be found in Malaysia. Satellite remote sensing data is an effective tool to be used in many marine applications, including monitoring seagrass distribution at large area coverage. The emphasizes of this thesis is to determine the best two steps satellite-based approach for mapping submerged seagrass and quantifying aboveground biomass at Merambong area and Pulau Tinggi, Johor. Multi-platforms satellite data that has different data specifications have been used at both Case 1 (water dominated by phytoplankton) and Case 2 (water concentrated with water floating substances and sediments). The satellite data used for Merambong are GeoEye-1, Worldview-2, ALOS AVNIR-2, Landsat-8 OLI and Landsat-5 TM, while the satellite data for Pulau Tinggi are Worldview-2, ALOS AVNIR-2, Landsat-8 OLI and Landsat-5 TM. The robustness of seagrass detecting techniques, namely Depth Invariant Index (DII) and Bottom Reflectance Index (BRI) on remotely sensed data at different water clarity have been tested. Both techniques require measurement of radiance, deep-water radiance and ratio of attenuation coefficients while BRI needs few additional elements from nautical chart and tide calendar to attain information of the sea bottom depth during satellite passes. Ground truth data has intensively been collected at both study areas to validate and assess the finding of this study. Comparative assessment and analysis between both techniques revealed that BRI is best to be used on Landsat-8 OLI (93.2% user accuracy) in Case 2 water while (95.0% user accuracy) in Case 1 water to identify submerged seagrass. An empirical model has been developed to devise quantification of aboveground biomass and the temporal changes by associating insitu seagrass coverage data with BRI value on the satellite images. Submerged seagrass biomass quantification using remotely sensed data is feasible in Case 2 water at required scale and accuracy (>80%), depending on the field data sufficiency, technique and choice of satellite data. In conclusion, Landsat-8 OLI with 16-bits quantization level produces more accurate results than Worldview-2 and GeoEye-1. It is able to cover a large area of study, hence it is very useful for spatio-temporal seagrass biomass monitoring project by local policy makers and related agencies.

ABSTRAK

Rumput laut berbilang spesies membentuk komuniti padat hidupan bentos di perairan pantai jernih (Kes 1) dan kurang jernih (Kes 2) di Malaysia. Terdapat dua jenis rumput laut, iaitu separa tenggelam dan tenggelam sepenuhnya boleh dijumpai di Malaysia. Data satelit penderiaan jauh adalah mekanisma yang efektif dalam pelbagai aplikasi marin, termasuk pemantauan taburan rumput laut meliputi kawasan yang luas. Tesis ini menekankan dua langkah terbaik berasaskan satelit bagi pemetaan rumput laut tenggelam dan pengiraan biojisim atas tanah di kawasan Merambong dan Pulau Tinggi, Johor. Beberapa data satelit yang berbeza spesifikasinya telah digunakan untuk perairan Kes 1 (air didominasi dengan fitoplankton) dan perairan Kes 2 (air berkepekatan tinggi dengan bahan terampai dan sedimen). Data satelit yang digunakan di Merambong ialah GeoEye-1, Worldview-2, ALOS AVNIR-2, Landsat-8 OLI dan Landsat-5 TM, manakala data satelit yang digunakan di Pulau Tinggi ialah Worldview-2, ALOS AVNIR-2, Landsat-8 OLI dan Landsat-5 TM. Keteguhan teknik pengesanan rumput laut iaitu indek kedalaman tidak berubah (DII) dan indek pemantulan dasar (BRI) telah diuji ke atas data penderiaan jauh dalam tahap kejernihan air yang berlainan. Kedua-dua teknik memerlukan pengukuran nilai radian pembalikan sinar, radian air dalam dan nisbah koefisien pengurangan cahaya dalam air, manakala BRI memerlukan beberapa elemen tambahan daripada carta nautika dan kalendar pasang surut air bagi mengetahui kedalaman dasar laut ketika satelit melintas. Data sebenar di lapangan dikutip secara intensif di kedua-dua kawasan kajian bertujuan mengesahkan dan menilai hasil kajian. Penilaian perbandingan dan analisa di antara kedua-dua teknik menunjukkan bahawa BRI lebih baik digunakan ke atas data Landsat-8 OLI (93.2% ketepatan pengguna) di kawasan perairan Kes 2 manakala (95.0% ketepatan pengguna) di perairan Kes 1 bagi mengenal pasti rumput laut yang tenggelam sepenuhnya. Sebuah model empirikal dibangunkan bagi pengiraan biojisim rumput laut atas tanah dan perubahan berkala dengan menghubungkait litupan rumput laut di lapangan dengan nilai BRI imej satelit. Pengiraan biojisim rumput laut tenggelam sepenuhnya menggunakan imej penderiaan jauh adalah boleh dilaksanakan di perairan Kes 2 pada skala yang dikehendaki dan ketepatan (>80%), bergantung kepada kecukupan data lapangan, teknik dan pemilihan data satelit. Kesimpulannya, Landsat-8 OLI yang mempunyai 16-bit tahap kuantisasi menghasilkan keputusan yang lebih tepat berbanding Worldview-2 dan GeoEye-1. Ia berupaya merangkumi kawasan kajian yang luas, maka ia sangat berguna bagi projek pemantauan berkala biojisim rumput laut oleh penggubal polisi tempatan dan agensi-agensi berkaitan.

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LIST OF ABBREVIATIONS

ALI	-	Advanced Land Imager
ANOVA	-	Analysis of Variance
ASTER	-	Advance Satellite Thermal and Emission Spectroradiometer
AVNIR	-	Advanced Visible and Near Infrared band
BRI	-	Bottom Reflectance Index
CASI	-	Compact Airborne Spectrographic Imager
CC	-	Cloud Coverage
CDOM	-	Color Dissolved Organic Material
CV	-	Coefficient of Variance
DII	-	Depth Invariant Index
DN	-	Digital Number
DW	-	Dry Weight
ETM	-	Enhance Thematic Mapper
GCP	-	Ground Control Point
GIS	-	Geographical Information System
GPS	-	Global Positioning System
IPCC	-	International Policy of Climate Change
ISODATA	-	Iterative Self-Organizing Data Analysis Technique
IUCN	-	International United of Coastal and New Energy
LAI	-	Leaf Area Index
LED	-	Light Electronic Device
LULC	-	Land-use Land Cover
LULUCF	-	Land Use, Land-Use Change and Forestry

MLC	-	Maximum Likelihood Classifier
MODIS	-	Moderate Resolution Imaging Spectrometer
MSS	-	Multispectral Sensor
NDVI	-	Normalized Different Vegetation Index
NIR	-	Near Infrared
NOAA	-	Navigation Oceanographic and Atmospheric Agency
NTU	-	Nephelone Turbidity Unit
OLI	-	Observe Land Imager
PAN	-	Panchromatic
PCA	-	Principal Component Analysis
PTP	-	Port of Tanjung Pelepas
RAAN	-	Right Ascension of Ascending Node
RMSE	-	Root Mean Square Error
ROI	-	Region of Interest
SAMSON	-	Spectroscopic Aerial Mapping System On-board Navigation
SAR	-	Synthetic Aperture Radar
SE	-	Standard Error
SNR	-	Signal-to-Noise Ratio
SONAR	-	Sound and Navigation Ranging
SPM	-	Suspended Particle Matter
SOS	-	Save Our Seahorse
SPOT	-	Systeme Probatoire de I’Observation de la Terre
STAGB	-	Seagrass Total Aboveground Biomass
SST	-	Sea Surface Temperature
SWIR	-	Short Wave Infrared
TAGB	-	Total Aboveground Biomass
TDS	-	Total Dissolved Solids

TIR	-	Thermal Infrared
TM	-	Thematic Mapper
TOA	-	Top of Atmosphere
UAV	-	Unmanned Aerial Vehicle
UN	-	United Nation
UNESCO	-	United Nation Environment,Science and Culture Organization
USD	-	United State Dollar
USGS	-	United State of Geographical Survey
WCMC	-	World Conservation Monitoring Centre
WGS	-	World Geographic System
WQI	-	Water Quality Index
WV-2	-	Worldview-2

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CHAPTER 1

INTRODUCTION

1.1 Background

Seagrass forms dense submerged vegetative communities in shallow water in global coastal environment. Seagrasses are the only aquatic flowering plant that are able to grow submerged in the marine environment (Den, 1970) from low to high biomass content that needs to be quantified. At the present time, at least 60 species (Green and Short, 2003) of submerged aquatic vegetation including seagrass, macroalgae and microalgae were reported to exist in global coastal water. Functioning as natural ecosystem engineers (Jones et al., 1998), seagrasses are angiosperm aquatic plants that are vital for coastal environment. A number of scientific reports state that seagrass meadows offer a diverse ecosystem services (Unsworth, 2014; Short, 2011; Orth, 2006; Mumby; 1997) such as dampening of flow, oxygenation of the water and sediments, help in maintaining water quality, stabilization of the sediments from the land, provision of a nursery and spawning grounds for numerous species and are a direct food resource for a number of species.

Globally, seagrass meadows can be found in most shallow on-shore areas (den Hartog, 1970). They also provide nursery habitat for copious juvenile fish and invertebrates, feeding grounds for endangered marine species like dugongs and sea turtles and protection against coastal erosion (Nagelkerken et al., 2000; Costanza et al., 1997; Bell and Pollard, 1989; Orth et al., 1984). However, natural and anthropogenic disturbances are key factors of global seagrass declination (Green and Short, 2003). Human activities and extreme natural disasters have significantly increased water turbidity and nutrient concentrations thus degrading the seagrass ecosystem (Yang and Yang, 2009). These are considered as being the primary cause of seagrass losses (Duarte, 2002; Short and Echeverria, 1996). As seagrass adapts well in coastal water, remote sensing satellite can be employed to monitor its changes over large areas (Kirkman, 1996).

1.2 Seagrass Total Aboveground Biomass (STAGB)

Seagrass Total Aboveground Biomass (STAGB) is defined as the biomass of seagrass body parts growing above the sea floor, excluding continuous and ramified roots. According to the IPCC Good Practice Guidance for Land Use, Land-Use Change and Forestry (LULUCF) in 2003, aboveground biomass is all living biomass above the soil including stem, stump, branches, bark, seeds, and foliage. For this purpose, the wet and dry weight of above part of multi-species seagrass is measured in the laboratory before and after drying process using oven at a specific time and temperature. The physical seagrass structure is shown in Figure 1.1 to distinguish below and above parts of seagrass in their natural habitats. Compared to intertidal seagrass, the quantification of aboveground biomass of submerged seagrass remains a challenge in remote sensing field. The loss of seagrass indicates the reduction of total biomass of submerged aquatic vegetation that plays an important role to marine species and coastal ecosystem. Seagrass biomass information is very valuable for managing and appraising marine environment including ocean carbon, ocean sedimentation, fisheries industry and sustainability of many ecosystems, since the respond of seagrass to environmental alterations is quick.

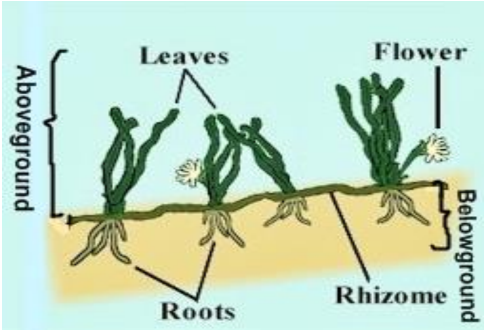


Figure 1.1 Above and below ground of seagrass physical structure.

(Source: Fourqurean, 2012)

For more than a decade, substantial ecological and benthic mapping research has been conducted with the aim of mapping seagrass spatial distribution, quantifying STAGB manually and developing at least rudimentary algorithm to detect seagrass and quantify STAGB from satellite data. Satellite remote sensing data offers synoptic view over large area and very good seagrass detection result if the acquired data fulfills the following criteria: i) spatial resolution depending the spatial scale of project site; ii) spectral and temporal resolution; iii) adequate radiometric and geometric quality and iv) cloud-free or low cloud coverage as short wave visible wavelength can penetrate to substrate level. Baseline maps and temporal changes of seagrass spatial extent can be created and determined using large spatial coverage of remote sensing images (Ferguson et al., 1993), including seagrass percentage cover (Gullstrom et al., 2006) and above ground biomass (Mumby et al., 1997). Fine pixel resolution offers high accuracy of remotely sensed maps of seagrass with 75%-100% overall accuracy in areas of shallow and clear water, large homogeneous seagrass meadows and water depth of less than 5m (Lyons et al., 2013; Robbins, 1997; Mumby et al., 1997). In contrast, many near shore areas in Malaysia are often characterized by small size and patchy seagrass areas with multiple-species growing in coastal waters. Some water area within seagrass habitat have limited visibility, which is an indicator for high (more than 4m transparency), medium (less than 4m transparency) or low water clarity (less than 1m transparency) (Lyons et al., 2013). This study focuses on the total aboveground biomass quantification of seagrass at both Case 1 and Case 2 tropical coastal water using remote sensing approach on satellite remote sensing data.

Case 1 water is water that has optical properties determined by high phytoplankton (chl-a) where the concentration with respect to scattering coefficient at 550nm (wavelength) is >1. Case 2 water is determined by everything else (man-made & natural substances) such as color-dissolved organic material (CDOM) and mineral where the concentration does not co-vary with phytoplankton (<1 ratio with scattering coefficient). In contrast to Case 1 water, Case 2 water represents a major challenge to STAGB quantification. The capability of remote sensing data with appropriate techniques has never been tested and reported for such non-ideal water condition. To distinguish seagrass from other submerged features that inhibit similar environment, such as seaweed on satellite image requires good compromise between satellite image characteristics and seagrass detection techniques. Similar to seagrass, various species of seaweed are green in color, as pigments on their leaf absorbs strongly in blue band (400-500nm) while reflecting sunlight peaked in green band (555-630nm) (Pinnel et al., 2004). Nevertheless, it is crucial to determine the accuracy of STAGB quantification in wider regions if remote sensing is to be effectively used to monitor STAGB temporal changes in such environments. Hence, more ground truth points were needed in order to attain better results of STAGB quantification.

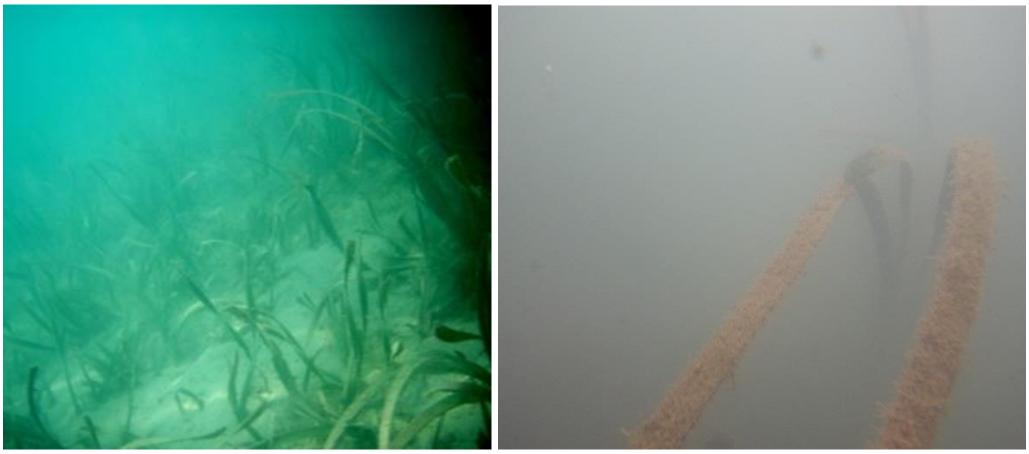
Quantifying seagrass biomass is vital for various inputs of coastal related studies. However, it is very time-consuming and costly especially for large area coverage using conventional method. Using satellite data, STAGB quantification at large areal coverage is feasible. Seagrass biomass is the main parameter for further quantification of carbon sequestration and carbon sink in the ocean because chlorophyll pigment on seagrass blade and leaf will require sunlight for food production through photosynthesis. Seagrass accounts for more than 10 percent of all the carbon buried in the oceans each year (Emily, 2009). As a byproduct, oxygen will be released out to the atmosphere for aquatic organisms and sustainable marine ecology in general. Therefore, seagrass also influences the climate changes that have occurred recently in global scale since seagrass will reduce a huge amount of carbon sink from the atmosphere because seagrass meadows are 50 times more proficient to absorb and sequester carbon compared to the same area of tropical forest (IPCC, 2012).

1.3 Problem Statement

Existing requirement of seagrass biomass quantification is very important and estimations have been done in tropical and temperate seagrass habitat. However, the previous work is limited to intertidal seagrass area in clear water only because the destructive sampling of seagrass biomass was done during low tide and clear water apparently enabling seagrass mapping using simple remote sensing approaches such as image enhancement method and zonal analysis. Nevertheless, seagrass occupies 0.1% of total ocean floor is expected to consist of more than 60% submerged as opposed to intertidal (UNEP-WCMC, 2005). Hence, two gaps are remained. Although satellite images have been used, the submerged seagrass has still not been detected in less clear water. In addition, there is still no such attempt for quantitative submerged STAGB in less clear water using water column correction technique on satellite images.

One of the critical issues regarding submerged seagrass detection using remote sensing approach is suitability of spatial resolution on different water clarity. Lack of study emphasized the detection of submerged seagrass in less clear water for large area, especially in Malaysia. Although seagrass is able to be detected using established water column correction and mapping of its extent is frequently reported in many studies, a method for submerged seagrass habitat in Case 2 coastal water from satellite remote sensing data is not generated. As a result, the suitability of satellite data characteristics for STAGB quantification for different scale and accuracy has never been revealed. Satellite data ranging from medium (30m) to fine resolution scale (less than 1 m) for seagrass is assessed to test the robustness of detection techniques at different water case. Furthermore, limited number of study has been conducted using digital satellite image as the main tool for STAGB quantification. Empirical model on STAGB estimation in Malaysia from two water column correction techniques, namely Depth Invariant Index (DII) and Bottom Reflectance Index (BRI) on satellite images, has rarely been explored, thus are intended to be assessed in this study. Moreover, evaluation of differences of STAGB in clear and less clear water in synoptic scale is rarely reported, even in ground-based approach. Thus, devastation of seagrass meadow in Malaysia at such scale has not been assessed until now.

Moreover, complex coastal environment for STAGB quantification using remote sensing technology remains unclear. STAGB quantification in Case 2 water as shown in Figure 2 has its own set of problems due to presence of suspended particle matter (SPM), CDOM or gelbstoff and algae bloom. Many studies have been conducted in identifying seagrass meadow along the coastal region in different climates. However, the robustness of remote sensing technique to quantify STAGB in coastal water study is still rare, less populated study and not been clearly proven yet by any global researchers. This is because the turbidity of Case 2 tropical water has a significant effect on contributing factors of extension or gradual shrinkage of seagrass bed areas such as light penetration ability, phytoplankton or zooplankton concentration and water leaving radiance.



(a) (b)

Figure 1.2 (a) Seagrass habitat in Case 1 water at Tinggi Island; (b) Case 2 water nearby Merambong shoal.

Despite the great importance of seagrass biomass quantification, the demand by environmental policy makers to obtain the actual amount and dynamic change of STAGB is increasing tremendously. Declining rate of seagrass in Malaysian coastal water is still not reported for large regions, thus the impact of coastal development on seagrass loss is not significantly measured. Therefore, remote sensing data has successfully assisted many researchers to obtain the TAGB of seagrass for wide and shorter time interval to avoid the high cost and time consumption. However, before satellite data was intensively used, conventional methods that require harvesting of seagrass from their habitat have been practiced widely. It is impractical to be operationalized in a long-term practice.

The following are the main research question focused in this study:

i. What is the influence of medium to fine spatial resolution of satellite images on the accuracy of submerged seagrass detection?
ii. Can STAGB be quantified in both Case 1 and Case 2 coastal waters using remote sensing approach?
iii. How can the changes of STAGB be feasibly quantified using multi-temporal remote sensing data?

These research questions are motivation for exploring the feasibility of various specifications of remotely sensed data for submerged seagrass detection and STAGB quantification in both clear and less clear water.

1.4 Objectives of Study

The main aim of the research is to map submerged seagrass using remote sensing approach on multi-platforms of remotely sensed data and to quantify submerged STAGB from satellite remote sensing image.

To ensure the research aim is successfully achieved, the specific objectives of study are:

i. To examine and analyze satellite spatial resolution suitable for mapping spatial distribution of submerged seagrass.
ii. To devise method for quantifying total aboveground biomass of seagrass in Case 1 and Case 2 tropical coastal water using remote sensing.

iii. To devise spatio-temporal quantification of STAGB using satellite multi-temporal image for detection of STAGB changes.

1.5 Scope of Study

The study has several scopes:

i) Subtidal seagrass habitat

Submerged seagrass specifically referred to seagrass grows under the water that is not exposed in any time even in the lowest low tide in the area and such area is called subtidal area. This means that the detection must compensate for water column correction model as it is not exposed. Using satellite-based approach, not only are continuous dense seagrass meadow but also, patchy seagrass was considered in STAGB quantification since water column correction model will correct water column effect on all satellite data. The compensation for water column correction is based on DII and BRI as both models set the mathematical solution in detecting submerged seagrass and STAGB. This is the main gap in remote sensing that has not been reported quantitatively for submerged STAGB in less clear water.

ii) Suitability of spatial resolution of satellite images

In this study, satellite image of medium to fine spatial resolution of optical passive satellite sensor that consist of Landsat-5 TM, Landsat-8 OLI , ALOS AVNIR-2, Worldview-2 and GeoEye-1are used for submerged STAGB quantification. All these digital images have unique specifications in terms of spatial resolution, spectral resolution, radiometric resolution and temporal resolution, which provide a comparative result at different spatial scale. This information is described in detail in Chapter 3. All these images were selected because the suitability of different spatial resolution and other characteristics for submerged seagrass detection was assessed by confusion matrix. The focus is to determine the best spatial resolution to enable STAGB quantification at large or small spatial scale. Low spatial resolution images such as MODIS (250m-1km), NOAA series (1km) and SeaWIFS (1km) are not fit in this study to quantify such small seagrass features from space since very large pixel size tends to underestimate seagrass presence compared to homogeneity properties shown by non-seagrass features, causing pixel misclassification. Close-range remote sensing such as SONAR is only used as a supporting data in validation process because it is collected from ground level that has more accurate measurement than satellite view.

iii) Water column correction model

Water column correction models, namely BRI and DII model for STAGB quantification, are important in this study. Both established models were selected because both are effective to be used in correcting water column effect for submerged seagrass detection in any levels of water clarity, but must have good compensation with depth. Determination of most suited model for seagrass detection on different spatial resolution was done through statistical inference. The focus of this approach is to generate STAGB quantification empirically from the detected spot of submerged seagrass. In this study, the method is newly introduced since no such attempt has been made to quantify TAGB for submerged seagrass in less clear water. All the results are validated using ground truth points at both study areas and statistical justification including overall accuracy, kappa statistic, user accuracy, determination coefficient (R^2), root mean square error (RMSE); is provided to assess the accuracy of seagrass detection and submerged STAGB quantification.

iv) Mixed-species seagrass biomass quantification

In this study, although seagrass occurrence may consist of more than one species, all the species are termed as seagrass. The quantification of STAGB is not specific to a particular species since the tropical coastal water has high richness of seagrass species and only multispectral satellite images were used in this study. In order to differentiate seagrass species, it is out of scope of this study as we do not use narrowband satellite data such as hyperspectral images such as ALI Hyperion that enable such differentiation of species. It is not used in this study because the technique is only tested on particular visible band on multispectral satellite images and hyperspectral image is difficult to obtain with low cloud coverage at these areas. In this study, there is an assumption that the biomass quantify at the ground for small seagrass species is relatively uniform. Only *Enhalus acoroides* shows significant difference in physical structure among seagrass species in terms of the long leaf blades. For ground based measurement, only one standard guideline sampling designed by McKenzie and Campbell (2002) which also practiced by Save Our Seahorse (SOS) organization is used in recoding the percentage of seagrass coverage within a designed quadrat during ground data collection at study site. This is described in more detail in Chapter 3. SOS is a periodic three-day environmental program organized by local environmentalist conducted on Merambong shoal to increase the awareness of public community like school students to save seahorses that live on seagrass meadow.

v) Only seagrass aboveground biomass

Only the morphological structure of above sea floor seagrass, including leaves, shoots, stem, and branch are considered to be quantified using satellite remote sensing image although roots and rhizome of certain species of seagrass have higher biomass content. Allometric quantification approach would consider biological physical structure of different species of seagrass. The quantification would be derived by voxel-based technique. Below part of the seagrass body structure is not considered for biomass quantification.

1.6 Significance of Study

Sustainability of coastal would support security of fishing resources in order to safeguard protein source and food security of the world. In order to do that, coastal conservation has been emphasized and this is within the millennium goal of Unite Nation (UN) where each country including Malaysia rectifies some authority management for coastal conservation. At global scale, seagrass biomass information is crucial in managing ocean productivity and mitigating unpredicted natural hazards due to climate change. Seagrass is very important in economy and ecology, similar to forest and coral reefs. A recent study estimated the annual economic value of seagrass bed is at US$19 000 per hectare (Unsworth and Cullen, 2013). Malaysia is well known for their mega-diversity of flora and fauna in coastal environment, including frequent sightings of dugong at the Straits of Johor because seagrass is their primary food source.

At regional scale, this study provides information of submerged seagrass in Malaysia to be integrated with information of another country in south-east Asia since this region has high number of seagrass species. To ensure coastal area is ideal for seagrass habitat, Malaysia takes many initiatives to improve such as gazette Marine Park, commercial fishery activities and policy managed and regulated by government agencies such as Department of Environment, continuity of fish resources and food security of the country. One of the main sources of blue carbon is seagrass biomass since seagrass requires a sufficient amount of light to synthesize food through photosynthesis by consuming carbon dioxide. Biomass is the absorption and accumulation of carbon into organic matter and is 50% contributed by carbon (Brown et al., 1997). At local scale, this study is benefited to related government agency, local authorities, fishery departments and research institutes to plan for conservation and restoration of seagrass habitat sustainability. The capability of receiving an average of 12 hours of intense sunlight a day serves great potential of plant biomass energy, carbon sequestration and carbon sink information to be explored, especially to cope with the problem of global warming and weak ecosystem sustainability in this country. Therefore, in desiring to create remarkable contribution in this field of knowledge, this study is purposely conducted to introduce new approach of STAGB quantification techniques for Case 1 and Case 2 water using satellite data where it is the novelty of this study.

Under National Environmental Act 1974, Malaysia is intended to reduce carbon emission in 2020 by 40%. Using remote sensing approach, this study provides a better approach to achieve the mission by quantification of submerged STAGB in any level of water clarity with implementation of remote sensing knowledge to avoid massive destructive sampling of their natural habitat. In fact, this study help to cut the cost and shorten the time required to quantify seagrass biomass while concurrently preserving their presence in nature. Through this study, a report based on the STAGB and seagrass extent trend of changes over few years for both seagrass habitat at different water clarity is written to confirm the coastal health status. This report will help marine agency to analyse the impact of vast coastal development and mitigate plans for conservation and preservation of seagrass habitat for fisheries, stabilize water clarity and sustain the ecological marine of nearby coastline and its vicinity.

In addition, this study provides suggestions related to STAGB sampling and technical operation on various resolutions of remote sensing data to yield the best reliable approaches for STAGB quantification using remotely sensed data. This study also served to enable people without prior knowledge of seagrass to obtain better understanding and information of the importance of seagrass in marine ecology and coastal environment sustainability. This study helps to inform people how critical the marine ecology is due to the sharp reduction of the extent of seagrass and STAGB in the present situation because seagrass is very important in reducing the excessive carbon dioxide in the atmosphere. Thus, quantification of STAGB leads in assisting the action of controlling the tremendous impact of global warming phenomenon by releasing more oxygen to the atmosphere through seagrass blade and leaf. Moreover, this study is expected to raise peoples' awareness of seagrass habitat conservation and coastal ecosystem in the long term by taking effective actions as suggested by the international and local expertise.

1.7 Study Area

Merambong shoal is located Northeast of Merambong Island, one of the most significant natural marine frontiers between Malaysia and Singapore as shown in Figure 1.3. It is 1.8 km from north to south and up to 200 m from east to west located in the Straits of Johor, Malaysia, situated at latitude of 01^{o} 19.979 ’ North and

103^o 35.965' East; covering an approximate area of $42.6km^2$ that covers Tanjung Kupang, Tanjung Adang, Merambong and Merambong Island. It is the largest single tract of intertidal seagrass bed in Malaysia that is, surrounded by Case 1 water. In Malaysia, the Merambong shoal is claimed to be the most extensive intertidal seagrass meadow (Sidik et al., 2006). This area is characterized as one of the Marine Parks in Malaysia and is home to myriad marine biodiversity including pipefish, seahorse, dugong, sea turtles; and extensive development of subtropical benthic habitat features in shallow to deep waters (Choo, 2006). Of the 15 seagrass species known from the region (UNEP-WCMC, 2005) claimed as the richest species of seagrass in the world, 10 species can be found here which is the maximum number of seagrass species in Malaysia (Sidik et al., 2006). Submerged benthic habitats present on site during fieldwork included seagrass (*Enhalus acoroides*, *Halophila ovalis*, *Cymodocea serrulata* and *Halodule univervis* (Sidik et al., 2012), seaweeds: *Sargassum*, *Chaetomorpha minima* (Phang, 1994; Phang, 2006) and insignificant population of coral reef (Toda et al., 2007), with a water depth range from 0.3 m to 11.9 m with the majority of seagrass habitats limited to water depth less than 2 m. Seagrass patches vary in size and density all outside this shoal. At Merambong shoal, oval-shaped seagrass, *Halophila ovalis* is the preferred food for dugong. Dugong feedings help to boost seagrass regenerative process and create microhabitats for smaller invertebrates. The substrate comprises unconsolidated soft sediments, including muddy to shelly sands with occasional hard bottom areas. Mangrove forest dominates the land and sea boundaries along the coast in muddy areas (Duke, 1992).

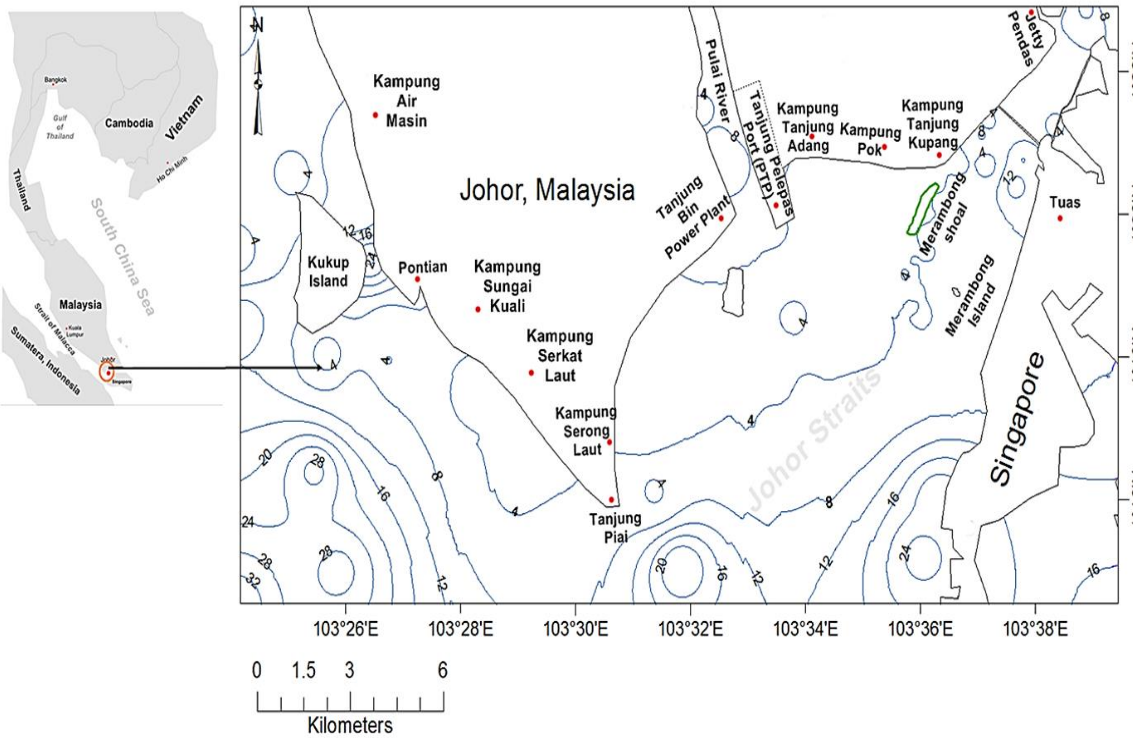


Figure 1.3 Straits of Johor surrounding Merambong shoal. Depth (blue line) is in meter.

Tanjung Piai and Pulai River were gazetted as a Ramsar site in 2003 and recognized as a Wetland of International Importance while Merambong shoal and Merambong Island are unprotected and vulnerable to the incessant development looming nearby. The water temperature remains 28^{o}C to 29^{o}C throughout the year with moderate water clarity, typical for an area with hectic coastal urbanization, busy shipping lanes of Tanjung Pelepas Port and sand dredging activity. It is intensively used for many scientific research activities. In addition, coastal development, including large port area, power plant project, vast development on the opposite site of Singapore and man-made island called 'Banker Island' are very close to Merambong shoal. Threats from human activities such as sand mining, oil pollution, transportation avenues and land reclamation for port facilities have destroyed most of these habitats (Sidik et al., 2006).

Another study site considered in this study is Pulau Tinggi or written as Tinggi Island in this study. It is one of continental isolated islands nearby Mersing, Johor and is located 12 km off to the southeast coast of Peninsular Malaysia as shown in Figure 1.4. Submerged features such as seagrass, coral reefs, seaweed and aquatic life are easily observed visually in shallow waters of less than 8 m since the water is very clear, categorized as Case 1 water where chlorophyll-a is dominant element in the water, with less sediment and dissolved material. Relatively, Tinggi Island water is deeper than Merambong Island as the subtidal seagrass habitat can be found as deep as 40 m. Only 5 to 7 seagrass species namely *Thalassia hempirichii, Cymodocea rotundata*, *Syringodium isoetifolium*, *Halophila ovalis* and *Cymodocea serrulata*, can be found here, which is less than the number of seagrass species that can be found at Merambong area. Seagrass patches around this area have various size. Compared to Merambong, many coral reefs can easily be found here especially at northern part of the island and along the white sandy area. In 1994, the Malaysian government gazetted Tinggi Island and a few adjacent continental islands as Marine Park under Fisheries Act 1985 (Amended, 1993). Hence, no significant and intensive construction work could be seen here which further leads to preservation of natural marine ecology including seagrass meadow and its density. This study site is important as a comparative site to Merambong area to analyse their differences and similarities in terms of capability of remote sensing knowledge for seagrass distribution and STAGB quantification in both Case 1 and Case 2 water.

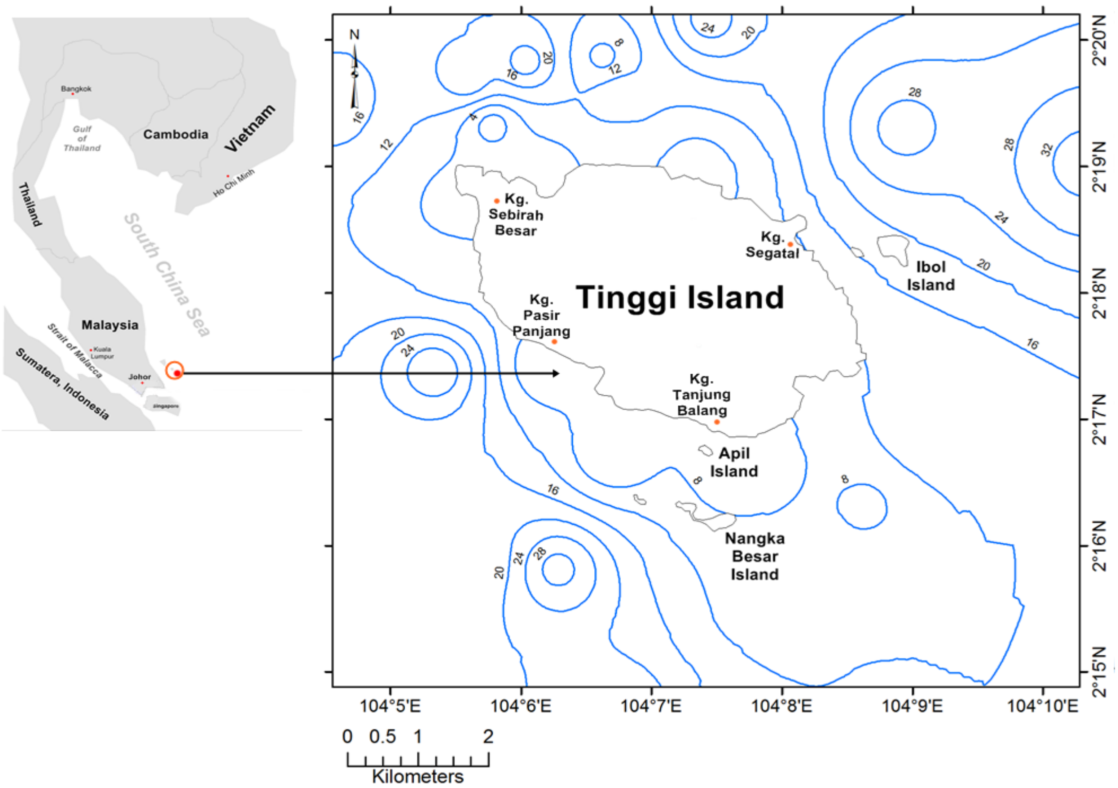


Figure 1.4 Tinggi Island at Mersing, Johor, facing the South China Sea.

1.8 Structure of Thesis

This thesis encompasses six chapters. Chapter 1 presents the main issue of seagrass aboveground biomass, a background explanation of the topic of study, objectives, scope, significant contribution and a succinct methodology of this study. In addition, this section gives a general illustration of what the study is all about and specifically explains the reason why this study should be conducted which is to contribute new knowledge and ideas to the related field especially for shallow substrate, in the context of remote sensing for seagrass aboveground biomass study in tropical region. Hence, this section effectively introduces seagrass aboveground biomass quantification using remotely sensed data as the main topic and specific mission of the study that needs to be accomplished.

Chapter 2 focused on summarization of a detailed description of background information on the research topic, including basic concepts of seagrass biomass study in relation to remote sensing data and conventional method, significant components of the study, previous studies and the expansion of related fields in global scale, ranging from ground-based techniques to satellite data utilization by existing techniques to be implemented. The strength and drawbacks of the current techniques in previous studies are also discussed in Chapter 2.

The research methodology and all the data involved in the study is structurally emphasized in detail in Chapter 3. The technique selected is described briefly and the sequence of utilization of remote sensing data for the research is explained in detail from pre-processing, processing and post processing stages.

The findings and results after the implementation of the methodology and selected data for this study will be displayed and discussed in Chapter 4 and Chapter 5. Quantitative and descriptive analysis is carried out thoroughly to justify and provide a better understanding of the correlation between result presentations with the objectives of the research as mentioned earlier in the thesis.

In Chapter 6, the summary and conclusion of the research are examined and recommendation for future research is briefly suggested. Appendix pages show the field sheet of this study, dry biomass measurement and marine biodiversity that found in study area.

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