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

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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' gazettement 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 merguiensis*) and jellyfish (i.e. *Lobonemoides robustus*) were the most commonly recorded. The abundance of two jellyfish species (*L. robutus* 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/km^2. 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 (ρ=-0.38) and diversity (ρ=-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 (ρ =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 merguiensis*) 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./km^2. 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.*

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LIST OF ABBREVIATIONS

ANOVA	-	Analysis of variance
CCA	-	Canonical correspondence analysis
Chl-*a*	-	Chlorophyll-*a*
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

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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 merguiensis*) 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 (Biusing, 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 additional 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 (Biusing, 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 merguiensis*) 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.