

**SPATIAL AND TEMPORAL VARIABILITY IN
THE COMMUNITY STRUCTURE OF FISHES
AND INVERTEBRATES OF MARUDU BAY,
SABAH**

CHEONG KAI CHING



UMS
PERPUSTAKAAN
UNIVERSITI MALAYSIA SABAH
UNIVERSITI MALAYSIA SABAH

**THESIS SUBMISSION IN FULFILLMENT FOR
THE DEGREE OF MASTER OF SCIENCE**

**BORNEO MARINE RESEARCH INSTITUTE
UNIVERSITI MALAYSIA SABAH
2018**

UNIVERSITI MALAYSIA SABAH

BORANG PENGESAHAN STATUS TESIS

JUDUL: **SPATIAL AND TEMPORAL VARIABILITY IN THE COMMUNITY STRUCTURE OF FISHES AND INVERTEBRATES OF MARUDU BAY, SABAH**

IJAZAH: **SARJANA SAINS (SAINS MARIN)**

Saya **CHEONG KAI CHING**, Sesi **2014-2018** mengaku membenarkan tesis Sarjana ini disimpan di Perpustakaan Universiti Malaysia Sabah dengan syarat-syarat kegunaan seperti berikut:

1. Tesis ini adalah hak milik Universiti Malaysia Sabah.
2. Perpustakaan Universiti Malaysia Sabah dibenarkan membuat salinan untuk tujuan pengajian sahaja.
3. Perpustakaan dibenarkan membuat salinan tesis ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. Sila tandakan (/):

☐

SULIT

(Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia seperti yang termaktub di dalam AKTA RAHSIA 1972)

☐

TERHAD

(Mengandungi maklumat TERHAD yang telah ditentukan oleh organisasi/badan di mana penyelidikan dijalankan)

☒

TIDAK TERHAD

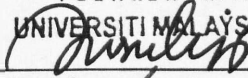


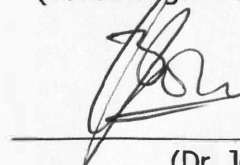
CHEONG KAI CHING
MY1321002T

Tarikh : 06 Sep 2018

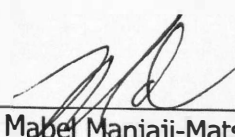
Disahkan oleh,
NURULAINI BINTU BOMAL,
PUSTAKAWAN KANAN

UNIVERSITI MALAYSIA SABAH


(Tandatangan Pustakawan)



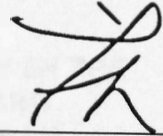
(Dr. John Madin)
Penyelia


(Dr. Bernadette Mabel Manjaji-Matsumoto)
Penyelia Bersama

DECLARATION

I hereby declare that the material in this thesis is my own except for quotations, excerpts, equations, summaries and references, which have been duly acknowledged.

21th July 2018



Cheong Kai Ching
MY1321002T



UMS
UNIVERSITI MALAYSIA SABAH

CERTIFICATION

NAME : CHEONG KAI CHING
MATRIC NO. : MY1321002T
TITLE : SPATIAL AND TEMPORAL VARIABILITY IN THE
COMMUNITY STRUCTURE OF FISHES AND
INVERTEBRATES OF MARUDU BAY, SABAH
DEGREE : MASTER OF SCIENCE (MARINE SCIENCE)
VIVA DATE : 19TH APRIL 2018

CERTIFIED BY

Signature

1. **SUPERVISOR**
Dr. John Madin



2. **CO-SUPERVISOR**
Dr. Bernadette Mabel Manjaji-Matsumoto

A handwritten signature in black ink, written over a horizontal line. The signature is stylized and appears to be 'B. Manjaji-Matsumoto'.

ACKNOWLEDGEMENTS

The completion of this thesis would not be possible without the help and encouragement of many individuals. First of all, I would like to thank both of my supervisors Dr. John Madin and Dr. B. Mabel Manjaji-Matsumoto for their never-ending guidance and patience in making this a success. Thanks to Dr. John for his valuable time and effort, reviewing and correcting my mistakes, I always learned hugely from his suggestions and comments on my study and writing. Dr. Mabel has been generously offered all the help I need, her kindness, passion, and wisdom guide me through this sea of knowledge.

My love goes to my family, who always give their full support and encouragement all the time. Special thanks to my soulmate Ying Xin, for your love and belief, always remind me not to surrender, you are the light that never goes out, thanks Lao Ma for giving you the kindest heart.

Thanks to every cabin crews who enriched my time at Sabah with joy and laughter. I wish to give my gratitude to all the individuals that aid me in the field and laboratory, namely Marinus, Kak Lydia, Kak Lulu, Agang, Herman, and Roy. Finally, I greatly appreciate all members in IPMB, UMS for their help to ensure a smooth sail on the course of this study.

This study is funded under Niche Research Grant Scheme NRGs 0003 from the Ministry of Higher Education Malaysia.

CHEONG KAI CHING
21st September 2017



UMS
UNIVERSITI MALAYSIA SABAH

ABSTRACT

Estuaries serve as refuge, foraging, breeding and nursery ground for fishes and invertebrates, securing the fisheries stock as well as maintaining biodiversity. Soft-bottom substrate contribute to nearly half the area of global estuarine habitats; however studies regarding community structure of this substrate are relatively scarce compared to other estuarine habitats (i.e. mangroves, seagrass) especially in Southeast Asia. The present study was conducted at subtidal flats in Marudu Bay (Sabah, Malaysia), which is now part of Tun Mustapha Park, Malaysia's largest marine park in Malaysia after its' gazettelement in 2016. This study aims to (1) determine spatial and temporal species composition and abundance of fishes and invertebrates in estuarine subtidal flats, (2) determine their relationship to environmental conditions, and (3) analyze the population dynamics of dominant and commonly marketed species to understand the status of the fisheries stock. The study sites are located at estuarine subtidal flats of five rivers which flows into the Marudu Bay, namely Matunggong River, Bandau River, Taritipan River, Bengkoka River and Telaga River. Sampling of fishes and invertebrates were conducted monthly from March 2014 until April 2015 using three fishing gears including otter trawl, trammel and cast net. Corresponding environmental variables including water parameters (i.e. salinity, temperature), nutrients (i.e. nitrogen, phosphorus) and sediment quality (i.e. particle size, carbon content) were determined. A total of 138 species of fish and invertebrates were recorded, comprised of 79 fish species and 59 invertebrate species. Fish community was dominated (nearly 90% of total fish abundance) by a small number of species, including pony fish (*Eubleekeria jonesi*, *Secutor megalolepis*, *Photopectoralis bindus*), catfish (*Arius venosus*) and scad (*Alepes djedaba*). In terms of invertebrate composition, commercially important crab (i.e. *Portunus pelagicus* and *Penaeus merguensis*) and jellyfish (i.e. *Lobonemoides robustus*) were the most commonly recorded. The abundance of two jellyfish species (*L. robustus* and *Catostylus townsendi*) were recorded as markedly seasonally abundant. The total abundance of fish and invertebrate was significantly higher ($p < 0.05$) from August to April with the highest at nearly 16,000 individual/km². Notably, the abundance of invertebrates was higher from March to June, with most of the abundance contributed by jellyfish (*L. robustus*). Diversity was higher at Matunggong and Bandau River with $H' > 0.68$ and $J' > 0.5$ compared to other sites. The population dynamics of six dominant and commonly marketed species was determined. Fishing pressure was observed in ponyfish (*E. jonesi*) and catfish (*A. venosus*), where fishing mortality was higher than natural mortality with 0.85 and 0.55 respectively. Increase in total abundance ($\rho = -0.38$) and diversity ($\rho = -0.32$) was significantly ($p < 0.05$) correlated with lower salinity and temperature, consequently related with higher rainfall. Salinity is believed to be a key factor triggering the seasonal bloom of jellyfish with significant ($p < 0.05$) correlation of 0.6, and high abundance of jellyfish is likely causing higher level of soluble reactive phosphorus ($\rho = 0.63$). Temporal changes of species aggregation were mainly affected by salinity and temperature, while particle size and sediment nutrients affecting species aggregation in different sites. Estuarine subtidal flats in Marudu Bay was found serving as nursery ground for several commercially important fish species (i.e. Carangidae, Sciaenidae, Polynemidae, Haemulidae), emphasizing the importance of the subtidal flats in terms of biodiversity and productivity. Essential biological, ecological and fisheries information obtained in this study is important in supporting future studies and management planning for Marudu Bay and the newly gazetted Tun Mustapha Park.

ABSTRAK

KEBOLEHUBAHAN SPATIAL DAN TEMPORAL DALAM STRUKTUR KOMUNITI IKAN DAN INVERTEBRATA DI TELUK MARUDU, SABAH

Muara sungai berfungsi sebagai tempat untuk perlindungan, pencarian makanan, pembiakan dan kawasan nurseri bagi ikan dan invertebrata, yang dapat menjamin stok perikanan dan biodiversiti. Habitat kawasan muara berlumpur lembut membentuk hampir separuh jumlah kawasan habitat muara seluruh dunia, namun secara relatif kajian yang berkenaan dengan struktur komunitinya kurang berbanding habitat muara lain (i.e. paya bakau, rumput laut) terutamanya di Asia Tenggara. Kajian ini telah dijalankan di dataran subtidal Teluk Marudu (Sabah, Malaysia) yang terletak dalam kawasan Taman Tun Mustapha, yang telah diwartakan pada tahun 2016 dan merupakan taman marin terbesar di Malaysia. Sasaran kajian adalah untuk (1) mengkaji kebolehubahan komposisi serta kelimpahan spesies ikan dan invertebrata mengikut spatial dan temporal di dataran subtidal muara, (2) hubungkaitnya dengan keadaan persekitaran, dan (3) dinamik populasi spesies yang dominan dan sering dipasarkan bagi memahami status stok perikanan. Kawasan kajian terletak di dataran subtidal muara lima sungai iaitu Sungai Matunggong, Sungai Bandau, Sungai Taritipan, Sungai Bengkoka dan Sungai Telaga. Penyampelan ikan dan invertebrata dijalankan setiap bulan dari Mac 2014 hingga April 2015 menggunakan tiga jenis alat tangkapan ikan iaitu pukat tunda (otter trawl), pukat tiga lapis dan jala. Faktor persekitaran termasuk parameter air (i.e. kemasinan, suhu), nutrien (i.e. nitrogen, fosforus) dan kualiti endapan (i.e. saiz partikel, kandungan karbon) telah ditentukan bagi setiap pensampelan. Sebanyak 138 spesies telah direkodkan, terdiri dari 79 spesies ikan dan 59 spesies invertebrata. Komuniti ikan telah didominasi (hampir 90% daripada jumlah kelimpahan ikan) oleh hanya beberapa spesis termasuk ikan kekek (*Eubleekeria jonesi*, *Secutor megalolepis*, *Photopectoralis bindus*) ikan duri (*Arius venosus*) dan ikan pelata (*Alepes djedaba*). Bagi komposisi invertebrata, spesies komersial yang penting (i.e. *Portunus pelagicus* dan *Peneaus merguensis*) dan ubur-ubur (*Lobonemoides robustus*) merupakan antara yang biasa direkodkan. Ubur-ubur seperti *L. robustus* dan *Catostylus townsendi* menyumbang kepada kelimpahan bermusim yang tinggi. Jumlah kelimpahan ikan dan invertebrata adalah lebih tinggi ($p < 0.05$) pada bulan Ogos hingga April dengan nilai tertinggi mencecah 16,000 ind./km². Namun begitu, kelimpahan invertebrata adalah lebih tinggi antara bulan Mac hingga Jun, dengan kebanyakannya terdiri dari ubur-ubur *L. robustus*. Diversiti adalah lebih tinggi di Sungai Matunggong dan Sungai Bandau dengan $H' > 0.68$ dan $J' > 0.5$ berbanding dengan kawasan lain. Tekanan penangkapan ikan turut diperhatikan keatas ikan kekek (*E. jonesi*) dan ikan duri (*A. venosus*), di mana kematian penangkapan ikan (0.85) adalah lebih tinggi berbanding dengan kematian semulajadi (0.55). Peningkatan dalam jumlah kelimpahan ($\rho = -0.38$) dan kepelbagaian ($\rho = -0.32$) adalah berkorelasi ($p < 0.05$) dengan kemasinan dan suhu yang lebih rendah ekoran daripada kadar hujan yang tinggi. Kemasinan dipercayai merupakan faktor utama pencetus perkembangan bermusim populasi ubur-ubur dengan korelasi 0.6 yang signifikan ($p < 0.05$), serta kelimpahan ubur-ubur yang tinggi mungkin menyebabkan aras fosforus reaktif terlarut menjadi tinggi ($\rho = 0.63$). Perubahan temporal agregasi spesis kebanyakannya dipengaruhi oleh kemasinan dan suhu, manakala saiz partikel dan nutrien endapan mempengaruhi agregasi di kawasan yang berbeza. Dataran subtidal muara di Teluk Marudu didapati berfungsi sebagai kawasan nurseri bagi beberapa

ikan yang mempunyai kepentingan komersial (i.e. Carangidae, Sciaenidae, Polynemidae, Haemulidae), sekaligus menekankan kepentingan dataran subtidal dari sudut biodiversiti dan produktiviti. Maklumat penting yang telah diperolehi dapat menyokong kajian di masa hadapan serta rancangan pengurusan di Teluk Marudu dan Taman Tun Mustapha.



UMS
UNIVERSITI MALAYSIA SABAH

TABLE OF CONTENTS

	Page
TITLE	i
DECLARATION	ii
CERTIFICATION	iii
ACKNOWLEDGEMENTS	iv
ABSTRACT	v
ABSTRAK	vi
TABLE OF CONTENTS	viii
LIST OF TABLES	xi
LIST OF FIGURES	xiii
LIST OF ABBREVIATIONS	xvi
LIST OF APPENDICES	xvii
CHAPTER 1: INTRODUCTION	1
1.1 Soft Bottom Estuarine Ecosystem	1
1.2 Overview of Marudu Bay	3
1.2.1 Geographical Characteristics	3
1.2.2 Fishery Activities	4
1.3 Statement of Issue	5
1.4 Scope and Objective of Study	7
1.5 Significance and Limitation of Study	7
CHAPTER 2: LITERATURE REVIEW	9
2.1 Shallow Estuarine Subtidal Flats	9
2.2 Fisheries Importance of Subtidal Flats	11
2.3 Factors Affecting Community Structure	13
2.4 Estuarine Habitats and Anthropogenic Impact	14
2.5 Fisheries Population Dynamics	15
CHAPTER 3: MATERIALS AND METHODS	16
3.1 Study Area and Sampling Sites	16
3.2 Field Sampling and Methods	19
3.2.1 Fish and Invertebrate Sampling	19
3.2.2 Physical and Chemical Parameters	22
3.3 Laboratory Treatment and Analysis	24

3.3.1	Water Quality Analysis	24
3.3.2	Sediment Analysis	25
3.3.3	Fish and Invertebrate Samples Analysis	26
3.4	Computation and Statistical Analysis	27
3.4.1	Catch per Unit Effort (CPUE)	27
3.4.2	Ecological Indices	28
3.4.3	Statistical Analysis	29
3.4.4	Population Dynamics	30
CHAPTER 4: RESULTS		31
4.1	Environmental Conditions	31
4.1.1	Rainfall	31
4.1.2	Water Parameters	32
4.1.3	Nutrients and Chlorophyll- <i>a</i>	35
4.1.4	Granulometry and Nutrients in Sediment	37
4.1.5	Summary of Connectivity of Environmental Parameters	41
4.2	Community Structure and Abundance of Fishes and Invertebrates	42
4.2.1	Species Composition	42
4.2.2	Total Abundance and Ecological Indices	50
4.2.3	Abundance and Diversity of Fish and Invertebrates	52
4.2.4	Species Assemblages of Fish and Invertebrates	57
4.2.5	Similarity in the Occurrence of Species Assemblages	58
4.2.6	Day and Night Species Assemblage	59
4.3	Population Dynamics of Fish and Invertebrates	61
4.3.1	Length-weight Relationship	61
4.3.2	Growth Parameters and Exploitation Rates	61
4.4	Community Structure in Relation to Environmental Parameters	65
CHAPTER 5: DISCUSSION		68
5.1	Species Composition and Diversity	68
5.2	Abundance of Fish and Invertebrates	71
5.3	Species Assemblages and Relationship	72
5.4	Population Dynamic and Exploitation Rates of Fishery Resources	75
5.5	Effect of Environmental Factors on Community Structure of Fish and Invertebrates	77

CHAPTER 6: CONCLUSION AND RECOMMENDATION	80
REFERENCES	83
APPENDICES	94



LIST OF TABLES

	Page
Table 3.1: Co-ordinates of each sampling stations in Figure 3.1. The station names were the name after the river where the sampling took place.	17
Table 3.2: Field sampling tasks achieved from March 2014 until April 2015 at different site. Note that sampling at BKR and TLR was not conducted during Jul, Nov 2014 and Feb 2015 due to rough weather condition. (*Night sampling was conducted using trammel net; NM-New moon; FN-Full moon)	24
Table 4.1: Loadings of principle component 1 and 2 for 19 environmental variables, with main factors highlighted with *.	41
Table 4.2: List of species found at five sampling sites (MR: Matunggong River, BR: Bandau River, TR: Taritipan River, BKR: Bengkoka River, TLR: Telaga River) in Marudu Bay caught by different gears, in which a: trawl net; b: trammel net; c: cast net; n: night sampling by trammel net (only at MR, BR and TR); "-" indicates not present.	43
Table 4.3: Most abundant species (only top 10 most abundant shown) caught by different fishing gear between March 2014 and April 2015. Number of species (S) collected by each gear was indicated in bracket.	48
Table 4.4: Records of juvenile of commercially important fish species and its occurrence in month and site. Sites are indicated by alphabet where M: Matunggong River, B: Bandau River, T: Taritipan River, b: Bengkoka River and t: Telaga river.	49
Table 4.5: SIMPER analysis of average dissimilarity among daytime (D), full moon nighttime (FN) and new moon nighttime (NN). Dissimilarity was based on Bray-Curtis Index, and dissimilarity contribution by species (cumulative to 60 %) was stated.	60
Table 4.6: Length-weight relationship of common species. (N: individual measured; TL: total length in mm; W: weight in g; a : intercept; b : slope, relative growth rate; r^2 : correlation)	61

Table 4.7:	Total mortality and growth parameters of common species. (L_{∞} : asymptotic length; K: growth coefficient; GPI: Growth Performance Index; Z: total mortality; M: natural mortality; F: fishing mortality; E: exploitation rate; t_{max} : longevity)	63
Table 5.1:	Comparison of fish community in different types of habitats from present study and past regional studies.	69
Table 5.2:	Length-weight relationship of fishes and invertebrates at different locations.	76



LIST OF FIGURES

	Page
Figure 3.1: Location of Marudu Bay and sampling sites, namely Matunggong River (MR), Bandau River (BR), Taritipan River (TR), Bengkoka River (BKR) and Telaga River (TLR). Source: United Kingdom Hydrographic Office (1990) for depth contour and Spalding <i>et al.</i> (2010) for mangrove coverage.	18
Figure 3.2: Measurements (left) and photo (right) of bottom otter trawl used for sampling. The trawl line is 12 meters connected to the boat, which was powered by 30 horsepower outboard engine and haul at speed of 1 – 3 knots.	20
Figure 3.3: Sample collection using trammel net, the measurements of the trammel net is indicated in the inset picture. Total length of net is 60 m and height is 1.5 m. The net comprised three layers nets with different mesh sizes (14 cm and 4 cm).	21
Figure 3.4: Sampling using cast net by fisherman, measurements of cast net is shown in inset picture. The net has a maximum radius of 2.1 m when fully expanded.	22
Figure 4.1: Rainfall data collected by Malaysian Meteorological Department at Langkon Estate Meteorology Station (97617, no. 22) from March 2014 to April 2015.	31
Figure 4.2: Spatial (MR, BR, TR, BKR and TLR) and temporal (March 2014 - April 2015) mean ($\pm$ SD) of (a) temperature, (b) salinity, (c) pH, (d) dissolved oxygen (DO), (e) total suspended solid (TSS) and (f) total organic matter (TOM), with averaged result indicated in dashed black line.	34
Figure 4.3: Spatial (MR, BR, TR, BKR and TLR) and temporal (March 2014 - April 2015) mean concentration ($\pm$ SD) of (a) $\text{NH}_3\text{-N}$, (b) $\text{NO}_2\text{-N}$, (c) $\text{NO}_3\text{-N}$, (d) SRSi, (e) SRP and (f) chlorophyll- <i>a</i> , with average concentration plotted in dashed black line.	36

- Figure 4.4: (a) Spatial (MR, BR, TR, BKR and TLR) and temporal (Mar 38
2014 – Apr 2015) mean particle size ($\pm$ SD); (b) Monthly
mean percentage ($\pm$ SD) of clay, silt and sand percentages at
each site.
- Figure 4.5: Spatial (MR, BR, TR, BKR and TLR) and temporal (March 2014 40
- April 2015) mean ($\pm$ SD) of pH, total organic carbon (TOC),
total phosphorus (T-P), total nitrogen (T-N) and C/N ratio in
sediment.
- Figure 4.6: PCA of environmental parameters, where symbols indicate 42
months and in each month different colours representing
different sites. The sampling sites can be separated into two
groups (dashed line) based on granulometry characteristics
of the sediment.
- Figure 4.7: Spatial (MR, BR, TR, BKR and TLR) and temporal (March 2014 51
- April 2015) mean ($\pm$ SD) of (a) abundance, (b) species
richness, (c) diversity (H') and (d) equitability (J').
- Figure 4.8: Spatial (MR, BR, TR, BKR and TLR) and temporal (March 2014 53
- April 2015) mean ($\pm$ SD) of (a) fish abundance, (b) diversity
(H') of fish, (c) equitability (J') of fish, (d) invertebrate
abundance, (e) diversity (H') of invertebrates and (f)
equitability (J') of invertebrates.
- Figure 4.9: Spatial (MR, BR, TR, BKR and TLR) and temporal (March 2014 55
- April 2015) mean ($\pm$ SD) of abundance of six most abundant
fishes, namely (a) *E. jonesi*, (b) *S. megalolepis*, (c) *P. bindus*,
(d) *A. djedaba* and (e) *J. carouna*.
- Figure 4.10: Spatial (MR, BR, TR, BKR and TLR) and temporal (March 2014 56
- April 2015) mean ($\pm$ SD) of abundance of six most abundant
invertebrates, namely (a) *L. robustus*, (b) *C. townsendi*, (c)
Malo sp., (d) *A. typicus*, (e) *P. pelagicus* and (f) *P.*
merguiensis.
- Figure 4.11: Cluster analysis of 26 species that contributed 98 % of total 57
abundance. Dashed box indicates three groups with at least
20% similarity.

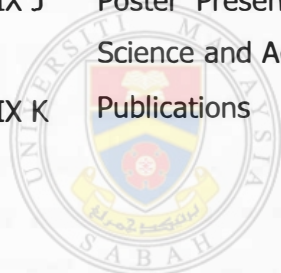
- Figure 4.12: nMDS ordination of species assemblage, where symbols indicate months and in each month different colours representing different sites. Vector indicates abundance of 17 most dominant species. Red and black dashed lines indicate differences groups in months (Apr-Jun, Jul-Mar) and sites (MR-BR-TR, BKR-TLR) respectively. 58
- Figure 4.13: Restructured length frequency distribution with growth curve output from FiSAT II for *E. jonesi*, *A. venosus*, *P. pelagicus* and *P. merguensis*. 64
- Figure 4.14: CCA ordination of 32 species (contributed 99% of total abundance) in relation to eight selected environmental parameters including salinity, temperature, SRP, TSS, NH₃, SRSi and PC1. 67
- Figure 5.1: Aggregation pattern of 10 dominant species during April until June. Number of species' figures is just for presentation purpose and does not indicate the actual abundance of these 10 species. 73
- Figure 5.2: Aggregation pattern of 10 dominant species during July until March. Number of species' figures is just for presentation purpose, and does not indicate the actual abundance of these 10 species. 74

LIST OF ABBREVIATIONS

ANOVA	-	Analysis of variance
CCA	-	Canonical correspondence analysis
Chl-<i>a</i>	-	Chlorophyll- <i>a</i>
CPUE	-	Catch per effort unit
DIN	-	Dissolved inorganic nitrogen
DO	-	Dissolved oxygen
ELEFAN I	-	Electronic Length Frequency Analysis
GPI	-	Growth performance index
HP	-	Horsepower
Kg.	-	Kampung (Village)
mg	-	Milligram
mm	-	Millimetre
NEM	-	Northeast monsoon
nMDS	-	Non-metric multidimensional scaling
PCA	-	Principal component analysis
PERMANOVA	-	Permutational multivariate analysis
ppm	-	Part per million
psu	-	Practical salinity unit
SD	-	Standard deviation
SIMPER	-	Similarity percentages analysis
SL	-	Standard length
SRP	-	Soluble reactive phosphorus
SRSi	-	Soluble reactive silica
SSME	-	Sulu-Sulawesi Marine Ecoregion
SWM	-	Southwest monsoon
TL	-	Total length
TMP	-	Tun Mustapha Park
TOC	-	Total organic carbon
TOM	-	Total organic matter
TSS	-	Total suspended solid

LIST OF APPENDICES

	Page
APPENDIX A	Determination of Total Ammonia-nitrogen (NH ₃ -N) 94
APPENDIX B	Determination of Nitrite (NO ₂ -N) and Nitrate (NO ₃ -N) 96
APPENDIX C	Determination of Soluble Reactive Phosphorus (SRP) 99
APPENDIX D	Determination of Soluble Reactive Silica (SRSi) 101
APPENDIX E	Determination of Chlorophyll- <i>a</i> 102
APPENDIX F	Determination of Total Suspended Solids 103
APPENDIX G	Determination of Total-P in Sediment 104
APPENDIX H	Statistical Analysis Output 105
APPENDIX I	List of common species sold at fish market around Marudu Bay, as observed during fish market survey on 22 nd August 2014. (K: Kudat, KM: Kota Marudu, T: Taritipan, TM: Tanah Merah) 126
APPENDIX J	Poster Presentation – International Conference of Marine Science and Aquaculture (ICOMSA) 2015 128
APPENDIX K	Publications 129



UMS
UNIVERSITI MALAYSIA SABAH

CHAPTER 1

INTRODUCTION

1.1 Soft Bottom Estuarine Ecosystem

Estuarine ecosystem is known to be one of the most complex system in nature and is vulnerable to environmental pressures and anthropogenic exploitation. As estuaries are located where the river meets the sea, salinity is known to be the critical factor influencing the community structure, and could vary from 0.5 ppt up to 30 ppt within the mixing zone of river and sea (Day, Crump, Kemp and Yáñez-Arancibia, 2012). Tropical estuarine ecosystem comprises of highly productive and ecologically important habitats, including vegetated and soft-bottom habitats. Vegetated habitats refer to mangroves, seagrass, marsh and reed bed. Most of these habitats are well known for their functions as nursery, foraging and breeding ground of marine organisms, water purification zone, coastline protection and carbon sink (Duarte and Cebrián, 1996; Donato, Kauffman, Murdiyarso, Kurnianto, Stidham and Kanninen, 2011; Blaber, 2013).

On the other hand, soft-bottom habitats such as mudflat or sandbar are also known for high primary productivity by providing wide illuminated area for benthic microalgae and macroalgae growth, subsequently contributing to high abundance and diversity of macrobenthic and nekton species (Newell, Marshall, Sasekumar and Chong, 1995; Solan, Raffaelli, Paterson, White and Pierce, 2006; Day *et al.*, 2012). The ecological function of soft-bottom habitats has gained much attention from researchers in the past 20 years, including high primary and secondary productivity, nutrient recycling, foraging ground for marine animals and birds, refuge and nursery for post larvae of fish and invertebrates (Bishop and Khan, 1999; Nielsen, Banta and Pedersen, 2004; Day *et al.*, 2012). In terms of carbon storage, export of carbon in soft-bottom habitats is low compared to rocky and reef system, and acting as one of

the major carbon sink only lower than mangroves and seagrass globally (Duarte and Cebrián, 1996; Phang, Chou and Friess, 2015). Consecutively, recycling of nutrient from sediment to biota by microalgae and grazer in these areas is the greatest in estuarine system where carbon and nutrients become biologically available (Nielsen *et al.*, 2004).

With its relative position to tidal exposure, estuarine soft-bottom habitats can be further categorized into intertidal and subtidal areas, where intertidal areas are temporally exposed during low tide, and subtidal area are fully submerged in shallow water at all time. Being temporally exposed during low tide, intertidal mudflat provides resourceful foraging ground for migrating birds and crab-eating macaques, foraging for infauna and epifauna such as Cerith snails, fiddler crabs (*Uca* spp.), soldier crabs (*Mictyris brevidactylus*), mudskippers and worms (Day *et al.*, 2012). Subtidal mudflats, however, being fully submerged, its habitat uses are only accessible for marine organism. It is known to inhabit high abundance of commercially important infauna and nekton species, including banana prawn (*Penaeus merguensis*) and yellow prawn (*Metapenaeus brevicornis*), blue swimmer crab (*Portunus pelagicus*), Asiatic hard clam (*Meretrix meretrix*), common geloina (*Geloina expansa*), blood cockle (*Tegillarca granosa*) as observed in Marudu Bay, which represent a typical example of tropical soft-bottom habitat system. The species richness of nekton in subtidal soft-bottom habitats is among the highest of other estuarine habitats in both temperate and tropic areas. They utilize subtidal shallow habitats mainly for foraging, followed by nursery, spawning and diadromy (Day *et al.*, 2012). More than 50% of the nekton species found in subtidal soft-bottom habitats are commercially important in a tropical example (Blaber, 1997).

Despite its high productivity, ecological importance and large coverage with up to half of the world's estuarine area (Day *et al.*, 2012), the function of subtidal soft-bottom habitats is often overlooked and relatively less studied globally compared to those of vegetated estuarine habitats and tidal mudflat, especially the habitat usage by nekton such as fishes and invertebrates (Ooi and Chong, 2011). This is also applicable in Marudu Bay area where vast areas of subtidal mudflat adjacent to main river are less studied and prone to environmental and anthropogenic pressures.

1.2 Overview of Marudu Bay

1.2.1 Geographical Characteristics

This study focused on estuarine subtidal mudflats in Marudu Bay located at northern Sabah (Malaysia). Marudu Bay covered a 150,000ha area at geographical coordinates 6°30' - 7°00' N (latitude), 116°46' - 117°07' E (longitude). Marudu Bay is located within Tun Mustapha Park (TMP), Malaysia's largest marine park gazetted in May 2016 covering an area of 898,762.76 hectares. Located at northern tip of Sabah, the climate at Marudu Bay is generally tropical climate where its seasonal changes is driven by southwest and northeast monsoons. Heavier rainfall usually occurs during northeast monsoon, from November to March, while lower rainfall occurs during southwest monsoon, from May to September. The highest rainfall usually happens in January while the lowest is in April (DeVantier, Alcala and Wilkinson, 2004; Malaysian Meteorological Department, 2016).

Marudu Bay possesses valuable mangrove forest along its coastal area, which covers approximately 23765 ha, distributed in the district of Kudat (2695 ha), Kota Marudu (8836 ha) and Pitas (12234 ha) (Spalding, Kainuma and Collins, 2010; Faridah-Hanum, Kudus and Saari, 2012). Most of the mangroves are managed as Class V forest reserves by the Sabah Forestry Department (Sabah Forestry Department, 2014). Pristine mangrove forest spreads along the coastline of Marudu Bay and extends into the river, a common feature found in tropical estuaries and function as nursery for fish and invertebrates. The rich riverine discharge feeds the mangroves and its adjacent waters with high load of nutrients and sediment, forming a variety of high productivity habitats.

Almost the entire southern part of the Bay near Kota Marudu and Matunggong consist of intertidal and subtidal mudflat. Some mudflat is exposed during extreme low tide. At Bandau River, mudflat can extend to more than 500 m seaward from the mangrove area. East of bay, rocky shore with mangrove patches can be found along the coastline from Kampung Marasimsim to further north until Kampung Rosob. Further to the north at Bengkoka peninsula, beach and sandy bank is found off

Bengkoka River and Telaga River, where casuarina trees dominate. Mangroves are found at the inner part of the river. Coral reef patches can be found at offshore of Kampung Pinggan-Pinggan (Zebra Reef, in Pitas District), Matunggung (Brandon Reef, Kudat district) and at center of the bay (Barraut Reef) (United Kingdom Hydrographic Office, 1990; Spalding *et al.*, 2010). Seagrass bed is also found around Marudu Bay, mainly at Berungus, Tanjung Limau-limauan, Kampung Rosob, Simpang Mengayau and Pantai Bak-Bak (Gumpil and De Silva, 2007).

1.2.2 Fishery Activities

The fishing zone of Marudu Bay falls within East Coast (or Sandakan) Fishing Zone based on Department of Fisheries Sabah zonation, and can be further divided into areas managed by Kudat, Pitas and Kota Marudu districts. Marudu Bay is part of the Sulu-Sulawesi Marine Ecoregion (SSME-1), which is an important large marine ecosystem (LME) comprised of Sulu Sea and Sulawesi Sea (Busing, 2001). The main commercial fishing port of Marudu Bay is located at Kudat, where most of the commercial trawlers and purse seiners are based. There are no purse seiners operating in Marudu Bay, but there is prawn trawling grounds located in the bay area between Kudat and Pitas (Manjaji-Matsumoto and Jumin, 2011). In addition to the shrimp trawling ground in the north, there is another important shrimp ground which encompassing the entire waters of Kota Marudu and southern most area of Kudat and Pitas districts, where shrimps are harvested mainly using gill net and trammel net by traditional fishermen and this usually take place at the subtidal mudflats. Marudu Bay contributed around 10 % of the SSME-1 total fisheries landing, which is mostly contributed by shallow areas such as subtidal mudflat located adjacent to rivers at southern and eastern part of Marudu Bay (Busing, 2001). Fisheries activities are important for the economy of this area and is practiced throughout the year.

Fisheries at Marudu Bay can be categorized into commercial and small-scale (artisanal) fisheries, where commercial fishing is concentrated at the offshore shelf of Kudat district. Artisanal fishing takes place at inner part of Marudu Bay mostly on subtidal mudflats at Kota Marudu, Pitas and Kudat districts. Various fishing gears are utilized including gill net, trammel net, long line, traps and shellfish collection.

Estuarine soft-bottom habitats in this case contribute most of the shrimp landing at Marudu Bay, with over 600 metric tonnes (Kota Marudu, Kudat and Pitas combined) mainly comprised of banana prawn (*Penaeus merguensis*) and yellow prawn (*Metapenaeus brevicornis*) landed in 2013 (Department of Fisheries Sabah, 2013). Other than the prawn industry, infauna production such as Asiatic hard clam (*Meretrix meretrix*), common geloina (*Geloina expansa*) and blood cockle (*Tegillarca granosa*) are exclusively contributed from estuarine soft-bottom habitats.

Lighted fish aggregation device with lift net ("Bagang" in local) for anchovy fishing has also contributed to large number of captured fisheries. They were mainly located at offshore area of Kampung Pinggang-Pinggan and Kampung Rosob, in Pitas district, but several Bagang could also can be found at Tanjung Limau-limauan. This fishing method uses light to attract fishes (mainly anchovies) at night. Captured anchovy contributes 858.52 metric ton to fisheries landing at Pitas district in 2010 (Department of Fisheries Sabah, 2010).

Aquaculture is another important fisheries source at Marudu Bay. Cultured products include green mussel, sea cucumber, shrimp, finfish and seaweed. Some of these aquacultures rely on shallow soft-bottom habitats as farming or ranching ground, such as sea cucumber, seaweed and green mussel farm at Tanjung Batu (Kota Marudu district), Tanjung Limau-limauan (Kudat district) and Kampung Berungus (Pitas district).

1.3 Statement of Issue

Human related activities were reported affecting the estuarine environment in either direct or indirect way. In Marudu Bay, uncontrolled fishing is believed to be the most direct threat of species diversity depletion based on study done in TMP (Manjaji-Matsumoto and Jumin, 2011). Although estuarine subtidal habitats are usually dominated by small-scaled fisheries which is of lower impact to the environment compared to commercial fishing, its unregulated activities are also capable to cause species depletion and habitat destruction (Johnson, 2006; Shester and Micheli, 2011), especially in estuarine soft-bottom habitats where food webs is relatively

simple and habitat-specific use by species is among the highest (Elliott and Hemingway, 2002; Day *et al.*, 2012).

Adjacent to the rivers, estuarine systems are prone to inland anthropogenic activities, pollution and sedimentation resulting from industries such as land clearing, agriculture, aquaculture and mining based around Marudu Bay. Heavy exploitation for agriculture including oil palm, rubber and coconut are scattered around Kudat, Kota Marudu and Pitas districts which are close to mangrove area (Department of Agriculture, Malaysia, 2010; Faridah-Hanum *et al.*, 2012). There is a newly established shrimp park located at Pitas for white shrimp (*Peneaus vannamei*) which is started in 2014. It has around 1500 shrimp ponds in an area of 1200 hectare where some areas of mangroves were cleared.

Sewage discharge from aquaculture and residential areas has high potential to cause coastal pollution by introducing excessive nutrients and toxic chemicals as most of these areas are located along rivers and coastal areas. Furthermore, oil tankers which transport crude palm oil at Sungai Matunggung expose Marudu Bay to potential risk of pollution via oil spill. Sand dredging activity also take place at several rivers in Kota Marudu. The sediment due to sand dredging activity could cause high turbidity and high sediment runoff from the rivers (Aris, Lim, Praveena, Yusoff, Ramli and Juahir, 2014), and eventually deposit at adjacent areas such as tidal creek, sandbank and mudflat, influencing the habitats and marine life.

Despite being so close to high anthropogenic pressures from the rivers and coastal areas, there is no study concerning the ecological status of subtidal mudflat at Marudu Bay. Assessing the species aggregation through time and location, and their relationship with environmental changes provide us the fundamental understanding of the ecology in subtidal flats. It is also essential for fisheries and development management and more importantly for the protection and preservation of the habitat.