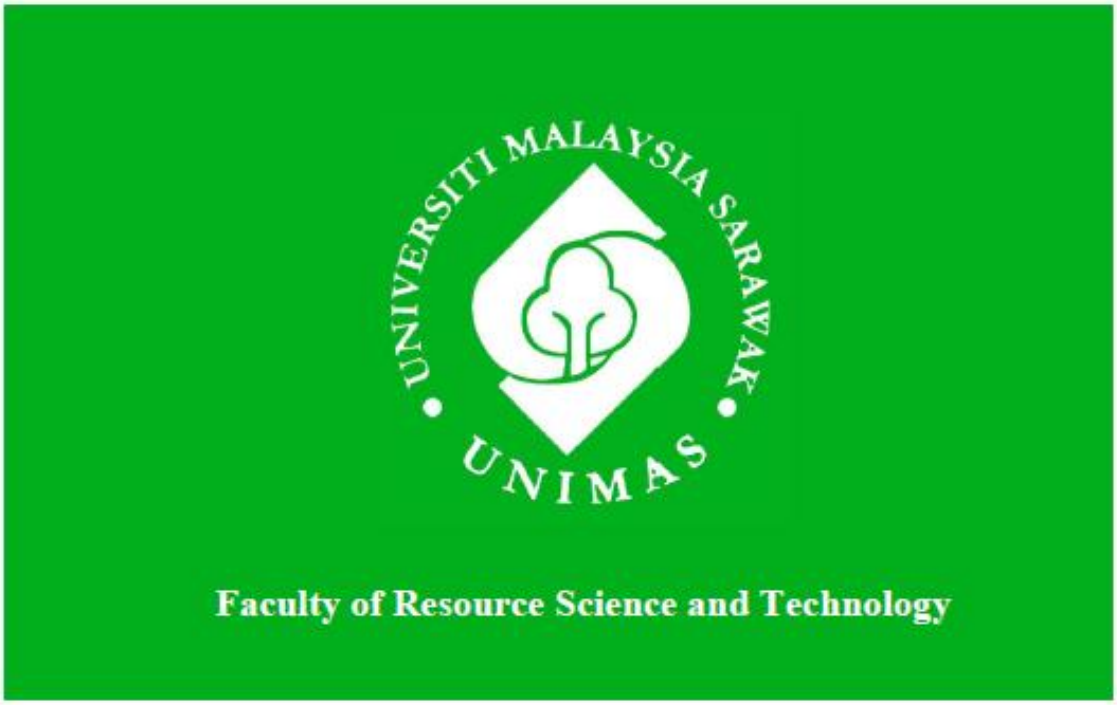

THE GASTROPOD AND BIVALVE OF BRUIT ISLAND, SARAWAK

Azzahra binti Ahmad Kamaruzzaman (34786)

Bachelor of Science with Honours

(Aquatic Resource Science and Management)

2015

The Gastropod and Bivalve of Bruit Island, Sarawak

Azzahra binti Ahmad Kamaruzzaman (34786)

This report is submitted in partial fulfillment of
Final Year Project II (STF 3015) Course

Supervisor: Prof. Dr. Shabdin Mohd. Long

Aquatic Resource Science and Management
Department of Aquatic Science

Faculty of Resource Science and Technology
Universiti Malaysia Sarawak
2015

ACKNOWLEDGEMENT

I would like to express my deepest and sincere gratitude to my supervisor Prof. Dr. Shabdin Mohd Long from Department of Aquatic Science, Faculty of Resource Science and Technology of UNIMAS for his helpful supervision, suggestions, encouragement and continual support throughout this study. I would like to thank to lab assistants of Department of Aquatic Science for helping us during field sampling in Patok and Bruit Islands, Sarawak.

Not to forget, to I would like to thank to Mdm Zakirah for helping me on how to conduct statistical analysis by using PRIMER and PRISM software. This study also would not have been possible without the generous support from my coursemates Nur Nasuha, Siti Noor Adibah, Nur Syahirah, Sajaratul Aqira, Wan Nur Syafina and Jayasri for their cooperation, spiritual support and motivation throughout the period of my study.

I would also like to express my deepest thanks to my parents Ahmad Kamaruzzaman and Ashah, my siblings, Azlin, Ahmad Syaharuzzaman, Ahmad Badruzzaman and my best friends, Noor Aimiliyana, Nur Amalina and Syazwani for their supports and prayers.

DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Sarawak (UNIMAS) or other institutions.

_____

AZZAHRA BINTI AHMAD KAMARUZZAMAN

Date:

Aquatic Resource Science and Management

Department of Aquatic Science

Faculty of Resource Science and Technology

Universiti Malaysia Sarawak

TABLE OF CONTENTS

LIST OF ABBREVIATIONS

Abbreviation	Description
g	Gram
mg	Milligram
%	Percentage
GPS	Global Positioning System
km	Kilometer
m	Meter
cm	Centimeter
L	Liter
mL	Milliliter
nm	Nanometer
°C	Degree Celsius
rpm	Revolutions per Minute
ind	Individual
M	Molarity
DO	Dissolved Oxygen
PSU	Practical Salinity Unit

LIST OF TABLES AND FIGURES

The Gastropod and Bivalve of Bruit Island, Sarawak

Azzahra binti Ahmad Kamaruzzaman
Aquatic Resource Science and Management
Faculty of Resource Science and Technology
Universiti Malaysia Sarawak

ABSTRACT

Bruit Island is located at the northern edge of Rajang Delta under Mukah division in the district of Daro, Sarawak. There is lacking information of molluscs community in Bruit Island. The objectives of this study are to document the community structure of gastropod and bivalve of Bruit Island and to determine the correlation between the community structure and environmental parameters of water. This study focused on species composition, species density, species diversity, species evenness and species richness of gastropod and bivalve. The molluscs were collected by using five replicates of 1m × 1m quadrat within $100m^2$ plot in every station on an intertidal area in Bruit Island. A total of 15 species of gastropods and one species of bivalve were collected and identified. *Cerithidea cingulata* was the most abundant species followed by *Assimineia brevicula* and *Nerita lineata*. Community structure parameters were recorded highest at the mangrove habitats whereas the community structure parameters were recorded lowest at sandy beach habitat. Species diversity and species evenness of mollusc were strongly significant correlated with size of sediments at $p<0.05$. Higher percentage of silt and clay in a habitat resulted in higher diversity and evenness of gastropod and bivalve. Dissolved oxygen and pH of water also significantly correlated with the species evenness of gastropod and bivalve in Bruit Island.

Keywords: Gastropod, bivalve, Bruit Island

ABSTRAK

Pulau Bruit terletak di utara Sungai Rajang di daerah Daro, Mukah, Sarawak. Kurang informasi berkaitan dengan komuniti moluska di Pulau Bruit. Objektif kajian ini adalah untuk mendokumentasikan struktur komuniti Gastropoda dan Bivalvia di Pulau Bruit dan untuk mengkaji kaitan di antara struktur komuniti dan parameter persekitaran air. Kajian ini tertumpu pada komposisi spesies, kepadatan spesies, kepelbagaian spesies, kesamarataan spesies dan kekayaan spesies Gastropoda dan Bivalvia. Sampel dipungut dengan menggunakan kaedah kuadrat lima replikasi 1m × 1m dalam plot berukuran $100m^2$ pada setiap stesen di kawasan pasang surut. Sebanyak 15 spesies Gastropoda dan satu spesies Bivalvia dikutip dan diidentifikasi. Cerithidea cingulata adalah spesies yang paling padat diikuti dengan Assimineia brevicula dan Nerita lineata. Parameter struktur komuniti direkodkan paling tinggi di kawasan paya bakau manakaka kawasan pantai berpasir mencatatkan parameter struktur komuniti yang paling rendah. Kepelbagaian spesies dan kesamarataan spesies menunjukkan perkaitan yang signifikan dengan saiz pasir ($p<0.05$). Peratusan tanah lumpur dan tanah liat di habitat kajian meningkatkan kepelbagaian dan kesamarataan spesies. Oksigen terlarut dan pH air juga berkorelasi signifikan dengan kesamarataan spesies Gastropoda dan Bivalvia di Pulau Bruit.

Kata kunci: Gastropoda, Bivalvia, Pulau Bruit

1.0 INTRODUCTION

Gastropod and bivalve belong to the phylum Mollusca (Saxena, 2005). Gastropod belongs to the class Gastropoda and bivalve belongs to the class Bivalvia (Saxena, 2005). Gastropods consist about 80% of all known molluscs species (Ponder and Lindberg, 2008). This means they are the most abundance molluscs in the world. They are distributed among marine, freshwater, and terrestrial environments and can be found in very diverse habitats like rivers, lakes, trees, deserts, the marine intertidal zone, the plankton, and the deep sea (Pechenik, 2010). Most bivalves can be found in marine, they also live in the freshwater but cannot be found in the terrestrials (Pechenik, 2010). Gastropod and bivalve also play an important role to the ecology (Newell, 2004) and contribute to the world's economy (Chellam *et al*., 1991).

Ecology is the scientific study of the processes influencing the distribution and abundance of organisms, the interaction among organisms, the interactions between organisms, and the transformation and flux of energy and matter (Likens, 1992). In the ecology, the community can be defined as assemblages of population of various species living close enough for potential interaction including competition, predation, symbiosis and disease (Likens, 1992). Two fundamental parameters which are the number of species and the number of individual within each of these species determine the basic structure of communities in ecosystem (Likens, 1992).

According to Gallagher (2010), community structure includes most of the things that can be measured from a set of samples and the basic unit of analysis of community structure is the sample by species matrix of abundances. Standard measures of community structure are

total abundance, numerically dominant taxa, spatial heterogeneity, species diversity (richness and evenness), faunal similarity/dissimilarity among samples and biomass (Gallagher, 2010).

In Malaysia, there are only few studies were done on the gastropods and bivalves (Hamli *et al*., 2012). Some of the few studies were a study on the population of freshwater molluscs in Crocker Range Park, Sabah that had been carried out by Supian and Ikhwanuddin (2002), the distribution of pen shell at seagrass bed of Sungai Pulai, Johor that had been studied by Idris *et al*. (2008) and the distribution of macrofauna including gastropod and bivalve in Rajang River, Sarawak (Shabdin, 2010). Marine mollusc studies are still overseen by many researchers even though marine science has received much attention in Malaysia in the recent years due to the lacks of basic information such as diversity data and species check list (Wong and Arshad, 2011).

In Sarawak, a study on diversity of edible mollusc (Gastropoda and Bivalvia) at selected division of Sarawak was done by Hamli *et al*. (2012). Besides that, there was a study on diversity and community ecology of crab and molluscan macrofauna had been carried out by Ashton *et al.* (2003) in the Sematan mangrove forest and a community study on marine gastropod and bivalves was done in Sampadi Island in Lundu by Shabdin *et al.* (2014).

Bruit Island holds about 60% of the waders and serves as nursery grounds for fishes and prawns (Edwards *et al*.,1986) which lead to questions such as what species of gastropod and bivalve exist within the area of the island? If there's any, how is the community structure? Do the environmental parameters influence their community structure? So far, there's lacking of information on the gastropod and bivalve's community structure in Sarawak especially in Bruit Island, therefore a research need to be done.

The objectives of this study are:

1) To document the community structure of gastropod and bivalve in Bruit Island.

2) To determine the correlation between the community structure of gastropod and bivalve in Bruit Island and the environmental parameters.

2.0 LITERATURE REVIEW

2.1 Bruit Island

According to Edwards *et al*. (1986), Bruit Island consists of a large and elongated island that covered 400 km^2 and aligned in north-south direction. It is located at the northern edge of Rejang Delta under Mukah division in the district of Daro, Sarawak. The origins of geological formation are depositional and connected with complex tidal regime and predominantly southward movement of long shore drift. The island is low-lying, with shores that are fringed by extensive mudflats.

The vegetation of Bruit Island is actively accreting mangrove forest within the intertidal zone. Mangrove serves as a feeding ground that contributes to the habitat diversity of the macrofauna associated in the mangrove ecosystem, while crustaceans and molluscs are the dominant macrofauna in this ecosystem (Sasekumar, 1974). Moreover, the gastropods are one of the dominant and most conspicuous macrofauna in mangrove systems, and occupy a wide range of ecological niches meanwhile although the mangrove-associated bivalves are only rarely studied, their diversity can be high (Nagelkerken *et al*., 2008).

2.2 Gastropod and Bivalve

2.2.1 Classification and Morphology

Aplacophora, Scaphopoda, Polyplacophora, Bivalvia, Monoplacophora, Cephalopoda and Gastropoda are living classes of phylum Mollusca (Saxena, 2005). Gastropod is within the class Gastropoda (Saxena, 2005). Gastropods include snails, abalones, cowries, conches, top shells and whelks. Gastropod has a visceral mass that is commonly protected by a typically coiled univalved shell, twisted 90-180˚ nervous system during embryonic development, and a proteinaceous shield on the foot (Pechenik, 2010). Its head possess tentacles, eyes and mouth and its ventral muscular flat foot forms the creeping sole (Saxena, 2005). The general features and typical shapes of gastropod are shown in Figure 2.1. The shell morphology is diverse, for example, the moon snail is globular in shape and tulip snail has spindle-shaped shell (Leal, 2002).

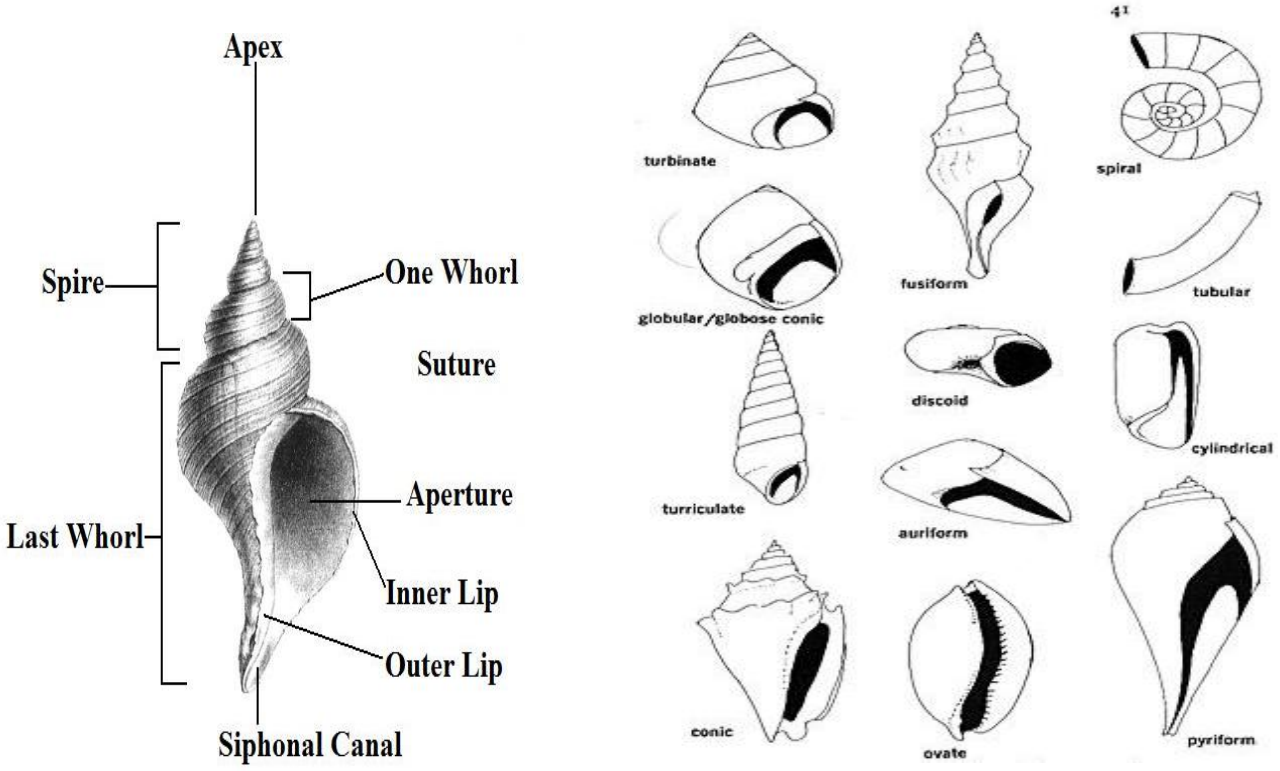

Figure 2.1: The general features and typical shapes of gastropod's shell (Jean, 1971)

Bivalve is within the class Bivalvia (Saxena, 2005). Bivalve has two-valved shell and a laterally flattened body (Pechenik, 2010). The body of bivalve is protected by left and right shell valves at a hinge at the dorsal margin (Saxena, 2005). However, bivalves have no head buccal mass (Saxena, 2005). Clams, oysters, cockles, mussels and scallops are examples of bivalves.

The growth of the shell valves is by accretion at their margins, which means the growth lines on the shell valves indicate the age of the bivalves (Saxena, 2005). They are vary in shapes, for examples, razor clams have elongated shells and cockles have nearly globular-shaped shells (Richardson *et al.*, 1993). The general features and typical shapes of bivalve are shown in Figure 2.2.

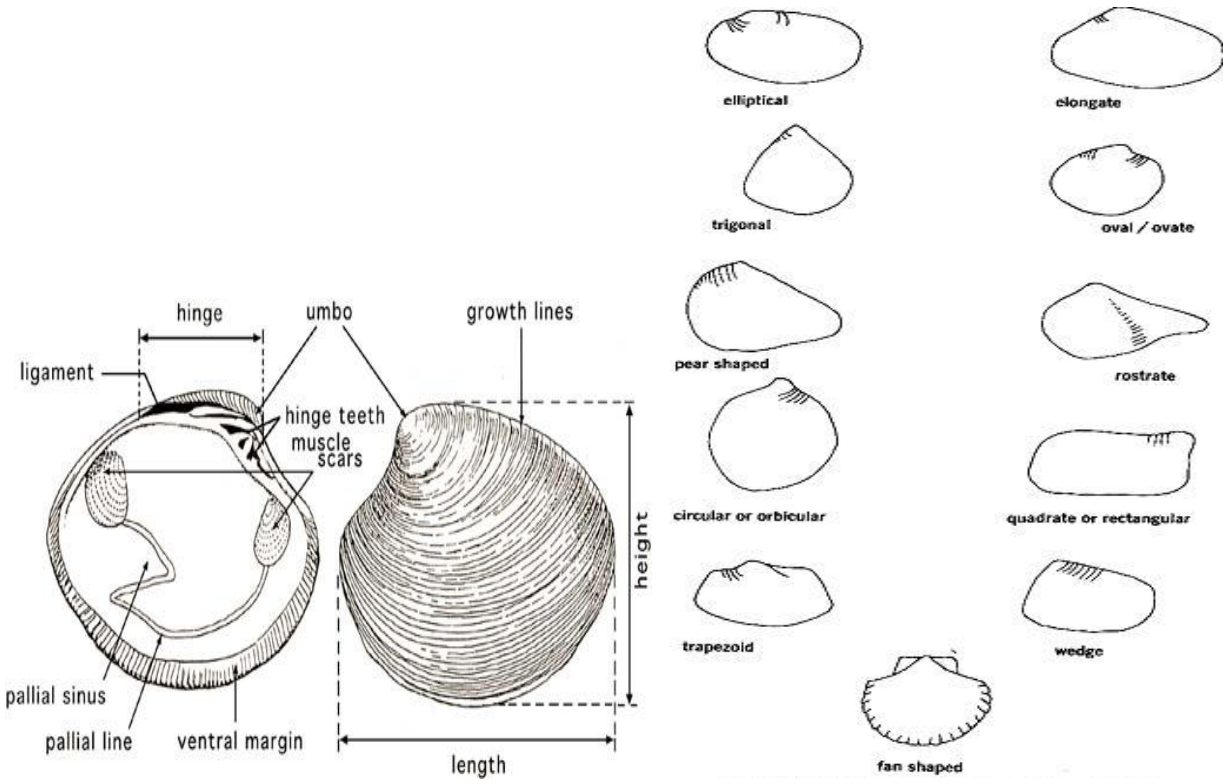

Figure 2.2: The general features and typical shapes of bivalve's shell (Jean, 1971)

2.2.2 Abundance

The phylum Mollusca is enormous with at least 50 000 and as many as 120 000 living species (Pechenik, 2010). The class Gastropoda is the largest molluscan class since it consists more than half of living mollusc species meanwhile there are about 15 000 species in the class Bivalvia (Pechenik, 2010).

Throughout the world, numerous studies had carried out on population study of molluscs, including: 83 species of gastropods and 52 species of bivalves in the Northeastern Chukchi Sea (Feder *et al.*, 1993), 47 species of molluscs (31 gastropods and 16 bivalves) in mangroves of the upper Gulf of Thailand (Printrakoon *et al.*, 2008), 45 mollusc species (22 gastropods and 15 bivalves) in a Venezuelan mangroves (Marquez and Jimenez, 2002), 8 species of gastropods and 30 species of bivalves were identified in Mersin Bay (Mutlu and Ergev, 2012), and 39 species of gastropods in an Australian mangroves (Camilleri, 1992).

At present, in Malaysian waters from various sources, 581 species marine gastropods and bivalves have been documented (384 species from class Gastropoda and 197 species from class Bivalvia) (Wong and Arshad, 2011). One of the first marine mollusc diversity surveys in Malaysia was conducted on the east and west coast of Peninsular Malaysia and Singapore (Purchon and Purchon, 1981).

According to Wong and Arshad (2011), the marine mollusc diversity study in Malaysia is normally carried out as a side product of other projects due to the lack of direct funding. There is a significant difference in specimens found among diversity studies of gastropod and bivalve in Malaysia (Table 2.1). Meanwhile in Sarawak, there are 78 species of Gastropoda and 31 species of Bivalvia recorded (Shabdin and Rosniza, 2010)

Table 2.1: Number of species of gastropod and bivalve found in Malaysia (Wong and Arshad, 2011)

Location	Substrates	Results	References
East and west coasts of Malaysia	Intertidal, sandy beach, rocky shore, mangrove, shallow reef, shallow and deep sandy bottom, trawler 'trash fish'	Gastropod: 301 species (52 families) Bivalve: 154 species (37 families)	Purchon and Purchon (1981)
Pulau Redang, Terengganu	Intertidal	Gastropod: 48 species (15 families) Bivalve: 9 species (6 families)	Aziz *et al.,* (2001)
Teluk Tekek, Pulau Tioman, Pahang	Coral reefs, rubbles and sand	Gastropod: 15 species (12 families) Bivalve: 12 species (7 families)	Kee Alfian *et al*., (2005)
Southwest Pulau Tioman, Pahang	Coral reefs, rubbles and sand	Gastropod: 24 species (13 families) Bivalve: 15 species (11 families)	Wong *et al.,* (2008)
Pulau Aur, Johor	Coral reefs	Gastropod:9 species (7 families) Bivalve: 13 species (6 families)	Tan *et al*., (2008)
Merambong Shoal, Johor	Seagrass bed	Gastropod: 27 species (12 families) Bivalve: 23 species (9 families)	Zaidi *et al.,* (2008)
Pulau Mabul, Sabah	Coral reefs	Gastropod and Bivalve: 89 species (30 families)	*Unpublished data

2.3 Community Structure

According to Miller and Spoolman (2008), a collection of populations of different species in a given area that potentially interact with one another is called a community. Biological communities differ in the types and number of species they contain and the ecological roles the species play (Miller and Spoolman, 2008). According to Kell (2006), communities can be more precisely described and quantified. One property of a community that is quantifiable is its structure (Kell, 2006). Community structure includes the number of species, relative abundance and species that comprising the community (Molles, 2005).

Species composition is the relative abundance of different species or of different functional group of species which has been a key measure to evaluate biological communities (Billheimer *et al*., 2001). Composition is an attribute that can be more easily visualized by those unfamiliar with rangelands or the range of that area (Aigner, 1965). Density is an expression of numerical strength of a species in a community (Curtis and McIntosh, 1950). Species density for macrofauna is expressed by organisms/ m^2 (Armenteros *et al*., 2007).

Species diversity is an appropriate term to understand the mechanisms and effects of certain ecological phenomena, such as pollution and environmental disturbances since it is a function of the number of species present (Spellerberg, 1991). Diversity indices are mathematical functions that combine richness and evenness in a single measure (Colwell, 2009). Diversity is a key component of any description of community structure (Gallagher, 2010). Shannon-Wiener Diversity Index (H') is one of the most commonly used diversity indices in ecology, the larger the value of H' the greater the species diversity and *vice versa* (Colwell, 2009). An ecosystem with H' value greater than 2 has been regarded as medium to high diverse in terms of species (Barbour *et al.,* 1999).

Species evenness or the similarity in species relative abundance in a community captures another aspect of diversity by determining diversity as a standardized index of relative species abundance (Krebs, 1999). Pielou's Evenness Index (J') is a measure for species evenness (Jost, 2010). The value of J′ ranges from 0 to 1, with larger values indicating more even distributions in abundance among species (Pielou, 1966). Species richness is the number of species of a particular taxon or life form that characterize a particular biological community, habitat, or ecosystem type (Colwell, 2009). According to Magurran (2004), the Margalef Index (D) measures species richness.

Biomass is one of the parameters in community structure too (Gallagher, 2010). According to Houghton (2008), biomass refers to living organisms' mass including plants, animals and microorganisms. Biomass is often reported as a mass per unit area (g/m^2) or (Mg/ha) and usually as dry weight which is water has been removed by drying (Houghton, 2008). However, it is relatively difficult to get good biomass estimates for all of the species in a community and one of the disadvantages of obtaining accurate biomass measurements is that many of the animals must be destroyed (Gallagher, 2010).

In Peninsular Malaysia, a total of 135 individuals of seven species of pen shell were found at four study areas in South Western Johor coast by Idris *et al.* (2008) with the highest density value of pen shells 0.027 ind./m^2 at station 1 and the lowest density value 0.004 ind./m^2 at station 2, both at Merambong Shoal. Merambong Shoal population recorded higher values for diversity index compared to Tanjung Adang Shoal and Merambong Island. The diversity index recorded highest value at Merambong Shoal station 1 (1.63) and the lowest value at Tanjung Adang Shoal station 3. Highest richness indices values were recorded at Merambong Shoal station 2 (1.737) and the lowest value at Merambong Island station 4 (0.96) meanwhile the highest evenness indices were recorded at Merambong Island station 4 (0.96) and the lowest value recorded at Tanjung Adang Shoal station 3 (0.71) (Idris *et al*., 2008).

In Sarawak, from August 2010 to May 2011, Hamli *et al*. (2012) had identified 29 species of molluscs on a study of diversity of edible mollusc at eight divisions of Sarawak. The data presented in this study has low diversity compared to estuarine and mangrove molluscs. The species number of bivalve was recorded highest (15 species) in Kuching while the species number of gastropod was recorded highest in Bintulu due to habitat preferences. The overall edible mollusc diversity was found 14 species in Bintulu and one species in the

division of Sarikei (Hamli *et al*., 2012). The marsh clam, *Polymesoda erosa* was found and distributed in six divisions namely Sibu, Mukah, Miri, Limbang and Lawas meanwhile *Polymesoda expansa* and *P. bengalensis* which are belong to Bivalvia and *Cerithidea rizophorarum* (Gastropoda) were distributed in four divisions namely Limbang, Sibu, Mukah and Kuching. Other species of gastropod and bivalve was found at least one species at one division only (Hamli *et al*., 2012).

In Sematan mangrove forest, Sarawak, a total of 44 species of gastropod and bivalve had been identified in nine study plots by Ashton *et al.* (2003). The maximum density recorded in a 1 m^2 quadrat was 130 molluscs at plot 9. In this quadrat, *Assiminea brevicula* reached the highest densities with a maximum of 102. The maximum total densities were recorded in this study were *A. brevicula* (192), followed by *Melampus* sp. 1 (65) and *A. woodmasoniana* (59). The mean densities recorded for *A. brevicula, Chicoreus capucinus, Ellobium aurisjudae, Laemodonta punctigera and L. punctatostriata* were 14.8, 4.1, 1.0, 3.5 and 1.3 ind./m^2 respectively which were found to be comparable with values published for densities in other Malaysian mangroves. The mean densities of same species were recorded by Ashton (1999) 12.0, 1.6, 2.0, 4.2 and 3.0 ind./ m^2 in the Merbok forest and 7.4, 1.2, 1.0, 3.0 and 1.9 ind./m^2 in the Matang forest in Peninsular Malaysia. In this study also, Ashton *et al*. (2003) had recorded the lowest molluscan wet biomass (3.6 g/m^2) which was at plot 2 near a low-lying tidal creek, while the highest biomass (50.4 g/ m^2) was recorded at plot 7 which was in the upper tidal zone.

In Sampadi Island in Lundu, Sarawak, a total of 33 species of gastropod and seven species of bivalve were recorded from the intertidal area (Shabdin *et al*., 2014). The total density of molluscs was high in Sampadi Island (612 - 4760 ind./m^2). Gastropods that

dominated the island were *Littorina pyramidales* (3720 ind./m^2). Meanwhile, the least abundant species were *Cerithium litteratum*, *Strombus canarium*, *Strombus quadrata* and *Thais tuerosa* (4 ind./ m^2). The diversity values ranged between 1.12 to 1.78 bits / individuals while species evenness ranged from 0.42 to 0.59. The species diversity values at station 1, station 2 and station 3 are 1.12, 1.25 and 1.78 bits / individuals respectively. *Littorina pyramidales*, *Nodilittorina milegrana* and *Nerita plicata* were the dominant gastropods in station 1, 2 and 3 (Shabdin *et al*., 2014).

2.4 Environmental Parameters

2.4.1 Physico-chemical of Water Parameters

Seawater parameters like temperature, salinity and pH were studied and correlated with ecological attributes of species in a study of intertidal distribution of *Cerithium scabridum* (gastropod) along the coastal Saurashtra, Gujarat, India (Trivedi and Vachhrajani, 2013) . It was observed that seasonal changes in abiotic factors and chemical properties of sea water have prominent effect on the intertidal distribution of the species (Trivedi and Vachhrajani, 2013).

Besides that, a study about distribution on *Cerastoderma glaucum* (cockles) along the Gabes coasts (Tunisia, Central Mediterranean) reported that water parameters affect the population of *C.glaucum* (Derbali*et al*., 2012). The contamination of different pollutants into the sea water also affects the distribution, density and abundance of the molluscan species (Bishop *et al*., 2002).

2.4.2 Grain Size of Sediment

Types of sediment affect the distribution of molluscs (Feder *et al*., 1994). For example, the epifaunal species of molluscs of northeastern Chukchi Sea are more abundant inshore where sandy-gravelly substrate prevails (Feder *et al*., 1994). The study on soft-bottom molluscs in Mersin Bay showed that a strong correlation exists between the abundance of molluscs and sediment features such as mud, silt contents, and TOC (Total Organic Carbon) (Mutlu and Ergev, 2012).

The community structure and intertidal distribution of the macrofauna have been related to abiotic factors such as grain size (Jaramillo and Gonzalez, 1991). Lana and Guiss (1991) found a positive correlation between increased macrofaunal abundance and decreased sediment grain size in the mangrove of southeast Brazil.

2.4.3 Chlorophyll *a* in Sediment

Tselepides and Eleftheriou (1992) found significant correlations between the macrofauna and sediment parameters, leading to the conclusion that food availability especially chlorophyll *a* is the principal regulating factor in the system. Another example is based on a study on distribution of *Cerastoderma glaucum* (cockles) along the Gabes coasts by Derbali *et al.*(2012) was found to be significantly correlated to the distribution of seagrass *Cymodocea nodosa* and *Zostera noltii* that covered the mud sandy bottoms more than 70%. This positive correlation was probably related to the chlorophyll *a* offered by *C. nodosa* (Derbali *et al.*, 2012).

In addition, in Kung Krabaen Bay, Chantaburi Province, Thailand, gastropod abundance showed a significant correlation with the biomass of seagrass *Halodule pinifolia* (65%), followed by bivalves (39%) meanwhile only bivalves significantly correlated with the biomass of *Enhalus acoroides* (36%) (Satumanatpan *et al*., 2011)

2.5 Roles of Gastropod and Bivalve

Gastropod and bivalve play important roles in ecosystem and economy. For example, gastropod *Biomphalaria glabrata* is an intermediate host for parasitic flatworms that can cause schistosomiasis in humans (Fneich *et al*., 2013). Gastropods also play an important role as bio-indicators for trace metal pollution since they have the ability to accumulate metals to high concentrations (Gupta and Singh, 2011). For example, *Cerithium scabridum* has been used as bio-indicator in Kuwait coast (Bu-Olayan and Thomas, 2001). Bivalves are filter feeders which contribute to the organic turnover in the intertidal zones of marine and freshwater (Newell, 2004).

Besides that, gastropod and bivalve contribute protein source for humans (Hamli *et al*., 2012). Because of the aesthetic and gastronomic appeals, marine molluscs received more attention rather than other molluscs (Subba Rao, 1993). For example, marine bivalves within the Indian marine habitat have been reported potential to use as antiviral drugs (Chatterji *et al*., 2002). Moreover, bivalves contribute to the world economy such as pearl oyster farming which is an important industry in Japan and many other countries bordering the Indian and Pacific Oceans (Chellam *et al*., 1991).