SEAGRASS MAPPING USING HABITAT SUITABILITY MODELING AND MULTIBEAM ECHOSOUNDER AROUND REDANG ARCHIPELAGO

MUHAMMAD ABDUL HAKIM BIN MUHAMAD

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy

Razak Faculty of Technology and Informatics
Universiti Teknologi Malaysia

JUNE 2022

DEDICATION

This thesis is dedicated to my father, Muhammad Bin Jusoh, who taught me that the best kind of knowledge to have is the one that is learned for Allah's sake. This is also dedicated to my mother, Hasnah Binti Daud, who taught me that even the largest task can be accomplished if it is done one step at a time.

ACKNOWLEDGEMENT

In preparing this thesis, I have gotten support from many people, researchers, academicians, and practitioners. They have contributed to my understanding and thoughts. Hence, I wish to express my sincere appreciation to my main thesis supervisor, Dr. Rozaimi Bin Che Hasan, for his encouragement, guidance, critics, and friendship. Without his continued support and interest, this thesis would not have been made possible.

I am also grateful to the Center for Coastal and Ocean Engineering staff, who had been very helpful in assisting with the task related to this study. I would also like to extend my gratitude to other lecturers for their advice, whether directly or indirectly, in improving my Ph.D. study.

Not to forget, the National Hydrographic Centre (NHC), Royal Malaysian Navy, for the acoustic data collection. Special thanks also to the team partners from the Department of Fisheries Malaysia (DoF) and the Institute of Oceanography and Environment (INOS), Universiti Malaysia Terengganu.

My fellow postgraduate student should also be recognized for their support, along with all my colleagues and others who have assisted on various occasions. Their views and tips are useful indeed. Unfortunately, it is not possible to list all of them in this limited space. Finally, yet importantly, I am grateful to all my family members.

ABSTRACT

Climate change and anthropogenic activities have caused the degradation of seagrass ecosystems. Hence, systematic habitat mapping and identification process are required to ensure that seagrass is protected and monitored continuously. This research aims to utilize a multibeam echosounder (MBES) system, habitat suitability modeling (HSM), and image classification to produce a seagrass seascape map at the Redang archipelago. Bathymetric map, backscatter mosaic, and their associated predictors like slope, eastness, northness, curvature, gray-level co-occurrence matrix (GLCM) texture features (homogeneity, entropy, and correlation), angular range analysis (ARA) parameters (phi and characterization) were used as the predictors. All predictors were tested for different spatial resolutions (1 and 50 m) and window sizes analysis (3 × 3, 9 × 9, and 21 × 21 pixels). For HSM, three machine learning algorithms were used: maximum entropy (MaxEnt), random forest (RF), and support vector machine (SVM). For image classification, only RF was used. Seagrass occurrence data was used to train and test the seagrass habitat suitability modeling (SHSM), while seascape feature data was used to classify and validate the seafloor classification map. The results showed that both fine and coarse spatial resolution datasets produced training models with high predictive accuracy (AUC >90%). Testing models derived from MaxEnt and RF achieved the highest predictive accuracy (AUC >90%), while the SVM models had the lowest predictive accuracy (AUC <85%). Bathymetry was found to be the most influential predictor for all models. For the coarse resolution models, backscatter predictors like ARA characterization, ARA phi, GLCM texture features, and backscatter mosaic 32-bit contributed more to produce SHSM. Different window sizes analysis and coarse spatial resolution dataset produced inconsistent habitat suitability models compared to the fine spatial resolution dataset. Overall, the MBES dataset and HSM produced a detailed seagrass habitat suitability map and provided precise information on the seagrass habitat in the Redang archipelago. The improved habitat model was proposed by integrating a seafloor classification map to associate seagrass habitat suitability index and seafloor features (i.e., seagrass on fine sand, seagrass on coarse sand, fine sand, medium sand, and coarse sand). The proposed integration method produced a detailed seascape seagrass map. The information produced from this seascape seagrass map will be useful for decision-makers like the marine park authorities to manage seagrass habitats in response to anthropogenic activities and climate change.

ABSTRAK

Perubahan iklim dan aktiviti-aktiviti antropogenik telah menyebabkan kemerosotan ekosistem rumput laut. Oleh itu, proses pemetaan dan pengecaman habitat yang sistematik diperlukan untuk memastikan rumput laut dilindungi dan dipantau secara berterusan. Kajian ini bertujuan untuk menggunakan sistem pemerum gema berbilang alur (MBES), pemodelan kesesuaian habitat (HSM), dan klasifikasi imej untuk menghasilkan peta landskap rumput laut di kepulauan Redang. Peta batimetri, mozek serak balik, dan peramal berkaitannya seperti cerun, *eastness*, *northness*, kelengkungan, ciri-ciri tekstur *gray-level co-occurrence matrix* (GLCM) (kehomogenan, entropi, dan korelasi), parameter *angular range analysis* (ARA) (*phi* dan pencirian) telah digunakan sebagai peramal. Semua peramal telah diuji dengan resolusi *spatial* yang berbeza (1 dan 50 m) dan analisis saiz tingkap yang berbeza (3 × 3, 9 × 9, 21 × 21 piksel). Untuk HSM, tiga algoritma pembelajaran mesin telah digunakan: entropi maksimum (MaxEnt), *random forest* (RF), dan *support vector machine* (SVM). Bagi klasifikasi imej, hanya RF yang digunakan. Data kewujudan rumput laut telah digunakan untuk melatih dan menguji pemodelan kesesuaian habitat rumput laut (SHSM), manakala data ciri landskap laut telah digunakan untuk mengklasifikasikan dan mengesahkan peta klasifikasi dasar laut. Keputusan menunjukkan bahawa kedua-dua set data resolusi *spatial* halus dan kasar menghasilkan model latihan dengan ketepatan ramalan tinggi (AUC >90%). Model ujian yang diterbitkan daripada MaxEnt dan RF mendapat ketepatan ramalan tertinggi (AUC >90%), manakala model daripada SVM mempunyai ketepatan ramalan terendah (AUC <85%). Batimetri didapati sebagai peramal yang paling berpengaruh untuk semua model. Bagi model resolusi kasar, peramal serak balik seperti ARA pencirian, ARA *phi*, ciri-ciri tekstur GLCM dan mozek serak balik 32-bit menyumbang lebih banyak untuk menghasilkan SHSM. Analisis saiz tingkap yang berbeza dan set data resolusi *spatial* kasar memaparkan model kesesuaian habitat yang tidak konsisten dibandingkan dengan set data resolusi *spatial* halus. Secara keseluruhannya, set data MBES dan HSM menghasilkan peta kesesuaian habitat rumput laut yang terperinci dan memberikan maklumat tepat tentang habitat rumput laut di kepulauan Redang. Model habitat yang dipertingkatkan telah dicadangkan dengan integrasi antara peta klasifikasi dasar laut untuk mengaitkan indeks kesesuaian habitat rumput laut dan ciri dasar laut (iaitu rumput laut di atas pasir halus, rumput laut di atas pasir kasar, pasir halus, pasir sederhana kasar, dan pasir kasar). Kaedah integrasi yang dicadangkan ini akan menghasilkan peta landskap rumput laut yang terperinci. Maklumat yang dihasilkan daripada peta landskap rumput laut ini akan berguna untuk pembuat keputusan seperti pihak berkuasa taman laut untuk menguruskan habitat rumput laut sebagai tindak balas kepada aktiviti-aktiviti antropogenik dan perubahan iklim.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ARA	-	Angular Range Analysis
ANN	-	Artificial Neural Networks
BRI	-	Bottom Reflect Index
CATAMI	-	Collaborative and Automated Tools for Analysis of Marine Imagery
CPCe	-	Coral Point Count with Excel extensions
CT	-	Classification Tree
DII	-	Depth Invariant Index
DOF	-	Department of Fisheries
PFA	-	Fisheries Prohibited Area
ETM+	-	Explore Enhanced Thematic Mapper Plus
GEBCO	-	General Bathymetric Chart of the Oceans
GLCM	-	Gray-Level Co-Occurrence Matrix
GPS	-	Global Positioning System
HIS	-	Hue-Saturation-Intensity
HSM	-	Habitat Suitability Model
k-NN	-	k-Nearest Neighbour
LED	-	Light-Emitting Diode
MaxEnt	-	Maximum Entropy
MBES	-	Multibeam Echosounder
MERIS	-	Medium Resolution Imaging Spectrometer
MPA	-	Marine Park Area
MRU	-	Motion Reference Unit
NB	-	Naive Bayes
OBIA	-	Object-Based Image Analysis
OLI	-	Operational Land Imager
RF	-	Random Forest
RMP	-	Redang Marine Park
ROV	-	Remotely Operated Underwater Vehicle
SAVEWS	-	Submerged Aquatic Vegetation Early Warning System

SDM	-	Species Distribution Modeling
SSS	-	Side Scan Sonar
STAGC	-	Seagrass Total Above-ground Carbon
SVM	-	Support Vector Machine
TM	-	Thematic Mapper

LIST OF SYMBOLS

θ	-	Theta
β	-	Beta
dz	-	Total differential of z
dy	-	Total differential of y
dx	-	Total differential of x

LIST OF APPENDICES

seagrass habitat suitability model based on seascape features.

CHAPTER 1

INTRODUCTION

1.1 Background of the Research

In marine botany, seagrass is classified as a submerged marine flowering plant (Green et al., 2003; Short et al., 2007; Fortes, 2018). Ecologically, seagrass ecosystems provide essential functions that influence the physical, chemical, and biological environment in coastal ecosystems (Hemminga and Duarte, 2000; Barbier et al., 2011; Campagne et al., 2014; Nordlund et al., 2016; Scott et al., 2018; Hearne et al., 2019). Seagrass is normally found in most tropical and temperate regions (Den Hartog, 1970; Short et al., 2007) distributed in shallow coastal water areas (Green et al., 2003; Short et al., 2007) and estuarine ecosystems (Heck and Orth, 1980). The seagrass distribution and species vary according to the condition of the surrounding coastal environment. In the tropical Indo-Pacific, Southeast Asia has the largest concentration of high seagrass diversity (Short et al., 2007). Malaysia's coast is divided into two, i.e., Peninsular Malaysia and East Malaysia (i.e., Sabah and Sarawak), which are relatively extensive with different environmental conditions. Partially, Malaysia's coastal water is covered by seagrass meadows (Ogawa et al., 2011) widely distributed throughout subtidal and intertidal areas, semi-enclosed lagoons, and shoals along the coastline of Malaysia (Zakaria and Bujang, 2013; Ondiviela et al., 2014). On the east coast of Peninsular Malaysia, seagrass is normally found on offshore islands (e.g., Sibu Island, Tinggi Island, and Redang Island) and colonizes the outer coastal area between the coral and semi-open seas (Bujang et al., 2006). Meanwhile, on the west coast of Peninsular Malaysia, seagrass is normally found in open-sea coastal waters (Bujang, 2012). In East Malaysia, most seagrass beds on the western coast of Sabah can be found near shores (e.g., Bak-Bak, Tanjung Mengayau, Sepangar Bay, and Gaya islands), south-eastern coast, and offshore islands (e.g., Sipadan, Maganting, Tabawan, and Bohey Dulang) (Bujang et al., 2006). Sub-tidal seagrasses also grow on coral rubble in the four isolated offshore islands of Maganting, Tabawan, Bohey Dulang, and Sipadan

(Ismail, 1993; Bujang et al., 1999; Bujang et al., 2000; Bujang et al., 2006). Meanwhile, in Sarawak, seagrass is normally found along the coastline of river estuaries, such as Bintulu river (Den Hartog, 1970; Bujang, 2012) and Lawas river estuary (Bujang et al., 2006; Al-Asif et al., 2020; Ismail et al., 2020).

Seagrass ecosystems are one of coastal ecosystem in Malaysia (Mazarrasa et al., 2018; Hossain and Hashim, 2019). They provide substantial diverse benefits to marine ecosystems, such as contributors that control the diversity of various fauna, including vertebrates and invertebrates (Sasekumar et al., 1989; Arshad et al., 2008). For example, seagrass ecosystems play a vital role as food sources and shelter for diverse animal communities (Peralta and Yusoff, 2015; Hossain et al., 2016; François et al., 2018; Hearne et al., 2019; Unsworth et al., 2019b) such as dugongs, seahorses, and turtles (Bujang et al., 2006; Unsworth et al., 2019b; de los Santos et al., 2020; Johan et al., 2020). Furthermore, they also function as a habitat for small marine fauna such as prawns, small fishes, and crabs (Jackson et al., 2001; Gillanders et al., 2003; Heck Jr et al., 2003; Bujang et al., 2006; Quang Le et al., 2020). They also provide nursery grounds for several different types of fish (Criales et al., 2011; Criales et al., 2015). In addition, seagrass ecosystems also serve as a source of food for seasonal migratory birds such as the little egret through ground-feeding (Bujang et al., 2006).

Seagrass ecosystems also provide many critical ecological functions that support the well-being and livelihoods of local communities (Cullen-Unsworth et al., 2014; Nordlund et al., 2016). They produce and export organic carbon and regulate carbon dioxide through photosynthesis. They play an important role as carbon sinks, absorbing carbon dioxide released from the air, animals, coral reefs, and plants; thus, reducing carbon dioxide (Short et al., 2011; Lavery et al., 2013; Ricart et al., 2017; Rozaimi et al., 2017; Mazarrasa et al., 2018). They are also known for their capacity to stabilize sediments and reduce coastal erosion (Lamb et al., 2017; Oreska et al., 2017; Gumusay et al., 2019) by trapping sediment flying through them (Verweij et al., 2008). Simultaneously, this process will control the nutrient cycle and turbidity of the surrounding water (Jeudy de Grissac and Boudouresque, 1985; Komatsu and Yamano, 2000; Hamana and Komatsu, 2016).

Nowadays, seagrass habitats are facing various pressures from both natural and anthropogenic threats (Waycott et al., 2009; Short et al., 2011), causing the number of seagrass habitats to decrease yearly in many regions (Boudouresque et al., 2009; Waycott et al., 2009; De'ath et al., 2012; Ponti et al., 2014; Hossain et al., 2015c). In Malaysia, many seagrass habitats continuously face serious threats from natural causes (e.g., erosion, flooding, surface water temperature, and turbidity) and are also impacted by anthropogenic activities (e.g., overfishing, dynamite fishing, sand mining, dredging, settlement, marine development, and tourism activities (Bujang et al., 2006; Boudouresque et al., 2009; Brown et al., 2011a; Short et al., 2011; Bujang et al., 2016) that cause significant degradation and possible habitat loss. For instance, anthropogenic activities such as port development and land reclamation have caused large areas of seagrass habitats to be reduced, especially meadows in the Sungai Pulai Estuary, Johor (Bujang and Zakaria, 2003; Bujang et al., 2006). Sand mining, filling, and land reclamation are marine activities that have an immediate and significant impact on the marine environment and its resources. Meanwhile, heavy loads of suspended sediments have resulted from land reclamation, which frequently deposits a coating of silt several centimeters thick over seagrass and benthic organisms (Bujang et al., 2016). Similarly, dynamite fishing and marine development significantly produced heavy loads of suspended sediments, which reduced the subsurface light intensity, causing the seagrass environment on Gaya Island in Sabah to deteriorate (Freeman et al., 2008). Seagrasses in Pengkalan Nangka in Kelantan, Paka in Terengganu, and Punang-Sari Lawas in Sarawak are degraded due to coastline changes (Hossain et al., 2015c). Thus, the preservation and conservation of seagrass habitats are important (Sagawa et al., 2010; Unsworth et al., 2019a) to manage and monitor seagrass habitats (Hamad et al., 2022) and it has become necessary to sustain and prevent the loss of their habitats (Cullen-Unsworth and Unsworth, 2016; Unsworth et al., 2019a). For this reason, an effective approach is required to manage and monitor the seagrass habitats in Malaysia.

Related bodies require detailed information to describe the geographic location and spatial distribution of seagrass to manage and monitor seagrass habitats. A seagrass habitat suitability map is an important tool to extract detailed information about seagrass habitat distribution. Having detailed information about seagrass habitat distribution would increase the efficiency of managing and monitoring the seagrass habitat distribution. Furthermore, detailed information about seagrass distribution will aid scientists in understanding seagrass. Full understanding through mapping allows the appropriate monitoring and management of the seagrass resources. Thus, seagrass habitat distribution maps are necessary tools for managing, protecting, and monitoring seagrass resources.

In the last few decades, underwater acoustic survey techniques have been used by scientists to determine the relationship between seafloor features and marine habitats (Brown and Blondel, 2009; Che Hasan et al., 2011; Che Hasan et al., 2014; Li et al., 2017; Janowski et al., 2018; Schimel et al., 2018). One of the acoustic techniques used to map the seafloor is the multibeam echosounder (MBES) sonar system. MBES is an effective acoustic technique due to the availability of simultaneous measurement of geo-located backscatter data with bathymetry data (Wright and Heyman, 2008; Brown and Blondel, 2009). Additionally, MBES provides full-coverage mapping with high-spatial resolution datasets and has been used to produce marine habitat suitability maps for fishes (Monk et al., 2010; Monk et al., 2011), corals (Rengstorf et al., 2012; Ross and Howell, 2012; Rengstorf et al., 2014; Miyamoto et al., 2017; Rowden et al., 2017), starfishes and crinoids (Rowden et al., 2017), seagrasses (Bakirman and Gumusay, 2020), and kelps (Bajjouk et al., 2015). The availability of the MBES dataset (i.e., bathymetry and backscatter data) has been previously used to characterize seafloor topography and sediment composition that influence the distribution of marine habitats (Kostylev et al., 2001; Ierodiaconou et al., 2007; Holmes et al., 2008; Rein et al., 2011; Che Hasan et al., 2012; Micallef et al., 2012; Costa and Battista, 2013; Rattray et al., 2015; Dunlop et al., 2018; Ierodiaconou et al., 2018).

Bathymetry data only provide information on bathymetric depth while multiple terrain analysis can be used to measure seafloor complexity and produce bathymetric predictors (e.g., aspect, slope, eastness, northness, and rugosity). These data have been demonstrated in previous studies, revealing the relationship between seafloor characteristics and marine habitats (Lundblad et al., 2006; Verfaillie et al., 2007; Wilson et al., 2007; Monk et al., 2010; Anderson et al., 2016b; Subarno et al., 2016; Rowden et al., 2017; Boswarva et al., 2018; Haggarty and Yamanaka, 2018; Ierodiaconou et al., 2018), especially seagrass habitat (Chefaoui et al., 2016;

Tyllianakis et al., 2019). Meanwhile, characterization of backscatter data could also distinguish the seafloor covered by various composited sediments (Blondel and Sichi, 2009; Diesing et al., 2014; Biondo and Bartholomä, 2017).

In mapping marine habitats, choosing the right spatial resolution dataset is crucial (Brown et al., 2011a; Lecours et al., 2015; Lecours et al., 2017b). Maps with detailed information produced using high-spatial resolution data are valuable for thorough marine spatial management and planning (Brown et al., 2011a). In contrast, a biogeographic study that required measuring and monitoring patterns of species richness across vast regional extents used a low-spatial resolution dataset (Chiarucci and Scheiner, 2011). Previous studies by Kinlan et al. (2020) and Nezer et al. (2017) have demonstrated habitat suitability modeling (HSM) using several spatial resolution datasets. Research into an appropriate spatial resolution in habitat suitability studies is still restricted. Choosing the right spatial resolution, on the other hand, is expected to produce an accurate habitat suitability model (Olivero et al., 2016), especially for seagrass habitats. Theoretically, predicted habitats may also react to predictors derived using various window sizes analysis (Freemark and Merriam, 1986; Monk et al., 2011). Bathymetric and backscatter predictors are normally measured using specific window size analysis (Ierodiaconou et al., 2018; Porskamp et al., 2018). Furthermore, no research on the impact of various window sizes analysis on seagrass HSM has been conducted. As a result, a thorough investigation into the ideal window size analysis for seagrass HSM is required.

Various machine learning algorithms are used to utilize a set of bathymetric and backscatter predictors, and ground-truth data to produce accurate habitat suitability models (Lauria et al., 2015; Porskamp et al., 2018; Cui et al., 2021; Viala et al., 2021) and classification maps (Calvert et al., 2014; Ariasari et al., 2019; Zhafarina and Wicaksono, 2019; Bayyana et al., 2020; Upadhyay et al., 2020; Benmokhtar et al., 2021). HSM is a frequently used modeling technique for forecasting the spatial distribution of species, and it has been applied in marine research (Monk et al., 2010; Monk et al., 2011; Zapata-Ramirez et al., 2014; Miyamoto et al., 2017; Rowden et al., 2017; Porskamp et al., 2018; Bowden et al., 2021). HSM analyzes the spatial distribution of a species and the response curve concerning environmental conditions by quantifying the relationship between ground-truth data and predictors (Franklin, 2010; Coll et al., 2019; Droz et al., 2019; Amiri et al., 2020). Meanwhile, supervised classification is a frequent image classification technique for seafloor characterization, demonstrated by several marine habitat studies (Brown and Blondel, 2009; Wang et al., 2018), especially for seagrass habitat (Micallef et al., 2012; Rende et al., 2020; Viala et al., 2021). The image classification technique categorizes all pixels in all MBES predictors to obtain seafloor features. HSM and image classification techniques will provide an in-depth measurement of seagrass habitat distribution. In addition, the results from previous studies demonstrated that HSM (Monk et al., 2010; Monk et al., 2011; Bakirman and Gumusay, 2020) and image classification techniques (Brown and Blondel, 2009; Viala et al., 2021) provide reliable and accurate marine habitat maps.

To date, there is no existing study that discusses the application of MBES dataset, associated predictors, and machine learning algorithms to produce seagrass habitat map in the Redang archipelago. Although several studies have demonstrated the use of MBES dataset and associated predictors in seagrass applications (Lurton et al., 2015; Lucieer et al., 2018; Bakirman and Gumusay, 2020), there are criteria that need to be considered to produce seagrass habitats using MBES dataset and machine learning algorithms, especially for seagrass habitats in Malaysia's coastal area. This study effort is an initial step to implement seagrass habitat mapping in Malaysia and proving these methods in the study of seagrass habitat mapping to be considered as reliable methods.

1.2 Problem Statement

Anthropogenic impacts in the world's oceans have led to the deterioration or destruction of seagrass habitats. The loss of seagrass habitats in oceans worldwide threatened the coastal ecosystems (Jordà et al., 2012; Fernandes et al., 2019; Prasad et al., 2019) and led to imbalanced ecosystems due to the structural and functional roles of seagrass habitats (Waycott et al., 2009; Pu and Bell, 2017; Topouzelis et al., 2018). The spatial extent of seagrass habitats in the world's oceans has decreased by almost 29% since the beginning of the 20th century (Fourqurean et al., 2012; Tyllianakis et al., 2019). Parts of Malaysia's coastal areas had already lost seagrass habitats due to the impact of anthropogenic activities (Zakaria and Bujang, 2011; Hossain et al., 2015b; Hossain et al., 2015c). Therefore, the protection of seagrass habitats is essential to prevent a major reduction in seagrass habitat distribution in Malaysia's coastal areas. Hence, it is vital to have accurate information on the distribution of seagrass habitats as a prerequisite to manage them.

The interest in protecting and managing marine resources to be more sustainable has grown in the past decades. Marine Park Malaysia is an initiative to meet the demand for a more sustainable marine resource in Malaysia's coastal area. Information on marine resources, especially their spatial distribution, is still limited due to the lack of field study. Related bodies (e.g., state government and marine park managers) are put in a difficult situation due to the lack of data that provided vital information. The initial strategy of extracting vital information from marine park areas could minimize risks in managing marine resources.

Previously, physical survey techniques (i.e., scuba dive, transect, underwater photo and video, and tow video) have been used to map seagrass habitats (Holmes et al., 2007; Ooi et al., 2011). Even though these techniques provide accurate information about seagrass habitat, they offer localized mapping purposes and are only efficient for small-scale mapping. Meanwhile, other mapping techniques like remote sensing (i.e., satellite and aerial imageries) and a combination of image classification techniques are widely used in mapping seagrass (Kendrick et al., 2002; Costello and Kenworthy, 2011; Hossain et al., 2016; Pu and Bell, 2017; Hossain and Hashim, 2019). Although these techniques have been used for seagrass detection and mapping, they are only suitable to be implemented during optimal environmental conditions, including high clarity water (McKenzie et al., 2001; Uhrin and Townsend, 2016) and low tide conditions (Roelfsema et al., 2013; Hossain et al., 2016). Furthermore, these techniques are preferable for shallow coastal water because deeper water depth does not allow high light penetration to the seafloor (Van der Meer and De Jong, 2001; Baumstark et al., 2016), leading to the inefficiency of spectral resolution to detect seagrass habitats.

Recently, most studies focusing on single beam echosounder, multibeam echosounder, and side-scan sonar that have been extensively used for high-spatial resolution seagrass habitat mapping (Ferretti et al., 2017; Pergent et al., 2017; Ierodiaconou et al., 2018; Prampolini et al., 2018; Tyllianakis et al., 2019), which are capable of solving the problems faced by physical survey and remote sensing technique. Acoustic techniques, particularly bathymetry and backscatter data, are effectively used to map seagrass habitats in relatively turbid waters (Hossain et al., 2015a). MBES has become a choice to map seagrass habitats due to its ability that simultaneously collects co-located full bottom coverage of bathymetry and backscatter data. Both data could describe seabed features, particularly seafloor topography and sediment composition. These features are generally known to influence benthic community structure and ecological process at various spatial scales (Bourget et al., 1994; Snelgrove and Butman, 1995; Cusson and Bourget, 1997; Guichard and Bourget, 1998).

In recent years, bathymetric and backscatter predictors and ground-truth data are combined (Ierodiaconou et al., 2007; Micallef et al., 2012; Lucieer et al., 2013; Diesing et al., 2016) and statistically analyzed using machine learning algorithms as an effort to produce accurate marine habitat suitability models (Lauria et al., 2015; Porskamp et al., 2018; Cui et al., 2021; Viala et al., 2021) and marine classification maps (Lucieer and Lamarche, 2011; Micallef et al., 2012; Calvert et al., 2014; Ierodiaconou et al., 2018; Ariasari et al., 2019; Zhafarina and Wicaksono, 2019; Bayyana et al., 2020; Upadhyay et al., 2020; Benmokhtar et al., 2021)

Although many predictors can be extracted from the MBES dataset to aid in producing marine habitat maps, suitable bathymetric and backscatter predictors to map seagrass habitats are not yet discovered, and the mapping framework has never been developed for seagrass habitat, especially in Malaysia's coastal area. Furthermore, existing processing parameters of the MBES predictor, such as spatial resolution and window size analysis to enhance the detection of seafloor topography features and sediment compositions, are still insufficient to obtain a suitable predictor that mimics the actual seagrass habitat. It is impossible to achieve an accurate seagrass habitat map without an initial assessment of the suitable processing parameters that lead to the characterization of seafloor topography and sediment composition to detect seagrass habitat features. Besides, using a single machine learning algorithm such as maximum entropy (MaxEnt) is insufficient, especially when seagrass presence-only occurrence data produce a seagrass habitat suitability model. Although MaxEnt is a high-performance machine learning algorithm to model habitat suitability, it is still inadequate to represent the overall predicted seagrass habitat as it does not use the seagrass absence occurrence data, which are important. Hence, for better modeling of suitable seagrass habitats, various machine learning algorithms that use presence-absence occurrence data should be referred to in achieving the desired seagrass habitat map. Unfortunately, these advanced mapping techniques are still poorly understood in applying seagrass habitat mapping in Malaysia. Moreover, SHSM illustrated only the habitat suitability index of seagrass habitats and was regarded as one of the limiting factors in this method to distinguish between the most suitable seagrass habitat and other features (e.g., coral and sand). Thus, the integrated assessment of SHSM is very limited, and this technique lacks vital information. The integration of SHSM and seascape features information from the seafloor classification map might aid in producing a reliably predicted seagrass habitat map and efficiently mapping seagrass habitat distribution.

1.3 Research Questions

This research addresses the gaps that have been identified from previous studies. The analysis of the gaps shaped a few fundamental research questions:

(a) Do different MBES predictors generate different contributions when producing seagrass habitat suitability models?

(b) Do different MBES processing parameters (i.e., spatial resolutions and window sizes analysis) affect the seagrass habitat suitability models?

(c) Do different machine learning algorithms affect the performance of seagrass habitat suitability models?

(d) Does the integration between seagrass habitat suitability models and classification maps generate different results? Can we improve the seagrass habitat suitability model by integrating other information such as sediment and substrate types?

1.4 Research Objectives

This research aims at producing a seagrass habitat distribution map using habitat suitability modeling and image classification approaches within the Redang archipelago. The following objectives have been identified to accomplish the aim of this research:

(a) To investigate the contribution of different types of predictors derived from the MBES data for the seagrass habitat suitability model.

(b) To determine the effect of different MBES processing parameters (spatial resolutions and window sizes analysis) that are commonly used with MBES data (predictor) in producing a seagrass habitat suitability model.

(c) To evaluate the performance of different machine learning algorithms when using MBES predictors in producing a seagrass habitat suitability model.

(d) To propose an improvement of the seagrass habitat prediction map by integrating information from habitat suitability and marine habitat classification maps.

1.5 Scope of the Research

This research analyzes the role of underwater acoustic technology, a swath MBES system used together with ground-truth data, machine learning algorithms, image classification techniques, and geographic information system (GIS) approaches to map the seagrass habitat distribution in the Redang archipelago. The scope of the research is restricted to the selected MBES datasets, specifically bathymetry and backscatter data, and will not involve the water column data. Further, this research also involves analysis of bathymetry and backscatter data using different MBES processing parameters (i.e., spatial resolutions and window sizes analysis) to depict the complex topographical features and sediment composition within the coastal water of the Redang archipelago. The scope of the study is restricted to two selected spatial resolutions, specifically 1 and 50 m, and limited to three window sizes analysis, specifically 3 × 3, 9 × 9, and 21 × 21 pixels.

For the seagrass species, this research is restricted to obtain information on seagrass species in coastal water within the Redang archipelago, specifically *Halophila decipiens*, *Halophila minor*, and *Halodule pinifolia*, and does not involve all species inhabited in the coastal water of Malaysia. This research also analyzes the role of ground-truthing survey to develop and validate the seagrass habitat map. This research is restricted to obtain ground-truth data by using underwater imagery sampling and will not involve scuba diving. The occurrence of seagrass, their species, and seafloor features are only determined from underwater imagery samples.

This research applied machine learning to develop (1) seagrass habitat suitability models and (2) a seafloor classification map. This research used three machine learning algorithms, including maximum entropy (MaxEnt), random forest (RF), and support vector machine (SVM) to produce SHSM. Only image classification using RF was carried out to produce a seafloor classification map. These multiple machine learning algorithms must be assessed for precise prediction and classification, specifically MaxEnt, RF, and SVM. The purpose of SHSM is to depict the habitat suitability index of seagrass habitat. Meanwhile, a seafloor classification map will be used to illustrate the seascape features in the study area.

1.6 Significance of the Research

Over recent decades, the interest in marine habitat mapping has grown significantly. Marine habitats, such as seagrass habitats, are important to be mapped because they play an important role in marine ecology. Seagrass habitat mapping using acoustic technologies is one of the mapping techniques to obtain a high-spatial resolution and accurate final output map. The research of seagrass habitat mapping using acoustic technologies and machine learning algorithms can be a mapping paradigm that could provide vital seafloor information and enhance decision-making to manage and monitor seagrass habitats.

The research goal is designed to investigate the application of acoustic technologies and machine learning algorithms to improve existing mapping techniques (e.g., remote sensing and in situ survey) to obtain reliable information. The mapping technique using MBES datasets and machine learning algorithms has never been implemented in Malaysia, especially for seagrass habitats. With the capacity of the MBES acoustic system, information on the distribution of seagrass habitats may be considered with greater accuracy than other mapping techniques (i.e., in situ survey and remote sensing). Directly, it is beneficial as a potential method for assisting and supporting the government institutions, authorities, agencies, and non-governmental organizations in strengthening the system of the marine park area in Malaysia's coastal area and implementing conservation and preservation of marine resources.

Generally, the seagrass habitat suitability index (SHSI) measures seagrass habitat suitability status. The foundation of SHSI is solely based on a habitat suitability model that provides the basis for the spatial distribution of the seagrass habitat in the study area. Meanwhile, the seafloor classification map is used as a “present seafloor cover” that classifies the Redang Marine Park (RMP) seafloor area. Unfortunately, the SHSI values cannot yield enough information on the locality of seagrass habitat in the RMP area. Therefore, this approach is not strong enough as the main tool to assess the status of seagrass habitat distribution because the SHSI could not clearly define and justify seagrass habitat on a specific seafloor cover, whether it is a suitable seafloor cover for seagrass habitat or vice versa. Therefore, integrating SHSM and seafloor classification map is necessary to complete the spatial information of seagrass habitat distribution. The integration between the SHSM and the seafloor classification map gives a broader perspective to describe the state of the seagrass resource in the RMP area.

The stakeholder who will directly benefit from this research is the Department of Fishery (DoF), the lead agency in conserving and managing sustainable marine resources, especially the RMP area. One of the major objectives of establishing RMP is to conserve and protect the biological diversity of the marine community and its habitats, especially the seagrass habitats. Although the DoF has implemented geographic information systems, such as the Marine Park Management Information System (MPMIS) and the global positioning system (GPS) for spatial features, those implementations are still unclear to produce detailed spatial information of seagrass habitat distribution. Due to the rapid growth of acoustic technologies and advanced data processing, it is time to revise the whole technique of managing and monitoring seagrass habitats. Hence, implementing the latest technology, such as the MBES and machine learning algorithms, can give many benefits in managing and monitoring marine biodiversity. Indeed, the positive output from this research can be used by the DoF as an effective technique to assess the spatial information of seagrass habitats. These findings provide the benefit of designing, coordinating, and implementing long-term monitoring programs of seagrass resources in the RMP area. The methods developed can also be widely used in the valuation of other marine habitats, such as coral reefs, fishes, and marine plants, because they involve a single measurement (i.e., MBES survey) but different targeted ground-truth data. The methods developed also provide comprehensive information related to the priority sites of marine habitats. The developed methods will also facilitate the monitoring work of marine resources in the RMP area and can be easily understood by general users.

1.7 Organization of the Thesis

This section describes the organization of the thesis, which starts from Chapter 1 to Chapter 5 (Figure 1.1). The first chapter is the introduction section. This chapter presents the background of the research, problem statement, as well as research questions and objectives to provide an appropriate research design to conduct the research. This chapter also discusses the scope of the research, defining the boundaries within which this research will be performed. This chapter also discusses the significance of this research to justify its importance.

The second chapter is the literature review section. This chapter presents the definition of marine biodiversity in Malaysia, seagrass, as well as current seagrass mapping techniques to obtain a seagrass habitat distribution map of coastal waters, including ground-truth survey, remote sensing, and underwater acoustic systems. This chapter also discusses current applications in seagrass habitat mapping by using the MBES system and the MBES dataset, including bathymetry and backscatter data. The section continues to discuss the MBES predictors used in the research and its processing parameters, including spatial resolution and window size analysis, to derive MBES predictors from bathymetric maps and backscatter mosaics. The next section of this chapter discusses the development of habitat suitability models and a classification map using machine learning algorithms. The summary of the literature review is discussed in the last section of the chapter.

The third chapter is the research methodology section. This chapter presents the materials and methods used to achieve the objectives of this research. The first section of this chapter discusses the introduction of this chapter and continues discussing the study area. The section continues to discuss the overall methodologies applied in the research. The next section of this chapter discusses the data acquisition used in the research, including the MBES survey, underwater imagery sampling, and secondary data collection. The section continues to discuss the data processing for bathymetry, backscatter, and ground-truth data. The next section of this chapter discusses the data analysis applied to produce a seagrass habitat suitability model and classification map, starting with data preparation, including MBES predictors (e.g., bathymetric and backscatter predictors), seagrass occurrence data, seascape feature data, and correlation of MBES predictors. The section continues to focus on the methodologies applied in HSM using three machine learning algorithms (e.g., MaxEnt, RF, and SVM). These machine learning algorithms were used to produce seagrass habitat suitability models and image classification was performed by using the RF machine learning algorithm to produce a classification map. The next section of this chapter discusses the integration of the seagrass habitat suitability model and the classification map to produce a seagrass seascape map. The last part of this chapter focuses on the summary of the chapter.

The fourth chapter presents the results and discussion of the research. The first section discusses the introduction of the chapter. The next part of this section presents the results of the bathymetric map, backscatter mosaic, MBES predictors, seagrass occurrence map, seascape feature map, and predictor selection. In addition, the results of seagrass habitat suitability models and a classification map using machine learning algorithms are also provided. The results of the integration between the seagrass habitat suitability model and the classification map are presented. The last part of this chapter presents the overall discussion of the presented results and the chapter summary.

The final chapter provides the research outcomes based on the research objectives. The next part of this chapter presents the research that creates new knowledge by implementing this extensive and innovative research. The limitations of the research are discussed in this chapter. Finally, this chapter discusses the recommendations for future research.

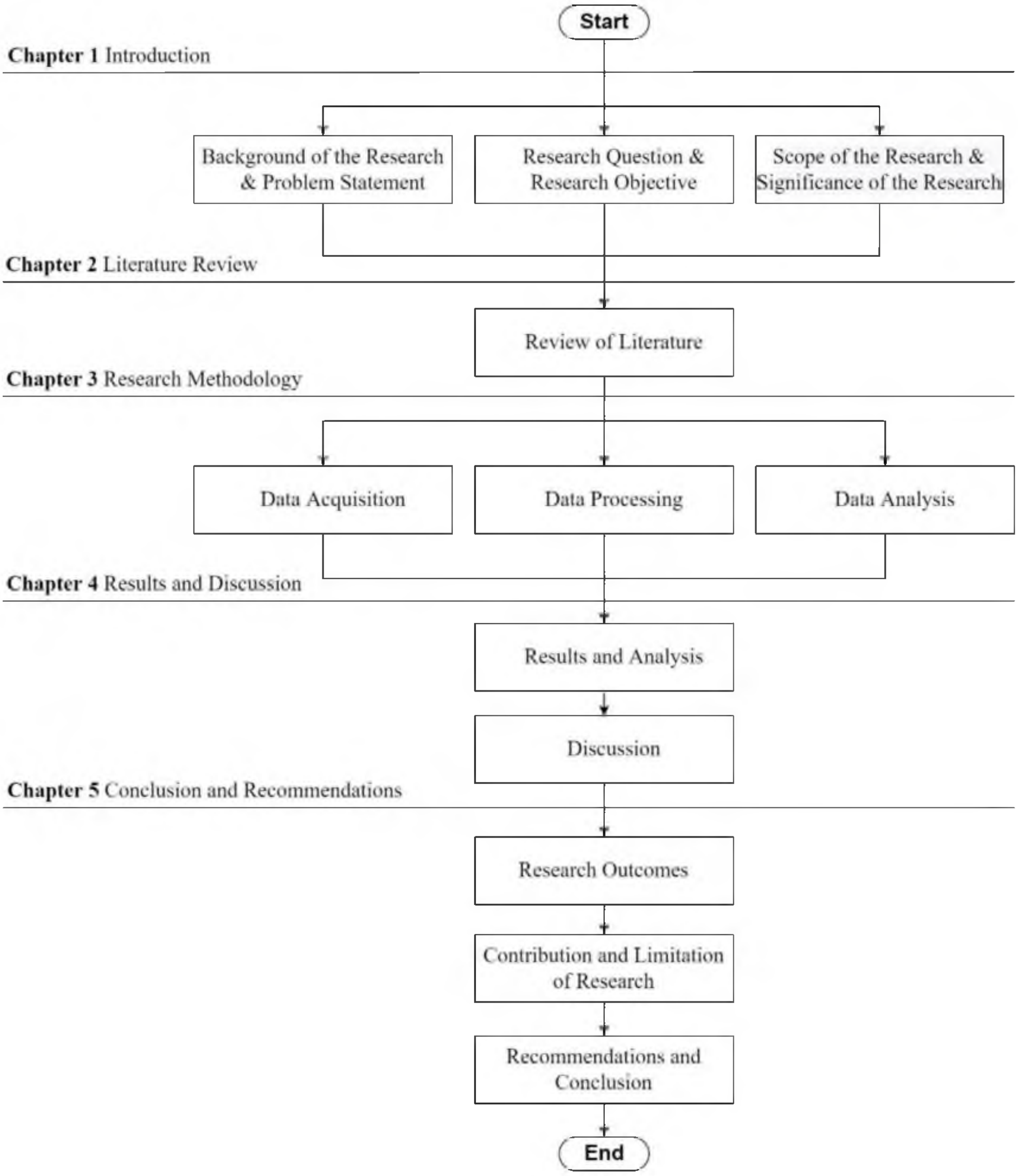

Figure 1.1 Flowchart showing the general research methodology of research.

REFERENCES

Ahmed, N., Atzberger, C. & Zewdie, W. (2021) Species Distribution Modelling performance and its implication for Sentinel-2-based prediction of invasive Prosopis juliflora in lower Awash River basin, Ethiopia. *Ecological Processes,* 10, 18.

Al-Asif, A., Hamli, H., Kamal, A. H., Idris, M. H., Gerusu, G., Ismail, J. & Karim, N. (2020) Benthic macrofaunal assemblage in seagrass-mangrove complex and adjacent ecosystems of Punang-Sari Estuary, Lawas, Sarawak, Malaysia. *Biodiversitas Journal of Biological Diversity,* 21, 4606-4615.

Albani, M., Klinkenberg, B., Andison, D. W. & Kimmins, J. P. (2004) The choice of window size in approximating topographic surfaces from Digital Elevation Models. *International Journal of Geographical Information Science,* 18, 577-593.

Alonso Aller, E., Eklöf, J. S., Gullström, M., Kloiber, U., Linderholm, H. W. & Nordlund, L. M. (2019) Temporal variability of a protected multispecific tropical seagrass meadow in response to environmental change. *Environmental Monitoring and Assessment,* 191, 774.

Alsaffar, Z., Pearman, J. K., Cúrdia, J., Ellis, J., Calleja, M. L., Ruiz-Compean, P., Roth, F., Villalobos, R., Jones, B. H., Morán, X. a. G. & Carvalho, S. (2020) The role of seagrass vegetation and local environmental conditions in shaping benthic bacterial and macroinvertebrate communities in a tropical coastal lagoon. *Scientific Reports,* 10, 13550.

Amiri, M., Tarkesh, M., Jafari, R. & Jetschke, G. (2020) Bioclimatic variables from precipitation and temperature records vs. remote sensing-based bioclimatic variables: Which side can perform better in species distribution modeling? *Ecological Informatics,* 57, 101060.

Anderson, O. F., Guinotte, J. M., Rowden, A. A., Clark, M. R., Mormede, S., Davies, A. J. & Bowden, D. A. (2016a) Field validation of habitat suitability models for vulnerable marine ecosystems in the South Pacific Ocean: Implications for the use of broad-scale models in fisheries management. *Ocean & Coastal Management,* 120, 110-126.

Anderson, O. F., Guinotte, J. M., Rowden, A. A., Tracey, D. M., Mackay, K. A. & Clark, M. R. (2016b) Habitat suitability models for predicting the occurrence of vulnerable marine ecosystems in the seas around New Zealand. *Deep Sea Research Part I: Oceanographic Research Papers,* 115, 265-292.

Aoki, L. R., Mcglathery, K. J., Wiberg, P. L. & Al-Haj, A. (2020) Depth Affects Seagrass Restoration Success and Resilience to Marine Heat Wave Disturbance. *Estuaries and Coasts,* 43, 316-328.

Ariasari, A., Hartono, Wicaksono, P. & Kanniah, K. D. (2019) Random Forest Classification and Regression for Seagrass Mapping using PlanetScope Image in Labuan Bajo, East Nusa Tenggara. *The 6th International Symposium on LAPAN-IPB Satellite*. 24 December 2019. Bogor, Indonesia.

Arshad, A., Jimmy, A., Nurul Amin, S., Zakaria, M. H. & Bujang, J. S. (2008) Length–weight and length–length relationships of five fish species collected from seagrass beds of the Sungai Pulai estuary, Peninsular Malaysia. *Journal of Applied Ichthyology,* 24, 328-329.

Asaad, I., Lundquist, C. J., Erdmann, M. V. & Costello, M. J. (2018) Delineating priority areas for marine biodiversity conservation in the Coral Triangle. *Biological Conservation,* 222, 198-211.

Assali, P., Grussenmeyer, P., Villemin, T., Pollet, N. & Viguier, F. (2014) Surveying and modeling of rock discontinuities by terrestrial laser scanning and photogrammetry: Semi-automatic approaches for linear outcrop inspection. *Journal of Structural Geology,* 66, 102-114.

Azman, B., Ramlan, O., Wan-Lotfi, W., Zaidi, C. & Othman, B. (2008) Seagrass biodiversity of Pulau Tinggi, Johor. Malaysia marine ecosystem: The studies of Johor Darul Takzim east coast. Research and Information Series of Malaysian Coasts, Malaysia, 1-176.

Bajjouk, T., Rochette, S., Laurans, M., Ehrhold, A., Hamdi, A. & Le Niliot, P. (2015) Multi-approach mapping to help spatial planning and management of the kelp species L. digitata and L. hyperborea: Case study of the Molène Archipelago, Brittany. *Journal of Sea Research,* 100, 2-21.

Bakirman, T. & Gumusay, M. U. (2020) A novel GIS-MCDA-based spatial habitat suitability model for Posidonia oceanica in the Mediterranean. *Environmental Monitoring and Assessment,* 192**,** 231.

Barbier, E. B., Hacker, S. D., Kennedy, C., Koch, E. W., Stier, A. C. & Silliman, B. R. (2011) The value of estuarine and coastal ecosystem services. *Ecological monographs,* 81**,** 169-193.

Baumstark, R., Duffey, R. & Pu, R. (2016) Mapping seagrass and colonized hard bottom in Springs Coast, Florida using WorldView-2 satellite imagery. *Estuarine, Coastal and Shelf Science,* 181**,** 83-92.

Bayyana, S., Pawar, S., Gole, S., Dudhat, S., Pande, A., Mitra, D., Johnson, J. A. & Sivakumar, K. (2020) Detection and mapping of seagrass meadows at Ritchie's archipelago using Sentinel 2A satellite imagery. *CURRENT SCIENCE,* 118**,** 1275-1282.

Beccari, O. (1904) Wanderings in the great forests of Borneo; travels and researches of a naturalist in Sarawak, London, Constable.

Bedulli, C., Lavery, P. S., Harvey, M., Duarte, C. M. & Serrano, O. (2020) Contribution of Seagrass Blue Carbon Toward Carbon Neutral Policies in a Touristic and Environmentally-Friendly Island. *Frontiers in Marine Science,* 7.

Bekkby, T., Rinde, E., Erikstad, L., Bakkestuen, V., Longva, O., Christensen, O., Isæus, M. & Isachsen, P. E. (2008) Spatial probability modelling of eelgrass (Zostera marina) distribution on the west coast of Norway. *ICES Journal of Marine Science,* 65**,** 1093-1101.

Benmokhtar, S., Robin, M., Maanan, M. & Bazairi, H. (2021) Mapping and Quantification of the Dwarf Eelgrass Zostera noltei Using a Random Forest Algorithm on a SPOT 7 Satellite Image. *ISPRS International Journal of Geo-Information,* 10.

Biondo, M. & Bartholomä, A. (2017) A multivariate analytical method to characterize sediment attributes from high-frequency acoustic backscatter and ground-truthing data (Jade Bay, German North Sea coast). *Continental Shelf Research,* 138**,** 65-80.

Biot, M. A. (1956) Theory of Propagation of Elastic Waves in a Fluid-Saturated Porous Solid. I. Low-Frequency Range. *The Journal of the Acoustical Society of America,* 28**,** 168-178.

Biot, M. A. (1962) Generalized Theory of Acoustic Propagation in Porous Dissipative Media. *The Journal of the Acoustical Society of America,* 34**,** 1254-1264.

Bittner, R., Roesler, E. & Barnes, M. (2020) Using species distribution models to guide seagrass management. *Estuarine, Coastal and Shelf Science,* 240**,** 106790.

Blaschke, T. (2010) Object based image analysis for remote sensing. *ISPRS Journal of Photogrammetry and Remote Sensing,* 65**,** 2-16.

Blaschke, T., Lang, S., Lorup, E., Strobl, J. & Zeil, P. (2000) Object-Oriented Image Processing in an Integrated GIS/Remote Sensing Environment and Perspectives for Environmental Applications. 2.

Blondeau-Patissier, D., Gower, J. F., Dekker, A. G., Phinn, S. R. & Brando, V. E. (2014) A review of ocean color remote sensing methods and statistical techniques for the detection, mapping and analysis of phytoplankton blooms in coastal and open oceans. *Progress in oceanography,* 123**,** 123-144.

Blondel, P., Prampolini, M. & Foglini, F. (2015) Acoustic textures and multibeam mapping of shallow marine habitats – Examples from Eastern Malta. *Proceedings of the Institute of Acoustics,* 37**,** 250-257.

Blondel, P. & Sichi, O. G. (2009) Textural analyses of multibeam sonar imagery from Stanton Banks, Northern Ireland continental shelf. *Applied Acoustics,* 70**,** 1288-1297.

Boswarva, K., Butters, A., Fox, C. J., Howe, J. A. & Narayanaswamy, B. (2018) Improving marine habitat mapping using high-resolution acoustic data; a predictive habitat map for the Firth of Lorn, Scotland. *Continental Shelf Research,* 168**,** 39-47.

Boudouresque, C. F., Bernard, G., Pergent, G., Shili, A. & Verlaque, M. (2009) Regression of Mediterranean seagrasses caused by natural processes and anthropogenic disturbances and stress: a critical review. *Botanica Marina,* 52**,** 395-418.

Bourget, E., Deguise, J. & Daigle, G. (1994) Scales of substratum heterogeneity, structural complexity, and the early establishment of a marine epibenthic community. *Journal of Experimental Marine Biology and Ecology,* 181, 31-51.

Bowden, D. A., Anderson, O. F., Rowden, A. A., Stephenson, F. & Clark, M. R. (2021) Assessing Habitat Suitability Models for the Deep Sea: Is Our Ability to Predict the Distributions of Seafloor Fauna Improving? *Frontiers in Marine Science,* 8.

Breiman, L. (2001) Random forests. *Machine learning,* 45, 5-32.

Breiman, L., Friedman, J. H., Olshen, R. A. & Stone, C. J. (2017) *Classification and regression trees*, Routledge.

Briscoe, D. K., Hiatt, S., Lewison, R. & Hines, E. (2014) Modeling habitat and bycatch risk for dugongs in Sabah, Malaysia. *Endangered Species Research,* 24, 237-247.

Brown, C. J. & Blondel, P. (2009) Developments in the application of multibeam sonar backscatter for seafloor habitat mapping. *Applied Acoustics,* 70, 1242-1247.

Brown, C. J., Hewer, A. J., Meadows, W. J., Limpenny, D. S., Cooper, K. M. & Rees, H. L. (2004) Mapping seabed biotopes at hastings shingle bank, eastern English Channel. Part 1. Assessment using sidescan sonar. *Journal of the Marine Biological Association of the United Kingdom,* 84, 481-488.

Brown, C. J., Smith, S. J., Lawton, P. & Anderson, J. T. (2011a) Benthic habitat mapping: A review of progress towards improved understanding of the spatial ecology of the seafloor using acoustic techniques. *Estuarine, Coastal and Shelf Science,* 92, 502-520.

Brown, C. J., Toddb, B. J., Kostylev, V. E. & Pickrill, R. A. (2011b) Image-based classification of multibeam sonar backscatter data for objective surficial sediment mapping of Georges Bank, Canada. *Continental Shelf Research,* 31, S110-S119.

Bujang, J. S. (1994) Status of seagrass resources in Malaysia. Proceedings of the Third Asean-Australian Symposium on Living Coastal Resources, 283-290.

Bujang, J. S. (2012) The marine angiosperms, seagrass. Dewan Taklimat, Universiti Putra Malaysia: Universiti Putra Malaysia Press.

Bujang, J. S., Ali, L., Zakaria, M. H. & Suliansa, M. S. (1997) *Halophila decipiens* (*Hydrocharitaceae*), a new seagrass record for Sabah. Sandakania.

Bujang, J. S., Arshad, A., Hishamuddin, O., Zakaria, M. H. & Misni, S. (1996) Seagrass and macroalgal communities of Sungai Pulai estuary, south-west Johore, Peninsular Malaysia. *Seagrass Biology: Scientific Discussion from an International Workshop, Rottnest Island, Western Australia.*

Bujang, J. S., Harah, Z. M., Pauzi, A. M. & Madhavan, S. (1999) Halodule species from Malaysia—distribution and morphological variation. *Aquatic botany,* 65**,** 33-45.

Bujang, J. S., Zakaria, M. & Arshad, A. B. (2006) Distribution and significance of seagrass ecosystems in Malaysia *Aquatic Ecosystem Health & Management,* 9**,** 203-214.

Bujang, J. S. & Zakaria, M. H. (2003) *The seagrasses of Malaysia,* University of California Press, Berkeley, USA.

Bujang, J. S., Zakaria, M. H., Fadzrullah, A. & Kamin, B. (2000) New observations on Halophila spinulosa (R. Br.) Aschers. *Neumayer, Malaysia. Biologia Marina Mediterranea,* 7**,** 75-78.

Bujang, J. S., Zakaria, M. H. & Short, F. (2016) Seagrass in Malaysia: Issues and Challenges Ahead. *The Wetland Book II: Distribution, description, and conservation,* 1**,** 1875-1883.

Bulthuis, D. A. (1987) Effects of temperature on photosynthesis and growth of seagrasses. *Aquatic Botany,* 27**,** 27-40.

Burkill, I. H. B. W. F. F. W. S. J. B. W. J. G. (1966) *A dictionary of the economic products of the Malay peninsula,* Kuala Lumpur, Malaysia, Published on behalf of the governments of Malaysia and Singapore by the Ministry of Agriculture and cooperatives.

Burrough, P. A., Mcdonnell, R., Mcdonnell, R. A. & Lloyd, C. D. (2015) *Principles of geographical information systems*, Oxford university press.

Calvert, J., Strong, J. A., Service, M., Mcgonigle, C. & Quinn, R. (2014) An evaluation of supervised and unsupervised classification techniques for marine benthic habitat mapping using multibeam echosounder data. *ICES Journal of Marine Science,* 72**,** 1498-1513.

Campagne, C. S., Salles, J. M., Boissery, P. & Deter, J. (2014) The seagrass Posidonia oceanica: Ecosystem services identification and economic evaluation of goods and benefits. *Marine Pollution Bulletin,* 97, 391-400.

Campbell, S. J., Kartawijaya, T. & Sabarini, E. K. (2011) Connectivity in reef fish assemblages between seagrass and coral reef habitats. *Aquatic biology,* 13, 65-77.

Carlson, D. F., Yarbro, L. A., Scolaro, S., Poniatowski, M., Mcgee-Absten, V. & Carlson, P. R. (2018) Sea surface temperatures and seagrass mortality in Florida Bay: Spatial and temporal patterns discerned from MODIS and AVHRR data. *Remote Sensing of Environment,* 208, 171-188.

Casas, E., Martín-García, L., Otero-Ferrer, F., Tuya, F., Haroun, R. & Arbelo, M. (2021) Economic mapping and assessment of Cymodocea nodosa meadows as nursery grounds for commercially important fish species. A case study in the Canary Islands. *One Ecosystem,* 6, e70919.

Chan, E. H. (2013) A report on the first 16 years of a long-term marine turtle conservation project in Malaysia. *Asian Journal of Conservation Biology,* 2, 129-135.

Chao, L., Zhipeng, J. & Yuanjie, Z. (2019) A novel reconstructed training-set SVM with roulette cooperative coevolution for financial time series classification. *Expert Systems with Applications,* 123, 283-298.

Che Hasan, R., Ierodiaconou, D. & Laurenson, L. (2012) Combining angular response classification and backscatter imagery segmentation for benthic biological habitat mapping. *Estuarine, Coastal and Shelf Science,* 97, 1-9.

Che Hasan, R., Ierodiaconou, D., Laurenson, L. & Schimel, A. (2014) Integrating multibeam backscatter angular response, mosaic and bathymetry data for benthic habitat mapping. *Plos one,* 9.

Che Hasan, R., Ierodiaconou, D., Rattray, A., Monk, J. & Laurenson, L. (2011) Applications of multibeam echosounder data and video observations for biological monitoring on the south east Australian continental shelf. *International Symposium and Exhibition on Geoinformation.* 1-16.

Chefaoui, R. M., Assis, J., Duarte, C. M. & Serrão, E. A. (2016) Large-Scale Prediction of Seagrass Distribution Integrating Landscape Metrics and

Environmental Factors: The Case of Cymodocea nodosa (Mediterranean–Atlantic). *Estuaries and Coasts,* 39**,** 123-137.

Chen, J. & Sasaki, J. (2021) Mapping of Subtidal and Intertidal Seagrass Meadows via Application of the Feature Pyramid Network to Unmanned Aerial Vehicle Orthophotos. *Remote Sensing,* 13**,** 4880.

Chiarucci, A. & Scheiner, S. (2011) Old and new challenges in using species diversity for assessing biodiversity. *Philosophical transactions of the Royal Society of London. Series B, Biological sciences,* 366**,** 2426-37.

Chilvers, B. L., Delean, S., Gales, N. J., Holley, D. K., Lawler, I. R., Marsh, H. & Preen, A. R. (2004) Diving behaviour of dugongs, Dugong dugon. *Journal of Experimental Marine Biology and Ecology,* 304**,** 203-224.

Christianen, M. J. A., Van Belzen, J., Herman, P. M. J., Van Katwijk, M. M., Lamers, L. P. M., Van Leent, P. J. M. & Bouma, T. J. (2013) Low-Canopy Seagrass Beds Still Provide Important Coastal Protection Services. *PLOS ONE,* 8**,** e62413.

Coll, M., Pennino, M. G., Steenbeek, J., Sole, J. & Bellido, J. M. (2019) Predicting marine species distributions: Complementarity of food-web and Bayesian hierarchical modelling approaches. *Ecological Modelling,* 405**,** 86-101.

Collier, C., Waycott, M. & Mckenzie, L. (2012) Light thresholds derived from seagrass loss in the coastal zone of the northern Great Barrier Reef, Australia. *Ecological Indicators,* 23**,** 211-219.

Collier, C. J., Uthicke, S. & Waycott, M. (2011) Thermal tolerance of two seagrass species at contrasting light levels: implications for future distribution in the Great Barrier Reef. *Limnology and Oceanography,* 56**,** 2200-2210.

Collier, J. S. & Brown, C. J. (2005) Correlation of sidescan backscatter with grain size distribution of surficial seabed sediments. *Marine Geology,* 214**,** 431-449.

Connor, D. W., Allen, J. H., Golding, N., Howell, K. L., Lieberknecht, L. M., Northen, K. O. & Reker, J. B. (2004) The Marine Habitat Classification for Britain and Ireland Version 04.05 *Joint Nature Conservation Committee (JNCC), Peterborough***,** 19.

Costa, B. M. & Battista, T. A. (2013) The semi-automated classification of acoustic imagery for characterizing coral reef ecosystems. *International Journal of Remote Sensing,* 34, 6389-6422.

Costello, C. T. & Kenworthy, W. J. (2011) Twelve-Year Mapping and Change Analysis of Eelgrass (Zostera marina) Areal Abundance in Massachusetts (USA) Identifies Statewide Declines. *Estuaries and Coasts,* 34, 232-242.

Criales, M. M., Cherubin, L. M. & Browder, J. A. (2015) Modeling larval transport and settlement of pink shrimp in South Florida: dynamics of behavior and tides. *Marine and Coastal Fisheries,* 7, 148-176.

Criales, M. M., Robblee, M. B., Browder, J. A., Cardenas, H. & Jackson, T. L. (2011) Field observations on selective tidal-stream transport for postlarval and juvenile pink shrimp in Florida Bay. *Journal of Crustacean Biology,* 31, 26-33.

Cui, X., Liu, H., Fan, M., Ai, B., Ma, D. & Yang, F. (2021) Seafloor habitat mapping using multibeam bathymetric and backscatter intensity multi-features SVM classification framework. *Applied Acoustics,* 174, 107728.

Cullen-Unsworth, L., Jones, B., Lilley, R. & Unsworth, R. (2018) Secret Gardens Under the Sea: What are Seagrass Meadows and Why are They Important? *Frontiers for Young Minds,* 6.

Cullen-Unsworth, L. & Unsworth, R. (2013) Seagrass meadows, ecosystem services, and sustainability. *Environment: Science and policy for sustainable development,* 55, 14-28.

Cullen-Unsworth, L. C., Nordlund, L. M., Paddock, J., Baker, S., Mckenzie, L. J. & Unsworth, R. K. (2014) Seagrass meadows globally as a coupled social–ecological system: Implications for human wellbeing. *Marine Pollution Bulletin,* 83, 387-397.

Cullen-Unsworth, L. C. & Unsworth, R. K. F. (2016) Strategies to enhance the resilience of the world's seagrass meadows. *Journal of Applied Ecology,* 53, 967-972.

Cusson, M. & Bourget, E. (1997) Influence of topographic heterogeneity and spatial scales on the structure of the neighbouring intertidal endobenthic macrofaunal community. *Marine Ecology Progress Series,* 150, 181-193.

Da Silva, U. B. T., Delgado-Jaramillo, M., De Souza Aguiar, L. M. & Bernard, E. (2018) Species richness, geographic distribution, pressures, and threats to bats in the Caatinga drylands of Brazil. *Biological Conservation,* 221**,** 312-322.

Dartnell, P. & Gardner, J. V. (2004) Predicting seafloor facies from multibeam bathymetry and backscatter data. *Photogrammetric Engineering & Remote Sensing,* 70**,** 1081-1091.

Daud, M., Pin, T. & Handayani, T. (Year) Published. The spatial pattern of seagrass distribution and the correlation with salinity, sea surface temperature, and suspended materials in Banten Bay. IOP Conference Series: Earth and Environmental Science, 2019. IOP Publishing, 012013.

De Falco, G., Tonielli, R., Di Martino, G., Innangi, S., Simeone, S. & Michael Parnum, I. (2010) Relationships between multibeam backscatter, sediment grain size and Posidonia oceanica seagrass distribution. *Continental Shelf Research,* 30**,** 1941-1950.

De Los Santos, C. B., Scott, A., Arias-Ortiz, A., Jones, B., Kennedy, H., Mazarrasa, I., Mckenzie, L., Nordlund, L. M., De La Torre-Castro, M. D. L. T. & Unsworth, R. K. (2020) Seagrass ecosystem services: assessment and scale of benefits. *Out of the blue: The value of seagrasses to the environment and to people***,** 19-21.

De'ath, G., Fabricius, K. E., Sweatman, H. & Puotinen, M. (2012) The 27–year decline of coral cover on the Great Barrier Reef and its causes. *Proceedings of the National Academy of Sciences,* 109**,** 17995-17999.

Degraer, S., Verfaillie, E., Willems, W., Adriaens, E., Vincx, M. & Van Lancker, V. (2008) Habitat suitability modelling as a mapping tool for macrobenthic communities: an example from the Belgian part of the North Sea. *Continental Shelf Research,* 28**,** 369-379.

Dekker, A., Brando, V., Anstee, J., Fyfe, S., Malthus, T. & Karpouzli, E. (2007) Remote sensing of seagrass ecosystems: use of spaceborne and airborne sensors, *Seagrasses: Biology, Ecologyand Conservation.* Springer.

Den Hartog, C. (1970) *The sea-grasses of the world*, North-Holland Pub. Co.

Diesing, M., Green, S. L., Stephens, D., Lark, R. M., Stewart, H. A. & Dove, D. (2014) Mapping seabed sediments: Comparison of manual, geostatistical, object-based image analysis and machine learning approaches. *Continental Shelf Research,* 84, 107-119.

Diesing, M., Mitchell, P. & Stephens, D. (2016) Image-based seabed classification: what can we learn from terrestrial remote sensing? *ICES Journal of Marine Science,* 73, 2425-2441.

Dmpm (2011) Handbook of the Living Marine Resources of Malaysia Marine Park. *In:* (DMPM), D. O. M. P. M. (ed.). Putrajaya: Department of Marine Park Malaysia (DMPM).

Downie, A.-L., Von Numers, M. & Boström, C. (2013) Influence of model selection on the predicted distribution of the seagrass Zostera marina. *Estuarine, Coastal and Shelf Science,* 121-122, 8-19.

Droz, B., Arnoux, R., Bohnenstengel, T., Laesser, J., Spaar, R., Ayé, R. & Randin, C. F. (2019) Moderately urbanized areas as a conservation opportunity for an endangered songbird. *Landscape and Urban Planning,* 181, 1-9.

Du, J., Hu, W., Nagelkerken, I., Sangsawang, L., Loh, K. H., Ooi, J. L.-S., Liao, J., Zheng, X., Qiu, S. & Chen, B. (2020) Seagrass meadows provide multiple benefits to adjacent coral reefs through various microhabitat functions. *Ecosystem Health and Sustainability,* 6, 1812433.

Duarte, C. M. (1991) Seagrass depth limits. *Aquatic botany,* 40, 363-377.

Duarte, C. M., Larkum, A. W. & Orth, R. J. (2006) *Seagrasses: biology, ecology and conservation*, Springer.

Duarte, C. M., Middelburg, J. J. & Caraco, N. (2005) Major role of marine vegetation on the oceanic carbon cycle. *Biogeosciences,* 2, 1-8.

Duffy, J. P., Pratt, L., Anderson, K., Land, P. E. & Shutler, J. D. (2018) Spatial assessment of intertidal seagrass meadows using optical imaging systems and a lightweight drone. *Estuarine, Coastal and Shelf Science,* 200, 169-180.

Dunlop, K. M., Jarvis, T., Benoit-Bird, K. J., Waluk, C. M., Caress, D. W., Thomas, H. & Smith, K. L. (2018) Detection and characterisation of deep-sea benthopelagic animals from an autonomous underwater vehicle with a multibeam echosounder: A proof of concept and description of data-processing methods. *Deep Sea Research Part I: Oceanographic Research Papers,* 134, 64-79.

Duque-Lazo, J., Van Gils, H., Groen, T. A. & Navarro-Cerrillo, R. M. (2016) Transferability of species distribution models: The case of Phytophthora cinnamomi in Southwest Spain and Southwest Australia. *Ecological Modelling,* 320**,** 62-70.

Edwards, B. D., Dartnell, P. & Chezar, H. (2003) Characterizing benthic substrates of Santa Monica Bay with seafloor photography and multibeam sonar imagery. *Marine Environmental Research,* 56**,** 47-66.

Effrosynidis, D., Arampatzis, A. & Sylaios, G. (2018) Seagrass detection in the mediterranean: A supervised learning approach. *Ecological Informatics,* 48**,** 158-170.

Eleftheriou, A. (2013) *Methods for the study of marine benthos*, John Wiley & Sons.

Elith, J., H. Graham, C., P. Anderson, R., Dudík, M., Ferrier, S., Guisan, A., J. Hijmans, R., Huettmann, F., R. Leathwick, J., Lehmann, A., Li, J., G. Lohmann, L., A. Loiselle, B., Manion, G., Moritz, C., Nakamura, M., Nakazawa, Y., Mcc. M. Overton, J., Townsend Peterson, A., J. Phillips, S., Richardson, K., Scachetti-Pereira, R., E. Schapire, R., Soberón, J., Williams, S., S. Wisz, M. & E. Zimmermann, N. (2006) Novel methods improve prediction of species' distributions from occurrence data. *Ecography,* 29**,** 129-151.

Elith, J. & Leathwick, J. R. (2009) Species distribution models: Ecological explanation and prediction across space and time. *Annual Review of Ecology, Evolution, and Systematics.*

Elith, J., Phillips, S. J., Hastie, T., Dudík, M., Chee, Y. E. & Yates, C. J. (2011) A statistical explanation of MaxEnt for ecologists. *Diversity and distributions,* 17**,** 43-57.

Esaias, W. E., Abbott, M. R., Barton, I., Brown, O. B., Campbell, J. W., Carder, K. L., Clark, D. K., Evans, R. H., Hoge, F. E. & Gordon, H. R. (1998) An overview of MODIS capabilities for ocean science observations. *IEEE Transactions on Geoscience and Remote Sensing,* 36**,** 1250-1265.

Evans, J. S., Murphy, M. A., Holden, Z. A. & Cushman, S. A. (2011) Modeling species distribution and change using random forest, *Predictive species and habitat modeling in landscape ecology.* Springer.

Fakiris, E., Blondel, P., Papatheodorou, G., Christodoulou, D., Dimas, X., Georgiou, N., Kordella, S., Dimitriadis, C., Rzhanov, Y., Geraga, M. & Ferentinos, G. (2019) Multi-Frequency, Multi-Sonar Mapping of Shallow Habitats—Efficacy and Management Implications in the National Marine Park of Zakynthos, Greece. *Remote Sensing,* 11.

Fakiris, E., Rzhanov, Y. & Zoura, D. (2012) On importance of acoustic backscatter corrections for texture-based seafloor characterization. *11th European Conference on Underwater Acoustics 2012, ECUA 2012*. Edinburgh, Scotland.

Farrell, A., Wang, G., Rush, S. A., Martin, J. A., Belant, J. L., Butler, A. B. & Godwin, D. (2019) Machine learning of large-scale spatial distributions of wild turkeys with high-dimensional environmental data. *Ecology and Evolution,* 9**,** 5938-5949.

Fazio, N. L., Perrotti, M., Andriani, G. F., Mancini, F., Rossi, P., Castagnetti, C. & Lollino, P. (2019) A new methodological approach to assess the stability of discontinuous rocky cliffs using in-situ surveys supported by UAV-based techniques and 3-D finite element model: a case study. *Engineering Geology,* 260**,** 105205.

Feldens, P. (2017) Sensitivity of Texture Parameters to Acoustic Incidence Angle in Multibeam Backscatter. *IEEE Geoscience and Remote Sensing Letters,* 14**,** 2215-2219.

Ferguson, R. L. & Korfmacher, K. (1997) Remote sensing and GIS analysis of seagrass meadows in North Carolina, USA. *Aquatic Botany,* 58**,** 241-258.

Fernandes, M. B., Van Gils, J., Erftemeijer, P. L., Daly, R., Gonzalez, D. & Rouse, K. (2019) A novel approach to determining dynamic nitrogen thresholds for seagrass conservation. *Journal of Applied Ecology,* 56**,** 253-261.

Ferretti, R., Bibuli, M., Caccia, M., Chiarella, D., Odetti, A., Ranieri, A., Zereik, E. & Bruzzone, G. (Year) Published. Machine learning methods for acoustic-based automatic Posidonia meadows detection by means of unmanned marine vehicles. OCEANS 2017 - Aberdeen, 19-22 June 2017 2017. 1-6.

Ferrini, V. L. & Flood, R. D. (2006) The effects of fine-scale surface roughness and grain size on 300 kHz multibeam backscatter intensity in sandy marine sedimentary environments. *Marine Geology,* 228**,** 153-172.

Fielding, A. H. & Bell, J. F. (1997) A review of methods for the assessment of prediction errors in conservation presence/absence models. *Environmental conservation,* 24**,** 38-49.

Fonseca, L., Brown, C., Calder, B., Mayer, L. & Rzhanov, Y. (2009) Angular range analysis of acoustic themes from Stanton Banks Ireland: A link between visual interpretation and multibeam echosounder angular signatures. *Applied Acoustics - APPL ACOUST,* 70.

Fonseca, L. & Mayer, L. (2007) Remote estimation of surficial seafloor properties through the application Angular Range Analysis to multibeam sonar data. *Marine Geophysical Researches,* 28**,** 119-126.

Fortes, M. D. (2018) Seagrass ecosystem conservation in Southeast Asia needs to link science to policy and practice. *Ocean & Coastal Management,* 159**,** 51-56.

Fourcade, Y., Engler, J. O., Rödder, D. & Secondi, J. (2014) Mapping species distributions with MAXENT using a geographically biased sample of presence data: a performance assessment of methods for correcting sampling bias. *PloS one,* 9**,** e97122.

Fourqurean, J. W., Duarte, C. M., Kennedy, H., Marbà, N., Holmer, M., Mateo, M. A., Apostolaki, E. T., Kendrick, G. A., Krause-Jensen, D., Mcglathery, K. J. & Serrano, O. (2012) Seagrass ecosystems as a globally significant carbon stock. *Nature Geoscience,* 5**,** 505.

François, R., Thibaud, M., Michel, L. N. & Gilles, L. (2018) Seagrass organic matter transfer in Posidonia oceanica macrophytodetritus accumulations. *Estuarine, Coastal and Shelf Science,* 212**,** 73-79.

Franklin, J. (2010) Mapping Species Distributions Spatial Inference and Prediction, Cambridge University Press.

Freeman, A. S., Short, F. T., Isnain, I., Razak, F. A. & Coles, R. G. (2008) Seagrass on the edge: Land-use practices threaten coastal seagrass communities in Sabah, Malaysia. *Biological Conservation,* 141**,** 2993-3005.

Freemark, K. E. & Merriam, H. G. (1986) Importance of area and habitat heterogeneity to bird assemblages in temperate forest fragments. *Biological Conservation,* 36**,** 115-141.

Fritz, G. (1971) C. den Hartog: The sea-grasses of the world. *Internationale Revue der gesamten Hydrobiologie und Hydrographie,* 56**,** 141-141.

Fukuda, S. & De Baets, B. (2016) Data prevalence matters when assessing species' responses using data-driven species distribution models. *Ecological Informatics,* 32**,** 69-78.

Gaida, T. C., Snellen, M., Van Dijk, T. a. G. P. & Simons, D. G. (2019) Geostatistical modelling of multibeam backscatter for full-coverage seabed sediment maps. *Hydrobiologia,* 845**,** 55-79.

Garner, N., Ross, P. M., Falkenberg, L. J., Seymour, J. R., Siboni, N. & Scanes, E. (2022) Can seagrass modify the effects of ocean acidification on oysters? *Marine Pollution Bulletin,* 177**,** 113438.

Gay, A., Lopez, M., Ondreas, H., Charlou, J. L., Sermondadaz, G. & Cochonat, P. (2006) Seafloor facies related to upward methane flux within a Giant Pockmark of the Lower Congo Basin. *Marine Geology,* 226**,** 81-95.

Georgian, S. E., Anderson, O. F. & Rowden, A. A. (2019) Ensemble habitat suitability modeling of vulnerable marine ecosystem indicator taxa to inform deep-sea fisheries management in the South Pacific Ocean. *Fisheries Research,* 211**,** 256-274.

Ghazali, A. F. & Jamil, N. R. (2019) Population and Trend Analysis for Green Turtle (Chelonia mydas) and Hawksbill Turtle (Eretmochelys imbricata) in Marine Park Centre Redang, Terengganu and Marine Park Centre Rusukan Besar, Labuan, Malaysia. *Pertanika Journal of Science & Technology,* 27.

Gillanders, B. M., Able, K. W., Brown, J. A., Eggleston, D. B. & Sheridan, P. F. (2003) Evidence of connectivity between juvenile and adult habitats for mobile marine fauna: an important component of nurseries. *Marine Ecology Progress Series,* 247**,** 281-295.

Gladstone-Gallagher, R. V., Hughes, R. W., Douglas, E. J. & Pilditch, C. A. (2018) Biomass-dependent seagrass resilience to sediment eutrophication. *Journal of Experimental Marine Biology and Ecology,* 501**,** 54-64.

Goff, J. A., Kraft, B. J., Mayer, L. A., Schock, S. G., Sommerfield, C. K., Olson, H. C., Gulick, S. P. S. & Nordfjord, S. (2004) Seabed characterization on the New

Jersey middle and outer shelf: Correlatability and spatial variability of seafloor sediment properties. *Marine Geology,* 209, 147-172.

González-Irusta, J. M., González-Porto, M., Sarralde, R., Arrese, B., Almón, B. & Martín-Sosa, P. (2015) Comparing species distribution models: a case study of four deep sea urchin species. *Hydrobiologia,* 745, 43-57.

Gonzalez-Mirelis, G. & Lindegarth, M. (2012) Predicting the distribution of out-of-reach biotopes with decision trees in a Swedish marine protected area. *Ecological applications : a publication of the Ecological Society of America,* 22, 2248-64.

Grech, A. & Coles, R. G. (2010) An ecosystem-scale predictive model of coastal seagrass distribution. *Aquatic Conservation: Marine and Freshwater Ecosystems,* 20, 437-444.

Green, E. P., Short, F. T. & Frederick, T. (2003) *World atlas of seagrasses*, Univ of California Press.

Greene, A., Rahman, A. F., Kline, R. & Rahman, M. S. (2018) Side scan sonar: A cost-efficient alternative method for measuring seagrass cover in shallow environments. *Estuarine, Coastal and Shelf Science,* 207, 250-258.

Guannel, G., Arkema, K., Ruggiero, P. & Verutes, G. (2016) The Power of Three: Coral Reefs, Seagrasses and Mangroves Protect Coastal Regions and Increase Their Resilience. *PLOS ONE,* 11, e0158094.

Guichard, F. & Bourget, E. (1998) Topographic heterogeneity, hydrodynamics, and benthic community structure: a scale-dependent cascade. *Marine Ecology Progress Series,* 171, 59-70.

Guisan, A. & Zimmermann, N. E. (2000) Predictive habitat distribution models in ecology. *Ecological modelling,* 135, 147-186.

Gumpil, J. & De Silva, M. R. N. (2007) *Issues and challenges of seagrass With special reference to Sabah, Malaysia*, Penerbit Universiti Malaysia Sabah.

Gumusay, M. U., Bakirman, T., Tuney Kizilkaya, I. & Aykut, N. O. (2019) A review of seagrass detection, mapping and monitoring applications using acoustic systems. *European Journal of Remote Sensing,* 52, 1-29.

Haggarty, D. & Yamanaka, K. (2018) Evaluating Rockfish Conservation Areas in southern British Columbia, Canada using a Random Forest model of rocky reef habitat. *Estuarine, Coastal and Shelf Science,* 208**,** 191-204.

Halpern, B., Walbridge, S., Selkoe, K., Kappel, C., Micheli, F., D'agrosa, C., Bruno, J., Casey, K., Ebert, C., Fox, H., Fujita, R., Heinemann, D., Lenihan, H., Madin, E., Perry, M., Selig, E., Spalding, M., Steneck, R. & Watson, R. (2008) A Global Map of Human Impact on Marine Ecosystems. *Science (New York, N.Y.),* 319**,** 948-52.

Halvorsen, R. (2013) A strict maximum likelihood explanation of MaxEnt, and some implications for distribution modelling. *Sommerfeltia,* 36**,** 1-132.

Hamad, I. Y., Staehr, P. a. U., Rasmussen, M. B. & Sheikh, M. (2022) Drone-Based Characterization of Seagrass Habitats in the Tropical Waters of Zanzibar. *Remote Sensing,* 14**,** 680.

Hamana, M. & Komatsu, T. (2016) Real-Time Classification of Seagrass Meadows on Flat Bottom with Bathymetric Data Measured by a Narrow Multibeam Sonar System. *Remote Sensing,* 8**,** 96.

Haralick, R., Shanmugam, K. & Dinstein, I. (1973) *Textural Features for Image Classification*.

Harrell Jr, F. E., Lee, K. L. & Mark, D. B. (1996) Multivariable prognostic models: issues in developing models, evaluating assumptions and adequacy, and measuring and reducing errors. *Statistics in medicine,* 15**,** 361-387.

Harris, P. & Baker, E. (2011) Seafloor Geomorphology as Benthic Habitat: GeoHab Atlas of seafloor geomorphic features and benthic habitats, Elsevier.

Harris, P. & Baker, E. (2012) Seafloor Geomorphology as Benthic Habitat: GeoHab Atlas of seafloor geomorphic features and benthic habitats.

Hashim, M., Ito, S., Numata, S., Hosaka, T., Hossain, M. S., Misbari, S., Yahya, N. N. & Ahmad, S. (2017) Using fisher knowledge, mapping population, habitat suitability and risk for the conservation of dugongs in Johor Straits of Malaysia. *Marine Policy,* 78**,** 18-25.

Hastings, K., Hesp, P. & Kendrick, G. A. (1995) Seagrass loss associated with boat moorings at Rottnest Island, Western Australia. *Ocean & Coastal Management,* 26**,** 225-246.

Hastings, R., Cummins, V. & Holloway, P. (2020) Assessing the Impact of Physical and Anthropogenic Environmental Factors in Determining the Habitat Suitability of Seagrass Ecosystems. *Sustainability,* 12**,** 8302.

Hays, G. C., Alcoverro, T., Christianen, M. J. A., Duarte, C. M., Hamann, M., Macreadie, P. I., Marsh, H. D., Rasheed, M. A., Thums, M., Unsworth, R. K. F., York, P. H. & Esteban, N. (2018) New Tools to Identify the Location of Seagrass Meadows: Marine Grazers as Habitat Indicators. *Frontiers in Marine Science,* 5.

Hearne, E. L., Johnson, R. A., Gulick, A. G., Candelmo, A., Bolten, A. B. & Bjorndal, K. A. (2019) Effects of green turtle grazing on seagrass and macroalgae diversity vary spatially among seagrass meadows. *Aquatic Botany,* 152**,** 10-15.

Heck, J. & Orth, R. (1980) Seagrass habitats: The roles of habitat complexity, competition and predation in structuring associated fish and motile macroinvertebrate assemblages.

Heck Jr, K., Hays, G. & Orth, R. J. (2003) Critical evaluation of the nursery role hypothesis for seagrass meadows. *Marine Ecology Progress Series,* 253**,** 123-136.

Hedley, J., Russell, B., Randolph, K. & Dierssen, H. (2016) A physics-based method for the remote sensing of seagrasses. *Remote Sensing of Environment,* 174**,** 134-147.

Hemminga, M. A. & Duarte, C. M. (2000) *Seagrass ecology*, Cambridge University Press.

Heng, H. W. K., Ooi, J. L. S., Affendi, Y. A., Kee Alfian, A. A. & Ponnampalam, L. S. (2022) Dugong feeding grounds and spatial feeding patterns in subtidal seagrass: A case study at Sibu Archipelago, Malaysia. *Estuarine, Coastal and Shelf Science,* 264**,** 107670.

Hidetake, H., Sharma, R. C., Tomita, M. & Hara, K. (2018) Evaluating multiple classifier system for the reduction of salt-and-pepper noise in the classification of very-high-resolution satellite images. *International Journal of Remote Sensing,* 40**,** 1-16.

Hill, N. A., Lucieer, V., Barrett, N. S., Anderson, T. J. & Williams, S. B. (2014) Filling the gaps: Predicting the distribution of temperate reef biota using high resolution biological and acoustic data. *Estuarine, Coastal and Shelf Science,* 147, 137-147.

Hoang, T. H., Lock, K., Mouton, A. & Goethals, P. L. M. (2010) Application of classification trees and support vector machines to model the presence of macroinvertebrates in rivers in Vietnam. *Ecological Informatics,* 5, 140-146.

Hoegh-Guldberg, O., Jacob, D., Bindi, M., Brown, S., Camilloni, I., Diedhiou, A., Djalante, R., Ebi, K., Engelbrecht, F. & Guiot, J. (2018) Impacts of 1.5 C global warming on natural and human systems. *Global warming of 1.5 C. An IPCC special report.*

Holmes, K. W., Van Niel, K. P., Kendrick, G. A. & Radford, B. (2007) Probabilistic large-area mapping of seagrass species distributions. *Aquatic Conservation: Marine and Freshwater Ecosystems,* 17, 385-407.

Holmes, K. W., Van Niel, K. P., Radford, B., Kendrick, G. A. & Grove, S. L. (2008) Modelling distribution of marine benthos from hydroacoustics and underwater video. *Continental Shelf Research,* 28, 1800-1810.

Hosmer Jr, D. W., Lemeshow, S. & Sturdivant, R. X. (2013) *Applied logistic regression*, John Wiley & Sons.

Hossain, M., Bujang, J. S., Zakaria, M. H. & Hashim, M. (2015a) The application of remote sensing to seagrass ecosystems: an overview and future research prospects. *International Journal of Remote Sensing,* 36, 61-114.

Hossain, M. & Hashim, M. (2019) Potential of Earth Observation (EO) technologies for seagrass ecosystem service assessments. *International Journal of Applied Earth Observation and Geoinformation,* 77, 15-29.

Hossain, M., Zakaria, M. H., Bujang, J. S. & Hashim, M. (2015b) Landsat image enhancement techniques for subtidal and intertidal seagrass detection and distribution mapping in the coastal waters of Sungai Pulai estuary, Malaysia. *Coastal marine science,* 38, 27-41.

Hossain, M. S., Bujang, J. S., Zakaria, M. H. & Hashim, M. (2015c) Application of Landsat images to seagrass areal cover change analysis for Lawas, Terengganu and Kelantan of Malaysia. *Continental Shelf Research,* 110, 124-148.

Hossain, M. S., Bujang, J. S., Zakaria, M. H. & Hashim, M. (2016) Marine and human habitat mapping for the Coral Triangle Initiative region of Sabah using Landsat and Google Earth imagery. *Marine Policy,* 72**,** 176-191.

Howard, J., Hoyt, S., Isensee, K., Telszewski, M. & Pidgeon, E. (2014) Coastal blue carbon: methods for assessing carbon stocks and emissions factors in mangroves, tidal salt marshes, and seagrasses.

Howell, K.-L., Piechaud, N., Downie, A.-L. & Kenny, A. (2016) The distribution of deep-sea sponge aggregations in the North Atlantic and implications for their effective spatial management. *Deep Sea Research Part I: Oceanographic Research Papers,* 115**,** 309-320.

Hu, W., Zhang, D., Chen, B., Liu, X., Ye, X., Jiang, Q., Zheng, X., Du, J. & Chen, S. (2021) Mapping the seagrass conservation and restoration priorities: Coupling habitat suitability and anthropogenic pressures. *Ecological Indicators,* 129**,** 107960.

Hu, Z., Hu, J., Hu, H. & Zhou, Y. (2020) Predictive habitat suitability modeling of deep-sea framework-forming scleractinian corals in the Gulf of Mexico. *Science of The Total Environment,* 742**,** 140562.

Ierodiaconou, D., Laurenson, L., Burq, S. & Reston, M. (2007) Marine benthic habitat mapping using Multibeam data, georeferencedvideo and image classification techniques in Victoria, Australia. *Journal of Spatial Science,* 52**,** 93-104.

Ierodiaconou, D., Schimel, A. C., Kennedy, D., Monk, J., Gaylard, G., Young, M., Diesing, M. & Rattray, A. (2018) Combining pixel and object based image analysis of ultra-high resolution multibeam bathymetry and backscatter for habitat mapping in shallow marine waters. *Marine Geophysical Research,* 39**,** 271-288.

Ismail, J., Kamal, A. H., Idris, M. H., Amin, S. M. N., Denil, N. A., Kumar, U. & Karim, N. (2020) Species composition and diversity of fishes from the seagrass habitat of Lawas, Sarawak, Malaysia. *Journal of Environmental Biology,* 41.

Ismail, N. (1993) Preliminary study of the seagrass flora of Sabah, Malaysia. *PERTANIKA,* 16**,** 111.

Jaaman, S. A. (2000) Malaysia's endangered marine species (Marine Mammals and Whale Shark). *Maritime Awareness Programme Forum Series 2000, 8 April 2000.*

Jackson, D. R., Winebrenner, D. P. & Ishimaru, A. (1986) Application of the composite roughness model to high-frequency bottom backscattering. *The Journal of the Acoustical Society of America,* 79**,** 1410-1422.

Jackson, E. L., Rowden, A. A., Attrill, M. J., Bossey, S. J. & Jones, M. B. (2001) The importance of seagrass beds as a habitat for fishery species. *Oceanography and Marine Biology,* 39**,** 269-304.

James, R. K., Lynch, A., Herman, P. M. J., Van Katwijk, M. M., Van Tussenbroek, B. I., Dijkstra, H. A., Van Westen, R. M., Van Der Boog, C. G., Klees, R., Pietrzak, J. D., Slobbe, C. & Bouma, T. J. (2021) Tropical Biogeomorphic Seagrass Landscapes for Coastal Protection: Persistence and Wave Attenuation During Major Storms Events. *Ecosystems,* 24**,** 301-318.

Janowski, L., Trzcinska, K., Tegowski, J., Kruss, A., Rucinska-Zjadacz, M. & Pocwiardowski, P. (2018) Nearshore benthic habitat mapping based on multi-frequency, multibeam echosounder data using a combined object-based approach: a case study from the rowy site in the Southern Baltic Sea. *Remote Sensing,* 10**,** 1983.

Jayathilake, D. R. M. & Costello, M. J. (2018) A modelled global distribution of the seagrass biome. *Biological Conservation,* 226**,** 120-126.

Jena, B., Kurian, P. J., Swain, D., Tyagi, A. & Ravindra, R. (2012) Prediction of bathymetry from satellite altimeter based gravity in the Arabian Sea: Mapping of two unnamed deep seamounts. *International Journal of Applied Earth Observation and Geoinformation,* 16**,** 1-4.

Jeudy De Grissac, A. & Boudouresque, C. (1985) Rôles des herbiers de phanérogames marines dans les mouvements des sédiments côtiers: les herbiers à Posidonia oceanica. *Les aménagements côtiers et la gestion du littoral, Coll. pluridisciplinaire franco-japonais océanographie***,** 143-151.

Johan, I., Hena, M. A., Idris, M., Amin, S., Denil, N., Kumar, U. & Karim, N. (2020) Species composition and diversity of fishes from the seagrass habitat of Lawas, Sarawak, Malaysia. *Journal of Environmental Biology,* 41**,** 1382-1389.

Jordà, G., Marbà, N. & Duarte, C. M. (2012) Mediterranean seagrass vulnerable to regional climate warming. *Nature Climate Change,* 2**,** 821.

Jung, D., Kim, J. & Byun, G. (2018) Numerical modeling and simulation technique in time-domain for multibeam echo sounder. *International Journal of Naval Architecture and Ocean Engineering,* 10**,** 225-234.

Kemp, W. M., Boynton, W. R., Adolf, J. E., Boesch, D. F., Boicourt, W. C., Brush, G., Cornwell, J. C., Fisher, T. R., Glibert, P. M. & Hagy, J. D. (2005) Eutrophication of Chesapeake Bay: historical trends and ecological interactions. *Marine Ecology Progress Series,* 303**,** 1-29.

Kendrick, G. A., Aylward, M. J., Hegge, B. J., Cambridge, M. L., Hillman, K., Wyllie, A. & Lord, D. A. (2002) Changes in seagrass coverage in Cockburn Sound, Western Australia between 1967 and 1999. *Aquatic Botany,* 73**,** 75-87.

Kendrick, G. A., Eckersley, J. & Walker, D. I. (1999) Landscape-scale changes in seagrass distribution over time: a case study from Success Bank, Western Australia. *Aquatic Botany,* 65**,** 293-309.

Kikuchi, T. (1980) Faunal relationships in temperate seagrass beds. *Holland book of Seagrass Biology, An Ecosystem Perspective*.

Kinlan, B. P., Poti, M., Drohan, A. F., Packer, D. B., Dorfman, D. S. & Nizinski, M. S. (2020) Predictive modeling of suitable habitat for deep-sea corals offshore the Northeast United States. *Deep Sea Research Part I: Oceanographic Research Papers,* 158**,** 103229.

Koch, R., Almeida-Cortez, J. S. & Kleinschmit, B. (2017) Revealing areas of high nature conservation importance in a seasonally dry tropical forest in Brazil: Combination of modelled plant diversity hot spots and threat patterns. *Journal for nature conservation,* 35**,** 24-39.

Kohler, K. E. & Gill, S. M. (2006) Coral Point Count with Excel extensions (CPCe): A Visual Basic program for the determination of coral and substrate coverage using random point count methodology. *Computers & Geosciences,* 32**,** 1259-1269.

Kohlus, J., Stelzer, K., Müller, G. & Smollich, S. (2020) Mapping seagrass (*Zostera*) by remote sensing in the Schleswig-Holstein Wadden Sea. *Estuarine, Coastal and Shelf Science,* 238**,** 106699.

Komatsu, T., Hashim, M., Nurdin, N., Noiraksar, T., Prathep, A., Stankovic, M., Phuoc, T., Phuoc Hoang Son, T., Minh-Thu, P., Luong, C., Wouthuyzen, S., Phauk, S., M Muslim, A., Yahya, N., Terauchi, G., Sagawa, T. & Hayashizaki, K. (2020) Practical mapping methods of seagrass beds by satellite remote sensing and ground truthing. 43, 1-25.

Komatsu, T. & Yamano, H. (2000) Influence of seagrass vegetation on bottom topography and sediment distribution on a small spatial scale in the Dravuni Island Lagoon, Fiji. *Biologia Marina Mediterranea,* 7, 243-246.

Kostylev, V. E., Todd, B. J., Fader, G. B., Courtney, R., Cameron, G. D. & Pickrill, R. A. (2001) Benthic habitat mapping on the Scotian Shelf based on multibeam bathymetry, surficial geology and sea floor photographs. *Marine Ecology Progress Series,* 219, 121-137.

Lamarche, G. & Lurton, X. (2018) Recommendations for improved and coherent acquisition and processing of backscatter data from seafloor-mapping sonars. *Marine Geophysical Research,* 39, 5-22.

Lamb, J., Van De Water, J., Bourne, D., Altier, C., Hein, M., Fiorenza, E., Abu, N., Jompa, J. & Harvell, C. (2017) Seagrass ecosystems reduce exposure to bacterial pathogens of humans, fishes, and invertebrates. *Science,* 355, 731.

Lauria, V., Gristina, M., Attrill, M. J., Fiorentino, F. & Garofalo, G. (2015) Predictive habitat suitability models to aid conservation of elasmobranch diversity in the central Mediterranean Sea. *Scientific Reports,* 5, 13245.

Lavery, P. S., Mateo, M.-Á., Serrano, O. & Rozaimi, M. (2013) Variability in the carbon storage of seagrass habitats and its implications for global estimates of blue carbon ecosystem service. *PloS one,* 8, e73748.

Le Bas, T. & Huvenne, V. (2009) Acquisition and processing of backscatter data for habitat mapping–comparison of multibeam and sidescan systems. *Applied Acoustics,* 70, 1248-1257.

Lecours, V., Devillers, R., Lucieer, V. L. & Brown, C. J. (2017a) Artefacts in marine digital terrain models: A multiscale analysis of their impact on the derivation of terrain attributes. *IEEE Transactions on Geoscience and Remote Sensing,* 55, 5391-5406.

Lecours, V., Devillers, R., Schneider, D., Lucieer, V., Brown, C. & Edinger, E. (2015) Spatial scale and geographic context in benthic habitat mapping: Review and future directions. *Marine Ecology Progress Series,* 535**,** 259-284.

Lecours, V., Devillers, R., Simms, A. E., Lucieer, V. L. & Brown, C. J. (2017b) Towards a framework for terrain attribute selection in environmental studies. *Environmental modelling & software,* 89**,** 19-30.

Lee, K.-S., Park, S. R. & Kim, Y. K. (2007) Effects of irradiance, temperature, and nutrients on growth dynamics of seagrasses: a review. *Journal of Experimental Marine Biology and Ecology,* 350**,** 144-175.

Lee, K. S. & Dunton, K. H. (1996) Production and carbon reserve dynamics of the seagrass Thalassia testudinum in Corpus Christi Bay, Texas, USA. *Marine Ecology Progress Series,* 143**,** 201-210.

Lefebvre, A., Thompson, C. E. L., Collins, K. J. & Amos, C. L. (2009) Use of a high-resolution profiling sonar and a towed video camera to map a Zostera marina bed, Solent, UK. *Estuarine, Coastal and Shelf Science,* 82**,** 323-334.

Li, D., Tang, C., Xia, C. & Zhang, H. (2017) Acoustic mapping and classification of benthic habitat using unsupervised learning in artificial reef water. *Estuarine, Coastal and Shelf Science,* 185**,** 11-21.

Li, J., Tran, M. & Siwabessy, J. (2016) Selecting optimal random forest predictive models: a case study on predicting the spatial distribution of seabed hardness. *PLoS One,* 11**,** e0149089.

Linders, T. E., Bekele, K., Schaffner, U., Allan, E., Alamirew, T., Choge, S. K., Eckert, S., Haji, J., Muturi, G. & Mbaabu, P. R. (2020) The impact of invasive species on social-ecological systems: relating supply and use of selected provisioning ecosystem services. *Ecosystem services,* 41**,** 101055.

Liu, C., Hong, L., Chu, S. & Chen, J. (Year) Published. A SVM ensemble approach combining pixel-based and object-based features for the classification of high resolution remotely sensed imagery. 2014 Third International Workshop on Earth Observation and Remote Sensing Applications (EORSA), 11-14 June 2014 2014. 140-144.

Liu, C., White, M. & Newell, G. (2011) Measuring and comparing the accuracy of species distribution models with presence–absence data. *Ecography,* 34**,** 232-243.

Lu, N., Jia, C.-X., Lloyd, H. & Sun, Y.-H. (2012) Species-specific habitat fragmentation assessment, considering the ecological niche requirements and dispersal capability. *Biological Conservation,* 152**,** 102-109.

Lucieer, V., Hill, N. A., Barrett, N. S. & Nichol, S. (2013) Do marine substrates 'look'and 'sound'the same? Supervised classification of multibeam acoustic data using autonomous underwater vehicle images. *Estuarine, Coastal and Shelf Science,* 117**,** 94-106.

Lucieer, V. & Lamarche, G. (2011) Unsupervised fuzzy classification and object-based image analysis of multibeam data to map deep water substrates, Cook Strait, New Zealand. *Continental Shelf Research,* 31**,** 1236-1247.

Lucieer, V., Roche, M., Degrendele, K., Malik, M., Dolan, M. & Lamarche, G. (2018) User expectations for multibeam echo sounders backscatter strength data-looking back into the future. *Marine Geophysical Research,* 39**,** 23-40.

Lundblad, E. R., Wright, D. J., Miller, J., Larkin, E. M., Rinehart, R., Naar, D. F., Donahue, B. T., Anderson, S. M. & Battista, T. (2006) A benthic terrain classification scheme for American Samoa. *Marine Geodesy,* 29**,** 89-111.

Lurton, X., Lamarche, G., Brown, C., Lucieer, V., Rice, G., Schimel, A. & Weber, T. (2015) *Backscatter measurements by seafloor-mapping sonars - Guidelines and Recommendations*.

Marine Park & Resource Management Division. 2021. *Terengganu Marine Park : Pulau Redang Archipelago* [Online]. Available: https://marinepark.dof.gov.my/en/locations/marine-parks/terengganu-marine-park/ [Accessed Septermber 15 2022].

Marsh, I. & Brown, C. (2009) Neural network classification of multibeam backscatter and bathymetry data from Stanton Bank (Area IV). *Applied Acoustics,* 70**,** 1269-1276.

Mazarrasa, I., Samper-Villarreal, J., Serrano, O., Lavery, P. S., Lovelock, C. E., Marbà, N., Duarte, C. M. & Cortés, J. (2018) Habitat characteristics provide insights of carbon storage in seagrass meadows. *Marine Pollution Bulletin,* 134, 106-117.

Mckenzie, L. J., Finkbeiner, M. A. & Kirkman, H. (2001) Methods for mapping seagrass distribution. *Global seagrass research methods*, 101-121.

Mckenzie, L. J., Nordlund, L. M., Jones, B. L., Cullen-Unsworth, L. C., Roelfsema, C. & Unsworth, R. K. F. (2020) The global distribution of seagrass meadows. *Environmental Research Letters,* 15, 074041.

Medialdea, T., Somoza, L., León, R., Farrán, M., Ercilla, G., Maestro, A., Casas, D., Llave, E., Hernández-Molina, F. J., Fernández-Puga, M. C. & Alonso, B. (2008) Multibeam backscatter as a tool for sea-floor characterization and identification of oil spills in the Galicia Bank. *Marine Geology,* 249, 93-107.

Micallef, A., Le Bas, T. P., Huvenne, V. A., Blondel, P., Hühnerbach, V. & Deidun, A. (2012) A multi-method approach for benthic habitat mapping of shallow coastal areas with high-resolution multibeam data. *Continental Shelf Research,* 39, 14-26.

Miller, R. J., Juska, C. & Hocevar, J. (2015) Submarine canyons as coral and sponge habitat on the eastern Bering Sea slope. *Global Ecology and Conservation,* 4, 85-94.

Misbari, S. & Hashim, M. (2016) Change Detection of Submerged Seagrass Biomass in Shallow Coastal Water. *Remote Sensing,* 8, 200.

Misiuk, B., Lecours, V., Dolan, M. F. J. & Robert, K. (2021) Evaluating the Suitability of Multi-Scale Terrain Attribute Calculation Approaches for Seabed Mapping Applications. *Marine Geodesy,* 44, 327-385.

Miyamoto, M., Kiyota, M., Murase, H., Nakamura, T. & Hayashibara, T. (2017) Effects of Bathymetric Grid-Cell Sizes on Habitat Suitability Analysis of Cold-water Gorgonian Corals on Seamounts. *Marine Geodesy,* 40, 205-223.

Mollalo, A., Sadeghian, A., Israel, G. D., Rashidi, P., Sofizadeh, A. & Glass, G. E. (2018) Machine learning approaches in GIS-based ecological modeling of the sand fly Phlebotomus papatasi, a vector of zoonotic cutaneous leishmaniasis in Golestan province, Iran. *Acta Tropica,* 188, 187-194.

Monahan, D. (2019) Bathymetry☆, in: COCHRAN, J. K., BOKUNIEWICZ, H. J. & YAGER, P. L. (eds.) *Encyclopedia of Ocean Sciences (Third Edition).* Oxford: Academic Press.

Monk, J., Ierodiaconou, D., Bellgrove, A., Harvey, E. & Laurenson, L. (2011) Remotely sensed hydroacoustics and observation data for predicting fish habitat suitability. *Continental Shelf Research,* 31**,** S17-S27.

Monk, J., Ierodiaconou, D., Versace, V., Bellgrove, A., Harvey, E., Rattray, A., Laurenson, L. & Quinn, G. (2010) Habitat suitability for marine fishes using presence-only modelling and multibeam sonar. *Marine Ecology Progress Series,* 420**,** 157-174.

Montereale-Gavazzi, G., Roche, M., Lurton, X., Degrendele, K., Terseleer, N. & Van Lancker, V. (2018) Seafloor change detection using multibeam echosounder backscatter: case study on the Belgian part of the North Sea. *Marine Geophysical Research,* 39**,** 229-247.

Moore, I. D., Grayson, R. B. & Ladson, A. R. (1991) Digital terrain modelling: A review of hydrological, geomorphological, and biological applications. *Hydrological Processes,* 5**,** 3-30.

Mountrakis, G., Im, J. & Ogole, C. (2011) Support vector machines in remote sensing: A review. *ISPRS Journal of Photogrammetry and Remote Sensing,* 66**,** 247-259.

Muhamad, M. a. H., Che Hasan, R., Md Said, N. & Ooi, J. L.-S. (2021) Seagrass habitat suitability model for Redang Marine Park using multibeam echosounder data: Testing different spatial resolutions and analysis window sizes. *PLOS ONE,* 16**,** e0257761.

Muñoz-Mas, R., Fukuda, S., Pórtoles, J. & Martínez-Capel, F. (2018) Revisiting probabilistic neural networks: a comparative study with support vector machines and the microhabitat suitability for the Eastern Iberian chub (Squalius valentinus). *Ecological Informatics,* 43**,** 24-37.

Mustafa, M. & Ariffin, M. (2011) Protection of Marine Biodiversity from Pollution: Legal Strategies in Malaysia. *International Journal of Bioscience, Biochemistry and Bioinformatics***,** 276-281.

Nahirnick, N., Reshitnyk, L., Campbell, M., Hessin‡ Lewis, M., Costa, M., Yakimishyn, J. & Lee, L. (2019) Mapping with confidence; delineating seagrass habitats using Unoccupied Aerial Systems (UAS). *Remote Sensing in Ecology and Conservation,* 5, 121-135.

Naimi, B. & Araújo, M. B. (2016) sdm: a reproducible and extensible R platform for species distribution modelling. *Ecography,* 39, 368-375.

Naimi, B., Skidmore, A. K., Groen, T. A. & Hamm, N. A. (2011) Spatial autocorrelation in predictors reduces the impact of positional uncertainty in occurrence data on species distribution modelling. *Journal of Biogeography,* 38, 1497-1509.

Neves, B. M., Du Preez, C. & Edinger, E. (2014) Mapping coral and sponge habitats on a shelf-depth environment using multibeam sonar and ROV video observations: Learmonth Bank, northern British Columbia, Canada. *Deep Sea Research Part II: Topical Studies in Oceanography,* 99, 169-183.

Nezer, O., Bar-David, S., Gueta, T. & Carmel, Y. (2017) High-resolution species-distribution model based on systematic sampling and indirect observations. *Biodiversity and Conservation,* 26, 421-437.

Nordlund, L. M., Koch, E. W., Barbier, E. B. & Creed, J. C. (2016) Seagrass ecosystem services and their variability across genera and geographical regions. *PLoS One,* 11, e0163091.

Novak, A. B., Pelletier, M. C., Colarusso, P., Simpson, J., Gutierrez, M. N., Arias-Ortiz, A., Charpentier, M., Masque, P. & Vella, P. (2020) Factors Influencing Carbon Stocks and Accumulation Rates in Eelgrass Meadows Across New England, USA. *Estuaries and Coasts,* 43, 2076-2091.

Ogawa, H., Bujang, J. S. & Zakaria, M. H. (2011) Seagrasses in Malaysia. In Seagrasses: Resource Status and Trends in Indonesia, Japan, Malaysia, Thailand and Vietnam, Seizando-Shoten.

Olivero, J., Toxopeus, A., Skidmore, A. & Real, R. (2016) Testing the efficacy of downscaling in species distribution modelling: A comparison between MaxEnt and Favourability Function models. *Animal Biodiversity and Conservation,* 39, 99-114.

Ondiviela, B., Losada, I. J., Lara, J. L., Maza, M., Galván, C., Bouma, T. J. & Van Belzen, J. (2014) The role of seagrasses in coastal protection in a changing climate. *Coastal Engineering,* 87**,** 158-168.

Ooi, J., Van Niel, K., Kendrick, G. & Holmes, K. (2014) Spatial Structure of Seagrass Suggests That Size-Dependent Plant Traits Have a Strong Influence on the Distribution and Maintenance of Tropical Multispecies Meadows.

Ooi, J. L. S., Kendrick, G. A., Van Niel, K. P. & Affendi, Y. A. (2011) Knowledge gaps in tropical Southeast Asian seagrass systems. *Estuarine, Coastal and Shelf Science,* 92**,** 118-131.

Oreska, M. P., Mcglathery, K. J. & Porter, J. H. (2017) Seagrass blue carbon spatial patterns at the meadow-scale. *PloS one,* 12.

Orth, R. J., Carruthers, T. J., Dennison, W. C., Duarte, C. M., Fourqurean, J. W., Heck, K. L., Hughes, A. R., Kendrick, G. A., Kenworthy, W. J. & Olyarnik, S. (2006) A global crisis for seagrass ecosystems. *Bioscience,* 56**,** 987-996.

Pacella, S. R., Brown, C. A., Waldbusser, G. G., Labiosa, R. G. & Hales, B. (2018) Seagrass habitat metabolism increases short-term extremes and long-term offset of CO2 under future ocean acidification. *Proceedings of the National Academy of Sciences,* 115**,** 3870-3875.

Pan, Z., Glennie, C., Fernandez-Diaz, J. C. & Starek, M. (2016) Comparison of bathymetry and seagrass mapping with hyperspectral imagery and airborne bathymetric lidar in a shallow estuarine environment. *International Journal of Remote Sensing,* 37**,** 516-536.

Parravicini, V., Rovere, A., Vassallo, P., Micheli, F., Montefalcone, M., Morri, C., Paoli, C., Albertelli, G., Fabiano, M. & Bianchi, C. (2012) Understanding relationships between conflicting human uses and coastal ecosystems status: a geospatial modeling approach. *Ecological Indicators,* 19**,** 253-263.

Pearce, J. & Ferrier, S. (2000) An evaluation of alternative algorithms for fitting species distribution models using logistic regression. *Ecological modelling,* 128**,** 127-147.

Peralta, G., Van Duren, L., Morris, E. & Bouma, T. (2008) Consequences of shoot density and stiffness for ecosystem engineering by benthic macrophytes in flow dominated areas: a hydrodynamic flume study. *Marine Ecology Progress Series,* 368, 103-115.

Peralta, H. M. & Yusoff, F. (2015) Status of Planktonic Copepod Diversity in the Merambong Seagrass Meadow, Johor, Peninsular Malaysia.

Pergent, G., Monnier, B., Clabaut, P., Gascon, G., Pergent-Martini, C. & Valette-Sansevin, A. (2017) Innovative method for optimizing Side-Scan Sonar mapping: The blind band unveiled. *Estuarine, Coastal and Shelf Science,* 194, 77-83.

Peterson, A. T., Soberón, J., Pearson, R. G., Anderson, R. P., Martínez-Meyer, E., Nakamura, M. & Araújo, M. B. (2011) *Ecological niches and geographic distributions (MPB-49)*, Princeton University Press.

Phang, S. M. (2000) *Seagrasses of Malaysia*, Institute of Biological Sciences, University of Malaya.

Phillips, S. J., Anderson, R. P. & Schapire, R. E. (2006) Maximum entropy modeling of species geographic distributions. *Ecological Modelling,* 190, 231-259.

Phillips, S. J. & Dudík, M. (2008) Modeling of species distributions with Maxent: new extensions and a comprehensive evaluation. *Ecography,* 31, 161-175.

Phinn, S. R., Kovacs, E. M., Roelfsema, C. M., Canto, R. F., Collier, C. J. & Mckenzie, L. J. (2018) Assessing the potential for satellite image monitoring of seagrass thermal dynamics: for inter- and shallow sub-tidal seagrasses in the inshore Great Barrier Reef World Heritage Area, Australia. *International Journal of Digital Earth,* 11, 803-824.

Pickrill, R. A. & Todd, B. J. (2003) The multiple roles of acoustic mapping in integrated ocean management, Canadian Atlantic continental margin. *Ocean & Coastal Management,* 46, 601-614.

Pillay, T., Cawthra, H. C., Lombard, A. T. & Sink, K. (2021) Benthic habitat mapping from a machine learning perspective on the Cape St Francis inner shelf, Eastern Cape, South Africa. *Marine Geology,* 440, 106595.

Pittman, S., Christensen, J., Caldow, C., Menza, C. & Monaco, M. (2007) Predictive mapping of fish species richness across shallow-water seascapes in the Caribbean. *ecological modelling,* 204, 9-21.

Ponti, M., Perlini, R. A., Ventra, V., Grech, D., Abbiati, M. & Cerrano, C. (2014) Ecological shifts in Mediterranean coralligenous assemblages related to gorgonian forest loss. *PloS one,* 9**,** e102782.

Porskamp, P., Rattray, A., Young, M. & Ierodiaconou, D. (2018) Multiscale and Hierarchical Classification for Benthic Habitat Mapping. *Geosciences,* 8.

Potouroglou, M., Bull, J. C., Krauss, K. W., Kennedy, H. A., Fusi, M., Daffonchio, D., Mangora, M. M., Githaiga, M. N., Diele, K. & Huxham, M. (2017) Measuring the role of seagrasses in regulating sediment surface elevation. *Scientific Reports,* 7**,** 11917.

Poursanidis, D., Traganos, D., Reinartz, P. & Chrysoulakis, N. (2019) On the use of Sentinel-2 for coastal habitat mapping and satellite-derived bathymetry estimation using downscaled coastal aerosol band. *International Journal of Applied Earth Observation and Geoinformation,* 80**,** 58-70.

Prampolini, M., Blondel, P., Foglini, F. & Madricardo, F. (2018) Habitat mapping of the Maltese continental shelf using acoustic textures and bathymetric analyses. *Estuarine, Coastal and Shelf Science,* 207**,** 483-498.

Prasad, A. M., Iverson, L. R. & Liaw, A. (2006) Newer Classification and Regression Tree Techniques: Bagging and Random Forests for Ecological Prediction. *Ecosystems,* 9**,** 181-199.

Prasad, M., Ganguly, D., Paneerselvam, A., Ramesh, R. & Purvaja, R. (2019) Seagrass litter decomposition: an additional nutrient source to shallow coastal waters. *Environmental monitoring and assessment,* 191**,** 5.

Pu, R. & Bell, S. (2017) Mapping seagrass coverage and spatial patterns with high spatial resolution IKONOS imagery. *International Journal of Applied Earth Observation and Geoinformation,* 54**,** 145-158.

Quang Le, D., Yin Fui, S., Tanaka, K., Suratman, S., Sano, Y. & Shirai, K. (2020) Feeding habitats of juvenile reef fishes in a tropical mangrove–seagrass continuum along a Malaysian shallow-water coastal lagoon. *Bulletin of Marine Science,* 96**,** 469-486.

Rahimian Boogar, A., Salehi, H., Pourghasemi, H. & Blaschke, T. (2019) Predicting Habitat Suitability and Conserving Juniperus spp. Habitat Using SVM and Maximum Entropy Machine Learning Techniques. *Water,* 11.

Rahnemoonfar, M., Rahman, A. F., Kline, R. J. & Greene, A. (2018) Automatic Seagrass Disturbance Pattern Identification on Sonar Images. *IEEE Journal of Oceanic Engineering,* PP**,** 1-10.

Ralph, P., Durako, M. J., Enriquez, S., Collier, C. & Doblin, M. (2007) Impact of light limitation on seagrasses. *Journal of Experimental Marine Biology and Ecology,* 350**,** 176-193.

Rattray, A., Ierodiaconou, D. & Womersley, T. (2015) Wave exposure as a predictor of benthic habitat distribution on high energy temperate reefs. *Frontiers in Marine Science,* 2**,** 8.

Rawi, S. B. (2012) The Use of Choice Modelling in Assessing Tourists Destinations: A Case Study of Redang Marine Park (RMP) Malaysia. PhD Thesis, Newcastle University.

Rebelo, H. & Jones, G. (2010) Ground validation of presence-only modelling with rare species: a case study on *barbastelles Barbastella barbastellus* (*Chiroptera*: *Vespertilionidae*). *Journal of Applied Ecology,* 47**,** 410-420.

Reed, T. R. & Dubuf, J. H. (1993) A review of recent texture segmentation and feature extraction techniques. *CVGIP: Image understanding,* 57**,** 359-372.

Rein, H. V., Brown, C. J., Quinn, R., Breen, J. & Schoeman, D. S. (2011) An evaluation of acoustic seabed classification techniques for marine biotope monitoring over broad-scales (>1 km2) and meso-scales (10 mR 1 km2). *Estuarine Coastal and Shelf Science,* 93**,** 336-349.

Rende, S. F., Bosman, A., Di Mento, R., Bruno, F., Lagudi, A., Irving, A. D., Dattola, L., Giambattista, L. D., Lanera, P. & Proietti, R. (2020) Ultra-High-Resolution Mapping of Posidonia oceanica (L.) Delile Meadows through Acoustic, Optical Data and Object-based Image Classification. *Journal of Marine Science and Engineering,* 8**,** 647.

Rengstorf, A. M., Grehan, A., Yesson, C. & Brown, C. (2012) Towards high-resolution habitat suitability modeling of vulnerable marine ecosystems in the deep-sea: resolving terrain attribute dependencies. *Marine Geodesy,* 35**,** 343-361.

Rengstorf, A. M., Mohn, C., Brown, C., Wisz, M. S. & Grehan, A. J. (2014) Predicting the distribution of deep-sea vulnerable marine ecosystems using high-resolution data: Considerations and novel approaches. *Deep Sea Research Part I: Oceanographic Research Papers,* 93, 72-82.

Reynolds, P. L., Duffy, E. & Knowlton, N. (2018) Seagrass and seagrass beds. *Ocean Portal.*

Ricart, A. M., Pérez, M. & Romero, J. (2017) Landscape configuration modulates carbon storage in seagrass sediments. *Estuarine, Coastal and Shelf Science,* 185, 69-76.

Rigby, P., Pizarro, O. & Williams, S. B. (2010) Toward adaptive benthic habitat mapping using gaussian process classification. *Journal of Field Robotics,* 27, 741-758.

Roelfsema, C. M., Kovacs, E. M., Saunders, M. I., Phinn, S., Lyons, M. & Maxwell, P. (2013) Challenges of remote sensing for quantifying changes in large complex seagrass environments. *Estuarine, Coastal and Shelf Science,* 133, 161-171.

Roelfsema, C. M., Lyons, M., Kovacs, E. M., Maxwell, P., Saunders, M. I., Samper-Villarreal, J. & Phinn, S. R. (2014) Multi-temporal mapping of seagrass cover, species and biomass: A semi-automated object based image analysis approach. *Remote Sensing of Environment,* 150, 172-187.

Rooper, C. N. & Zimmermann, M. (2007) A bottom-up methodology for integrating underwater video and acoustic mapping for seafloor substrate classification. *Continental Shelf Research,* 27, 947-957.

Rosa, S. & Luis, A. (Year) Published. Seafloor characterization of the Historic Area Remediation Site using angular range analysis. 2007.

Ross, R. & Howell, K. (2012) Use of predictive habitat modeling to assess the distribution and extent of the current protection of 'listed' deep-sea habitats. *Diversity and Distributions,* 19.

Rowden, A. A., Anderson, O. F., Georgian, S. E., Bowden, D. A., Clark, M. R., Pallentin, A. & Miller, A. (2017) High-Resolution Habitat Suitability Models for the Conservation and Management of Vulnerable Marine Ecosystems on the Louisville Seamount Chain, South Pacific Ocean. *Frontiers in Marine Science,* 4.

Rozaimi, M., Fairoz, M., Hakimi, T. M., Hamdan, N. H., Omar, R., Ali, M. M. & Tahirin, S. A. (2017) Carbon stores from a tropical seagrass meadow in the midst of anthropogenic disturbance. *Marine Pollution Bulletin,* 119**,** 253-260.

Saad, S., Khodzori, F. A., Shahbudin, S., Faiz, M. & Yusof, M. (2019) Diversity and Abundance of Scleractinian Corals in the East Coast of Peninsular Malaysia: A Case Study of Redang and Tioman Islands. *Ocean Science Journal,* 54.

Sabol, B. M., Eddie Melton, R., Chamberlain, R., Doering, P. & Haunert, K. (2002) Evaluation of a digital echo sounder system for detection of submersed aquatic vegetation. *Estuaries,* 25**,** 133-141.

Sagawa, T., Boisnier, E., Komatsu, T., Mustapha, K. B., Hattour, A., Kosaka, N. & Miyazaki, S. (2010) Using bottom surface reflectance to map coastal marine areas: a new application method for Lyzenga's model. *International Journal of Remote Sensing,* 31**,** 3051-3064.

Sánchez-Carnero, N., Rodríguez-Pérez, D., Couñago, E., Aceña, S. & Freire, J. (2012) Using vertical Sidescan Sonar as a tool for seagrass cartography. *Estuarine, Coastal and Shelf Science,* 115**,** 334-344.

Sani, D. A. (2020) Modelling Seagrass Blue Carbon Stock in Seagrass-Mangrove Habitats Using Remote Sensing Approach. Universiti Teknologi Malaysia

Sani, D. A. & Hashim, M. (2019) Satellite-Based Mapping of Above-Ground Blue Carbon Storage In Seagrass Habitat Within The Shallow Coastal Water. *ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences,* XLII-4/W16**,** 587-593.

Sankey, T., Donager, J., Mcvay, J. & Sankey, J. B. (2017) UAV lidar and hyperspectral fusion for forest monitoring in the southwestern USA. *Remote Sensing of Environment,* 195**,** 30-43.

Santos, Rolando o. & Lirman, D. (2012) Using habitat suitability models to predict changes in seagrass distribution caused by water management practices1. *Canadian Journal of Fisheries and Aquatic Sciences,* 69**,** 1380-1388.

Sany, S. B. T., Tajfard, M., Rezayi, M., Rahman, M. A. & Hashim, R. (2019) The West Coast of Peninsular Malaysia, *World Seas: an Environmental Evaluation.* Elsevier.

Sasekumar, A., Leh, C., Chong, V. C., D'cruz, R. & Audrey, M. (1989) *The Sungai Pulai (Johor): a unique mangrove estuary*, Persatuan Sains Lautan Malaysia.

Schimel, A., Beaudoin, J., Parnum, I., Le Bas, T., Schmidt, V., Keith, G. & Ierodiaconou, D. (2018) Multibeam sonar backscatter data processing. *Marine Geophysical Research,* 39.

Scott, A. L., York, P. H., Duncan, C., Macreadie, P. I., Connolly, R. M., Ellis, M. T., Jarvis, J. C., Jinks, K. I., Marsh, H. & Rasheed, M. A. (2018) The role of herbivory in structuring tropical seagrass ecosystem service delivery. *Frontiers in plant science,* 9**,** 127.

Sen, A., Ondréas, H., Gaillot, A., Marcon, Y., Augustin, J.-M. & Olu, K. (2016) The use of multibeam backscatter and bathymetry as a means of identifying faunal assemblages in a deep-sea cold seep. *Deep Sea Research Part I: Oceanographic Research Papers,* 110**,** 33-49.

Seo, C., Thorne, J. H., Hannah, L. & Thuiller, W. (2009) Scale effects in species distribution models: implications for conservation planning under climate change. *Biology Letters,* 5**,** 39-43.

Shafer, D., Swannack, T., Saltus, S., Kaldy, J., Davis, A. & Saltus, C. (2016) Development and validation of a habitat suitability model for the non-indigenous seagrass Zostera japonica in North America. *Management of Biological Invasions,* 7**,** 141-155.

Sharma, S., Arunachalam, K., Bhavsar, D. & Kala, R. (2018) Modeling habitat suitability of Perilla frutescens with MaxEnt in Uttarakhand—A conservation approach. *Journal of Applied Research on Medicinal and Aromatic Plants,* 10**,** 99-105.

Short, F., Carruthers, T., Dennison, W. & Waycott, M. (2007) Global seagrass distribution and diversity: a bioregional model. *Journal of Experimental Marine Biology and Ecology,* 350**,** 3-20.

Short, F. T. & Coles, R. G. (2001) *Global seagrass research methods*, Elsevier.

Short, F. T., Polidoro, B., Livingstone, S. R., Carpenter, K. E., Bandeira, S., Bujang, J. S., Calumpong, H. P., Carruthers, T. J., Coles, R. G. & Dennison, W. C. (2011) Extinction risk assessment of the world's seagrass species. *Biological Conservation,* 144**,** 1961-1971.

Siccardi, A., Bozzano, R. & Bono, R. (Year) Published. Seabed vegetation analysis by a 2 MHz sonar. Oceans' 97. MTS/IEEE Conference Proceedings, 1997. IEEE, 344-350.

Sillero, N. & Barbosa, A. M. (2021) Common mistakes in ecological niche models. *International Journal of Geographical Information Science,* 35, 213-226.

Snelgrove, P. & Butman, C. (1995) Animal-sediment relationships revisited: cause versus effect. *Oceanographic Literature Review,* 8, 668.

Sokiman, M. S., Syed Nooh, S. N. F. & Abdullah, N. A. (2014) Sedimentology And Geochemistry of Redang Island Sediments, Terengganu. *National Geoscience Conference*. Kuala Lumpur, Malaysia. 70-72.

Stankovic, M., Kaewsrikhaw, R., Rattanachot, E. & Prathep, A. (2019) Modeling of suitable habitat for small-scale seagrass restoration in tropical ecosystems. *Estuarine, Coastal and Shelf Science,* 231, 106465.

Stephens, D. & Diesing, M. (2014) A Comparison of Supervised Classification Methods for the Prediction of Substrate Type Using Multibeam Acoustic and Legacy Grain-Size Data. *PLOS ONE,* 9, e93950.

Stewart, T. A., Booth, D. T. & Rusli, M. U. (2018) Influence of sand grain size and nest microenvironment on incubation success, hatchling morphology and locomotion performance of green turtles (<i>Chelonia mydas</i>) at the Chagar Hutang Turtle Sanctuary, Redang Island, Malaysia. *Australian Journal of Zoology,* 66, 356-368.

Subarno, T., Siregar, V. P., Agus, S. B. & Sunuddin, A. (2016) Modelling Complex Terrain of Reef Geomorphological Structures in Harapan-kelapa Island, Kepulauan Seribu. *Procedia Environmental Sciences,* 33, 478-486.

Sudo, K., Quiros, T. E. a. L., Prathep, A., Luong, C. V., Lin, H.-J., Bujang, J. S., Ooi, J. L. S., Fortes, M. D., Zakaria, M. H., Yaakub, S. M., Tan, Y. M., Huang, X. & Nakaoka, M. (2021) Distribution, Temporal Change, and Conservation Status of Tropical Seagrass Beds in Southeast Asia: 2000–2020. *Frontiers in Marine Science,* 8.

Summers, G., Lim, A. & Wheeler, A. J. (2021) A Scalable, Supervised Classification of Seabed Sediment Waves Using an Object-Based Image Analysis Approach. *Remote Sensing,* 13, 2317.

Sun, K., Cui, W. & Chen, C. (2021) Review of Underwater Sensing Technologies and Applications. *Sensors,* 21, 7849.

Sutherland, T. F., Galloway, J., Loschiavo, R., Levings, C. D. & Hare, R. (2007) Calibration techniques and sampling resolution requirements for groundtruthing multibeam acoustic backscatter (EM3000) and QTC VIEW™ classification technology. *Estuarine, Coastal and Shelf Science,* 75, 447-458.

Swets, J. A. (1988) Measuring the accuracy of diagnostic systems. *Science,* 240, 1285-1293.

Temino-Boes, R., Romero, I., Pachés, M., Martinez-Guijarro, R. & Romero-Lopez, R. (2019) Anthropogenic impact on nitrification dynamics in coastal waters of the Mediterranean Sea. *Marine Pollution Bulletin,* 145, 14-22.

Thangaradjou, T. & Bhatt, J. R. (2017) Status of seagrass ecosystems in India. *Ocean & Coastal Management.*

Thuiller, W., Lafourcade, B., Engler, R. & Araújo, M. B. (2009) BIOMOD – a platform for ensemble forecasting of species distributions. *Ecography,* 32, 369-373.

Topouzelis, K., Makri, D., Stoupas, N., Papakonstantinou, A. & Katsanevakis, S. (2018) Seagrass mapping in Greek territorial waters using Landsat-8 satellite images. *International Journal of Applied Earth Observation and Geoinformation,* 67, 98-113.

Townsend, M., Thrush, S. F., Lohrer, A. M., Hewitt, J. E., Lundquist, C. J., Carbines, M. & Felsing, M. (2014) Overcoming the challenges of data scarcity in mapping marine ecosystem service potential. *Ecosystem Services,* 8, 44-55.

Trzcinska, K., Janowski, L., Nowak, J., Rucinska-Zjadacz, M., Kruss, A., Von Deimling, J. S., Pocwiardowski, P. & Tegowski, J. (2020) Spectral features of dual-frequency multibeam echosounder data for benthic habitat mapping. *Marine Geology,* 427, 106239.

Tuceryan, M. & Jain, A. K. (1993) Texture analysis. *Handbook of pattern recognition and computer vision*, 235-276.

Tyllianakis, E., Callaway, A., Vanstaen, K. & Luisetti, T. (2019) The value of information: Realising the economic benefits of mapping seagrass meadows in the British Virgin Islands. *Science of The Total Environment,* 650, 2107-2116.

Ubertini, M., Lefebvre, S., Gangnery, A., Grangeré, K., Le Gendre, R. & Orvain, F. (2012) Spatial variability of benthic-pelagic coupling in an estuary ecosystem: consequences for microphytobenthos resuspension phenomenon.

Uhrin, A. V. & Townsend, P. A. (2016) Improved seagrass mapping using linear spectral unmixing of aerial photographs. *Estuarine, Coastal and Shelf Science,* 171, 11-22.

Unsworth, R. K. F., Mckenzie, L. J., Collier, C. J., Cullen-Unsworth, L. C., Duarte, C. M., Eklöf, J. S., Jarvis, J. C., Jones, B. L. & Nordlund, L. M. (2019a) Global challenges for seagrass conservation. *Ambio,* 48, 801-815.

Unsworth, R. K. F., Nordlund, L. M. & Cullen-Unsworth, L. C. (2019b) Seagrass meadows support global fisheries production. *Conservation Letters,* 12, e12566.

Upadhyay, A., Singh, R. & Dhonde, O. (2020) Random forest based classification of seagrass habitat. *Journal of Information and Optimization Sciences,* 41, 613-620.

Van Audenhaege, L., Broad, E., Hendry, K. R. & Huvenne, V. a. I. (2021) High-Resolution Vertical Habitat Mapping of a Deep-Sea Cliff Offshore Greenland. *Frontiers in Marine Science,* 8.

Van Der Meer, F. D. & De Jong, S. M. (2001) *Imaging Spectrometry Basic Principles and Prospective Applications,* United States, Springer Science & Business Media.

Verfaillie, E., Doornenbal, P., Mitchell, A., White, J. & Van Lancker, V. (2007) The bathymetric position index (BPI) as a support tool for habitat mapping. *Worked Example for the MESH Final Guidance,* 14.

Veron, J. E., Devantier, L. M., Turak, E., Green, A. L., Kininmonth, S., Stafford-Smith, M. & Peterson, N. (2009) Delineating the coral triangle. *Galaxea, Journal of Coral Reef Studies,* 11, 91-100.

Verweij, M. C., Nagelkerken, I., Hans, I., Ruseler, S. M. & Mason, P. R. (2008) Seagrass nurseries contribute to coral reef fish populations. *Limnology and Oceanography,* 53, 1540-1547.

Viala, C., Lamouret, M. & Abadie, A. (2021) Seafloor classification using a multibeam echo sounder: A new rugosity index coupled with a pixel-based process to map Mediterranean marine habitats. *Applied Acoustics,* 179**,** 108067.

Vierod, A. D. T., Guinotte, J. M. & Davies, A. J. (2014) Predicting the distribution of vulnerable marine ecosystems in the deep sea using presence-background models. *Deep Sea Research Part II: Topical Studies in Oceanography,* 99**,** 6-18.

Walbridge, S., Slocum, N., Pobuda, M. & Wright, J. D. (2018) Unified Geomorphological Analysis Workflows with Benthic Terrain Modeler. *Geosciences,* 8.

Wang, B., Xu, Y. & Ran, J. (2017) Predicting suitable habitat of the Chinese monal (Lophophorus lhuysii) using ecological niche modeling in the Qionglai Mountains, China. *PeerJ,* 5**,** e3477.

Wang, M., Wu, Z., Yang, F., Ma, Y., Wang, X. H. & Zhao, D. (2018) Multifeature extraction and seafloor classification combining LiDAR and MBES data around Yuanzhi Island in the South China Sea. *Sensors,* 18**,** 3828.

Waycott, M., Duarte, C. M., Carruthers, T. J., Orth, R. J., Dennison, W. C., Olyarnik, S., Calladine, A., Fourqurean, J. W., Heck, K. L. & Hughes, A. R. (2009) Accelerating loss of seagrasses across the globe threatens coastal ecosystems. *Proceedings of the national academy of sciences,* 106**,** 12377-12381.

Wedding, L. M., Friedlander, A. M., Mcgranaghan, M., Yost, R. S. & Monaco, M. E. (2008) Using bathymetric lidar to define nearshore benthic habitat complexity: Implications for management of reef fish assemblages in Hawaii. *Remote Sensing of Environment,* 112**,** 4159-4165.

Williams, K. L. (2001) An effective density fluid model for acoustic propagation in sediments derived from Biot theory. *The Journal of the Acoustical Society of America,* 110**,** 2276-2281.

Wilson, M. F., O'connell, B., Brown, C., Guinan, J. C. & Grehan, A. J. (2007) Multiscale terrain analysis of multibeam bathymetry data for habitat mapping on the continental slope. *Marine Geodesy,* 30**,** 3-35.

Winters, G., Edelist, D., Shem-Tov, R., Beer, S. & Rilov, G. (2017) A low cost field-survey method for mapping seagrasses and their potential threats: an example from the northern Gulf of Aqaba, Red Sea. *Aquatic Conservation: Marine and Freshwater Ecosystems,* 27, 324-339.

Worm, B., Barbier Edward, B., Beaumont, N., Duffy, J. E., Folke, C., Halpern Benjamin, S., Jackson Jeremy, B. C., Lotze Heike, K., Micheli, F., Palumbi Stephen, R., Sala, E., Selkoe Kimberley, A., Stachowicz John, J. & Watson, R. (2006) Impacts of Biodiversity Loss on Ocean Ecosystem Services. *Science,* 314, 787-790.

Wright, D. J. & Heyman, W. D. (2008) Introduction to the special issue: marine and coastal GIS for geomorphology, habitat mapping, and marine reserves. *Marine Geodesy,* 31, 223-230.

Wu, X. B. & Smeins, F. E. (2000) Multiple-scale habitat modeling approach for rare plant conservation. *Landscape and Urban Planning,* 51, 11-28.

Xu, S., Xu, S., Zhou, Y., Zhao, P., Yue, S., Song, X., Zhang, X., Gu, R., Wang, P. & Zhang, Y. (2019) Single beam sonar reveals the distribution of the eelgrass Zostera marina L. and threats from the green tide algae Chaetomorpha linum K. in Swan-Lake lagoon (China). *Marine Pollution Bulletin,* 145, 611-623.

Yu, J., Henrys, S. A., Brown, C., Marsh, I. & Duffy, G. (2015) A combined boundary integral and Lambert's Law method for modelling multibeam backscatter data from the seafloor. *Continental Shelf Research,* 103, 60-69.

Zainuddin Lubis, M., Pujiyati, S., Prasetyo, B. & Choanji, T. (2019) Review : Bathymetry Mapping Using Underwater Acoustic Technology. *Journal of Geoscience, Engineering, Environment, and Technology,* 4, 135.

Zajac, R. (2001) Organism–sediment relations at multiple spatial scales: implications for community structure and successional dynamics.

Zajac, R. N. (2008) Challenges in marine, soft-sediment benthoscape ecology. *Landscape Ecology,* 23, 7-18.

Zakaria, M. H. & Bujang, J. S. (2004) Seagrass communities of Punang-Bt. Sari-Lawas river estuary, Sarawak, East Malaysia. *Bio-Sci. Res. Bull,* 20, 1-8.

Zakaria, M. H. & Bujang, J. S. (2005) Morphometrics of seagrasses in relation to their distribution at Punang-Bt. Sari-Lawas river estuary, Sarawak, East Malaysia. *Bulletin of Pure and Applied Sciences,* 24, 15-23.

Zakaria, M. H. & Bujang, J. S. (2011) Disturbances in seagrasses ecosystem in Malaysia. Seagrasses: resource status and trends in Indonesia, Japan, Malaysia, Thailand and Vietnam. Seizando-Shoten, Tokyo, 67-78.

Zakaria, M. H. & Bujang, J. S. (2013) Occurrence and distribution of seagrasses in waters of Perhentian Island Archipelago, Malaysia. *Journal of Fisheries and Aquatic Science,* 8, 441.

Zakaria, M. H., Bujang, J. S. & Abdul Razak, F. R. (2003) Occurrence and Morphological Description of Seagrasses from Pulau Redang, Terengganu, Malaysia. *Jurnal Teknologi,* 38.

Zapata-Ramirez, P. A., Huete-Stauffer, C., Coppo, S. & Cerrano, C. (Year) Published. Using Maxent to understand and predict the distribution of coralligenous environments. Proceedings 2nd Mediterranean Symposium on the Conservation of Coralligenous and Other Calcareous Bio-concretions, Portoroz, 2014. 183-188.

Zevenbergen, L. W. & Thorne, C. R. (1987) Quantitative analysis of land surface topography. *Earth Surface Processes and Landforms,* 12, 47-56.

Zhafarina, Z. & Wicaksono, P. (Year) Published. Benthic Habitat Mapping on Different Coral Reef Types Using Random Forest and Support Vector Machine Algorithm. 6th International Symposium on LAPAN-IPB Satellite (LISAT), Sep 17-18 2019 Bogor, INDONESIA.

Zhai, H., Zhang, H., Zhang, L., Li, P. & Plaza, A. (2016) A New Sparse Subspace Clustering Algorithm for Hyperspectral Remote Sensing Imagery. *IEEE Geoscience and Remote Sensing Letters,* PP, 1-5.

Zhang, J., Huang, Y., Pu, R., Gonzalez-Moreno, P., Yuan, L., Wu, K. & Huang, W. (2019) Monitoring plant diseases and pests through remote sensing technology: A review. *Computers and Electronics in Agriculture,* 165, 104943.

Zheng, H., Shen, G., Shang, L., Lv, X., Wang, Q., Mclaughlin, N. & He, X. (2016) Efficacy of conservation strategies for endangered oriental white storks (Ciconia boyciana) under climate change in Northeast China. *Biological Conservation,* 204, 367-377.

Zhu, Z., Cui, X., Zhang, K., Ai, B., Shi, B. & Yang, F. (2021) DNN-based seabed classification using differently weighted MBES multifeatures. *Marine Geology,* 438**,** 106519.

Zucchetta, M., Venier, C., Taji, M. A., Mangin, A. & Pastres, R. (2016) Modelling the spatial distribution of the seagrass Posidonia oceanica along the North African coast: Implications for the assessment of Good Environmental Status. *Ecological Indicators,* 61**,** 1011-1023.

Zuur, A., Ieno, E. N., Walker, N., Saveliev, A. A. & Smith, G. M. (2009) *Mixed effects models and extensions in ecology with R*, Springer Science & Business Media.

LIST OF PUBLICATIONS

Journal with Impact Factor

1. **Muhamad, M. A. H.**, Che Hasan, R., Md Said, N., and Ooi, J. L. S. (2021). Seagrass habitat suitability model for Redang Marine Park using multibeam echosounder data: Testing different spatial resolutions and analysis window sizes. PLOS ONE 16(9): e0257761. https://doi.org/10.1371/journal.pone.0257761. **(Q2, IF: 3.24)**

Indexed Conference Proceedings

1. **Muhamad, M. A. H.**, Che Hasan, R. (2022). Seagrass Habitat Suitability Models Using a Multibeam Echosounder Data and Multiple Machine Learning Algorithms. Paper accepted for IGRSM International Conference and Exhibition on Geospatial & Remote Sensing. **(Indexed by SCOPUS)**

2. **Muhamad, M. A. H.**, Che Hasan, R. (2019). Seagrass habitat suitability map at Merambong shoal, Johor: a preliminary study using multibeam echosounder and maxent modelling. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLII-4/W16, 2019 6th International Conference on Geomatics and Geospatial Technology (GGT 2019). https://doi.org/10.5194/isprs-archives-XLII-4-W16-463-2019. **(Indexed by SCOPUS)**

3. **Muhamad, M. A. H.**, Che Hasan, R. (2018). Multibeam echosounder sonar for seagrass mapping. Paper presented at the Tropical Ocean and Marine Sciences International Symposium (TOMSY2018).