DETERMINATION OF SHALLOW SUBSTRATE FROM SATELLITE REMOTE SENSING DATA WITH BIO-OPTIC BASED ALGORITHM

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DEDICATION

This work is dedicated to my beloved

parents Hamid bin Keling and Asmah binti Isnin,

my caring sister Azwa Hashima and Nadia Nurulzanna,

my responsible younger brothers Aidia Nadzir and Nur Aqib

and my soulmate

my husband Mohd Samsuri Md Nor

and little caliph Nur Raisha Sofia binti Mohd Samsuri

……thank you for your great love and supports…..

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ABSTRACT

Remote sensing techniques have been widely used for extraction of coastal information including the sea surface, in the water and within beneath of shallow substrates. The coastal water where the substrates are found is classified into ‘case 1’ and ‘case 2’. They are differs based on the water constituents such as phytoplankton, suspended particulate matter (SPM) and coloured dissolved organic materials (CDOM). The interactions of incoming radiance and water-leaving irradiance within the water in both these coastal types have been formulated in the bio-optic algorithm. The bio-optical algorithm has been previously used in mapping ocean-colour, mapping total suspended matter (TSM) and deriving water properties. In this study, the applicability of bio-optical algorithm was examined and analysed over coastal water for detection and mapping of shallow substrates using satellite remote sensing data. Two satellite data sets examined are: (i) the fine resolution Worldview-2, and (ii) medium resolution Landsat-8 OLI, with 0.5m and 30m spatial resolution respectively. The test sites were conducted in Pulau Tinggi and Pulau Merambong, Johor that representing the coastal type 1 and II as well as the shallow (less than 20m) and deep areas (less than 40m). In-situ samples consisted of seagrass, seaweed, coral, mud, sand and ancillary information on water depth were divided into two independent mutual sets and used as input to the algorithm and the respective validations. The results indicated that shallow substrates could be extracted at 91.6 percents overall accuracy with 0.55 of kappa coefficient (k), hence showing good agreement at Pulau Merambong. However, at Pulau Tinggi, the overall accuracy of substrates derived at 52.17 percent (k = 0.33) and 42.22 percent (k=0.26) for Worldview-2 and Landsat OLI, respectively. It is therefore concluded that the bio-optical algorithm has been identified as restricted on deeper water even on the clearer water (type 1) with less TSM. Hence, the potential of bio-optical algorithm for mapping shallow (less than 20m) substrates within Malaysian coastal water is very high with the improvement of water-leaving radiance from deep water model.

ABSTRAK

Teknik penderiaan jauh telah digunakan dengan meluas untuk mengekstrak maklumat pantai merangkumi permukaan laut, di dalam ruang air dan di bawah substrat cetek dalam laut. Substrat yang dijumpai di dalam ruang air laut dikelaskan kepada ‘kes 1’ dan ‘kes 2’. Ianya berbeza berdasarkan unsur air seperti fitoplankton, zarah bahan terampai (SPM) dan bahan organik larut air (CDOM). Interaksi terhadap sinaran masuk dan pembalikan sinaran air keluar di dalam ruang air bagi kedua-dua jenis pantai telah diformulasi di dalam algoritma bio-optik. Algoritma bio-optik telah digunakan dalam pemetaan warna kelautan, pemetaan jumlah bahan terampai (TSM) dan menerbitkan sifat-sifat air. Di dalam kajian ini, kebolehan algoritma bio-optik dikaji dan dianalisa terhadap air pantai untuk mengesan dan memetakan substrat di air cetek menggunakan data satelit penderiaan jauh. Dua data satelit yang diuji adalah i) Worldview-2 beresolusi tinggi ii) Landsat-8 OLI beresolusi sederhana dengan masing-masing mempunyai spatial resolusi 0.5 meter dan 30 meter. Kawasan kajian adalah di Pulau Tinggi dan Pulau Merambong, Johor yang mewakili pantai jenis 1 dan 2 dengan kecetekan kurang 20m dan kedalaman kurang 40m. Sampel data lapangan merangkumi rumput laut, rumpai laut, batu karang, lumpur, pasir dan maklumat sampingan mengenai kedalaman air yang dibahagikan kepada dua set tidak bersandar dan digunakan sebagai input kepada algoritma dan pengesahan. Keputusan menunjukkan substrat cetek boleh diekstrak adalah 91.6 peratus dengan keseluruhan ketepatan adalah 0.55 pekali kappa (k) dan seterusnya menunjukkan persetujuan yang baik di Pulau Merambong. Walau bagaimanapun, di Pulau Tinggi dapatan keseluruhan ketepatan bagi substrat adalah 52.17 peratus (k=0.33) dan 42.22 peratus (k=0.26) masing-masing untuk Worldview-2 dan Landsat OLI. Oleh itu, dapat disimpulkan bahawa, algoritma bio-optik telah dikenalpasti adalah terhad terhadap air dalam walaupun pada air jernih (jenis 1) dengan TSM yang kurang. Maka, potensi algoritma bio-optikal untuk pemetaan substrat cetek (kurang 20m) di perairan pantai di Malaysia adalah sangat tinggi dengan penambah baikan terhadap model pembalikan sinaran keluar dari air dalam.

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LIST OF ABBREVIATIONS

ADEOS-II	: Advanced Earth Observation Satellite II
AOP	: Apparent Optical Properties
BRI	: Bottom Reflectance Index
CASI	: Compact Airborne Spectral Imager
CDOM	: Coloured Dissolved Organic Matter
CZCS	: Coastal Zone Color Scanner
DIB	: Depth-Invariant Bottom
DII	: Depth Invariant Index
DN	: Digital Number
ETM	: Enhanced Thematic Mapper
GLI	: Global Imager
GPS	: Global Positioning System
GSD	: Ground Sample Distance
IOP	: Inherent Optical Properties
MERIS	: MEdium Resolution Imaging Spectrometer
MSS	: Multi Spectral Sensor
NIR	: Near Infrared
OCTS	: Ocean Color and Temperature Sensor
OLI	: Operational Land Imagery
Pan	: Panchromatic

RGB	: Red, Green, Blue
SPM	: Suspended Particulate Matter
SPOT	: Satellite Pour I'Observation de la Terre (French) or Satellite for Observation of Earth
SWIR	: Short-wave Infrared
TIRS	: Thermal Infrared Sensor
TM	: Thematic Mapper
TOA	: Top of Atmosphere
UTM	: Universal Transverse Mercator
VIS	: Visible
WCR	: Wider Caribbean Region
WGS	: World Geographical System

LIST OF SYMBOLS

R	-	Irradiance reflectance
r_{rs}	-	Remote sensing reflectance
P	-	Probability
$L_i(VIS)'$	-	Deglinted image
$L_i(VIS)$	-	Pixel value in band i
Bi	-	Regression slope
$L\,(NIR)$	-	Pixel value in NIR band
$L_{min}\,(NIR)$	-	Minimum pixel value in NIR band
ρ_{λ}	-	TOA reflectance values
L_{λ}	-	TOA radiance value
θs	-	Solar Zenith angle
d_{ES}	-	Earth-Sun distance
α	-	Total absorption coefficient
β_b	-	Total backscattering coefficient
ρ	-	Bottom reflectance

θ	-	Illumination
θ_w	-	Viewing geometry
H	-	Bottom depth
a_w	-	Absorption of water
a_φ	-	Absorption of phytoplankton
a_{spm}	-	Absorption of suspended particulate matter
a_{cdom}	-	Absorption of coloured dissolved organic matter
b_w	-	Backscattering of water
b_φ	-	Backscattering of phytoplankton
b_{spm}	-	Backscattering of suspended particulate matter
Λ	-	Wavelength
Z	-	depth
CHL	-	Chlorophyll concentration

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CHAPTER 1

INTRODUCTION

1.1 Background

Remote sensing technique has been broadly used to extract remotely information by using a sensor, attached to a flying object at different levels of height from the surface of the earth. It is widely used in many applications involving land, atmosphere and ocean studies. A mathematical equation can be applied to the remote sensing method to generate a new algorithm to extract information. Furthermore, these algorithms are useful in producing accurate output.

In this study, the satellite remote sensing data, Worldview-2 and Landsat OLI (Operational Land Imager) were used for processing imagery and developing the mathematical equation namely bio-optic-based algorithm and then applied to the data. The water substrate function can be found in the algorithm. Thus, the algorithm was used to characterize the underwater substrates and study the bio-physical oceanography attributes.

Bio-optic is defined as a process where the sun radiates the energy to the surface of the water and transferred into the water column. Upon reaching the sea bottom, the energy is then reflected back and reaches the sensor. During this process, some energy is scattered and absorbed by the air and water particles. However, these elements for each coastal and sea water are different from one another. The backscattering and the absorption of water particles as well as water depth, have become the main elements that influence the bio-optic parameters. Thus, the bio-optic-based algorithm was applied to detect the water substrates available at shallow depth.

In the ocean environment, the optical properties can be divided into three major groups: (1) phytoplankton, (2) suspended particulate matters (SPM), and (3) yellow substances (commonly known as coloured dissolved organic matter; CDOM). On the contrary, for the coastal study, the optical properties are more complex because of the water constituents and ocean current. Life and activities near the coastal areas, such as the development areas, the industrial areas or tourism areas trigger to the complexity of optical properties across the coastal areas.

In the scope of bio-optic studies, the ocean water optical properties can be categorised into two: 'Case 1' and 'Case 2'. In Case 1, only phytoplankton plays an important role in the variations of the water optical properties, whereas in Case 2 water, the properties of the water not only influenced by phytoplankton but also by the suspended particles and yellow substances. Therefore, this study will focus on Case 2 waters at shallow depth.

The scattered sunlight before reaching the water surface is affected by the atmospheric constituents before reaching back to remote sensor. Therefore, in case of Case 2 water, the atmospheric correction is essential. The water-leaving signal decreases because of the absorption and scattering of water molecules and various materials present in the water. Remote sensing technique provides spatially and temporarily high-resolution data which is better in terms of time consumed and crucial compared to other conventional approaches. Furthermore, remote sensing technique can potentially produce information in broad-scale map especially in ocean management, biodiversity assessment, and ecosystem monitoring (Pearce and Pattiaratchi, 1997).

Most studies which used the bio-optical algorithm in detecting chlorophyll and ocean colour were conducted in and off Malaysian waters. A study was conducted in Peninsular Malaysia's waters on bio-optical properties and its application for ocean colour algorithm (Bowers *et al.*, 2012). Besides, outside Malaysia, a study was also conducted in Brazil on implications of bio-optical properties to the ocean colour algorithm (Carvalho *et al.*, 2014). Moreover, a study conducted by Orek (2013) used concept of bio-optic to determine the inherent optical properties during the period of maximum runoff at Lena River (northern Siberia, Russia). There was also a study conducted in discriminating sea bottom features by using different water column correction methods, such as depth invariant index (DII), bottom reflectance index (BRI), and different satellite data. However, the bio-optic algorithm, used in this study to detect the sea bottom substrates, was the first time effort.

1.2 Problem Statement

Understanding water column properties of coastal water is very crucial in the remote sensing feature extractions of substrates. These substrates include seagrass, benthic mud, coral, seaweed, and other pertinent features to coastal and marine ecology. Interaction of irradiance into the water column is best described by the bio-optic algorithm.

Within the water column, the interactions of radiative sunlight with suspended sediments, turbidity, and other water properties including the returns from the bottom's surfaces have been formulated in various bio-optic algorithms. In fact, the bio-optic algorithm has been used for extraction sediments such as phytoplankton from remote sensing data. However, the return from sea bottom substrates is rarely reported. Hence, this thesis is address the applicability of bio-optic algorithm for detecting and mapping shallow coastal substrates with high resolution satellite data.

1.3 Objectives of Study

The main objective is to produce a sea bottom map in Merambong Island and Tinggi Island using the bio-optic algorithm. Specific objectives of this study are:

(i) to investigate the suitability of the selected bio-optic algorithms for detecting shallow sea-bottom substrates;

(ii) to formulate and assess the suitability of the selected bio-optic algorithm for shallow coastal water with high-resolution satellite data; and

(iii) to verify the relationship between water constituent of bio-optic algorithm and substrate leaving radiance/reflectance, and to map the sea bottom features of Merambong and Tinggi Island area.

1.4 Scope of Study

The scope of this study are as follows:

(i) Bio-optic-based algorithm was chosen in this study due to its high potential to determine water substrate at shallow water area and impressively in complex water type at two different areas. They were located at Merambong Island; south part of Peninsular Malaysia, exactly at Johor Straits and the other area is at Tinggi Island; located further east of Johor. Previous studies used depth invariant index (DII) and bottom reflectance index (BRI) to detect the water substrate at the eastern Peninsular Malaysia (Rasib and Hashim, 1997; Nurul, 2012), whereas some studies used different method which was bio-optic algorithm at the same site for different purposes, which is to study the sea colour .

(ii) The selected bio-optic-based algorithm had been analysed as best fit with high-resolution data. This was proven by Lyons (2011) who used Quickbird data as their high spatial resolution data which potentially provide coastal information routinely. In this study, the satellite Worldview-2 data with high spatial resolution was used. Furthermore, the satellite imagery with good bandwidth penetration can penetrate through the shallow water and near the coastal area that contains numerous suspended sediment and particles. Even so, the satellite imagery still provides good results, with less time consuming, cheaper and more outgoing especially on ocean study, where the point location is not easily pinned and a huge area to cover as compared to fieldwork observation.

(iii) The relationship between the water properties and the sea bottom substrates was studied. The bio-optic algorithm used was a mathematical equation that combines with many parameters. Some of the parameters, such as water properties and depth will affect the water leaving radiance/reflectance. Thus, this study will investigate the relationship between the water parameters, such as the depth and clarity, and different type of areas and conditions. Merambong Island is near to an industrial area and under development while Tinggi Island is a tourism area (Marine Park) and reserve forest. Finally, the maps of sea bottom substrate for both Merambong Island and Tinggi Island were produced.

(iv) Substrate in marine biology is define as the earthy materials in the bottom of a marine habitat like dirt, rocks, sand and gravel. However, in this study the substrate refer to seagrass, seaweed, coral/mud and sand.

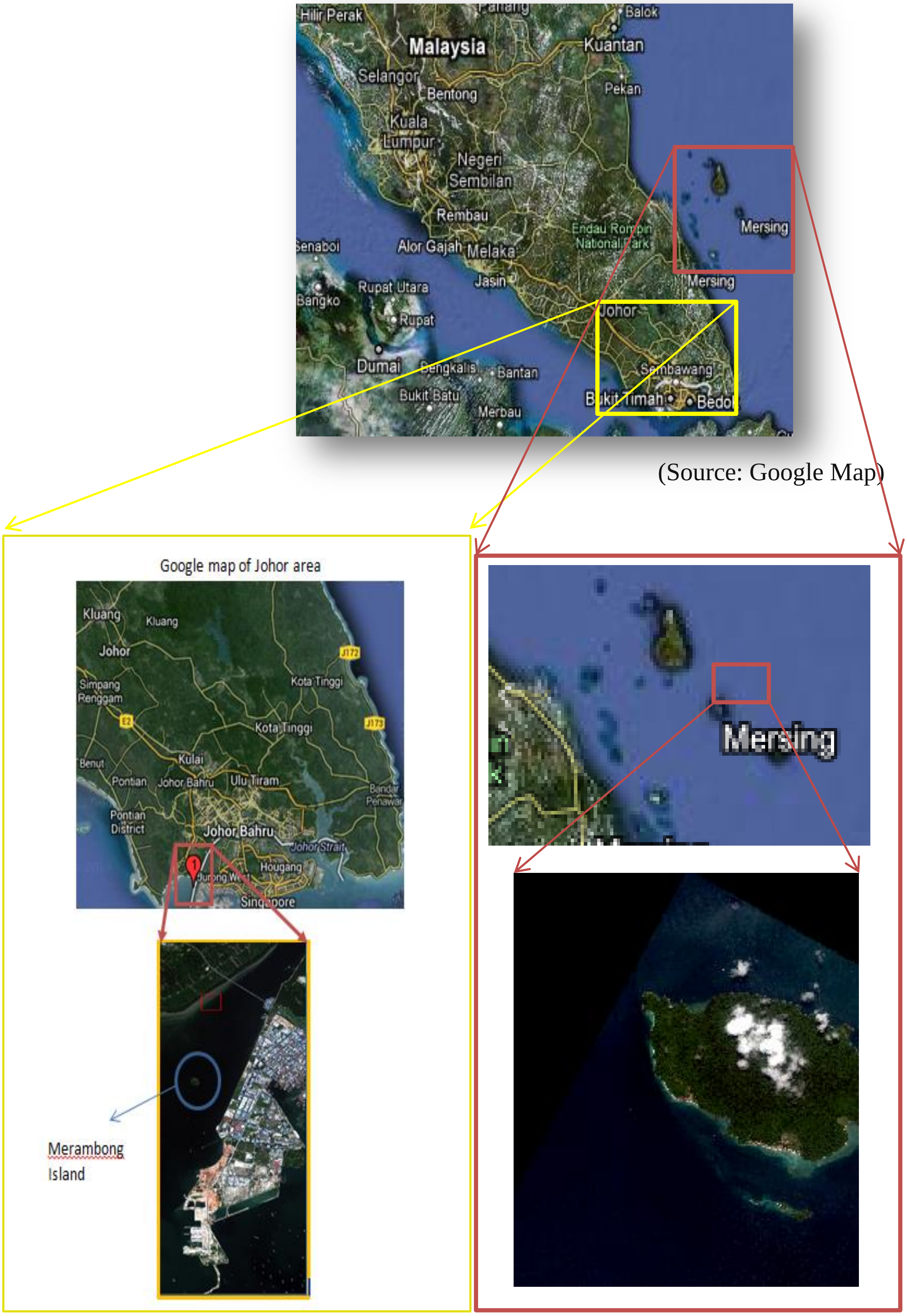
(v) Shallow water area where we start to feel a wave on the seabed, longer wavelengths and period swells. In this scope, shallow water areas refer to depth below 20 meter from the seabed.

1.5 Study area

Two study areas were selected in this study, which are Merambong Island located at the south-east part of Johor coastal waters at the Straits of Johor and Tinggi Island, Mersing located at the east part of Johor coastal water, facing the South East China Sea as shown in Figure 1.1. Merambong Island is closely located to Tanjung Adang, Tanjung Kupang and Tanjung Pelepas Port (PTP). They are surrounded by narrow and busy navigational channel. Merambong Island is also known as habitat of seagrass species where nine species can be found (Japar *et al.*, 2006).

In contrast, the physical characteristic of Tinggi Island is well known as tourism area with good quality of water and was chosen for Marine Park. It has also become a protected area for coral habitat and other marine life.

There is a new development near the Merambong Island and this certainly will disturb the marine habitat such as dugongs. As a result, many suspended sediments under the sea water will be produced. Human activities such as land reclamation for building a port, chalet or floating restaurant, sand mining, transportation avenues and oil pollution have destroyed most of the marine life habitats (Japar *et al.*, 2006). Merambong can be a very important area in the future as this area is rich in marine organisms, such as gastropods, seaweeds, sea cucumbers, commercial fishes, and echinoderms. As a matter of fact, Merambong has become a good fishing spot for fishermen to catch fishes as one of their major income source. Additionally, it is the feeding ground of dugongs and birds, gleaning site for bivalves, and nursery ground for vertebrates and invertebrates that portray its uniqueness.



a) Merambong Island, Johor, Malaysia b) Tinggi Island, Johor, Malaysia

Figure 1.1 Area of study

On the other hand, Tinggi Island was developed as a tourism area with the attraction of Marine Park such as Jahat Island, Ceben Island, Babi Tengah Island, Babi Hujong Island, Babi Besar Island, Gual Island, Sibu Hujong Island and Mentigi Island as referred to the Establishment of Marine Parks Malaysia (Amendment) Order 2012. These small islands have become the source of economic development of Malaysia. Various underwater activities such as snorkelling and diving can be offered because of the clear and shallow water (Figure 1.2).

Figure 1.2 Tinggi Island area

(Source: Marine Park Malaysia, 2012)

1.6 Significance of Study

Due to the development in the area, Merambong Island is facing challenges when the area is dumped by sand, consequently, degrading habitats of seagrass, flora, fauna and other marine life that play an important role in stabilising the marine ecosystem. The water substrate will increase significantly as this happens. Even the Fisheries Act 1985 stated that permission is required to import or export fishes from the port (https://www.dof.gov.my). This endangers the marine life in that area. This study aims to map the area that has the potential to be highly destructive by the sea water substrate and provide earlier information to the fishery industry, marine scientists and tourism industry. This information is beneficial as the Merambong Island is in a developing phase to become an attractive place.

The importance of study on Case 2 focused on the values of economic, social and ecological significance. Therefore, it is important to study existing condition of the water substrate so that the stabilisation of the ecology in the potential area can be maintained for various purposes. Furthermore, the coastal water is important for the ecological zone where it has become the habitat for fishes, seaweeds, seagrasses, sea animals, sea shelves, coral reefs, dugongs, seahorses and other living organisms. Figure 1.3 shows the example of marine life in *Anthozoa* class such as coral, the threatened species that has been protected under International Trade in Endangered Species Act of 2008 act 686.

Table 1.1: Example of endangered species in Malaysia ocean

CLASS ANTHOZOA (CORALS, SEA ANEMONES)		
I	II	III
ANTIPATHARIA		
	Antipatharia spp.	
HELIOPORACEA		
Family: *Helioporidae* (Blue coral)		
	Helioporidae spp. [Includes only the species *Heliopora coerulea*. (Fossils are not subject to the provisions of the Convention)]	
SCLERACTINIA (Stony coral)		
Family : *Scleractinia* (Stony coral)		
	Scleractinia spp. (Fossils are not subject to the provisions of the Convention)	
STOLONIFERA		
Family: *Tubiporidae* (Organ-pipe coral)		
	Tubiporidae spp. (Fossils are not subject to the provisions of the Convention)	
CLASS HYDROZOA (SEA FERNS, FIRE CORALS, STINGING MEDUSAE)		
I	II	III
MILLEPORINA		
Family: *Milleporidae* (Fire coral)		
	Milleporidae spp. (Fossils are not subject to the provisions of the Convention)	
STYLASTERINA		
Family: Stylasteridae (Lace coral)		
	Stylasteridae spp. (Fossils are not subject to the provisions of the Convention)	

(Source: Laws of Malaysia, 2008)

1.7 Thesis Structure

This thesis consists of five chapters: Chapter 1 (Introduction), Chapter 2 (Literature review), Chapter 3 (Methodology), Chapter 4 (Results and Discussions) and Chapter 5 (Conclusions and Recommendations).

Chapter 1 describes the fundamentals and background study, problem statement, objectives, the scope of the study, study area and significance of the research. This chapter also describes briefly on the concepts and the difference between present study compared to previous studies.

In order to relate the concept of this study as stated in Chapter 1, literature reviews on previous studies have been presented in Chapter 2. Chapter 2 discusses previous studies on remote sensing data suitability for shallow water substrate and bio-optical-based algorithm in a different perspective, as well as the application of bio-optic-based algorithm used in this study.

After reviewing the previous studies, Chapter 3 explains the method used in this study in detail including the processing data technique and materials used to carry out this study, especially during the data acquisition and laboratory work. This chapter also explains the pre-processing steps such as satellite data correction and extracting substrate information.

The analysis and discussion of the results obtained are written in Chapter 4. The results are shown in detail for every processing, and comparisons were made where the difference in each processed data were discussed. The output/results were analysed using two different way; transection and confusion matrix, to clearly observe the findings of this study. In addition, comparison of this study with previously related studies, also discussed.

Finally, the conclusions and recommendations are given in Chapter 5. The conclusions were drawn based on the objectives of the study, either it has fully fulfilled the objectives or needed any enhancement. Thus, some recommendations were made to provide ideas for further researches for improving this study.

References

Allen G.P. and Chambers J.L.C. (1998). Sedimentation in the modern and miocene Mahakam Delta, Indonesian Petroleum Association, P235.

Alsubaie N. M. (2012). The potential of using Worldview-2 imagery for shallow water depth mapping. Master of Science, University of Calgary

Ambarwulan, W. (2002). Mapping of TSM concentrations from SPOT and Landsat TM satellite images for Integrated Coastal Zone Management in Teluk Banten, Indonesia. Master of Science, ITC, Enschede, The Netherlands; 130 p.

Annia S. S., James A. G., Lenio S. G., Claudio C. F. B., Thiago S. F. S. and Evlyn M. L. de M. N. (2013). Sunglint removal in high spatial resolution hyperspectral images under different viewing geometrie. *Anais XVI Simpósio Brasileiro de Sensoriamento Remoto - SBSR*, Foz do Iguaçu, PR, Brasil, 13 a 18 de abril de 2013, INPE.

Anatoly A.G., Daniela G., Wesley M and Tadd B. (2009). A bio-optical algorithm for the remote estimation of the chlorophyll-a concentration in case 2 waters. *Papers in Natural Resources*, 284.

Austin, R.W. and Petzold, T.J. (1981). The determination of the diffuse attenuation coefficient of sea water using the coastal zone color scanner. In: *Oceanography from space, J.F.R. Gower (Ed.).* Plenum Press, New York, 239-256.

Beck, M. W., Heck, K. L., Jr., Able, K. W., Childers, D. L., Eggleston, D. B., Gillanders, B. M., Halpern, B. S., Hays, C. G., Hoshino, K., Minello, T. J., Orth, R. J., Sheridan, P. F., & Weinstein, M. P. (2003). The Role of Nearshore Ecosystems as Fish and Shellfish Nurseries. Washington, D.C: Ecological Society of America 12 pp.

Bierwirth P.N., Lee T.J. and Burne R.V. (1993). Shallow seam floor reflectance and water depth derived by unmixing multispectral imagery. *Photogrammetric Engineering & Remote Sensing*, Vol. 59, No. 3, March 1993, pp. 331-338.

Bowers D. G., Md-Suffian I. and Mitchelson-Jacob, E. G. (2012). Bio-optical properties of east coast Malaysia waters in relation to remote sensing of chlorophyll. *International Journal of Remote Sensing, 33*(1), 150-169. doi: 10.1080/01431161.2011.584917.

Carder K.L., Chen R.F., Lee Z.P. and Hawes S.K. (1991). Semianalytical moderate-resolution imaging spectrometer algorithms for chlorophyll a and absorption with bio-optic domain based on nitrate-depletion temperatures. *Journal of Geophysical Research104:5403-5421.*

Carvalho M., Ciotti A. M., Gianesella S. M. F., Correa F. M. P. S. and Costa R. R. (2014). Bio-Optical properties of the inner continental shelf off Santos Estuarine System, Southeastern Brazil, and their implications for ocean color algorithm performance. *Brazilian Journal of Oceanography.* Braz. j. oceanogr. vol.62 no.2 Sao Paulo.

Cob Z.C., Ghaffar M.A., Arshad A. and Bujang J. S. (2009). Exploring the Use of Empirical Methods to Measure the Secondary Production of Strombus canarium (Gastropoda: Strombidae) Population in Johor Straits, Malaysia. Sains Malaysiana 38(6)(2009).

Congalton R.G. (2005). Thematic and Positional Accuracy Assessment of Digital Remotely Sensed Data. *Proceedings of the Seventh Annual Forest Inventory and Analysis Symposium.* Page 149-154.

Congalton R.G. and Green K. (1999). Assessing the accuracy of remotely sensed data.: principle and practices. (2nd ed.) CRC Press.Taylor and Francis Group. United State of America

Doerffer, R. and Fischer, J. (1987). Sun stimulated chlorophyll fluorescence within a daily cycle. In: *The Use of Chlorophyll Fluorescence Measurements from Space for Separating Constituents of Sea Water.* ESA Contract No. RFQ 3-5059/84/NL/MD Vol.2.

Dekker A.G., Brandon V.E., Anstee J.M., Pinnel N., Kutser T., Hogenboom H.J., Asterkamp R., Peters S.W.M., C. Olbert R.J. Vos and Malthus T.J. (2001). Imaging spectrometry of water, Imaging Spectrometry: Basic principles and perspective applications. *Dord recht: Kluwer Academic Publisher,* p.p 307-359.

Dekker, A.G., S.W.M. Peters, M. Rijkeboer, and H. Berghuis. (1998). Analytical processing of multitemporal SPOT and Landsat images for estuarine management in Kalimantan Indonesia. In: Nieuwnhuis, G.J.A., R.A. Vaughan, and M. Molenaar (Eds.). 1999. *Operational Remote Sensing for Sustainable Development*. A.A. Balkema Publishers, Rotterdam, The Netherlands; pp.315-323.

DigitalGlobe (2013) Worldview Satellite Imagery Products: Product Guide. Longmount, Colorado.

Elsharkawy, A., M. Elhabiby and N. El-Sheimy. (2012). Quality control on the Radiometric Calibration of the Worldview-2 Data. *Proceeding of Global Geospatial Conference 2012.*

Fearns P.R.C, Klonowski W., Babcock R.C, England P. and Phillips J. (2011). Shallow water substrate mapping using hyperspectral remote sensing. *Continental Shelf Research*, 31 (2011) 1249-1259.

Fischer, J. (1983). Remote sensing of suspended matter, phytoplankton and yellow substances over coastal waters, part 1: aircraft measurements. In: Degens, E. T., Kempe, S. and Soliman, H. (Eds) *Transport of Carbon and Minerals in Major World Rivers, Pt.2*. Mitt. Geol.-Paläont. Inst. Univ. Hamburg, SCOPE/UNEP Sonderbd. **55**, pp. 85-95.

Gitelson A.A., Gurlin D., Moses W.J. and Barrow T. (2009). A bio-optical algorithm for the remote estimation of the chlorophyll-a concentration in case 2 waters. *Environment research letters doi:10.1088/1748-9326/4/4045003.*

Goodman, J.A., Lee Z. and Ustin S.L. (2008). Influence of Atmospheric and Sea-Surface Corrections on Retrieval of Bottom Depth and Reflectance Using a Semi-Analytical Model: A Case Study in Kaneohe Bay, Hawaii. *Appl. Opt.* 2008, *47*, F1-F11.

Gordon H.R. (1991). Absorption and scattering estimates from irradiance measurement. Monte Carlo simulations. *Limnology and Oceanography, 36: 769-777.*

Green E.P., Mumby P.J., Edwards E.J. and Clark C. D. (2000). Remote sensing Handbook for Tropical Coastal Management. Coastal Management Source Books 3. 121-128. Paris:UNESCO.

Hamid, N. N., Hashim, M., & Misbari, S. (2015). Analyzing the effective of bio-optic algorithm to detect sea bottom substrate using remote sensing data. In *ACRS 2015 - 36th Asian Conference on Remote Sensing: Fostering Resilient Growth in Asia, Proceedings* Asian Association on Remote Sensing.

Hedley J. D., Harborne A. R. and Mumby P. J. (2005). Technical Note: Simple and robust removal of sun glint for mapping shallow water benthos. *International Journal of Remote Sensing.* 26:10, 2107-2112.

Japar Sidik, B., Muta Harah, Z. & Aziz, A. (2006). Distribution and significance of seagrass ecosystems in Malaysia. Aquatic Ecosystem Health and Management 9: 203-214.

Jennifer P. C. andKendall L. C. (2009). Estimating chlorophyll a concentrations from remote-sensing reflectance in optically shallow waters. *Remote Sensing of Environment*, 101, 13-24.

Jensen, J. R. (2005). Introductory Digital Image Processing: A Remote Sensing Perspective. (3rd ed.). Upper Saddle River, NJ: Prentice Hall.

Jupp, D. L. B. (1988) *Background and extensions to depth of penetration (DOP) mapping in shallow coastal waters.* Proceedings of the Symposium on Remote Sensing of the Coastal Zone, pp. IV.2.1-IV.2.19. Gold Coast, Queensland.

Kishino M., Tanaka A. and Ishizika J. (2005). Retrieval of Chlorophyll a, suspended solids, and colored dissolved organic matter in Tokyo Bay using ASTER data. *Remote Sensing of Environment*, 99**,** 66-74.

Kishino M., Ishimaru T., Furuya K., Oishi T. and Kawasaki K. (1998). In-water Algorithms for ADEOS/OCTS. *Journal of Oceanography. Vol 54 pp 431 to 436.*

Landsat8 Data Users Handbook.pdf (2016). Department of the Interior U.S. Geological survey.

Lee Z., Carder K.L., Mobley C.D., Steward R.G. and Patch J.S. (1998). Hyperspectral remote sensing for shallow waters: 1. A semianalytical model. *Applied optics.* Vol 37 No. 27 pg 6329-6338.

Lee Z., Carder K.L., Mobley C.D., Steward R.G. and Patch J.S. (1999). Hyperspectral remote sensing for shallow waters: 2. Deriving bottom depths and water properties by optimization. *Applied optics.* Vol 38 No. 18 pg 3831-3843.

Liew S. C., Chia A.S., Lim K. H. and Kwoh L. K. (2001). Modeling the reflectance spectra of tropical coastal waters. *Ocean optics: Remote Sensing and Underwater Imaging, Ed.* G.D. Gilbert, R.J. Frouin, SPIE Proc. Vol. 4488, pp. 248-255,2001.

Linhai L., Lin L. and Kaishan S. (2010). A Bio-optical approach to estimating chlorophyll-a concentration from hyperspectral remote sensing. *Remote Sensing and Modelling of Ecosystem for Sustainaability VII,* Proc. Of SPIE Vol. 7809, doi:10.1117/12.859484.

Lyons M., Phinn S. and Roelsfema C. (2011). Integrating Quickbird multi-spectral satellite and field data: mapping bathymetry, seagrass cover, seagrass species and change in Moreton bay, Australia in 2004 and 2007. *Remote sensing 3*, 42-64, doi: 10.3390/rs3010042.

Malthus T.J. and Karpouzli E. (2003). Integrating field and high spatial resolution satellite based methods for monitoring shallow submersed aquatic habitats in the Sound of Eriskay, Scotland, UK. *Int. J Remote sensing* 24: 2585-2593.

Mitchell B. G. and Kahru M. (2009). Bio-Optical Algorithms for ADEOS-, GLI. *Journal of The Remote Sensing Society of Japan.* Vol. 29 No.1(2009) pp 80-85.

Morel A. (2001). Bio-optical Models. *Academic Press,* doi:10.1006/rwos.2001.0407.

Mustard J., Staid M. and Fripp W. (2001). A Semianalytical approach to the calibration of AVIRIS data to reflectance over water application in a Temperate Estuary. *Remote Sensing of Environment,* 75, 335-349.

Mueller, J. L. (2000). SeaWiFS algorithm for the diffuse attenuation coefficient, K(490), using water-leaving radiances at 490 and 555 nm, in SeaWiFS Postlaunch Calibration and Validation Analyses. *NASA Goddard Space Flight Cent., Greenbelt, Md*. Part 3, edited by S. B. Hooker, 24 – 27, Nurul. N. Y. (2012). Mapping of sea bottom features using high resolution satellite data. Master of Science, Universiti Teknologi Malaysia.

Orek H., Doerffer R., Rottgers R. Boersma M. and Wilfshire K. H. (2013). Contribution to a bio-optic model for remote sensing of Lena river water. *Biogeosciences.* 10, 7081-7094, 2013.

Pasterkamp R., Peters S.W.M. and Laanen M. (2001). Measurement protocol for the determination of specific inherent optical propertiesof Natural surface waters. Report Number wa/15. Institute for Environment Studies, Vrije University, Amsterdam, The Netherlands.

Pearce, A.F. and Pattiaratchi, C.B. (1997). Applications of satellite remote sensing to the marine environment in Western Australia. *Journal of the Royal Society of Western Australia*, 80 (1),1-14.

Peters S.W.M., Vos R.J., Hoogenboom E.J., Hakvoort H., Vand der Woerd HJ., Rijkeboer M. and Pasterkamp R. (2001). *MERIMON-2000 MERIS for water quality monitoring in the Belgian-Dutch-German coastal zone*. USP-2 01-25, Netherlands Remote Sensing Board (BCRS), Program Bureau, Rijkswaterstaat Survey Department, Delft, The Netherlands; 122 p.

Pope, R.M. and Fry E.S. (1997). Absorption spectrum (380 – 700 nm) of pure water :II. Intergrating cavity measurements. Applied optics 36(33), 8710-8723.

Rasib A. W and Hashim M. (1997). Mapping seagrass from satellite remote sensing data. *Asian Conference on Remote Sensing (ACRS).* Proceeding papers.

Sathyendranath S. (2000). Remote sensing of Ocean colour in Coastal and other optically-complex waters. Reports of the International Ocean-Colour Coordinating Group. IOCCG Report Number 3,2000. Chapter 1.

Sathyendranath S, Morel A (1983) Llght emerging from the sea-interpretation and uses in remote sensing. In: Cracknell AP fed) Remote sensing applications in marine science and technology. D Reidel Publishing Company. Dordrecht, p 323-357

Simis S.G.H., Peter S.W.M. and Gons H.J., (2005). Remote sensing of the cyanobacterial pigment phycocyanin in turbid inland water. Limnology and Oceanography 50(1), 237-245.

Sipelgas L, Ossipova V., Raudsepp U. and Lindfors A. (2009). A bio-optical model for the calculation of suspended matter concentration from MODIS data in the Pakri Bay, the Gulf of Finland. *Boreal Environment Research 14: 415-426.*

Stramski, D, Kiefer D. A. (1991). Light-Scattering by Microorganisms in the Open Ocean. Progress in Oceanography. 28:343-383.

Susan K., John D. H. and Samantha L. (2009). Sun Glint Correction of High and Low Spatial Resolution Images of Aquatic Scenes: a Review of Methods for Visible and Near-Infrared Wavelengths. *Remote Sensing*. 2009, 1, 697-730.

Syarif B. Tjeerd H. and Zoltan V. (1992). Remote Sensing for Mapping TSM Concentration in Mahakam Delta: an Analytical Approach. *International Institute for Geo-Information Science and Earth Observation – ITC, The Netherlands.*

Updike T. and Comp C. (2010). Radiometric Use of Worldview-2 Imagery. Technical Note, Digital Globe Inc.

Akta Peraturan Perintah Penubuhan Taman Laut Malaysia (Pindaan) 2012.pdf

Tide Table and Solunar Charts for Fishing, 2014

Vanderstraete T., Goossens R. and Ghabour T. K. (2004). Coral Reef Bottom-Type Mapping in the Red Sea (Hurghada, Egypt) Based on Remote Sensing. EARSeL eProceedings, Vol. 3, No. 2, pp. 191-207.

Wabnitz C.C., Andrefoute S., Torres-Pulliza D., Muller-Karger F. E., and Kramer P.A. (2008). Regonal-scale seagrass habitat mapping in the Wider Caribbean region using Landsat sensor: Applications to conservation and ecology. *Remote sensing of Environment, 200.* doi:10.1016/j.rse.2008.01.020

Zimmermann N.E. (2001). Simtest. Swiss Federal Research Institute WSL, Birmensdorf, Switzerland.