SEAFLOOR MAPPING USING MULTIBEAM SONAR

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DEDICATION

This thesis is dedicated to my parents and my beloved family,

Zerin, Ayra, Afia…

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ABSTRACT

Seafloor habitat and its marine community have greatly affected by anthropogenic pressures from various human activities. Efforts to conserve and manage the marine habitat are challenging due to the difficulty to get the details of the seafloor data. Attention has been focused towards the multibeam echo sounder system (MBES), a tool in mapping the seafloor habitats, due to its ability to produce a detailed seafloor map. The aim of this study is to utilize MBES output, namely the bathymetry, backscatter, and its derivatives in order to produce a seafloor habitat map using automated classification technique in Malaysian water. The objectives are: (i) to investigate the correlation between MBES backscatter image and signal-based method for seafloor sediment classification; (ii) to evaluate the importance of bathymetry and its derivatives in producing coral reef classification map; (iii) to perform automated technique in producing the coral reef classification map, and finally (iv) to assess the accuracy of the coral reef classification maps constructed from the techniques above. The study was conducted in two different locations: Sembilan Island, Perak and Tawau, Sabah. The results of the data reduction analysis using the Principal Component Analysis (PCA), Linear Pearson Correlation, and variable importance analysis showed four most significant derivative layers for the production of coral reef classification map were identified: (i) bathymetry, (ii) benthic position index (BPI), (iii) slope, and (iv) grey level co-occurrence matrices (GLCM) mean. The classification map constructed with the selected MBES derivatives using four different techniques (Support Vector Machine, Neural Network, QUEST decision trees, and CRUISE decision trees) had shown an encouraging results with two classifiers achieved the accuracy of more than 70% (Support Vector Machine with 73.61% and Neural Network with 70.14%). In sum, this classification seafloor habitat map has enhanced coral reef spatial distribution information, and this finding has an important contribution to the seafloor habitat mapping in Malaysia.

ABSTRAK

Habitat dasar laut dan komuniti marin sangat dipengaruhi oleh tekanan antropogenik dari pelbagai aktiviti manusia. Usaha untuk memulihara dan mengurus habitat laut sangat mencabar kerana kesukaran untuk mendapatkan perincian data dasar laut. Perhatian telah tertumpu pada sistem pemerum gema berbilang alur (MBES), alat untuk memetakan habitat dasar laut, kerana kemampuannya untuk menghasilkan peta dasar laut yang terperinci. Tujuan kajian ini adalah untuk menggunakan data MBES iaitu batimetri, *backscatter* serta derivatifnya untuk menghasilkan peta habitat dasar laut menggunakan kaedah klasifikasi secara automatik di perairan Malaysia. Objektif kajian ini adalah: (i) untuk mengkaji korelasi antara kaedah imej *backscatter* MBES dan kaedah *signal-based* dalam menghasilkan klasifikasi sedimen dasar laut; (ii) untuk menilai kepentingan data batimetri dan derivatifnya dalam menghasilkan peta klasifikasi terumbu karang; (iii) untuk menggunakan teknik automatik dalam menghasilkan peta klasifikasi terumbu karang, dan yang terakhir (iv) untuk menilai ketepatan peta klasifikasi terumbu karang yang dihasilkan melalui kaedah di atas. Kajian ini dijalankan di dua lokasi berbeza; Pulau Sembilan, Perak dan Tawau, Sabah. Hasil analisis pengurangan data menggunakan *Principal Component Analysis* (PCA), *Linear Pearson Correlation* dan *variable importance analysis* menunjukkan empat lapisan derivatif yang paling signifikan dalam penghasilan peta klasifikasi terumbu karang telah dikenal pasti: (i) batimetri, (ii) *benthic position index* (BPI), (iii) cerun, dan (iv) *grey level co-occurrence matrices (GLCM) mean*. Peta klasifikasi terumbu karang yang dihasilkan dengan derivatif MBES yang terpilih menggunakan empat teknik yang berbeza (*Support Vector Machine, Neural Network, QUEST decision tree's* dan *CRUISE decision trees*) telah menunjukkan hasil yang memberangsangkan dengan dua jenis teknik klasifikasi mencapai ketepatan melebihi 70% (*Support Vector Machine* dengan 73.61% dan *Neural Network* dengan 70.14%). Secara keseluruhannya, peta klasifikasi habitat dasar laut ini telah meningkatkan maklumat taburan spatial terumbu karang, dan penemuan ini mempunyai sumbangan penting dalam pemetaan habitat dasar laut di Malaysia.

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LIST OF ABBREVIATIONS

MBES	-	Multibeam Echo Sounder System
PCA	-	Principal Component Analysis
GLCM	-	Grey Level Co-Occurrence Matrices
SVM	-	Support Vector Machine
NNC	-	Neural Network Classifier
QUEST	-	Quick, Unbiased and Efficient Statistical Tree
CRUISE	-	Classification Rule with Unbiased Interaction Selection and Estimation
UTM	-	Universiti Teknologi Malaysia
GIS	-	Geographic Information System
FMGT	-	Fledermaus Geocoder Tools
GPS	-	GPS Global Positioning
MRU	-	Motion Reference Unit
GIS	-	Geographic Information System
SBES	-	Single Beam Echo Sounder
WGS 84	-	World Geodetic System 1984

CHAPTER 1

INTRODUCTION

1.1 Introduction

The first chapter gave an outline of the objectives and general approach of this study, followed by a short literature review of the background of study related to similar topics. It gave a complete summary to the state of the art in the science of seafloor habitat mapping, ecosystem-based management, marine protected areas, and current technology to produce a seafloor habitat map. More specifically, this chapter also presented the statement of research problem, research question, scope of study and organization of the thesis.

1.2 Background of Problem

Habitat is generally defined as any places that can provide shelter and resources for living to survive. According to Davies and Young (2008), habitat can be identified as both physical and ecological environments that maintained a specific biological community within the society itself. The International Council for the Exploration of the Seas (ICES, 2006), had classified marine habitats as "particular environments differentiated by their abiotic features and related biological joints operating at specific but dynamic spatial and temporal ranges in an identifiable geographical field". This definition obviously indicated that abiotic features and biotic assemblages were the two primary components in outlining a habitat. Abiotic features can be referred as non-living components that could affect the ecosystem such as substrate type, geomorphic features, spatial structure, and their hydrodynamic properties. Eventually, the species and the living organisms that inhabited a particular zone were recognised as biotic assemblages (Ismail, 2016). For instance, forests, swamps, and grazing land were some habitats on terrestrial land. On the contrary, marine habitats can be classified into four categories which were coral reef, seagrass bed, mangrove, and seaweed meadow (Komatsu, 2011).

Seafloor habitat or commonly known as benthic habitat referred to marine communities that inhabiting the seafloor. Seafloor habitat varied largely relying upon their depth and area; frequently typified by primary structural characteristics and biological populations (LaFrance *et al.*, 2010). Seafloor habitats were crucial in sustaining a large diversity of life for many reasons. Their commonly known function was to provide spawning and nursery grounds for various fish species. Furthermore, they also played a crucial part in maintaining the quality of seawater by recycling the nutrient and eliminating the waste product from the water column. They also performed an essential role in each stage of marine 'food-chain' such as consuming phytoplankton and other small organisms, acting as food source for higher-level eaters or robustly preying on other species (Schelfaut, 2005).

To date, seafloor habitat and its community were significantly experiencing the anthropogenic tension from human activities for instance, the commercial uncontrolled fisheries, aggregated extraction, offshore oil and gas activities, marine shipping and vessel traffic, and the laying of submarine cables. Meanwhile, the awareness on seafloor conservation was increasing and management plans were being established accordingly, even outside the national waters (Barbier *et al.*, 2014; Ismail, 2016). According to Schmiing (2013), effective conservation and resource management were mandatory in maintaining the marine ecosystem services. In this standpoint, the ecosystem-based management (EBM) was the ideal strategy which integrated all the features and relationships within and among the ecosystems, coupled with human activities, rather than reviewing them separately (Leslie and McLeod, 2007; Katsanevakis *et al.*, 2011). Marine protected areas (MPAs) were the crucial elements of EBM and played an essential part in complementing the habitats and biodiversity, safeguarding threatened species, administering a sustainable usage of natural resources, and preserving significant historical sites (McNeely and Harrison, 1994). Hence, in order to geographically handle the ocean related activities and assign marine protected areas at crucial sites (Van Lancker and Van Heteren, 2013), a proper seafloor habitat map was needed so as to supervise and restrain human activities from disturbing and altering the seafloor habitat.

Mapping seafloor habitat had become a dependable method in defining topography of the seafloor environment and distribution of the main features. It had turned into an essential tool to recognize the areas that required special marine management involvements such as the formation of marine protected areas and identification of significant fisheries habitats. According to Davies and Young (2008), '*habitat mapping*' can be defined as: "*Plotting the dispersal and degree of habitats in order to build a comprehensive coverage map of the seabed with clear borders dividing adjoining habitats*." Furthermore, it also emphasized that a habitat map is "*an assertion of our finest estimation of habitat dispersal at one point in time, utilizing the best available knowledge we had at that period of time*" (Verfaillie, 2008). Designation of the new marine protected areas (MPAs), marine spatial planning, along with the implementation of national and international legislation and guidelines were some examples of seafloor habitat map utilisation (Blæsbjerg *et al.*, 2009). Furthermore, the development of regional framework for marine planning demanded crucial inputs such as High-resolution bathymetric maps along with the seafloor characterisation habitats distribution.

Conventionally, data collection during marine survey only involved limited quantity of collected points. Conversely, the fast advancement of seafloor mapping technologies, geographic information system (GIS) methods, and data visualization have increasingly improved its efficiency. Numerous approaches had been established in order to utilise the information and provide as much accurate characterisation of the seafloor environment as possible, varying from immediate observations to remote sensing techniques (Hamana and Komatsu, 2016). Immediate observations were obtained from the in-situ methodologies such as scuba diving, sampling, coring, underwater photography, and video (Schimel *et al.*, 2010). It allowed the efficient local illustration of the seabed, albeit laborious and lengthy (Komatsu, 2003; Hamana and Komatsu, 2016). On the other hand, remote sensing approach can save more time with less manpower employed. Optical-based and hydro acoustics-based were the two sub classes obtained from remote sensing methodology which was adopted for seafloor mapping purpose (Hamana and Komatsu, 2016). High-resolution satellite footage (Sagawa *et al.*, 2010; Yahya *et al.*, 2014), compact airborne spectrographic footage (e.g., airborne Portable Remote Imaging Spectrometer (PRISM)) (Phinn *et al.*, 2008), or Light Detection and Ranging (LiDAR) (Kotchenova *et al.*, 2004; Maltamo *et al.*, 2004; Hamana and Komatsu, 2016) were some models of optical remote sensing methodology that have been adopted in mapping the seafloor habitat. Similarly, the hydroacoustic remote sensing methods for instance, the single beam echo sounder, side scan sonars, and multibeam sonar utilised the transmission of acoustic sound wave above the water column and their reflected signals from the seafloor surface to map a wide-ranging seafloor area in the water up to several thousand metres deep (Dartnell and Gardner, 2004; McGonigle *et al.*, 2009; Brown *et al.*, 2011a; Huang *et al.*, 2012). Although optical remote sensing fitted the job of large-scale mapping, it had a restriction in which it was not applicable in the deep bottom or turbid waters, due to the decreased light in the water column. Albeit having the advantages for huge area mapping, the ability of the optical remote sensing was limited to shallow and clear water area as the light decreased within the water column. In addition, this methodology also possessed restrictions in identifying tiny, dispersed, or low-populated seafloor habitat caused by its territorial and radiometric resolution of the satellite visuals (Komatsu, 2003). On the contrary, hydroacoustic remote sensing has no restriction to be utilised in deeper or highly turbid waters (Komatsu, 2003).

In Comparison with all the hydroacoustic seafloor mapping systems available nowadays, a rising attention had recently been narrowed down towards the multibeam echosounder system (MBES). With its capability to produce diversified outputs such as bathymetry, backscatter, water-column data, and angular response which led to multiple methods available for producing the habitat and seafloor classification mapping (Schimel, 2011). A manifold classification methods fell into two wide classes which were the manual and automated classification (Stephens and Diesing, 2014). Each method demanded a distinct set of hydro-acoustic data in order to generate the classification habitat map. Recently, the requirements for computerized technologies had been emerging so as to speed up the analysis of geographical data from wide-ranging areas (Galparsoro *et al.*, 2015; Lucieer, 2008). The purpose of this study was to utilise the MBES acoustic data such as bathymetry, backscatter and its derivatives in order to construct the seafloor habitat maps using automated classification techniques.

1.3 Problem Statement

A recent study showed that the research that adopted the Multibeam echosounder backscatter as the instrument in generating the habitat maps were still lacking in Malaysia (Mustajap *et al.*, 2015; Abdullah *et al.*, 2016). Moreover, data on the distribution of marine species and habitats were frequently limited, generally due to the complexity, surveying costs, and the time-consuming sampling as the sea areas covered were wide-ranging. Based on the literature (Salm *et al.*, 2000; ReefCheck, 2012a), majority of the seafloor habitat distribution mapping specifically the coral reef area still depended on the in-situ measurement techniques such as line intercept transect technique, sampling, underwater photography, and video (Brown and Coggan, 2007; Schimel *et al.*, 2010) . The in-situ measurement techniques allowed the effective localised illustration of the seafloor, but it possessed restriction in covering the broad-scale map, thus putting high risks to the diver, despite being time-consuming and costly.

Conversely, present technology such as optical and hydroacoustic remote sensing offered a better alternative in terms of coverage for the broad-scale mapping compared to the in-situ measurement method, but the optical remote sensing technique was subjected to water transparency and irrelevant in highly turbid waters (Komatsu, 2003; Zoffoli *et al.*, 2014; Pandian *et al.*, 2009). Moreover, this technique was only efficient in the shallow water with the depth ranging between 0 to 15 m (Zoffoli *et al.*, 2014). Whilst the optical remote sensing was restricted to depth and water transparency, a hydroacoustic system such as the single beam echosounder, side scan sonar, and multibeam echosounder system provided another option to resolve this restriction. Single beam echosounder system was considered as the cheapest and simplest technique among hydro acoustic systems but it delivered low spatial resolution of depth data (Parnum *et al.*, 2009) and the output needed substantial interpolation as to produce seafloor maps with 100 % coverage (Kenny *et al.*, 2003).

Compared to the single beam echosounder system, side scan sonar system offered an improved alternative in terms of coverage for seafloor habitat mapping as it could provide an extensive and comprehensive area coverage with high resolution footages of the seafloor (Kenny *et al.*, 2003; Pandian *et al.*, 2009; Schimel, 2011), but this system only generated the seafloor image, without bathymetry data which was a crucial component in generating a complete seafloor habitat map. Among all the methodologies and mechanisms available for seafloor habitat mapping, multibeam echosounder system had shown significant strengths compared to the others. According to Micallef *et al.* (2012), in comparison with an in-situ methodology which was limited to small scale seafloor habitat mapping, multibeam echosounder system could offer continuous acoustic coverage of wide hallway of seafloor. In addition, multibeam echosounder system was similar to any other hydroacoustic systems which were not restricted by water depth and turbidity. The rapid development of marine acoustic technology for seafloor habitat mapping had enabled the echosounder system to match the other hydro acoustic mapping systems (e.g., single beam echosounder and side scan sonar system) as a preferable seafloor habitat mapping tool (Brown and Blondel, 2009; Micallef *et al.*, 2012). This was due to its ability in obtaining high-resolution bathymetric and backscatter data concurrently (Brown *et al.*, 2011b; Micallef *et al.*, 2012) which was an essential component of the seafloor habitat mapping production.

With the advancement in devices available for seafloor habitat mapping today, one of the primary coral reef areas in the West coast of Peninsular Malaysia, known as Pulau Sembilan had experienced a huge anthropogenic pressure as a result of tourism activities which required careful consideration and a complete seafloor habitat mapping so as to supervise the anthropogenic pressure on that valuable biodiversity area (Razak *et al.*, 2014). With unprotected status (ReefCheck, 2012b), tourism and fishing activities kept pressuring this area, which in future, would give negative effects on the health of the coral reefs within the islands, thus daunting their economic potential and ecological value. The latest seafloor habitat map of Pulau Sembilan was contributed by Reef Check Malaysia through the in-situ measurement approach conducted in January 2012. The purpose of this study was to utilise the multibeam echosounder acoustic data: bathymetry, backscatter, and its derivative in order to construct the seafloor habitat maps for coral reef areas in Pulau Sembilan using the automated classification method.

The latest seafloor habitat maps of this area were required in order to monitor the changes in seafloor habitat caused by anthropogenic pressure. Figure 1.1 showed fishing activities that harmed the coral reefs in Pulau Sembilan.

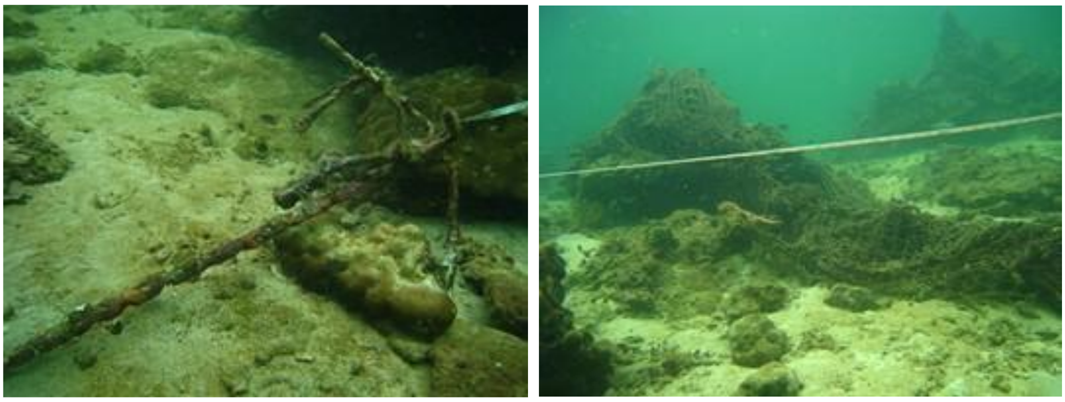

Figure 1. 1 (left) Abandoned anchor; (Right) Discarded net smothering corals in Pulau Sembilan (ReefCheck, 2012b)

1.4 Research Objectives

The aim of this study is to utilise MBES output which are bathymetry, backscatter, and its derivative in order to produce seafloor habitat maps by using automated classification technique in Malaysian water. For this study, there are a few objectives that needed to be accomplished:

1) To investigate the correlation between MBES backscatter image and signal-based method for seafloor sediment classification

2) To evaluate the importance of bathymetry and its derivatives in producing coral reef classification map

3) To perform an automated technique in producing coral reef classification map

4) To assess the accuracy of the coral reef classification maps constructed from all the techniques above.

1.5 Research Question

To achieve the above research objectives, the following research questions (RQ) were used:

Objective 1: To investigate the correlation between MBES backscatter image and signal-based method for seafloor sediment classification

RQ1. What are the correlations between MBES backscatter image and signal-based method for seafloor sediment classification?

Objective 2: To evaluate the importance of bathymetry and its derivatives in producing coral reef classification map

RQ2. What are the importance of bathymetry data and its derivatives and their contributions towards producing a high accuracy of coral reef classification map?

Objective 3: To perform an automated technique in producing coral reef classification map

RQ3. What is the best method that can be adopted to produce a coral reef classification map?

Objective 4: To assess the accuracy of the coral reef classification maps constructed from the techniques above.

RQ4. What are the levels of accuracy among the coral reef classification maps constructed from the techniques above?

1.6 Significance of the Research

This classification of seafloor habitat map could be one of the useful approaches in enhancing the seafloor habitats distribution database in Malaysia, especially for the coral reef distributions. Other than that, this classification map can also provide the current status of seafloor habitats distribution in Malaysian water with the reduction in cost and time. In response to that, it can also be an alternative method besides transect survey in providing complete large scale coral reef mapping in Malaysia. This classification map can also be used to assess the areas with greatest prospective for coral reef conservation and monitoring purposes in Malaysia. Moreover, it can be significant to the Department of Marine Park Malaysia, scientists, and students for future research of seafloor habitat in Malaysian water.

1.7 Scope and Limitation of the Research

The scope of this study will cover multibeam data acquisition in Tawau, Sabah and Pulau Agas, Perak coupled with several ground truth data using the Van Veen Grab Sampler and underwater video camera. The raw multibeam acoustic data was processed to produce a bathymetry and backscatter. Next, the sediment sample will be analysed in lab to get the percentage of sediment types for each ground truth station and underwater video will be observed to identify the seafloor habitat occurrence for each ground truth station. A set of multibeam bathymetry and backscatter derivatives will then be generated using Benthic Terrain Modeler software for classification purpose. A coral reef classification map will be produced using four automated supervised classification techniques namely the Support Vector Machine (SVM), Neural network classifier (NNC), Quick Unbiased Efficient Statistical Tree (QUEST) decision tree, and Classification Rule with Unbiased Interaction Selection and Estimation (CRUISE).

Accuracy for each map will be assessed by computing an error matrix, producer accuracies and user accuracies metrics using the ground truth data (Galparsoro *et al.*, 2015). An accuracy assessment from each classification technique would be carried out by computing the error matrix , producer accuracy (PA) and user accuracy (UA); for the total classification, and for each of the classes (Stehman, 1997; Galparsoro *et al.*, 2015; Congalton and Green, 2009).

1.8 Organization of the Thesis

Chapter 1 gave an overview of this research work by presenting the background of the study, statement of problem, research questions, research objectives, scope and limitation of the study, significance of research, and lastly, thesis organization

Chapter 2 would be presenting the literature review. This comprises reviews of literatures from previous researches and related topics associated with the production of seafloor habitat map using conventional methods until current technologies were developed.

Chapter 3 would focus on the research methods and data acquisition. It would include a brief description of the study area, equipment used for data acquisition, multibeam echosounder system description, methods for data analysis, and accuracy assessment.

Chapter 4 comprised results and data analysis conducted for this study, consisting of multibeam backscatter and bathymetry data analysis, and production of coral reef habitat mapping from the automated supervised classification technique. This chapter would also provide discussions for each objective of this study.

Chapter 5 gave a conclusion and recommendations for future research related to this study.

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LIST OF PUBLICATION

1. Samsudin, S. A. & Hasan, R. C. (2017). Assessment of Multibeam Backscatter Texture Analysis for Seafloor Sediment Classification. *International Archives of the Photogrammetry, Remote Sensing & Spatial Information Sciences, 42*. **(Published)**