Faculty of Resource Science and Technology

Diversity and Distribution of Gastropods and Bivalves from Sarawak Intertidal and Malaysia Exclusive Economic Zone (EEZ) of Sarawak Waters

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Diversity and Distribution of Gastropods and Bivalves from Sarawak Intertidal and Malaysia Exclusive Economic Zone (EEZ) of Sarawak Waters

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DECLARATION

The work presented in this thesis is original and my own work except for quotations and citations which have been duly acknowledged. The thesis has not been accepted for any degree and is not concurrently submitted in candidature for any other degree.

(JAYASRI A/P PONNUSAMI)

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ABSTRACT

The information on the distribution of gastropods and bivalves in Sarawak is still lacking. The objectives of this study are to (i) determine the diversity and distribution of gastropods and bivalves in Sarawak Intertidal and Malaysia Exclusive Economic Zone (EEZ) of Sarawak waters, (ii) evaluate the influence of water depth on the distribution of gastropods and bivalves at Malaysia EEZ of Sarawak waters, and (iii) evaluate the influence of the environmental parameters on the distribution of gastropods and bivalves at Sarawak intertidal. Samples were collected using the Smith McIntyre grab at Malaysia EEZ of Sarawak waters from 32 stations and using the Ekman grab from 20 intertidal stations. The intertidal stations were selected from Pandan beach, Kabong beach, Tanjung Batu beach, and Tusan beach. A total of 95 taxa (61 gastropod and 34 bivalve) and 88 taxa (52 gastropod and 36 bivalve) were recorded from EEZ of Sarawak waters and Sarawak intertidal, respectively. *Limopsis* sp., *Turritella cingulifera*, *Pitar citrinus*, and *Cavolinia globulosa* were the most abundant species in Malaysia EEZ of Sarawak waters. The highest density was recorded by *Limopsis* sp. at station 2 with 610 ind./m^2. The total density of gastropod and bivalve at Sarawak EEZ showed negative relationship with the depth of water. Commonly found Bivalvia and Gastropoda in the intertidal study were *Donax* sp. from family Donacidae and *Architectonica perdix* from family Architectonicidae. At Pandan beach, species richness of gastropod and bivalve was positively correlated with turbidity and negatively correlated with the total organic matter. Study at Kabong beach showed species evenness was positively correlated with chlorophyll *a* whereas the total density was negatively correlated with chlorophyll *a*. The percentage of sand at Tanjung Batu beach was positively correlated with the Simpson's Reciprocal index, species richness and total density of gastropod and bivalve. In contrast, the percentage of silt and clay showed negative correlation with them. Study at Tusan beach resulted that Shannon diversity value was positively correlated with the dissolved oxygen while, the total density was positively correlated with the dissolved oxygen and pH. The findings on the abundance and distribution of gastropod and bivalve in this study can support the future monitoring study of mollusc.

Keywords: Gastropod, bivalve, intertidal and Malaysia EEZ of Sarawak waters.

Kepelbagaian dan Taburan Gastropoda dan Bivalvia dari Kawasan Pasang Surut, dan Kawasan Zon Ekonomi Eksklusif (ZEE), Sarawak

ABSTRAK

Maklumat mengenai struktur komuniti Gastropoda dan Bivalvia di Sarawak masih kurang. Objektif kajian ini adalah untuk (i) menentukan kepelbagaian dan taburan Gastropoda dan Bivalvia di kawasan Zon Ekonomi Eksklusif (ZEE) dan di kawasan pasang surut, Sarawak (ii) mengkaji pengaruh kedalaman air terhadap struktur komuniti Gastropoda dan Bivalvia di kawasan ZEE Sarawak, dan (iii) mengkaji pengaruh parameter persekitaran air dan tanah terhadap struktur komuniti Gastropoda dan Bivalvia di kawasan pasang surut, Sarawak. Sampel dikumpulkan menggunakan 'Smith McIntyre grab' di ZEE Sarawak dari 32 stesen dan menggunakan 'Ekman grab' dari 20 stesen kawasan pasang surut, Sarawak. Stesen-stesen kawasan pasang surut, Sarawak yang dipilih adalah dari pantai Pandan, pantai Kabong, pantai Tanjung Batu, dan pantai Tusan. Sebanyak 95 spesies (61 Gastropoda dan 34 Bivalvia) dan 88 spesies (52 Gastropoda dan 36 Bivalvia) masing-masing dicatatkan dari ZEE Sarawak dan kawasan pasang surut, Sarawak. Limopsis sp., Turritella cingulifera, Pitar citrinus, *dan* Cavolinia globulosa *merupakan spesies yang paling banyak direkodkan di ZEE Sarawak. Kepadatan tertinggi dicatatkan oleh spesies Limopsis di stesen 2 dengan 610 ind./m^2. Kepadatan keseluruhan Gastropoda dan Bivalvia di ZEE Sarawak menunjukkan hubungan negatif dengan kedalaman air. Bivalvia dan Gastropoda yang sering dijumpai di kawasan pasang surut, Sarawak ialah* Donax sp., *dari famili Donacidae dan* Architectonica perdix *dari famili Architectonicidae. Di pantai Pandan, kekayaan spesies Gastropoda dan Bivalvia menunjukkan hubungan positif dengan kekeruhan air dan hubungan negatif dengan jumlah keseluruhan bahan organik. Kajian di pantai Kabong menunjukkan kesamaan spesies berkorelasi positif dengan klorofil a manakala kepadatan keseluruhannya dikaitkan secara* *negatif dengan klorofil a. Peratusan pasir di pantai Tanjung Batu berkorelasi positif dengan kepelbagaian, kekayaan dan kepadatan spesies Gastropoda dan Bivalvia. Manakala, peratusan lumpur dan tanah liat menunjukkan korelasi negatif dengan kepelbagaian, kekayaan dan kepadatan spesies. Kajian di pantai Tusan menunjukkan kepelbagaian spesies dikaitkan secara positif dengan oksigen terlarut dan kepadatan spesies dikaitkan secara positif dengan oksigen dan pH yang terlarut. Kepelbagaian dan taburan Gastropoda dan Bivalvia dalam kajian ini dapat membantu dalam kajian pemantauan moluska di masa hadapan.*

Kata kunci: *Gastropoda, Bivalvia, kawasan pasang surut dan ZEE, Sarawak*.

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LIST OF ABBREVIATIONS

<	Lesser than
>	Greater than
%	Percentage
°C	Degree Celsius
µg	Microgram
µm	Micrometer
µS	Microsiemens
ANOVA	Analysis of Variance
BOD	Biochemical Oxygen Demand
$CaCO_3$	Calcium Carbonate
cm	Centimeter
COD	Chemical Oxygen Demand
DO	Dissolved Oxygen
EEZ	Exclusive Economic Zone
g	Gram
GPS	Global Positioning System
ha	Hectare
HCl	Hydrochloric acid
ind	Individual
km	Kilometer
L	Liter
m	Meter

M	Molarity
Ma	Million years ago
MDS	Multidimensional Scaling
mg	Milligram
mL	Mililiter
mm	Milimeter
mS	Millisiemens
nm	Nanometer
NTU	Nephelometric Turbidity Unit
PCA	Principal Component Analysis
ppm	Parts per million
PRIMER	Plymouth Routines in Multivariate Ecological Research
PSU	Practical Salinity Unit
rpm	Revolutions per Minute
SEAFDEC	The Southeast Asian Fisheries Development Center
SPSS	Statistical Package for the Social Sciences
TOM	Total organic matter
TSS	Total suspended solid
UNCLOS	The United Nations Convention on the Law of the Sea

CHAPTER 1

GENERAL INTRODUCTION

1.1 General Introduction

Malaysia is separated into two major land masses which are Peninsular Malaysia and East Malaysia on the island of Borneo, and has an area of 329,750 km^2, a land area of 328,550 km^2 and a coastline of 4,675 km (Peninsular Malaysia 2,068 km; East Malaysia 2,607 km) (Morton & Blackmore, 2001). The Sarawak coastline is about 1,035 km long (Shabdin, 2014). In contrast to temperate shores, tropical shores have been regarded as having high levels of free space, and great diversity of consumers (Williams, 1993).

This study will only focus on marine bivalves and gastropods as they are the largest classes of Mollusca. Gastropods encompass 80% of living mollusc species (Venkatesan & Mohamed, 2015a) and the number of species of bivalve is only about 20% of that documented for gastropods. Yet, there has been substantial interest in bivalve because so many of its members are eaten by humans in large amounts (Gosling, 2004). Ecologically, the importance of molluscs cannot be underestimated (Dolorosa & Picardal, 2014). Molluscs, predominantly gastropods and bivalves, were among the earliest taxa used to investigate patterns of diversity (Aldea *et al.,* 2008). They provide an ideal test assemblage for testing many hypotheses about gradients of diversity, replacement of species with depth, and correlated factors since they comprise a wide range of phylogenetic (Aldea *et al.,* 2008). Diversity patterns are important topics at both species and assemblage levels where these patterns may be attributed to complex and combined physical and/or biological factors (Aldea *et al.*, 2008).

Studies involving benthic communities are being extensively used in monitoring pollution effects, using both the methodologies provided by the national laws in various countries and experimental innovative methodologies of research (Bedini *et al.*, 2003). Monitoring can be defined as systemic observations and measurements of ecosystems to detect changes over time and it is an integral part of any effort to reduce the loss of biodiversity (Naser, 2011). For example, gastropods and bivalves are used as bio-indicators of aquatic health (Babahmadi *et al.*, 2013; Irma & Sofyatuddin, 2012) because they are useful and reliable bio-indicators of changing aquatic conditions (Kumar *et al.*, 2013). The application of these indicators in water quality assessment is based on the fact that the macrobenthic community structure may be changed after the environmental disturbances (Abbaspour *et al.*, 2013). Macrobenthic studies have attained an essential role in marine impact assessment and marine management because they usually exhibit well-defined responses to environmental change, especially those stresses which influence the sediment structure (Simin *et al.*, 2012).

1.2 Problem Statements

In recent decades, biological diversity has received greater interest (Naser, 2011). Due to the sensitivity and the relationship of macrobenthic to their environmental conditions, numerous researchers around the world focused their attention since a few decades ago to use this group of organisms to measure the water condition (Abbaspour *et al.*, 2013). The disturbances on marine waters have the potential to affect the distribution of animals in natural and man-made waterways and are the subject of a rising number of studies (Bishop, 2006). In addition, the benthic fauna remain to be the subject of much research in the fields of hydrobiology and ecology because of their importance in the nutrition of fishes (Piamthipmanus, 1998), its ecological importance, and obvious presence within the marine ecosystem (Degraer *et al.*, 2007). However, most studies in this world are related to terrestrial systems, and knowledge of marine biodiversity lags behind that of land systems (Naser, 2011). Such benthic studies are really needed in the tropics to provide the required basic data for comparison to any critical disorders that might arise in the future (Yasin & Razak, 1998).

Though, comprehensive surveys on the macrobenthic profile found within the Malaysian waters are hardly conducted due to the numerous logistical problems and high costs incurred (Yasin & Razak, 1998). This operation is also highly labour intensive and the problem becomes even more severe in regions of the world where the taxonomic literature is inadequate (Warwick, 1988). The sorting, identification and enumeration stages to compile species abundance and biomass arrays require considerable taxonomic expertise and familiarity with the local fauna (Warwick, 1988). Further, the current researches on marine mollusc diversity focus only a small geographical area and limited habitat.

About 5,000-6,000 species of marine mollusc have been discovered in Panglao Island, Philippines (Wong & Arshad, 2011). Located in the same high biodiversity region, Malaysia should be able to contribute valuable data. In recent years, foreign scientists have been collecting and documenting the marine mollusc found in Malaysian waters even described a new species (Wong & Arshad, 2011). However, in Malaysia, the studies on gastropod and bivalve are very few (Hamli *et al.*, 2012). The basic information of marine mollusc such as diversity data and species check list is still lacking (Wong and Arshad, 2011). The development of marine shelled mollusc taxonomy in Malaysia is still slow even though this country is blessed with rich biodiversity resources. To date, no published information on the actual number of marine shelled molluscan species exist in Malaysia.

Previous study at Malaysia EEZ (covering Sarawak waters) reported that highest density of macrobenthic fauna were occurred at water depth of 0 m to 60 and mollusc was not found at water depths of 181 m to 240 m indicating a decrease in abundance of gastropod and bivalve in deeper depth (Piamthipmanus, 1998). However, in Malaysia, depth relationship studies are very little. Studies involving the influence of environmental parameters such as water quality and sediment characteristics on the distribution of mollusc are also very poor and greatly needed in Malaysia.

To conclude, there is a lack of information on the distribution of gastropods and bivalve's community in Sarawak. Thus, more studies are needed to gather the distribution pattern of the molluscan group in Malaysia. A better understanding on the influence of environmental parameters on the distribution of gastropod and bivalves are required. Hence, the main hypotheses tested in present research were (i) more species can be obtained in this study compared to previous gastropod and bivalve survey in Malaysia, particularly Sarawak, (ii) gastropod and bivalve abundance decrease with increasing water depth at Malaysia Exclusive Economic Zone (EEZ) of Sarawak waters, (iii) abiotic factors influence the gastropod and bivalve assemblages in Sarawak intertidal.

1.3 Objectives

The objectives of this study are to:

i. determine the species composition, species density, species diversity, species evenness, and species richness of gastropods and bivalves in Sarawak intertidal and Malaysia Exclusive Economic Zone (EEZ) of Sarawak waters.
ii. evaluate the influence of water depth on the distribution of gastropods and bivalves at Malaysia EEZ of Sarawak waters.
iii. evaluate the influence of the environmental parameters on the distribution of gastropods and bivalves at Sarawak intertidal.

Upon completion of this study, data obtained could help the future monitoring survey at the respective area as baseline evidence, besides helping in constructing the checklist of gastropod and bivalve species recorded in Sarawak.

1.4 Layout of Thesis

This thesis consists five chapters. Chapter 1 is the general introduction, followed by Chapter 2 which comprises the literature review of the gastropod and bivalve, its distribution, importance, threats, abundance, community structure, and the environmental parameters involved in the study. The diversity and distribution of gastropod and bivalve at Sarawak EEZ and intertidal zone is highlighted in Chapter 3 and Chapter 4, respectively. Chapters 4 will also covers the relationship of the gastropod and bivalve's distribution with the environmental parameters. Lastly, Chapter 5 contains the conclusion and recommendation, which concludes the findings.

CHAPTER 2

LITERATURE REVIEW

2.1 Taxonomy and Classification

Benthic animals are commonly categorized according to size: microbenthos < 0.063 mm, meiobenthos 0.063 mm to 0.5 mm (or 1.0 mm), macrobenthos > 0.5 mm (or 1.0 mm) and sometimes, megabenthos > 10.0 mm (Tagliapietra & Sigovini, 2010). The term "benthos" (from ancient Greek meaning "depth, depth of the sea, bottom") was introduced by the eminent German naturalist and artist Ernst Haeckel (1834–1919), who also introduced the term "ecology" (Tagliapietra & Sigovini, 2010). Macrobenthos are defined as organisms that live on or inside the deposit at the bottom of a water body (Kumar *et al.*, 2013). Benthos is a foundation of living organisms in aquatic ecosystems (Babahmadi *et al.*, 2013). The macrobenthos includes a heterogeneous assemblage of different organisms, representing different functional feeding groups and feeding modes (Kumar *et al.*, 2013). They are separated into four major taxonomic groups which are polychaetes, crustaceans, molluscs, and others (echinoderms, nemerteans, tunicates, and coelenterates) that occupies separate network compartments (Link *et al.*, 2006).

The Phylum Mollusca can be divided into seven classes which are Polyplacophora, Aplocophora, Monoplachopora, Gastropoda, Bivalvia, Cephalopoda and Scaphopoda (Shabdin *et al.*, 2014b). Two major benthic molluscan classes, the Bivalvia and the Gastropoda, can commonly found in marine and freshwater sediments (Higgins & Thiel, 1988). They have a soft, fleshy body and either one shell or a pair of shells (Foster & Whiteley, 2002). A mollusc that has one shell is placed in the class Gastropoda while those with two shells are grouped in the class Bivalvia (Foster & Whiteley, 2002; Shabdin *et al.*, 2014b). The external form of the shell was the key character used in species-level taxonomy, including diverse groups (Tan *et al.,* 2015). This study focused only on two classes that are Gastropoda and Bivalvia.

Gastropods and bivalves are representative of lower trophic levels (Aldea *et al.*, 2008). While gastropods contribute to entrap primary production within the system, bivalves are efficient filter feeders, able to capture suspended particles of various origins (Cannicci *et al.*, 2008). Bivalves depend on phytoplankton from the water column as their main energy source (Gosling, 2004). The production, abundance, biomass, and horizontal dispersion of them in different coastal habitats have been the essential interest for many years (Gondal *et al.*, 2012). In the study of the biological form, shells are traditionally used in classifications and taxonomic descriptions (Tan *et al.*, 2015). Mollusc shells have developed their structure and mechanical properties through natural selection over hundreds of millions of years to protect themselves from attack by a various marine predators, which try to break it using a compressive force application, prying attack or nipping attempt (Yang *et al.*, 2010).

2.2 Morphology and Characteristics

2.2.1 Bivalves

Most bivalves are marine (Venkatesan & Mohamed, 2015b) and few bivalve families are can only be found in freshwater (Ponder *et al.,* 2002). There are no terrestrial forms (Venkatesan & Mohamed, 2015b). The first bivalve molluscs appeared in the sea during the Cambrian period about 620 Ma and well, before organisms had invaded the land (Dame, 2012). Examples of bivalves are mussels, oysters, scallops and clams (Foster & Whiteley, 2002; Gosling, 2015). Most marine bivalves live within a temperature range from -3 °C to 44 °C and generally early embryos and larvae have a narrower temperature tolerance than adults (Dame, 2012; Gosling, 2004). Bivalves are both economically and ecologically crucial; they can be a dominant benthic organism, influencing the surrounding environment through particle depletion, nutrient cycling, and bio-deposition (Ward *et al.*, 1993).

Bivalves were well represented in the fossil record and are often used as paleontological markers since their shells are made of calcium carbonate (Dame, 2012). Possessing a hard mineralized exoskeleton, they provide an abundant material for archaeological investigations (Georgiev *et al.,* 2009). Bivalve's shell properties, considering the simple constituents, are much better than man-made materials (Yang *et al*., 2010). The shell is composed of both an organic matrix and crystals of calcium carbonate ($CaCO_3$) (Dame, 2012). Their components are about 95% calcium carbonate and less than 5% organic materials. The two primary polymorphs of calcium carbonate in shells are calcite and aragonite (Yang *et al*., 2010).

The best way to explore bivalve morphology is on the shell because the shell provides a wide array of variability (Tan *et al.,* 2015). The surface morphology of molluscan shells is affected by the seasonal changes in rate of shell formation (Hutchings & Haedrich, 1984). Shell morphometry and sculpture are regarded as essential for species discrimination (Tan *et al.,* 2015). The shape, colour and markings on the shell differ noticeably between the different groups of bivalves (Gosling, 2004). Therefore, shell characters are regularly used in species identification (Gosling, 2004). Figure 2.1 and Table 2.1 show the typical shapes of bivalves and major shell characters used in species identification.

The shell protects against predators, acts as a skeleton for the attachment of muscles, and in burrowing species, it helps to keep mud and sand out of the mantle cavity (Gosling, 2004). The typical shell of bivalve molluscs consists of two symmetrical valves (Higgins & Thiel, 1988; Gosling, 2015; Ponder *et al.,* 2002; Salgeback, 2006). They are connected by elastic ligament and are held together by one or two adductor muscles (Foster & Whiteley, 2002; Salgeback, 2006; Venkatesan & Mohamed, 2015b). When these are relaxed, the shell is opened by the elasticity of the ligament. Contraction of the adductor muscles closes the shell (Gosling, 2004). Often these valves are transparent or translucent so that some internal anatomical detail can be seen which separate this taxon from the other bivalved benthic invertebrates (Higgins & Thiel, 1988). When a bivalve dies, adductor muscles can no longer contract and the ligament forces the shell open. A dead bivalve always has a gaping shell (Gosling, 2004).

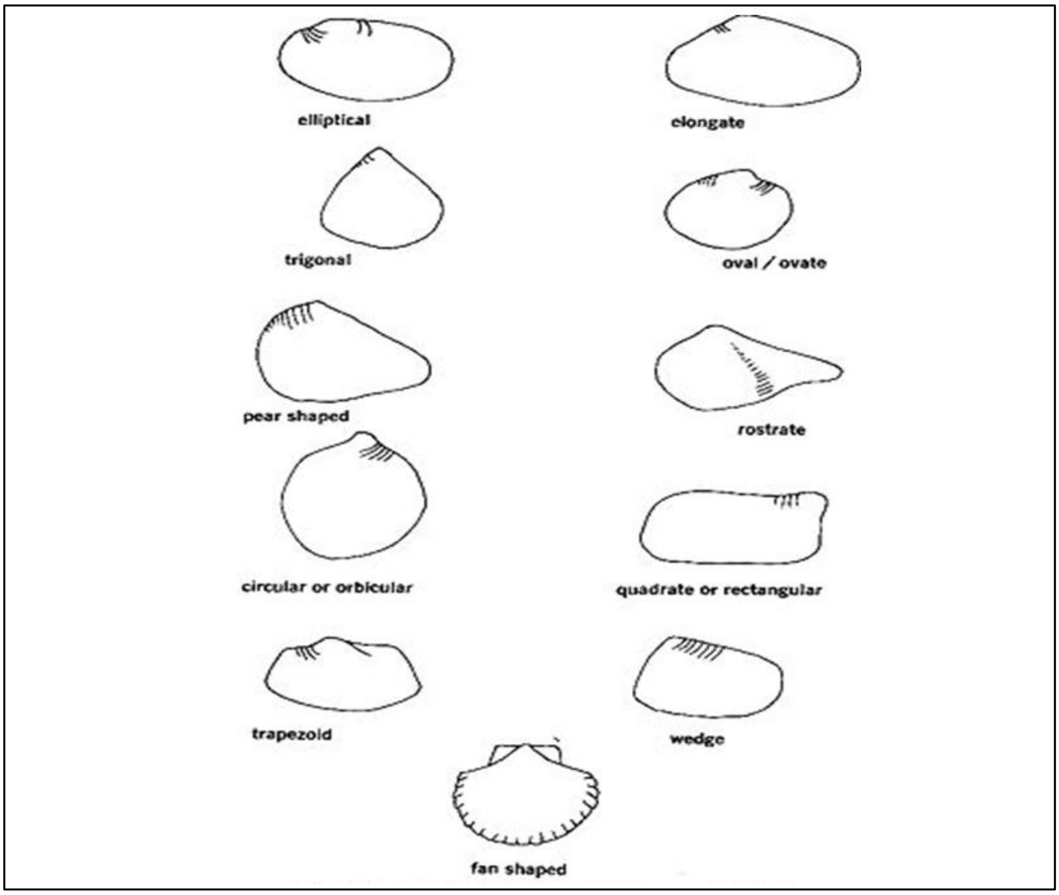


Figure 2.1: The typical shapes of bivalve shell (Jean, 1971).

Table 2.1: The major shell characters used in species identification (Gosling, 2004).

Character	Variations
Shell shape	Oval, circular, triangular, elongate, quadrate
Shell valves	Similar (equivalve), or dissimilar (inequivalve)
Colour	Shell exterior: background/surface; patterns Shell interior: white, pearly etc.
Ribs	Number, width, prominence (distinct, flattened)
Sculpturing	Concentric lines, ridges, grooves
Ligament	Position (internal, external)
Umbo	Position (anterior, terminal, subterminal)
Adductor scars	Number, size, position
Hinge line	Straight or curved, presence of 'ears' (size, shape)
Hinge teeth	Number, type
Pallial line	With or without a sinus
Pallial sinus	Size

The common mode of food collection in Bivalvia is suspension feeding (Ward *et al.*, 1993). Some are deposit feeders, microcarnivores, or rely partially or wholly on symbiotic bacteria in the gills for their nutrition. (Ponder *et al.*, 2002). Bivalves feed on a various suspended particles (seston) such as bacteria, micro-zooplankton, phytoplankton, detritus, and also on dissolved organic material (DOM), such as amino acids and sugars (Gosling, 2004). The filter feeders processed organic matter from the water column, while deposit feeders utilized the deposited detritus at the bottom (Sivadas *et al.*, 2013).

Consequently, suspension-feeding bivalves need sufficient water motion to bring in new supplies of suspended food and take away waste. In contrast, deposit-feeding bivalves require low water flow to allow the accumulation of deposited seston as a food resource. Therefore, deposit-feeding bivalves commonly inhabit low energy environments of finer sediments while suspension-feeders are more frequently associated with coarser sediments in more energetic environments dominated by tidal and wave-induced currents (Dame, 2012). Link *et al.* (2006)

found that the bivalve molluscs such as *Arctica islandica*, *Spisula solidissima*, and *Pitar morrhuanus* are filter feeders, but the bivalves *Nucula proxima* and *Tellina agilis* are deposit feeders. Some bivalve deposit feeders can switch back and forth from suspension-feeding to deposit-feeding or feed in both modes simultaneously depending on the conditions in their environment. Thus the classification of a bivalve's status as a deposit feeder may not be flawless (Dame, 2012).

Fresh input of food supply has been shown to modify their growth, reproduction, and behaviour (Ingole *et al.*, 2014). Besides, declines in feeding activity and calcification rates at low temperatures produce shell rings that can be used for age determination (Hutchings & Haedrich, 1984). Compared with suspension-feeding bivalves that pump large quantities of water and filter this water for small quantities of suspended particulate food, deposit feeding bivalves not only pump water, but also remove large quantities of deposit sediments from the surrounding benthic environment in order to increase a relatively low percentage of quality organic material (Dame, 2012).

Feeding in bivalves involves pumping water through a set of ctenidia, removal of particles from suspension, and transport of collected material to the mouth (Ward *et al.*, 1993). Bivalve deposit feeders use the same pumping mechanism as is used by bivalve suspension-feeders to move water through the animal (Dame, 2012). The suspended particles passing through ctenidial filaments are mechanically trapped by rows of laterofrontal cilia or cirri and transferred onto the frontal ciliary tracts of the filaments (Ward *et al.*, 1993). Particles are then carried in mucus by the frontal cilia to the dorsal or ventral margins of the ctenidia, where they are incorporated into compact mucus strings and transported to the mouth for ingestion via ciliated food tracts (Ward *et al.*, 1993). Marine bivalves produce excretory waste in various forms of carbon, nitrogen, phosphorus, and silicon as a result of incomplete digestion and metabolism (Dame, 2012).

Growth of the shell is quite different from the growth of somatic and reproductive tissues (Dame, 2012). Growth in bivalves is usually described in terms of an increase in some dimension of the shell valves (Gosling, 2004). There are three major aspects of shell growth and formation: (1) the role of metabolism in $CaCO_3$ formation and the synthesis of the organic matrix; (2) secretion of shell components by the mantle; and (3) $CaCO_3$ crystal growth (Dame, 2012). The growth rate can be measured as the rate of growth of one size variable is related to that of another variable (allometric growth) (Gosling, 2004). Figure 2.2 shows the convention used for the shell measurements in bivalves.

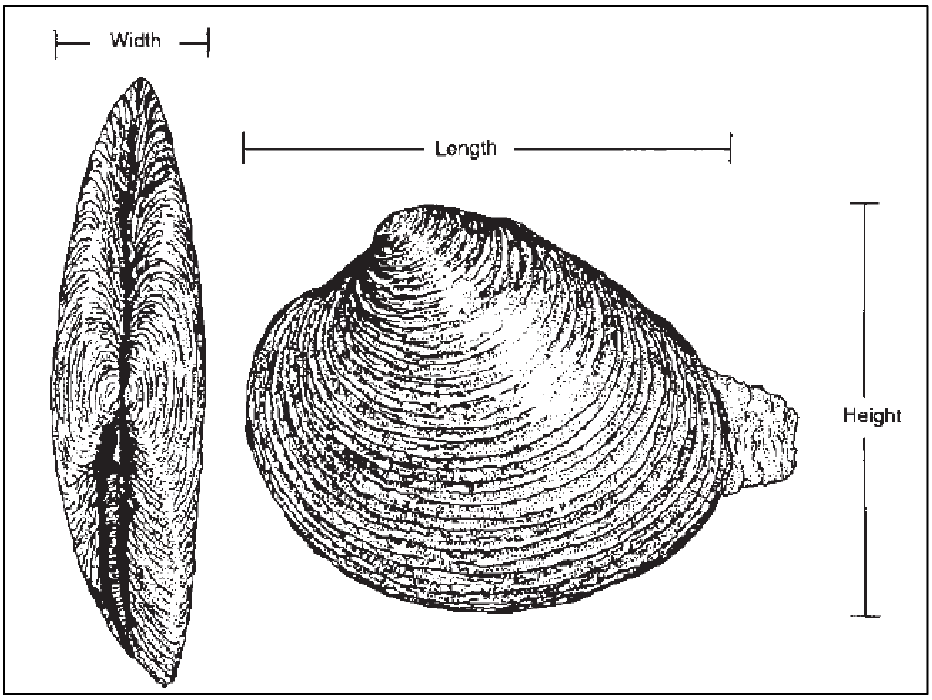


Figure 2.2: The convention used for the shell measurements in bivalves (Gosling, 2004).

All bivalves are nearly sedentary and most common lifestyles of bivalves are buried within burrows in unconsolidated soft sediments and as semi-mobile members of the epibenthos

(Dame, 2012; Ponder *et al.,* 2002). Epifaunal bivalves living attached by proteinaceous threads (byssus) or cement to the surface of stones or other organisms (Ponder *et al.,* 2002). Although most bivalves have adopted the burrowing lifestyle, there is a large and successful group that lives permanently attached on the surface (Gosling, 2004). For burrowing bivalves, additional physical factors such as substrate type and oxygen concentration come into play, while predation and competition once again are important biological factors (Gosling, 2004). In bivalve-dominated systems, the most common predators are gastropods, starfish, crabs, fish, birds, and mammals (Dame, 2012). Because bivalve larvae live in a different habitat, they suffer predation from an entirely different group of predators than do the benthic adult stages. The most commonly reported bivalve larval predators are ctenophores and jellyfish (Dame, 2012). The inner surface of a bivalve shell is shown in Figure 2.3.

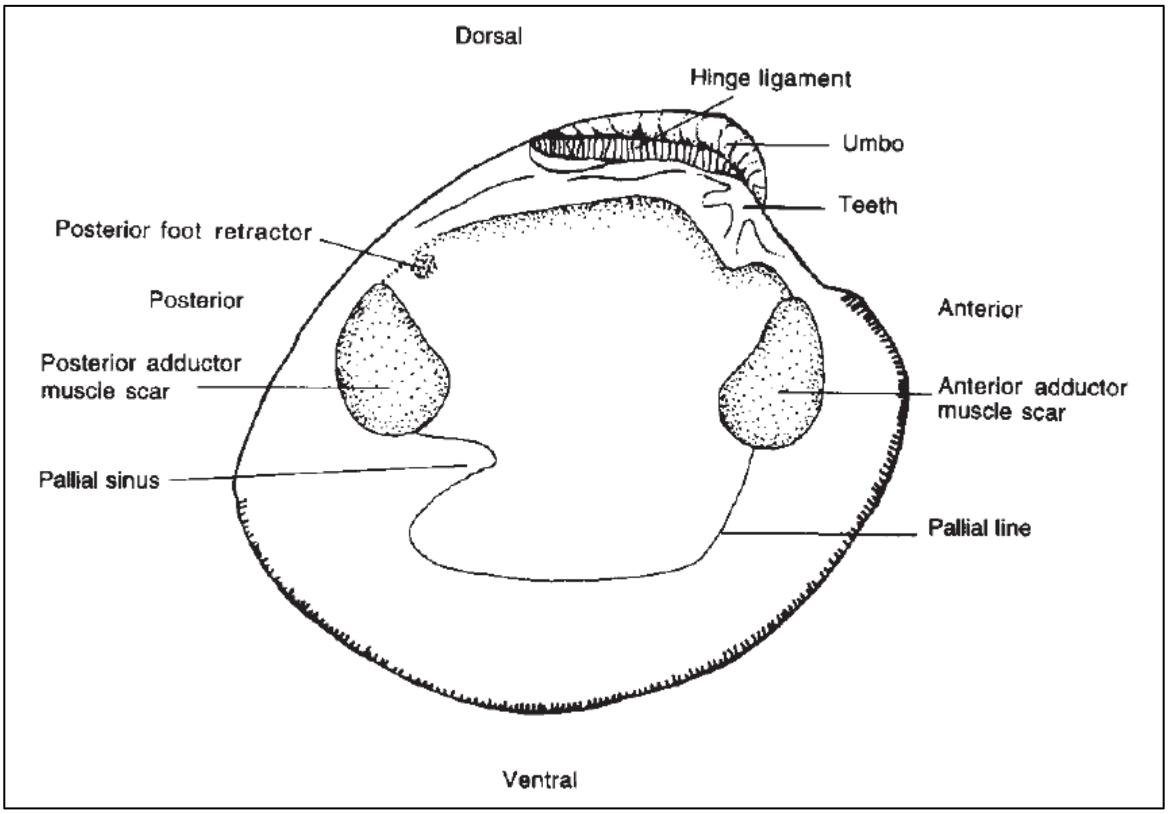


Figure 2.3: Inner surface of the left shell valve (Gosling, 2004).

2.2.2 Gastropods

Gastropods are considered as the oldest known fossils (Venkatesan & Mohamed, 2015a). The gastropod originated in the early Cambrian period about 550 Ma (Chase, 2002). Some of these gastropods are terrestrial while other gastropods live in marine or freshwater habitat (Ponder *et al.,* 2002; Venkatesan & Mohamed, 2015a). They include the sea and land snails and slugs, limpets, abalones, cowries, and cones (Gosling, 2004; Ponder *et al.,* 2002). Both the whelk and the winkle are also gastropods (Foster & Whiteley, 2002). Gastropod taxonomy has been well studied, and most studies have been devoted to quantifying their patterns of distribution with a very detailed level of taxonomic resolution (Zamprogno *et al.,* 2013). Many gastropods possess a shell, whereas some are without shells (Venkatesan & Mohamed, 2015a). Gastropods usually invest a lot of energy in specializing and strengthening the shell (Salgeback, 2006).

The shelled gastropods are also called univalves (Venkatesan & Mohamed, 2015a). Ponder *et al.* (2002) stated that most have a single coiled shell, but in some, the shell is limpet-like, rudimentary, or lost. The shell is coiled and carried on the animal's back (Foster & Whiteley, 2002). Most gastropods are helically coiled and consist of several whorls (Salgeback, 2006). In most species, the coiled shell opens on the right-hand side (dextral). Rarely, right-hand coiled species will produce left-hand coiled (sinistral) shells and vice versa (Venkatesan & Mohamed, 2015a). In the large majority of species, each whorl is cemented onto and partly overlaps the preceding whorl. Both bivalve and gastropod grow by marginal accretion (Salgeback, 2006). A gastropod grows by adding new shell material at the margin of the existing shell, so the earlier shell is maintained by the growing individual (Sturm *et al.*, 2006). Figure 2.4 shows the direction of growth in a gastropod shell.

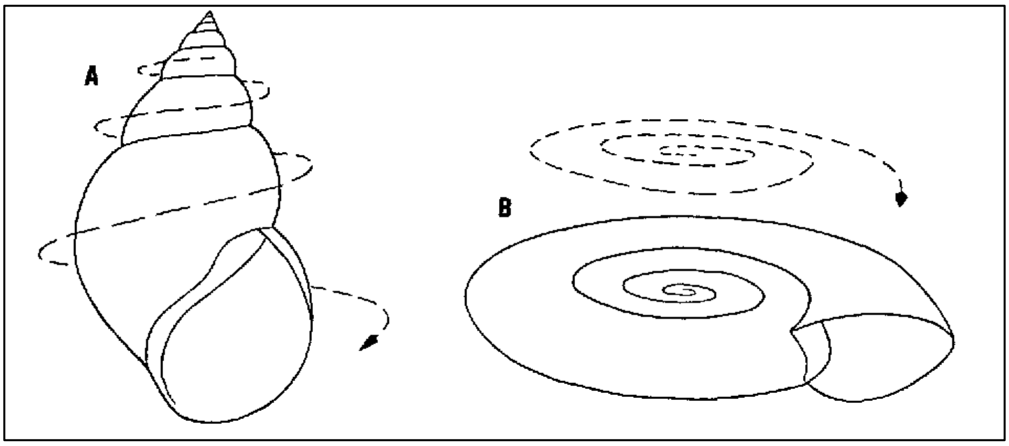


Figure 2.4: Direction of growth in a gastropod shell (**A**, shell with a well-developed spire; **B**, discoidal shell) (*A Guide for the Identification*, 1968).

The characteristics of gastropods are a clearly recognizable head bearing tentacles and eyes, a radula for rasping food, and nerve cells segregated in ganglia (Chase, 2002). They possess a distinct head with 2 - 4 sensory tentacles and bear eyes that are located near the base of the tentacles or on separate eye stalks (Venkatesan & Mohamed, 2015a). Besides that, most of the gastropods have gills for the respiration (Ray, 2008). The morphological traits that define the Gastropoda are the larval operculum, the shape of the larval shell and, most importantly, torsion (Chase, 2002). Many species have an operculum that assists to protect the animal in addition to the shell (Venkatesan & Mohamed, 2015a). Most often, morphological characters of the shell can be related to concurrent functions, although sometimes a primary function can be identified due to a high degree of morphological specialization (Salgeback, 2006). Figure 2.5 showed the typical shapes of gastropod shell.

During early larval stage development, gastropod body undergoes torsion (Ray, 2008). Torsion refers only to the twisting of the body; it is entirely different from the spiralling of the shell (Chase, 2002). A part of the body is twisted through 180° with respect to the other (Ray, 2008; Venkatesan & Mohamed, 2015a). Torsion is the single most distinguishing characteristics of gastropods (Chase, 2002). In a basic molluscan organization, mouth and anus are placed at the opposite end of the body (Ray, 2008). However, the torsion in gastropod body brings them to the same end, anus being placed above the mouth (Ray, 2008; Venkatesan & Mohamed, 2015a). This creates problems in the functioning of both the openings. Different groups of gastropods develop different means to overcome this difficulty, which brings in some corresponding changes in shells too (Ray, 2008).

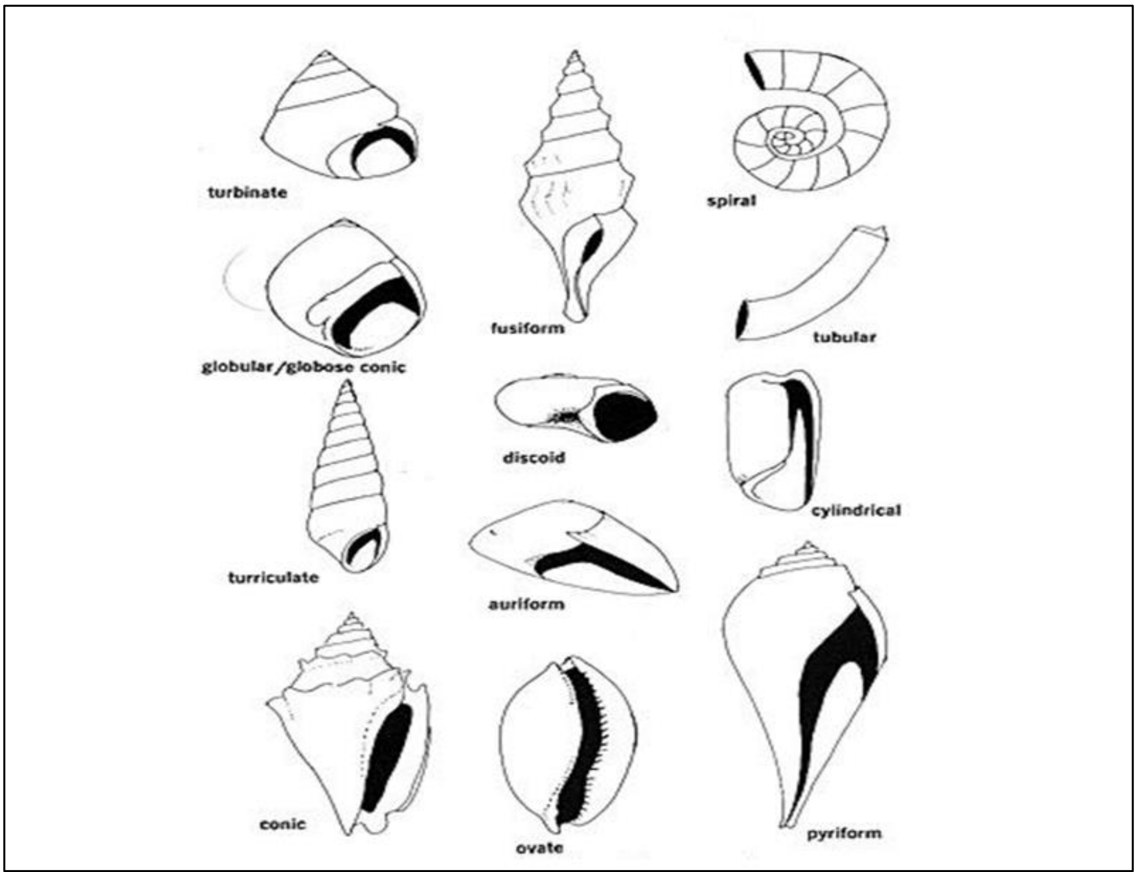


Figure 2.5: The typical shapes of gastropod shell (Jean, 1971).

Gastropods use a wide variety of feeding methods (Ponder *et al.,* 2002). Gastropod molluscs are generally carnivores and scavengers (Link *et al.*, 2006). Some of gastropods are herbivore animals and are thought to play a significant ecological role in the structure and function of the seagrass community (Shabdin *et al.,* 2014b). Although most species (herbivorous / carnivorous) use a radula (tongue like apparatus) for feeding, the feeding habits of them are varied. Other species may be detritus feeder, scavengers or ciliary feeders (Venkatesan &

Mohamed, 2015a). Gastropods feed on algae or other plants growing on wet substratum of basins or other smaller organisms living there (Ray, 2008). The time of delivery of organic matter to the seafloor can have a significant effect on their community (Ingole *et al*., 2014).

In gastropods, the shell is of major importance to the survival (Salgeback, 2006; Sturm *et al*., 2006). Many gastropods possess a shell that protects the soft body of the animal (Venkatesan & Mohamed, 2015a) and as a protection again predators (Sturm *et al*., 2006). Carrying a large and thick shell is in most cases a good defense against predators (Salgeback, 2006). The shells of gastropods also provide additional functions, such as protection against hostile environmental conditions, a variety of functions in connection with locomotion or other behaviour, and a gill-chamber for filter feeding (Salgeback, 2006). There is strong evidence that hermit crabs do not randomly enter into gastropod shells, but rather choose them according to the species and characteristics associated with the shape, coverage, dimension, and shell weight, as well as the availability of the shelters in nature (Peres & Mantelatto, 2010). Shells are available for the hermit crabs only for short periods before they become eroded, buried, broken, or used by other hermits (Peres & Mantelatto, 2010). Gastropods are often able to repair the shell in the case of an unsuccessful attack by predators (Salgeback, 2006).

Gastropods are the main predators of mussels and oysters worldwide. Gastropod predators of clams tend to be the same species that prey on mussels and oysters. They are also predators of scallops (Gosling, 2004). Many gastropods are used as food items throughout the world. For example, abalone, conchs, periwinkle gastropods are the popular food items (Venkatesan & Mohamed, 2015a). The global seashell trade has ruined populations of gastropods which results in banning the import and export of some shells (Venkatesan & Mohamed, 2015a). The general features of a gastropod are shown in Figure 2.6.

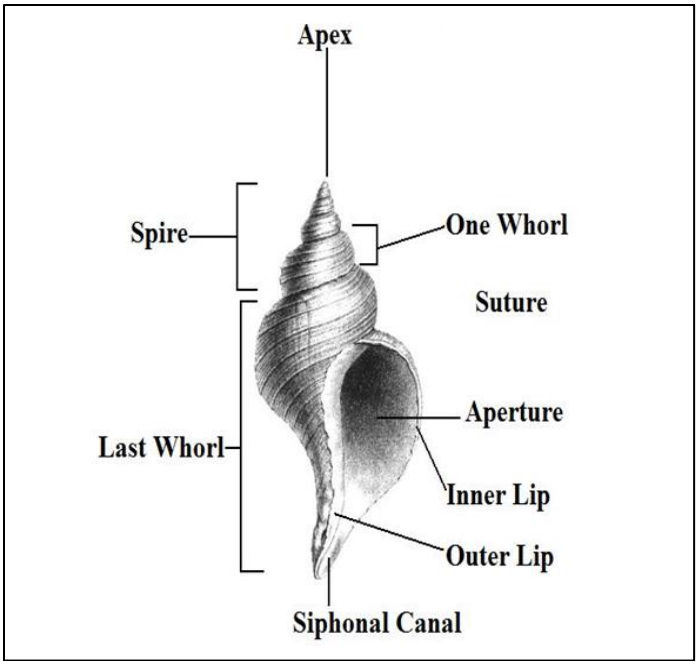


Figure 2.6: The general features of gastropod shell (Jean, 1971).

2.3 Habitat and Distribution

The phylum Mollusca is among the most diverse invertebrates (Gosling, 2015) and can be found in many parts of the world such as marine, brackish, fresh and terrestrial areas (Hamli *et al.*, 2012). Oceans cover about 70% of the earth, and soft sediment habitats cover most of the bottom of marine environments (Ingole *et al.*, 2014). These habitats support a various array of macrobenthic communities (Naser, 2011). Majority of mollusc in marine habitat are found in the shallow areas on the continental shelf, estuaries, coastal lagoons, and intertidal areas (Jara *et al.*, 2009). There are around 50,000 to 120,000 described living molluscan species among which about 30,000 species are found in marine environments (Gazeau *et al.*, 2013).

The benthic community is complex (Tagliapietra & Sigovini, 2010) and these organisms are diverse biologically especially those found on the continental shelf (Yasin & Razak, 1998). They inhabit the bottom substrates (sediments, debris, logs, macrophytes, filamentous algae) of water habitats, for at least part of their life cycle (Rosenberg & Resh, 1993). Coastal zones are variable environments, directly subject to continental, atmospheric, and oceanic influences. The instability of the coastal zone affects their community and determines the patterns of distribution (Santos & Vanin, 2014). Furthermore, physical and ecological factors such as depth of water, sediment grain size and predation interrupt the distribution of bivalve and gastropods across and along a beach (Ponder *et al.*, 2002).

Molluscs can be differentiated by the position they occupy on or in bottom sediments which are *infauna* and *epifauna* (Tagliapietra & Sigovini, 2010). Bivalves are animals that live in the sediments known as *infauna*. Gastropods are organisms that live on the surface of bottom sediments known as *epifauna* (Tagliapietra & Sigovini, 2010). The main factors that influence the composition and distribution of the benthic communities are the amount and size of substrate particles, sedimentation rate, amount of organic matter, upwelling currents, primary productivity and physical disturbance (Fletcher *et al.*, 2011; Naser, 2011).

Besides that, many species of marine gastropod and bivalve are tied to specific habitats and their existence is closely related to the salinity (Georgiev *et al.*, 2009). Gradients in salinity and nutrients are important in determining gastropod and bivalve distribution and abundance (Bishop, 2006). Many evidences suggest that 6% to 60% of net annual primary production of phytoplankton reaches the seafloor providing a prime source of high-quality food for them (Ingole *et al.*, 2014). Consolidation of the soil, the level of the water table and shade are further factors controlling species distributions (Dittmann, 2000).

2.4 Importance of Gastropods and Bivalves

Molluscs are common, highly visible, and ecologically and commercially important on a global scale (Zamprogno *et al.,* 2013). They can reach a remarkably high biomass and they occupy very different levels of the ecosystem food web (Cannicci *et al.,* 2008). Mollusc play an important role in food web, nutrient cycling and decomposition processes (Shabdin *et al.,* 2014a). Besides that, certain country exploits gastropod and bivalve for food (Georgiev *et al.,* 2009; Hamli *et al.,* 2012; Zamprogno *et al.,* 2013) as mollusc provides an important source of protein for human besides fish (Hamli *et al.,* 2012). Bivalves including the scallops, oysters, cockles, mussels and clams are all major sources of food for humans (Ponder *et al.,* 2002). Most of the bivalves, not only were consumed by the local people, but also were used as a commercial alternative livelihood of local people to increase their income (Irma & Sofyatuddin, 2012).

Furthermore, marine gastropod and bivalve consists various species that use for many purposes besides their nutritional source (Hamli *et al.,* 2012). Shells of dead gastropods are an important resource in marine benthic communities, especially in those areas with limited hard substratum (Mclean, 1983). Shells provide an excellent substrate for the settlement of many fouling organisms such as barnacles (Mclean, 1983) and seaweed (Gosling, 2004). Gastropod shells provide shelter for hermit crabs, octopuses, and fishes, provide an attachment substratum for hermit crab symbionts, and directly or indirectly modify hermit crab predation (Mclean, 1983). Gastropod shells occupied by hermit crabs are an important attachment substrate for epifauna in many predominantly soft-bottom benthic communities (Peres & Mantelatto, 2010).

Generally, mollusc from marine habitat received more attention because of their aesthetic and gastronomic appeals (Hamli *et al.,* 2012). From the time immemorial, seashells have been used as ornamentation, cooking utensils, oil lamps, musical instruments, currency and so on (Venkatesan & Mohamed, 2015a). Many big mollusc species were used in the past (and at present as well) as tools or decorations (Georgiev *et al.,* 2009; Hamli *et al.,* 2012). Also, gastropods and bivalves with high economic importance are widely cultivated (Dolorosa & Picardal, 2014). Pearl oyster culture and pearl farming is a multi-million dollar industry (Dolorosa & Picardal, 2014). In Malaysia, some of marine bivalve such as *Anadara granosa* is being cultured for commercialization (Hamli *et al.,* 2012). Some species (e.g. *Tectus niloticus*) used in the production of pearl buttons had been transplanted outside their natural range of distribution, while efforts to restore the populations of overharvested species are widely undertaken to satisfy the rapidly increasing demand in the global market (Dolorosa & Picardal, 2014). Besides that, bivalve from the Indian marine have been reported potential to use as antiviral drugs (Hamli *et al.,* 2012).

In addition, the Bivalvia family of molluscs is highly valued for the ecological processes in which its members are involved (Dame, 2012). Bivalves as filter feeders can help purify silted marine waters (Dolorosa & Picardal, 2014). Like strictly suspension-feeding bivalves, deposit-feeding bivalves remove phytoplankton, microzooplankton, organic and inorganic particles, and microbes, including bacteria, fungi, and microalgae, from the sediments and surrounding waters (Dame, 2012). Of equally important, grazing gastropods can control ephiphytic and macro algal bloom (Dolorosa & Picardal, 2014). Under laboratory condition, 20,000 juveniles of hatchery produced gastropod *Tectus (Trochus) niloticus* of 4-7 mm in diameter can consume sessile diatoms covering an area of 6.5 m^2 within a week (Dolorosa & Picardal, 2014).

One of the most practical and economical methods to determine whether human activity has any impact on reduced water quality or not, is biological monitoring (Abbaspour *et al.*, 2013). Bioindicators are used to assess the quality of the environment and how it changes over time (Nowak & Kozlowski, 2013). Soft-sediment macrobenthic assemblages are useful and sensitive indicators of the quality of the environment (Naser, 2011; Babahmadi *et al.*, 2013; and Kumar *et al.*, 2013). The physico-chemical analyses of the water quality are capable of detecting a disturbance directly and only reflect the water quality at the moment of sampling. In contrast, the biological communities provide more faithful reflection of environmental conditions, since they are continually exposed to pollutants (Ghasemi & Kamali, 2014). Gastropods and bivalves are a good and frequently used indicator (Georgiev *et al.*, 2009). Worldwide bivalves have been used to assess concentrations of bioavailable contaminants in waters (Nowak & Kozlowski, 2013).

Moreover, molluscs are used in the monitoring as the organisms are mostly sessile and integrate with the effects of pollutants over time (Gray *et al.*, 1990). The sedentary habit makes molluscs a prime candidate for use in studies of bioaccumulation and/or biomagnification of pollutants (Zamprogno *et al.*, 2013). Such indicators are more accurate than indicators based on chemical or microbiological variables (Kumar *et al.*, 2013). Monitoring could provide decision makers with information on the state of biodiversity, and consequently, assist in identifying management goals and assessing priorities for conservation (Naser, 2011). A number of attributes of bivalves and gastropods have led to their use as "monitors," "sentinels," or "indicator" of environmental stress (Dame, 2012) which are:-

i. They have wide geographical distributions.
ii. They are relatively tolerant of a wide range of environmental conditions.

iii. They have several behavioural and physiological responses to stress that are easily and quickly measured.

Thus, gastropods and bivalves provide an ideal invertebrate model system for aquatic (and especially marine) environmental monitoring and toxicology (Zamprogno *et al.*, 2013). With so many advantages, it is not surprising that they have been successfully used as short-term and long-term monitors of environmental stress in coastal and estuarine waters (Dame, 2012).

2.5 Threats

Marine water quality has become a serious issue for its effects on human health and aquatic ecosystems, including a huge group of marine life (Zhou *et al.*, 2007). The tropical coastal environments are the most biologically diverse of all marine ecosystems, but are being degraded worldwide by human activities potentially leading to numerous extinctions (Jara *et al.*, 2009). The increasingly rapid growth of coastal populations with increased availability of leisure time enlarged the pressure (Dada *et al.*, 2012). The growth of human populations and commercial industries causes marine water to receive large amounts of pollution from recreation activities, fish culture, toilet flushing, and the assimilation and transport of pollution effluents (Zhou *et al.*, 2007).

Lately, coastlines are under threat worldwide from a variety of human pressures, including coastal pollution from industrial and anthropogenic courses in addition to the effects of global climate change (Dada *et al.*, 2012; Dong *et al.*, 2010). Different type of water pollution becomes a vital problem in many countries worldwide (Nowak & Kozlowski, 2013). Man-made activities such as those related to petroleum/gas drilling, shipping, commercial fishing and recreational fishing greatly increase pressure on the marine habitat (Yasin & Razak, 1998). Consequently, the increase of anthropogenic nutrient inputs in many coastal areas has resulted in severe eutrophication problems (Zhaohui *et al.,* 2009).

In addition to that, studies over the past twenty years indicate that commercial fishing is one of the most important human impacts on the marine benthic environment (Biasi & Ranieri, 2006; Thrush *et al.*, 1998). Fishing gears (trawls and dredges) are dragged across the seafloor and potentially impact many species that live on or near the seafloor (Thrush *et al.*, 1998). The principal biological impacts of dredging are the direct removal of benthic organisms, their burial due to re-deposition of sediments and alteration of the seabed topography upon which colonization and feeding activity depends (Ware & Kenny, 2011).

A study stated that species and individual numbers of both the Gastropoda and Bivalvia had declined approximately two thirds because of extensive dredging activities for major construction projects (Morton, 1996). Similarly, according to the survey conducted by Thrush *et al.* (1998), 15% to 20% of the variability in the macrofauna community composition sampled in the cores and grab/suction dredge samples was attributed to fishing. Furthermore, between 1992 and 1995, total number of species of gastropods and bivalves had decreased from 67 to 47 and 47 to 36, respectively because of dredging activities in Hong Kong. Thin-shelled bivalves too had largely disappeared (Morton & Blackmore, 2001). Therefore, with no incentives to monitor public beaches or to use them in a sustainable manner, they might eventually degenerate in quality as a result of the influx of pollutants (Dada *et al.,* 2012).

The community structure of marine soft-bottom habitats can be shaped by natural, physical and biological disturbances which affect the substratum stability (Ong & Krishnan, 1995). The deployment of artificial reefs in marine environments can significantly alter the macrobenthos in the adjacent sediment due to variations in the local current regime (Machado *et al.*, 2013). The presence of artificial reef modules raises a decrease in the current velocity around the structures, allowing the deposition of finer material, including organic particles, which can interfere with the structure of macrobenthos community (Machado *et al.*, 2013).

Physical disturbances can also enhance community variability (Biasi & Ranieri, 2006). Reduced complexity and diversity in the benthic community, increased variation in the benthic assemblage distributional pattern, decrease in large, long-lived species, and altered physical sediment properties are clues to disturbance (Biasi & Ranieri, 2006). Disturbance in natural habitat may alter the sedimentation processes, resulting in variable deposition rates, particle size and amount of organic matter in the sediment (Machado *et al.*, 2013). Besides that, storm induced waves have caused erosion of sand bottoms and has been reported to cause reduction of species due to mortality, removal by erosion or mortality by reduced salinity from rainfall (Ong & Krishnan, 1995).

Besides, boating adds many disturbances in natural environments. Engines leak fuel and oil, heads dump sewage, hulls spread inorganic chemicals and metals used in antifouling paints such as tributylin, propellers scar seagrass beds and boat moorings, and anchors dig holes in sediments (Bishop, 2006). Furthermore, habitat modification, turbidity from wave actions, and sediment changes might also affect benthic molluscs' population (Mustaffa *et al.*, 2013). Only some species are able to overcome these stresses and inhabit unfavourable environments (Mustaffa *et al.*, 2013). It is therefore crucial to prevent and control marine water pollution, and frequently implement monitoring programs which help to understand the temporal and spatial variations in marine water quality (Zhou *et al.*, 2007).

2.6 Abundance

The class Gastropoda is the largest and most diverse within the phylum Mollusca (Gosling, 2004; Ponder *et al.,* 2002; Venkatesan & Mohamed, 2015a). They comprise one of the most abundant taxonomic groups (Zamprogno *et al.,* 2013) comprising more than half of all mollusc species (Ponder *et al.,* 2002). Marine gastropods comprise approximately 60,000 shelled gastropods and approximately 13,000 sea slugs (Sturm *et al.,* 2006). On the other hand, bivalve is the second most dominant class in the phylum Mollusca (Venkatesan & Mohamed, 2015b). They consists about 7,500 species (Gosling, 2004).

Throughout the world, numerous studies had carried out on population study of molluscs. For example, a total of 647 individuals of gastropods belonging to 82 species and a total of 2,934 individuals of bivalves belonging to 52 species were collected in West Antarctica, from the South Shetland Islands to the Bellingshausen Sea (Aldea *et al.,* 2008). Approximately 1,640 bivalve species have been described from Australia (Ponder *et al.,* 2002). Besides that, 160 species of bivalves belong to 31 families and 566 species of gastropods belong to 60 families were recognized at Southern Ocean (Brandt *et al.,* 2009). There are around 6,300 described species of marine gastropods in Australian waters (Ponder *et al.,* 2002). A study at Ubatuba Bay, Southeastern Brazilian Coast reported that of the 205 macrobenthic species identified, Mollusca (70 species) were the most diverse groups with Gastropoda represented 93% of the total species of Mollusca (Santos & Vanin, 2014). Moreover, a total of 53 taxa and 2,964 specimens of gastropods were recorded in Camburi, Manguinhos and Capuba, Brazil (Zamprogno *et al.,* 2013).

Besides that, the taxonomic composition of 78 bivalve species and 82 gastropod species were recorded in the Gulf of Tehuantepec, Mexico (Jara *et al.,* 2009). Biodiversity study of marine invertebrates on the rocky shores of Dokdo, Korea recorded 29 species of Gastropoda and 10 species of the Bivalvia (Ryu *et al.,* 2012). In addition, 8 gastropod species were recorded from the six sampling plots in Jiulongjiang Estuary, China and the dominant gastropod species at mangrove plots was *Littoraria melanostoma* (Chen *et al.,* 2007). Furthermore, a sum of 3,271 species of molluscs was reported from India in which gastropods (58.1%) formed the largest numbers of species (Venkatesan & Mohamed, 2015a) while, bivalves formed 33.6% (Venkatesan & Mohamed, 2015b).

A distribution and diversity study at Tamil Nadu Coast, India shows that bivalves consist of 12 species and gastropods consist of 17 species contribute to 4.11% and 5.82% of the total fauna production, respectively (Thilagavathi *et al.,* 2013). Besides, a study at intertidal zone in sonmiani bay, Pakistan, shows that the mollusc was the most diverse and abundant group of animals that formed 39.37% of the total faunal assemblage (Gondal *et al*., 2012). Dolorosa & Picardal (2014) reported 108 species of gastropods and bivalves in Turtle and Binunsalian Bays, Philippines where 19 species of them are bivalves while others are gastropods. Also, in Southeast Asia, about 1,211 species of bivalves were reported, and it is the highest diversity for bivalves compared to 29 regions around the world (Hamli *et al.,* 2012). Besides, there were 14 species of gastropods and 5 species of bivalves belonging to seven and four families, respectively found in Banda Aceh, Indonesia (Irma & Sofyatuddin, 2012). In addition, more than 350 species of shelled molluscs were recorded from Pulau Seribu and Jakarta Bay (Tan & Kastoro, 2004).

Distribution record in Malaysia showed a sum of 581 species was recorded in Malaysia consisting of 384 species from class Gastropoda and 206 species from class Bivalvia (Wong & Arshad, 2011). In the coastal waters of Penang National Park, 21 families, 21 genera, and

25 species of molluscs were recorded (Mustaffa *et al.*, 2013). A distribution study of pen shells study in Peninsular Malaysia by Idris *et al.* (2008) recorded a total of 135 individuals of pen shells from four study areas at the south western Johor coast. Among them, 78 individuals were recorded from Merambong Shoal, 35 individuals from Tanjung Adang and 22 individuals from Merambong Island. Besides that, studies on accumulation and depuration of heavy metal using *Nerita lineate* and *Faunusa ater* was conducted by Kanakaraju & Arfiziah, (2009) and Yap *et al.* (2010), respectively (Hamli *et al.*, 2012). The studies by Chan, (2010) recorded the new genus *Rhachis* in Peninsular Malaysia (Hamli *et al.*, 2012). The distribution records of gastropod and bivalve found in Malaysia are shown in Table 2.2.

2.7 Community Structure

The term "community" describes a group of species populations occurring together and interacting with one another within an environment, thus forming a distinctive living system with its own composition, structure, and functions (Giller, 2012). In most ecosystems, community structure emerges as a result of the complex interaction between biotic and environmental variable (Shabdin *et al.*, 2014a). Communities have many characteristics which can be considered as aspects of their structure, including species composition, species diversity, and the relative abundance of species (Tilman, 1982). Changes in the community structure have been associated with biotic factors and abiotic factors (Williams, 1994). Examples of biotic factors are competition and predation and abiotic factors such as depth, current speed, salinity, temperature, pH, dissolved oxygen, sediment type, organic loading and disturbance (Babahmadi *et al.*, 2013; Santos & Vanin, 2014; Williams, 1994).

Table 2.2: Comparison of data on gastropod and bivalve found in Malaysia (Wong & 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	Gastropod: 301 species (52 families) Bivalve: 154 species (37 families)	Purchon & 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

Species diversity is the effective number of different species that is represented in a collection of individuals which help in calculating the unequal representation of species within a collection (Milroy, 2015). The commonly used measures of diversity are Simpson's index, Shannon-Wiener index, and the total number of species (Hill, 1973). Among them, the Shannon-Wiener index is a well-known biotic index which provides a quantification of species diversity (Hurlbert, 1971; Milroy, 2015; Treuting, 2012). The advantage of this index is it incorporates a diverse range of taxa and takes into account their abundance (Treuting, 2012). Different indices measure different aspects of the partition of abundance between species (Hill, 1973). As an alternative to Shannon index, Simpson index of species dominance calculates the probability that two individuals randomly selected from the community will actually belong to the same species (Milroy, 2015). Simpson's index is regarded as a measure of "dominance concentration" because it is only sensitive to the abundance of the more plentiful species in a sample (Hill, 1973). Other statistics, such as the total number of species, are strongly affected by the presence of rarities (Hill, 1973).

Species diversity consists of two components which are species evenness and richness (Hurlbert, 1971; Jackson, 2008). Generally, the species richness and evenness are influenced by environmental factors and were inversely correlated with anthropogenic disturbances (Bhadja *et al.*, 2014).The indices for characterizing species richness and evenness are richness indices and evenness indices (Boonyapiwat, 1997). Species richness will be calculated with Margalef index using the number of species obtained. Richness can be assessed at any taxonomic level, which can be particularly useful if the researcher has difficulty in identifying organisms to the species level (Milroy, 2015). Meanwhile, species evenness evaluates if the number of species all have similar abundance, or if some species have higher abundance than other species (Jackson, 2008). Species evenness will be calculated using the Pielou’s Similarity Index (Heip, 1974). From the formula, the numerator of this ratio will tend to 0 when H decreases. Its maximum value is 1, when H = In S (Heip, 1974). Species diversity is often used as a more representative measure of community richness, as it incorporates both species number and relative abundance (Giller, 2012). Also, species diversity and species richness are often positively correlated (Hurlbert, 1971).

Often the simplest population attributes to determine are density and abundance (Dame, 2012). In species density calculation, presence of organisms can be measured as a count, and as a relative quantity within the community. These measures can then be easily related in terms of the two-dimensional (area) or three-dimensional (volume) space they occupy (Milroy, 2015). Generally, density refers to the population size at a given time calculated as number of individuals per unit area (Dame, 2012). On the other hand, species composition is the identity of all the different organisms that make up a community. Composition is proportion of species relative to total in a given area. Species with their abundance more than 1% are considered common.

A research conducted by Chen *et al.* (2007) at Haicang mangroves of Jiulongjiang Estuary, China found that gastropods were a main composition of macro-benthic fauna with the highest density of was 11 ± 4 ind./m^2. Moreover, Irma & Sofyatuddin (2012) found that at Banda Aceh, Indonesia, total abundance of gastropods and bivalves was 371 individual with average density of 74 ind./m^2 and 28 individuals with average density of 6 ind./m^2, respectively. Study of pen shells at the south western Johor coast found that the overall density was low with higher density of 0.027 ind./m^2 and lower density of 0.004 ind./m^2 both at Merambong Shoal (Idris *et al.*, 2008). A study conducted by Azzahra (2015) in Bruit Island, Sarawak, recorded the highest diversity index value of 1.69 whereas the lowest diversity was 0.00.The highest species evenness and richness was 0.72 and 2.16, respectively. Additionally, the total density of gastropod and bivalve's value ranged from 0.2 to 49.2 ind./m^2 (Azzahra, 2015).

Besides that, Ashton *et al.* (2003) found that maximum density recorded in a 1-m^2 quadrat was 130 molluscs in Sematan, Sarawak. *Assiminea brevicula* reached the highest densities with a maximum of 102 in this quadrat. Densities of gastropod species in Sematan were found to be comparable with values published for densities in other Malaysian mangroves. For example, in this study, mean densities recorded for *Assiminea 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. For the same species, Ashton (1999) recorded mean densities of 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.

2.8 Environmental Parameters

2.8.1 Physico-chemical of Water Parameters

Biological and ecological studies of water resources are the major topic in research and scientific investigations of ecosystems and have attracted the attention of many international organizations (Babahmadi *et al.*, 2013). Any changes in the hydrology will have often-irreversible effects on the functioning of these fragile ecosystems (Gasim *et al.*, 2007). Serious scientific and international measures are needed to take on them because these regions are important reservoirs of plant and animal genes in the biosphere (Babahmadi *et al.*, 2013). Water quality can be discovered through the measurement of physical and chemical factors such as DO, pH, temperature, conductivity, turbidity, TSS, BOD, COD and etc. (Abbaspour *et al.*, 2013; Bhadja *et al.*, 2014). However, the commonly measured in situ water parameters in the marine environment are dissolved oxygen, pH (chemical parameters), salinity and temperature (physical parameters) (Deliman, 1979).

Basically, the pH is determined by the amount of dissolved carbon dioxide (CO_2), which forms carbonic acid in water (Gasim *et al.*, 2007). The pH value in marine water ranges from 7.7 to 8.5 (Deliman, 1979). The cumulative influence of freshwater influx, dilution of saline water with rain, and reduction of salinity and temperature can lower the pH value (Bhadja *et al.*, 2014). In strongly reducing marine sediments, pH values can drop to approximately pH 6 (Higgins & Thiel, 1988). The normal oceanic range of temperature, conductivity and dissolved oxygen are -2 °C to 30 °C, 17 to 60 mS/cm, and 0 to 15 ppm (Deliman, 1979). Yet, in Malaysia, the coast is affected by warm waters from the South China Sea, which is approximately 30°C (Williams, 1993). Generally, the surface water temperature is influenced by the intensity of solar radiation, evaporation, freshwater influx, and cooling (Bhadja *et al.*, 2014). The average salinity value of seawater is 35 PSU (Gondal *et al.*, 2012; Gosling, 2004; Millero, 2010). Depending on the geographical location, salinity may vary seasonally due to the seasonal river input and freshwater runoff and precipitation (Dame, 2012). Thus, the value of the seawater salinity can vary from 20 to 40 ppt (Deliman, 1979).

Temperature and salinity are significant abiotic factors that have major influences on biological processes (Dame, 2012).When it comes to distribution on a large geographic scale, temperature plays a more important role than salinity. However, in coastal and estuarine regions salinity is probably the most important limiting factor (Gosling, 2004). During the last decade, the refractometric determination of salinity has become more and more common (Higgins & Thiel, 1988). Salinity may affect the structural and functional properties of animals through changes in (1) total osmotic concentrations; (2) relative proportions of solutes; (3) coefficients of adsorption and saturation of dissolved gases; and (4) density and viscosity (Dame, 2012). Furthermore, salinity gradients and salinity variation are the primary environmental driving forces determining gastropod and bivalve abundance and distribution (Bhadja *et al.*, 2014; Rolston & Dittmann, 2009).

On the contrary, surface turbidity measurements reflect suspended material of fine insoluble particles, either inorganic (clay, silt, sand) or organic, e.g. industrial or domestic waste (Gosling, 2004). Turbidity levels in the water column are strongly affected by time of day and wind speed, and will influence standing primary productivity levels. Increased turbidity may reduce light penetration and result in decreasing levels and maximum depths of benthic primary productivity in the littoral zone. In addition, increases in the suspended sediment loads that are carried by influent water masses can alter rocky benthic habitats in several ways (Alin *et al*., 1999).

Fletcher *et al.* (2011) found the average surface water temperature at the Colombian Pacific coast in all localities varied between 26.8 °C and 30.6 °C. Temperature, dissolved oxygen, and pH are strongly variable due to tidal changes, high turbidity, high organic decomposition, and freshwater input. A study at Ubatuba Bay, Southeastern Brazilian Coast reported the bottom water temperature varied between 21.1 °C and 34.5 °C. The bottom salinity values ranged from 32.80 PSU to 35.00 PSU and showed no temporal or spatial pattern. The dissolved oxygen content varied between 3.51 ml/L and 5.35 ml/L (Santos & Vanin, 2014).

Besides that, at Tamil Nadu Coast, India, Thilagavathi *et al.* (2013) stated that the temperature, salinity, and pH of water ranged from 18.2 °C to 30.1 °C, 18 PSU to 35 PSU, and 7.3 to 8.4, respectively, while the values of dissolved oxygen ranged from 3.22 mg/L to 5.65 mg/L. Moreover, a research in Daya Bay, South China Sea show that the dissolved oxygen annual cycles ranged from 4.91 to 13.26 mg/L with a mean of 7.77 mg/L in station 1 and 6.97 mg/L in station 2 (Zhaohui *et al.*, 2009). On the other hand, the water quality in the South China Sea shows the high nutrient concentrations by 5% to 25% polluted area presented the level IV eutrophication (Dong *et al.*, 2010). The conservation of water resources is one of the most important elements to maintain aquatic biodiversity and biome (Babahmadi *et al.*, 2013).

2.8.2 Sediment

Sediment character has been identified as one of the driving forces in determining the gastropod and bivalve communities (Thilagavathi *et al.*, 2013) and seems to play a role in their spatial distribution (Dame, 2012). Particle size, as categorized into sand, silt, and clay, is used to describe sediments (Dame, 2012). These textures play an important role in the ecology of benthic invertebrates (Thilagavathi *et al.*, 2013) by both direct and indirect mechanisms (Trannum *et al.*, 2006). For instance, Degraer *et al.* (2007) found that median grain size and sediment mud content were selected to represent the most important environmental variables determining the macrobenthic community distribution. Besides that, the most significant factors responsible for the structure of molluscs in Ubatuba Bay are linked to sediment granulometry, as has been pointed out by many authors (Santos & Vanin, 2014).

Also, the distribution of the macrobenthic communities of soft-bottom sediments at the Belgian Continental Shelf highly correlated with the type of sediment, which is related to a wider set of environmental conditions, such as current speed and organic content of the sediment (Hoey *et al.*, 2004). Thilagavathi *et al.* (2013) found that at Tamil Nadu Coast, India, species diversity is negatively correlated with sand and positive correlation is obtained between density and silt. Moreover, sediment characteristics in the South China Sea (Sarawak, Brunei and Sabah) were described as sand, sandy clay, clayey sand and clay. The bottom sediment of the survey area is mainly covered by sandy clay. It accounts for 38.30% of the survey area. Others are clayey sand and clay which account for 27.66% and 19.15%

respectively. Sand sediment is the lowest sediment fraction in the survey areas which account for 14.89% (Piamthipmanus, 1998).

Furthermore, total organic matter is another important sediment parameter. Organic matter in the sediments consists of compounds containing carbon, nitrogen and phosphorous compounds (Trannum *et al.,* 2006). The retention of organic matter in sediment is influenced by the particle size (Sivadas *et al.,* 2013) and the instability of surface sediments can also lead to variations of total organic matter (Simin *et al.*, 2012), which in turn is largely governed by the hydrodynamics of the region (Sivadas *et al.*, 2013). Often zones of low energy or less water flow are dominated by finer sediments while areas of high energy are composed of coarser sediments like sand (Dame, 2012; Fletcher *et al.*, 2011). Since sediments and water flow are correlated, gradients of sediments are often found, particularly in coastal waters and in the intertidal zone (Dame, 2012). Generally, sediment composed of fine sand has lower holding capacity than mud, resulting in washing out of organic matter (Sivadas *et al.,* 2013).

According to Rolston & Dittmann (2009), sediment organic content ranged from 0.36% to 11.8% ash free dry weight at Murray Mouth, North Lagoon and South Lagoon in South Australia. Their study identified sediment characteristics such as particle size and organic content have been shown to have a significant effect on colonization by bivalves and gastropods. Changes in community structure associated with moderate organic enrichment are represented by an increase in species richness, abundance and biomass (Naser, 2011). However, excessive organic enrichment reduces species richness, and increases densities and numbers of few opportunistic species. The study at Bahrain, Arabian Gulf showed a reduction in biodiversity, richness and evenness of macrobenthos due to the increase in organic enrichment mainly ammonia and phosphate (Naser, 2011). Macrobenthic responses show that organic enrichment could only favor certain opportunistic taxa (Simin *et al.*, 2012).

On the other hand, chlorophyll is an indicator of the microalgal biomass, which plays a significant role in nutrient cycling within sediments, as well as being an important primary food resource available to benthic grazers (Wazniak, 2004). The establishment and productivity of benthic microalgae are influenced by sediment type (Wazniak, 2004). Many studies involving the relationship between sediment chlorophyll *a* and the mollusc distribution have been carried out by many researchers. Most of the studies specify the existence of their relationship. For example, In Kalbadevi Bay along the west coast of India, sand was dominant (> 95%) at all stations, while silt fraction ranged from 0.2% to 2%. High sediment chlorophyll *a* value recorded was $1.27 \pm 0.21\ \mu g\ g^{-1}$ and low value was $0.4 \pm 0.1\ \mu g\ g^{-1}$ (Sivadas *et al.*, 2013). In addition, the chlorophyll *a* concentration of sediment in Sampadi Island was ranged from 0.8 mg/m^3 to 1.2 mg/m^3 (Shabdin *et al.*, 2014a).

CHAPTER 3

GASTROPOD AND BIVALVE AT MALAYSIA EXCLUSIVE ECONOMIC ZONE (EEZ) OF SARAWAK WATERS

3.1 Introduction

The South China Sea with a maximum depth deeper than 5,000 m is the largest marginal sea in the Southeast Asia (Hu *et al.*, 2000) located at the southwest corner of the North Pacific (Shaw, 1991). Since it is a marginal sea, it is largely surrounded by land with accesses to it (Morton & Blackmore, 2001). It joins the Pacific Ocean through the Luzon Strait between Taiwan and the Philippines. Water masses in the basin can be traced to the waters in the western North Pacific: the deep water below 2,000 m in the South China Sea is similar in temperature and salinity (T-S) characteristic to the Pacific Deep Water at the sill depth in the Luzon Strait, while the water above the thermocline is produced by mixing of the Pacific waters with coastal waters (Shaw, 1991).

The Luzon Strait is the principal passage through which the Pacific water enters the South China Sea; therefore the transport of salt and heat in the Luzon Strait is critical in determining the characteristics of waters in the South China Sea (Shaw, 1991). Countries that have a major influence on and claims to the sea include China, Malaysia, Philippines and Vietnam. The coastal fringes of the South China Sea are home to about 270 million people and consequently anthropogenic impacts, such as over-exploitation of resources and pollution, are anticipated to be huge (Morton & Blackmore, 2001). It is located in the monsoon regime (Hu *et al.*, 2000).

According to the United Nations Convention on the Law of the Sea 1982, the Exclusive Economic Zone (EEZ) is an area beyond and adjacent to the territorial sea, subject to the specific legal regime established in this Part, under which the rights and jurisdiction of the coastal State and the rights and freedoms of other States are governed by the relevant provisions of this Convention. In the EEZ, the coastal State has jurisdiction as provided for in the relevant provisions of this Convention with regard to marine scientific research. The exclusive economic zone shall not extend beyond 200 nautical miles from the baselines from which the breadth of the territorial sea is measured.

Jamil & Hadil (2012) reported that UNCLOS 1982 came into force on the 16th of November 1994. The Government of Malaysia formally declared Malaysia's proclamation of the EEZ on 25 of April 1980. Malaysia then signed the UNCLOS on 10 December 1982 and ratified it fourteen years later on 14 October 1996. During the period leading to Malaysia's ratification of the Law of the Sea Convention in 1996, many written national laws of the sea were established among them are; the declaration of Malaysia EEZ of 200 nautical miles as in the Exclusive Economic Zone Act, 1984. The total area of the Malaysian EEZ is 548,800 km^2, of which 46% or approximately 250,000 km^2 is the combined EEZ off the coast of Sarawak, Sabah and the Federal Territory of Labuan.

Tan & Kastoro (2004) stated that gastropod and bivalve’s distribution study was conducted at Hainan, Anambas and Natuna Islands in the South China Sea. The first fishery resources survey in the EEZ of Malaysia was conducted from 1985 to 1987 followed by the second survey from 1996 to 1997. A third survey was conducted in 2004 to 2005 off Sarawak with the objective of assessing the fishery resources in the area of 30 NM offshore, which have been exploited by deep-sea fishing vessels (Jamil & Hadil, 2012). There was a survey on the community structure of benthic fauna at South China Sea covered almost all parts of the Gulf of Thailand and the east coast of Peninsular Malaysia (Yasin & Razak, 1998). In addition, there was also a study on the abundance of macrobenthos in the South China Sea along Sarawak, Brunei and Sabah about 20 years before (Piamthipmanus, 1998).

However, the South China Sea is poorly understood in terms of its marine biota, ecology and the human impacts upon it (Morton & Blackmore, 2001). Jamil & Hadil, (2012) stated that the current knowledge of the biology of deep-water species in the Malaysian EEZ is still new. With a total of 4,675 km of coastline (Peninsular Malaysia 2,068 km, East Malaysia 2,607 km), there are still many undocumented habitats in our seas. With the lack of exposure, it would be hard to attract young enthusiast to gain interest in the mollusc taxonomy study. Currently, in Malaysia, there is no facility for such exposure. Central depository facilities such as a natural history museum where researchers could deposit their collections and hold records for the diversity of marine shelled mollusc in Malaysia are still unavailable (Wong & Arshad, 2011). These shortcomings and the lack of trained taxonomist have contributed to the weak database of marine molluscs studies (Wong & Arshad, 2011).

Furthermore, the distribution patterns of deep-sea benthic fauna in depth > 150 m of the Malaysian EEZ waters off Sabah and Sarawak are unknown (Jamil & Hadil, 2012). What is known is most often contained in reports and workshop and conference documents that are not available to the wider scientific community (Morton & Blackmore, 2001). Since, there is rarely any clear distribution record of gastropod and bivalve at Sarawak EEZ, this study will help to increase the distribution data. This study also indicates the relationship between the depth of water and community structure of gastropod and bivalve at Sarawak EEZ.

3.2 Methodology

3.2.1 Study Area

East Malaysia (Sabah and Sarawak) is situated on the Sunda Shelf in relatively shallow water (Morton & Blackmore, 2001). The study area covered the Malaysia Exclusive Economic Zone (EEZ) of Sarawak waters starting from Kuching to Miri. A total of 32 stations of various depths were selected in this research and the coordinates of each station were recorded (Table 3.1). The depths of the stations were from 20 m to 200 m. The samplings were conducted for 2 months, from 16th August until 9th October 2015 and the samplings were assisted by trained workers and researchers of SEAFDEC 2. The Training and Research Vessel, MV SEAFDEC 2 from SEAFDEC Training Department (TD), Bangkok was deployed for this survey. Figure 3.1 showed the location of sampling stations at Sarawak EEZ.

3.2.2 Gastropod and Bivalve Sampling

Marine gastropods and bivalves were collected from the bottom sediment using the Smith-McIntyre grab sampler. The Smith-McIntyre bottom sampler is designed to take samples ranging from soft mud to hard bottom ground (Figure 3.2 and 3.3). The area of the grab opening is 0.1 m^2. Due to the limited time, only one sample of bottom sediment was collected at each station in this study without replicates. The reason is this is only a preliminary study. The collected materials were washed and sieved (mesh size 500 µm) using seawater. The collected benthic specimens were placed in a plastic bag and preserved in 70% ethanol. The specimens were labelled accordingly and stored in a cooler box. Then, the samples were transferred to the laboratory for analysis.

Table 3.1: Coordinates and depths of each station.

Station	Position		Depth (m)
	Latitude (N)	Longitude (E)	
1	2° 17.50’	109° 52.50’	30
2	2° 07.50’	110° 07.50’	50
3	2° 07.50’	110° 52.50’	50
4	2° 12.50’	110° 42.50’	30
5	2° 42.50’	110° 07.50’	100
6	2° 47.50’	110° 22.50’	100
7	3° 02.50’	110° 17.50’	100
8	2° 57.50’	110° 52.50’	20
9	3° 07.50’	111° 22.50’	50
10	3° 27.50’	111° 12.50’	50
11	3°22.50’	110° 22.50’	100
12	3° 12.50’	110° 07.50’	50
13	3° 32.50’	109° 57.50’	100
14	3° 42.50’	110° 07.50’	100
15	3° 57.50’	110° 02.50’	100
16	4° 17.50’	110° 07.50’	80
17	4° 47.50’	110° 12.50’	100
18	5° 22.50’	110° 07.50’	150
19	5° 17.50’	110° 57.50’	120
20	5° 27.50’	111° 22.50’	150
21	5° 22.50’	111° 47.50’	200
22	5° 32.50’	112° 02.50’	200
23	5° 37.50’	112° 07.50’	200
24	5° 07.50’	112° 02.50’	100
25	4° 57.50’	111° 22.50’	100
26	4° 47.50’	111° 22.50’	100
27	4° 37.50’	111° 12.50’	50
28	4° 02.50’	111° 17.50’	80
29	4° 02.50’	112° 02.50’	100
30	4° 07.50’	112° 37.50’	63
31	3° 37.50’	112° 32.50’	50
32	3° 37.50’	112° 52.50’	30

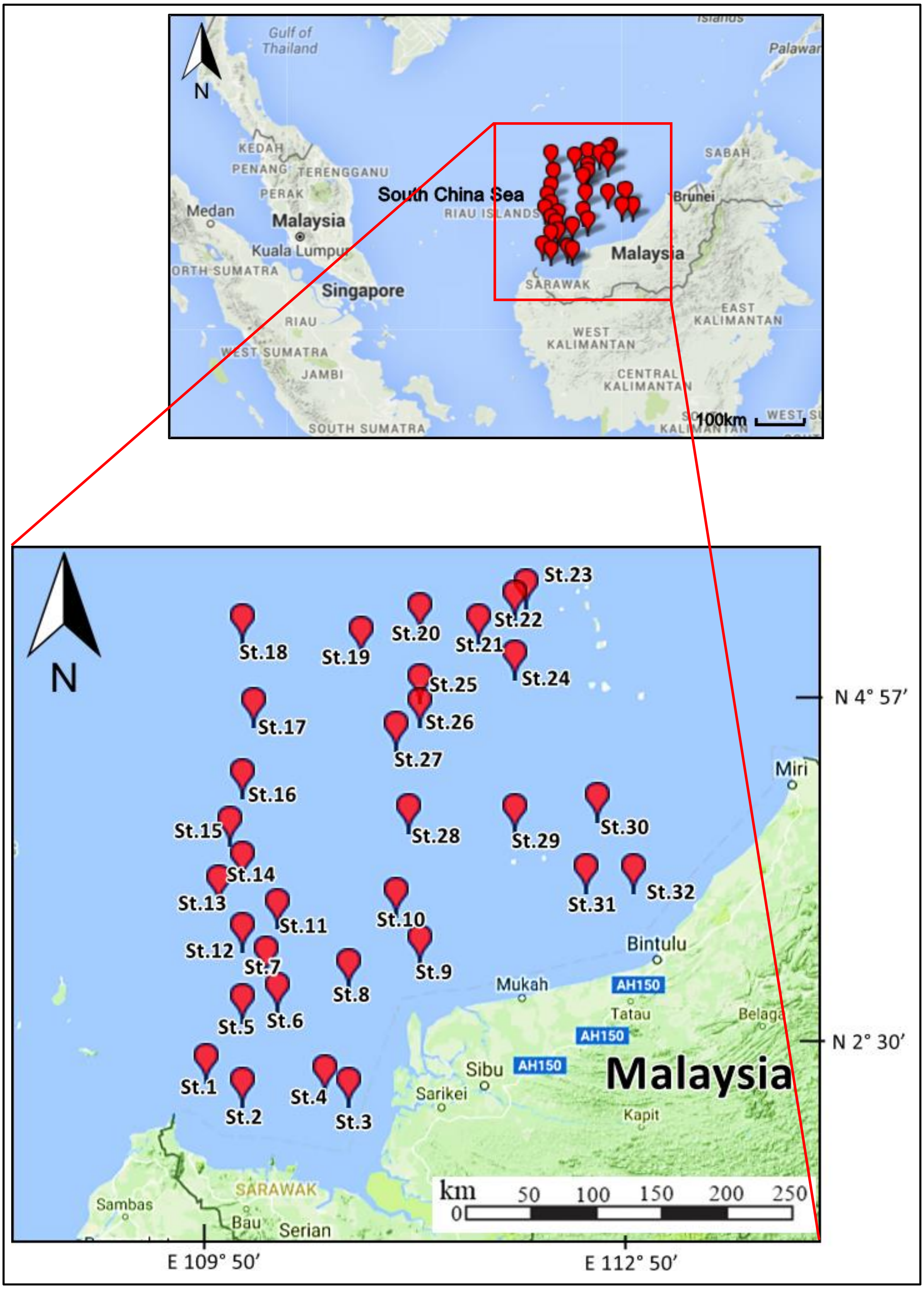


Figure 3.1: Map showing the location of sampling stations at Malaysia EEZ of Sarawak waters.

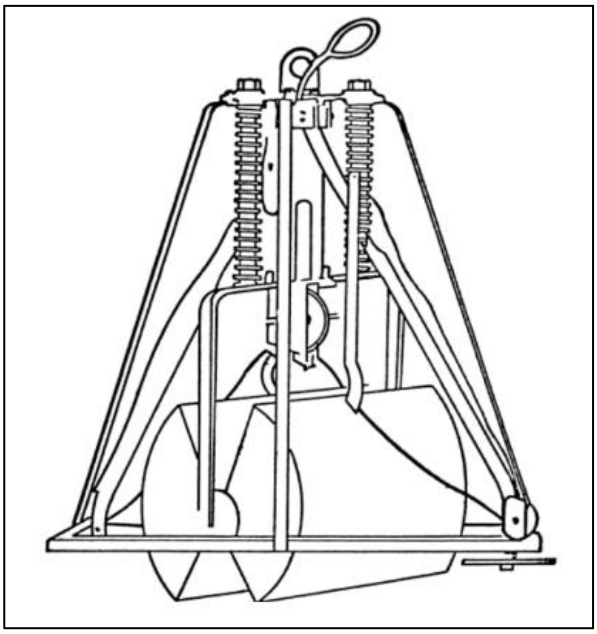


Figure 3.2: Smith McIntyre Grab (*Handbook for Sampling and Sample*, 1982).

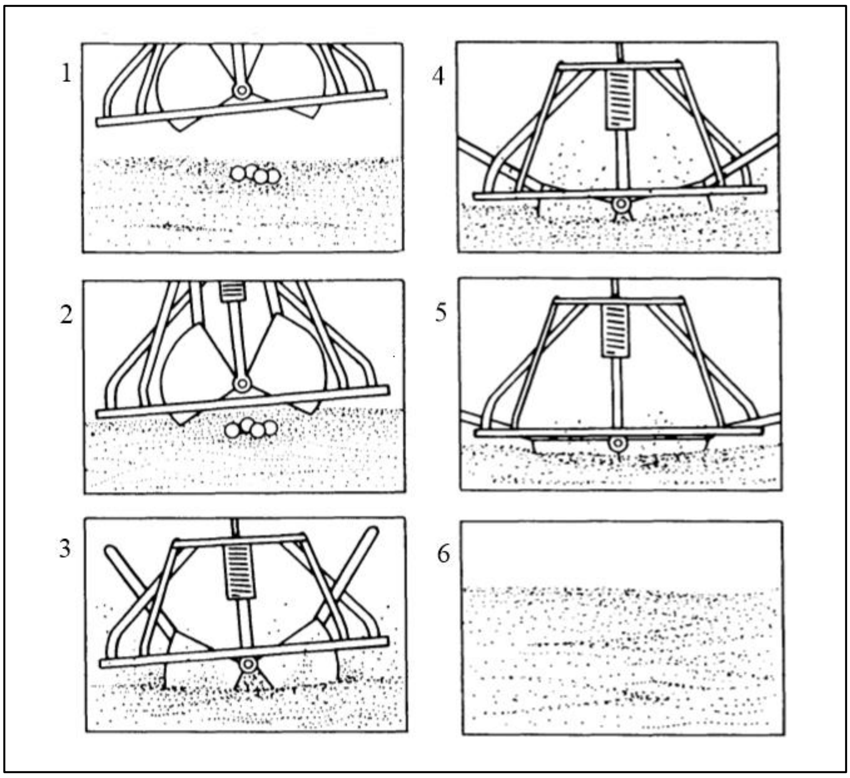


Figure 3.3: Sketches of motion pictures illustrating the efficiency of Smith-McIntyre sampler (Wigley, 1967).

3.2.3 Lab Analysis

3.2.3.1 Sorting and Counting

In the laboratory, the samples from each station were sieved using 500 µm sieve using tap water. The sample in the sieve was washed using distilled water to transfer them into a petri dish/tray. The specimens were hand-picked using forceps to sort the gastropods and bivalves. The sorted samples were placed in specimen bottle, added with 70% ethanol and labelled accordingly.

3.2.3.2 Identification of Gastropod and Bivalve

The sorted samples were identified to the species level with the aid of stereo microscope. The gastropod and bivalves identifications were following the key by Dolorosa & Picardal (2014); Hamli (2012); Shabdin & Rosniza (2010); Bernard *et al.* (1993); and *The Mac Donald Encyclopedia of Shell* (1982). Shell characteristics in the adult stage, such as the shape of the shell, length and shape of the spire, mouth opening, opercular shape, color, ornamentation, umbo and type of hinge teeth were used for the species identification of gastropod and bivalve.

3.2.4 Data Analysis

3.2.4.1 Analysis of Community Structure

The data was analyzed to study the community structures which include the species composition, species density, species diversity, species evenness and species richness. A list of all identified species in every station was documented. Species diversity indices are used to characterize species abundance and its relationships in communities. Species diversity was calculated using the Shannon Diversity index (Ludwig & Reynolds, 1988) emphasizing variation in rare species and the ecosystem status, and the Simpson's Reciprocal index (Heip, 1974) emphasizing the number of species present, as well as the abundance of each species. Diversity is composed of two components. The first being the number of species in the community; ecologists refer to this as species richness and the second component is species evenness which refers to how the species abundances are distributed among the species. Species evenness was calculated using the Pielou's evenness index (Heip, 1974), while species richness was calculated using the Margalef richness index (Margalef, 1958).

Shannon Diversity index (H') was calculated from Shannon & Weaver (1949) formula as reported in Ludwig & Reynolds (1988).

$$H' = -\sum (Pi \ln Pi)$$

$$H' = -\sum (ni/N) \ln (ni/N)$$

Where ni is the total number of individuals for each species,

N is the total number of individuals in a sample and Pi is equal to ni/N

Simpson's Reciprocal Index (1/D) was calculated from the formula reported in Heip (1974).

$$1/D = 1 / \sum (Pi^2)$$

Pielou's evenness index (J) was calculated from Pielou (1966) formula as reported in Heip (1974).

$$J' = H' / \ln S$$

H' is the species diversity value obtained from Shannon Diversity Index, and

S is the total number of species in a sample.

Margalef richness index (D) was calculated from Margalef (1958) formula.

$$D = (S-1)/\ln N$$

S is the number of species, and

N is the total number of organisms in samples

Species percentage was calculated as follow:

$$\%\text{ of species A} = \frac{\text{number of individuals of species A}}{\text{total number of individuals}} \times 100$$

Species density was calculated as follow:

$$\text{Density} = \frac{\text{number of individuals}}{\text{area of grab in m}^2}$$

3.2.4.2 Statistical Analysis

Pearson-linear correlation and linear regression were applied to determine the relationship of the water depth with the gastropod and bivalve's community structure. The correlation was performed by using the Statistical Package for the Social Sciences (SPSS) software. Cluster analysis was performed using the Bray-Curtis similarity measure to investigate the similarities of gastropods and bivalve's abundance between the stations. The relationship was based on the comparison of similarity matrices and was displayed using hierarchical agglomerative clustering technique (group average). Ordination using nonmetric multi-dimensional scaling (MDS) was performed to determine the variation of species abundance and to confirm the groups formed by the cluster. The cluster analysis was conducted using Plymouth Routines in Multivariate Ecological Research (PRIMER v7.0) software with the aid of Microsoft Excel 2010.

3.3 Results

3.3.1 Abundance of Gastropod and Bivalve

A total of 2,388 individuals of gastropod (1,158) and bivalve (1,230) were collected within all stations in Sarawak EEZ, representing 35 families and 61 species of gastropod and 18 families and 34 species of bivalve. Overall, 53 families were identified with a total of 95 species. There wasn't any station that comprised all these 53 families. No same family can be found at every station either. The most abundant species in Sarawak EEZ were *Limopsis* sp. with a total of 365 individuals followed by *Turritella cingulifera* (282) and *Pitar citrinus* (228). Appendix D shows the photos of the dominant gastropod and bivalve species in EEZ of Sarawak waters.

Some species were found to be very rare as can only be seen in one station from the overall of 32 stations. For example, *Calliostoma* sp.1, *Vexillum gouldi, Latirus constrictus, Paradrillia* sp., *P. inconstans, Subcancilla* sp., *Nassarius dorsatus, Pyramidella* sp., *Rissoina otohimeae, Zebinella herosae, Dolomena* sp., and *V. scitulum* from the class Gastropoda and *Arca navicularis, Myadora* sp.2 and *Acila divaricate* from the class Bivalvia. Meanwhile, some species were very commonly found from more than 20 stations such as *Diacavolinia longirostris* and *T. cingulifera* from Gastropoda, and *Limopsis* sp. and *P. citrinus* from Bivalvia. Checklist of gastropod and bivalve found in the study area is shown in Table 3.2 and Table 3.3.

Table 3.2: Checklist of gastropod in Malaysia EEZ of Sarawak waters.

Taxa	Station																															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Acteonidae																																
Acteon dancei															+		+															
Architectonicidae																																
Architectonica sp.		+	+	+	+	+			+								+	+								+	+			+		+
Atlantidae																																
Atlanta peroni	+							+					+								+						+					
Cerithiidae																																
Bittium sp.1		+	+	+	+	+	+	+	+	+	+			+		+	+	+			+	+	+	+	+	+	+	+	+	+	+	+
Bittium sp.2	+				+						+				+														+			
Borsoniidae																																
Microdrillia niponica	+		+							+																+						
Tomopleura reevii		+												+							+			+						+	+	
Bursidae																																
Bufonaria rana																		+										+			+	
Calliostomatidae																																
Calliostoma sp.1													+																			
Calliostoma sp.2					+		+																+					+	+	+		+
Cassidae																																
Semicassis sp.																	+														+	
Cavoliniidae																																
Cavolinia globulosa	+		+			+	+		+	+		+	+	+	+	+	+	+		+	+			+	+						+	+
Diacavolinia longirostris	+		+	+	+	+		+	+	+	+	+	+	+	+	+		+	+	+	+		+	+	+	+	+	+	+	+	+	+
Diacria trispinosa	+											+	+				+			+												
Clathurellidae																																
Paraclathurella celebensis		+						+							+																	
Glyphostoma carmen					+	+											+								+				+	+		

Table 3.2 continued

Taxa	Station																															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Conidae																																
Bathyconus comatosa					+		+		+	+													+			+				+		+
Costellariidae																																
Vexillum altisuturatum													+																			
Vexillum epigonus									+		+							+	+				+			+						+
Vexillum gouldi														+																		
Vexillum jackylenae																										+				+		
Vexillum scitulum																												+				
Vexillum sagamiense	+												+							+											+	
Vexillum sp.		+						+			+																				+	+
Cylichnidae																																
Adamnestia bizona	+			+																												
Drilliidae																																
Clavus fusconitens																		+								+					+	
Fasciolariidae																																
Latirus constrictus																										+						
Haminoeidae																																
Atys sp.									+																							+
Horaiclavidae																																
Paradrillia inconstans		+																														
Paradrillia sp.	+																															
Mangeliidae																																
Pseudoraphitoma bipyramidata	+							+											+													
Cythara sp.								+																		+		+				

Table 3.2 continued

Taxa	Station																														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Marginellidae																																
Cryptospira strigata	+					+		+						+						+	+			+		+		+				
Cryptospira fischeri		+						+													+					+	+					
Mitridae																																
Subcancilla amoena						+					+																					+
Subcancilla sp.																										+						
Nassariidae																																
Nassarius euglyptus			+	+										+				+														
Nassarius dorsatus									+																							
Nassaria pusilla																										+			+			
Nassarius sp.1																			+								+				+	
Nassarius sp.2					+									+				+					+			+			+			
Nassarius sp.3						+					+						+			+						+			+		+	
Naticidae																																
Neverita sp.	+	+	+		+				+		+			+	+		+			+			+	+		+				+	+	+
Olivellidae																																
Olivella sp.															+		+															
Pseudomelatomidae																																
Inquisitor sp.1	+											+																				
Inquisitor sp.2																					+									+		
Pyramidellidae																																
Pyramidella sp.	+																															
Turbonilla sp.																			+				+									
Ranellidae																																
Reticutriton pfeifferianus											+																		+			

Table 3.2 continued

Taxa	Station																															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Retusidae																																
Pyrunculus pyriformis	+											+								+												
Rimellidae																																
Varicospira cancellata		+			+														+													
Ringiculidae																																
Ringicula sp.						+								+						+											+	
Rissoinidae																																
Rissoina otohimeae																															+	
Rissoina sp.													+	+		+			+						+							
Zebinella herosae	+																															
Strombidae																																
Dolomena sp.									+																							
Triphoridae																																
Triphora sp.						+					+				+		+									+						
Viriola corrugata			+	+						+	+							+								+		+				
Trochidae																																
Monilea callifera					+				+																							
Turridae																																
Gemmula ambara					+		+								+		+		+	+					+							
Turritellidae																																
Turritella cingulifera	+	+	+	+	+	+	+	+	+	+	+			+	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Total	17	10	9	7	13	11	6	10	12	7	12	5	8	12	10	4	13	11	9	11	9	2	9	7	7	20	7	9	10	11	15	12

Table 3.3: Checklist of bivalve in Malaysia EEZ of Sarawak waters.

Taxa	Station																															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Arcidae																																
Anadara craticulata		+		+	+		+		+	+																						+
Anadara rotundicostata			+				+		+		+			+	+				+		+		+	+		+	+		+	+	+	
Arca navicularis				+																												
Striarca sp.													+				+			+	+				+							
Cardiidae																																
Ctenocardia virgo				+					+	+	+								+				+	+		+	+	+	+		+	+
Frigidocardium sp.			+				+	+		+						+							+		+				+			+
Laevicardium multipunctatum												+					+															
Cardiliidae																																
Cardilia semisulcata		+																										+				
Carditidae																																
Arcturellina elegantula		+		+	+			+	+	+	+		+	+				+		+			+			+	+	+	+	+		+
Corbulidae																																
Corbula scaphoides				+						+	+																	+				+
Glossidae																																
Meiocardia cumingi										+	+			+	+			+	+		+								+			+
Glycymerididae																																
Glycymeris sp.		+		+	+		+	+	+	+	+							+				+	+			+		+	+	+		+

Table 3.3 continued

Taxa	Station																														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Limopsidae																																
Limopsis sp.		+		+	+		+	+	+	+	+	+		+				+	+	+	+	+	+	+		+	+	+	+	+	+	+
Myochamidae																																
Myadora sp.1	+		+																	+								+				
Myadora sp.2																												+				
Nuculanidae																																
Saccella sp.																		+			+								+			
Nuculidae																																
Acila divaricata																+																
Pectinidae																																
Amusium pleuronectes						+		+																								
Annachlamys striatula				+						+		+					+				+						+	+	+	+	+	
Cryptopecten bullatus		+		+				+						+												+	+	+	+	+		
Mimachlamys cloacata		+		+	+		+			+					+																	+
Mimachlamys sanguinea																	+				+								+	+		
Pharidae																																
Ensiculus cultellus													+		+																	
Propeamussiidae																																
Parvamussium pauciliratum		+	+	+	+	+		+	+		+				+		+				+	+	+					+	+	+	+	

Table 3.3 continued

Taxa	Station																															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Psammobiidae																																
Gari lessoni		+		+		+			+		+						+	+	+		+	+	+			+	+	+			+	+
Solecurtidae																																
Azorinus coarctatus			+			+	+		+		+			+	+		+	+	+		+			+			+	+	+	+	+	+
Tellinidae																																
Clathrotellina pretium					+					+										+						+		+				+
Tellina tokunagai						+	+		+								+	+	+		+		+	+		+	+	+	+	+		+
Veneridae																																
Dosinia laminata					+	+				+	+			+			+			+	+	+										
Paphia semirugata																	+	+	+	+			+			+			+			
Paphia sp.						+									+								+								+	
Pitar citrinus	+	+	+	+	+	+	+	+	+	+	+			+	+		+	+	+	+	+	+	+	+		+	+	+	+	+	+	+
Placamen calophyllum		+	+	+	+				+					+			+	+	+	+	+	+				+	+		+		+	+
Timoclea subnodulosa		+		+	+		+	+	+	+	+			+				+	+		+	+	+	+		+	+	+	+	+	+	+
Total	2	12	7	15	11	8	10	9	13	14	13	3	3	10	8	2	12	12	11	9	15	8	13	7	2	13	12	17	18	12	11	16

3.3.2 Species Density and Percentage

The maximum density values of gastropod and bivalve species in the study areas was not more than 610 ind./m^2 and the minimum value was 10 ind./m^2 (Table 3.4 and 3.5). The highest density was recorded by *Limopsis* sp. at station 2 (610 ind./m^2) followed by *Pitar citrinus* at station 4 (380 ind./m^2) and *Cavolinia globulosa* at station 1 (350 ind./m^2). Highest total density was recorded at station 2 with 1,940 ind./m^2.

The percentage values below the density values in the table were calculated by stations to indicate which species represented the most in every station. The percentage of gastropod and bivalve representing each station were from 0.5% to 49.0% of the total density of each station. The highest percentage was shown by *C. Globulosa* at station 16 representing almost half of the total density in that station, followed by *Diacavolinia longirostris* at station 13 with 48.9%, and *Gari lessoni* in station 17 (48.3%).

Table 3.4: Comparison of species density (ind./m^2) and percentage (%) of gastropod and bivalve at Malaysia EEZ of Sarawak waters (Station 1- Station 16).

Taxa	Station															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Gastropoda																
Acteon dancei	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10 (1.6%)	-
Architectonica sp.	-	10 (0.5%)	10 (1.3%)	10 (0.6%)	20 (4.5%)	20 (2.6%)	-	-	10 (1.1%)	-	-	-	-	-	-	-
Atlanta peroni	20 (1.9%)	-	-	-	-	-	-	10 (2.7%)	-	-	-	-	10 (2.0%)	-	-	-
Bittium sp.1	-	140 (7.2%)	30 (4.1%)	90 (5.7%)	70 (15.9%)	80 (10.5%)	110 (16.9%)	20 (5.5%)	120 (13.3%)	180 (21.6%)	230 (20.3%)	-	-	20 (2.2%)	-	60 (10.9%)
Bittium sp.2	60 (5.7%)	-	-	-	10 (2.2%)	-	-	-	-	-	30 (2.6%)	-	-	-	130 (21.6%)	-
Microdrillia niponica	10 (0.9%)	-	10 (1.39%)	-	-	-	-	-	-	20 (2.4%)	-	-	-	-	-	-
Tomopleura reevii	-	20 (1.0%)	-	-	-	-	-	-	-	-	-	-	-	10 (1.1%)	-	-
Bufonaria rana	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Calliostoma sp.1	-	-	-	-	-	-	-	-	-	-	-	-	10 (2.0%)	-	-	-
Calliostoma sp.2	-	-	-	-	20 (4.5%)	-	10 (1.5%)	-	-	-	-	-	-	-	-	-
Semicassis sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cavolinia globulosa	350 (33.3%)	-	70 (9.72%)	-	-	50 (6.58%)	10 (1.5%)	-	10 (1.1%)	20 (2.4%)	-	140 (31.1%)	130 (26.5%)	40 (4.4%)	40 (6.6%)	270 (49.0%)
Diacavolinia longirostris	260 (24.7%)	-	80 (11.1%)	110 (7.0%)	10 (2.2%)	120 (15.79%)	-	20 (5.5%)	50 (5.5%)	20 (2.4%)	20 (1.7%)	160 (35.5%)	240 (48.9%)	130 (14.2%)	30 (5.0%)	180 (32.7%)
Diacria trispinosa	20 (1.9%)	-	-	-	-	-	-	-	-	-	-	30 (6.6%)	10 (2.0%)	-	-	-

Table 3.4 continued

Taxa	Station															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Gastropoda																
Paraclathurella celebensis	-	10 (0.5%)	-	-	-	-	-	10 (2.7%)	-	-	-	-	-	-	10 (1.6%)	-
Glyphostoma carmen	-	-	-	-	10 (2.2%)	10 (1.3%)	-	-	-	-	-	-	-	-	-	-
Bathyconus comatosa	-	-	-	-	10 (2.2%)	-	10 (1.5%)	-	10 (1.1%)	10 (1.2%)	-	-	-	-	-	-
Vexillum gouldi	-	-	-	-	-	-	-	-	-	-	-	-	-	10 (1.1%)	-	-
Vexillum altisuturatum	-	-	-	-	-	-	-	-	-	-	-	-	10 (2.0%)	-	-	-
Vexillum sagamiense	10 (0.9%)	-	-	-	-	-	-	-	-	-	-	-	10 (2.0%)	-	-	-
Vexillum sp.	-	10 (0.5%)	-	-	-	-	-	10 (2.7%)	-	-	20 (1.7%)	-	-	-	-	-
Adamnestia bizona	10 (0.9%)	-	-	10 (0.6%)	-	-	-	-	-	-	-	-	-	-	-	-
Clavus fusconitens	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Latirus constrictus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Atys sp.	-	-	-	-	-	-	-	-	10 (1.1%)	-	-	-	-	-	-	-
Paradrillia inconstans	-	10 (0.5%)	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Paradrillia sp.	10 (0.9%)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pseudoraphitoma bipyramidata	10 (0.9%)	-	-	-	-	-	-	20 (5.5%)	-	-	-	-	-	-	-	-
Cythara sp.	-	-	-	-	-	-	-	10 (2.7%)	-	-	-	-	-	-	-	-
Cryptospira strigata	20 (1.9%)	-	-	-	-	20 (2.6%)	-	10 (2.7%)	-	-	-	-	-	10 (1.1%)	-	-

Table 3.4 continued

Taxa	Station															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Gastropoda																
Cryptospira fischeri	-	10 (0.5%)	-	-	-	-	-	10 (2.7%)	-	-	-	-	-	-	-	-
Subcancilla amoena	-	-	-	-	-	10 (1.3%)	-	-	-	-	10 (0.8%)	-	-	-	-	-
Subcancilla sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nassarius euglyptus	-	-	10 (1.3%)	70 (4.4%)	-	-	-	-	-	-	-	-	-	10 (1.1%)	-	-
Nassarius dorsatus	-	-	-	-	-	-	-	-	10 (1.1%)	-	-	-	-	-	-	-
Nassaria pusilla	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nassarius sp.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nassarius sp.2	-	-	-	-	10 (2.2%)	-	-	-	-	-	-	-	-	10 (1.1%)	-	-
Nassarius sp.3	-	-	-	-	-	60 (7.8%)	-	-	-	-	10 (0.8%)	-	-	-	-	-
Neverita sp.	10 (0.9%)	10 (0.5%)	10 (1.3%)	-	20 (4.5%)	-	-	-	30 (3.3%)	-	10 (0.8%)	-	-	20 (2.2%)	10 (1.6%)	-
Olivella sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10 (1.6%)	-
Inquisitor sp.1	10 (0.9%)	-	-	-	-	-	-	-	-	-	-	10 (2.2%)	-	-	-	-
Inquisitor sp.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pyramidella sp.	20 (1.9%)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Turbonilla sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Reticutriton pfeifferianus	-	-	-	-	-	-	-	-	-	-	10 (0.8%)	-	-	-	-	-
Pyrunculus pyriformis	30 (2.8%)	-	-	-	-	-	-	-	-	-	-	20 (4.4%)	-	-	-	-
Varicospira cancellata	-	10 (0.5%)	-	-	10 (2.2%)	-	-	-	-	-	-	-	-	-	-	-

Table 3.4 continued

Taxa	Station															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Gastropoda																
Ringicula sp.	-	-	-	-	-	10 (1.3%)	-	-	-	-	-	-	-	10 (1.1%)	-	-
Rissoina otohimeae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Rissoina sp.	-	-	-	-	-	-	-	-	-	-	-	-	20 (4.0%)	10 (1.1%)	-	10 (1.8%)
Zebinella herosae	10 (0.9%)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dolomena sp.	-	-	-	-	-	-	-	-	10 (1.1%)	-	-	-	-	-	-	-
Triphora sp.	-	-	-	-	-	30 (3.9%)	-	-	-	-	10 (0.8%)	-	-	-	10 (1.6%)	-
Viriola corrugata	-	-	10 (1.3%)	10 (0.6%)	-	-	-	-	-	10 (1.2%)	20 (1.7%)	-	-	-	-	-
Monilea callifera	-	-	-	-	10 (2.2%)	-	-	-	20 (2.2%)	-	-	-	-	-	-	-
Gemmula ambara	-	-	-	-	10 (2.2%)	-	10 (1.5%)	-	-	-	-	-	-	-	20 (3.3%)	-
turritella cingulifera	80 (7.6%)	130 (6.7%)	140 (19.4%)	120 (7.6%)	40 (9.0%)	120 (15.7%)	130 (20.0%)	20 (5.56%)	140 (15.56%)	170 (20.4%)	210 (18.5%)	-	-	70 (7.6%)	80 (13.3%)	-
Vexillum epigonus	-	-	-	-	-	-	-	-	10 (1.11%)	-	10 (0.8%)	-	-	-	-	-
Vexillum jackylenae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Vexillum scitulum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bivalvia																
Anadara craticulata	-	30 (1.5%)	-	80 (5.1%)	10 (2.2%)	-	20 (3.0%)	-	10 (1.1%)	10 (1.2%)	-	-	-	-	-	-
Anadara rotundicostata	-	-	40 (5.5%)	-	-	-	10 (1.5%)	-	10 (1.1%)	-	30 (2.6%)	-	-	40 (4.4%)	10 (1.6%)	-
Arca navicularis	-	-	-	10 (0.6%)	-	-	-	-	-	-	-	-	-	-	-	-

Table 3.4 continued

Taxa	Station															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Bivalvia																
Striarca sp.	-	-	-	-	-	-	-	-	-	-	-	-	10 (2.0%)	-	-	-
Ctenocardia virgo	-	-	-	10 (0.6%)	-	-	-	-	10 (1.1%)	20 (2.4%)	10 (0.8%)	-	-	-	-	-
Frigidocardium sp.	-	-	90 (12.5%)	-	-	-	20 (3.0%)	30 (8.3%)	-	10 1.2%	-	-	-	-	-	20 (3.6%)
Laevicardium multipunctatum	-	-	-	-	-	-	-	-	-	-	-	10 (2.2%)	-	-	-	-
Cardilia semisulcata	-	10 (0.5%)	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Arcturellina elegantula	-	280 (14.4%)	-	80 (5.1%)	10 (2.2%)	-	-	10 (2.7%)	20 (2.2%)	40 (4.8%)	50 (4.4%)	-	30 (6.12%)	20 (2.2%)	-	-
Corbula scaphoides	-	-	-	20 (1.2%)	-	-	-	-	-	10 (1.2%)	10 (0.8%)	-	-	-	-	-
Meiocardia cumingi	-	-	-	-	-	-	-	-	-	10 (1.2%)	10 (0.8%)	-	-	10 (1.1%)	10 (1.6%)	-
Glycymeris sp.	-	40 (2.0%)	-	70 (4.4%)	20 (4.5%)	-	40 (6.1%)	20 (5.5%)	40 (4.4%)	30 (3.6%)	50 (4.4%)	-	-	-	-	-
Limopsis sp.	-	610 (31.4%)	-	260 (16.6%)	30 (6.8%)	-	150 (23.0%)	50 (13.8%)	200 (22.2%)	60 (7.2%)	150 (13.2%)	70 (15.5%)	-	200 (21.9%)	-	-
Myadora sp.1	20 (1.9%)	-	10 (1.39%)	-	-	-	-	-	-	-	-	-	-	-	-	-
Myadora sp.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Saccella sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Acila divaricata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10 (1.8%)
Amusium pleuronectes	-	-	-	-	-	10 (1.3%)	-	10 (2.7%)	-	-	-	-	-	-	-	-
Annachlamys striatula	-	-	-	30 (1.9%)	-	-	-	-	-	10 (1.2%)	-	10 (2.2%)	-	-	-	-

Table 3.4 continued

Taxa	Station															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Bivalvia																
Cryptopecten bullatus	-	30 (1.5%)	-	40 (2.5%)	-	-	-	30 (8.3%)	-	-	-	-	-	20 (2.2%)	-	-
Mimachlamys cloacata	-	10 (0.5%)	-	10 (0.6%)	10 (2.2%)	-	10 (1.5%)	-	-	10 (1.2%)	-	-	-	-	10 (1.6%)	-
Mimachlamys sanguinea	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ensiculus cultellus	-	-	-	-	-	-	-	-	-	-	-	-	10 (2.0%)	-	10 (1.6%)	-
Parvamussium pauciliratum	-	10 (0.5%)	20 (2.7%)	30 (1.9%)	20 (4.5%)	30 (3.9%)	-	10 (2.7%)	10 (1.1%)	-	10 (0.8%)	-	-	-	10 (1.6%)	-
Gari lessoni	-	150 (7.7%)	-	20 (1.2%)	-	20 (2.6%)	-	-	10 (1.1%)	-	20 (1.7%)	-	-	-	-	-
Azorinus coarctatus	-	-	20 (2.78%)	-	-	50 (6.5%)	30 (4.6%)	-	10 (1.1%)	-	10 (0.8%)	-	-	60 (6.5%)	50 (8.3%)	-
Clathrotellina pretium	-	-	-	-	10 (2.2%)	-	-	-	-	10 (1.2%)	-	-	-	-	-	-
Tellina tokunagai	-	-	-	-	-	20 (2.6%)	30 (4.6%)	-	20 (2.2%)	-	-	-	-	-	-	-
Dosinia laminata	-	-	-	-	10 (2.2%)	30 (3.9%)	-	-	-	10 (1.2%)	10 (0.8%)	-	-	10 (1.1%)	-	-
Paphia semirugata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Paphia sp.	-	-	-	-	-	10 (1.3%)	-	-	-	-	-	-	-	-	10 (1.6%)	-
Pitar citrinus	90 (8.5%)	180 (9.2%)	160 (22.2%)	380 (24.3%)	20 (4.5%)	60 (7.8%)	40 (6.1%)	50 (13.8%)	70 (7.7%)	50 (6.0%)	90 (7.9%)	-	-	140 (15.3%)	140 (23.3%)	-
Placamen calophyllum	-	10 (0.5%)	10 (1.3%)	10 (0.6%)	10 (2.2%)	-	-	-	10 (1.1%)	-	-	-	-	30 (3.3%)	-	-
Timoclea subnodulosa	-	220 (11.3%)	-	90 (5.7%)	40 (9.0%)	-	20 (3.0%)	10 (2.7%)	50 (5.5%)	120 (14.4%)	90 (7.9%)	-	-	30 (3.3%)	-	-
Total	1050	1940	720	1560	440	760	650	360	900	830	1130	450	490	910	600	550

Table 3.5: Comparison of species density (ind./m^2) and percentage (%) of gastropod and bivalve at Malaysia EEZ of Sarawak waters (Station 17- Station 32).

Taxa	Station															
	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Gastropoda																
Acteon dancei	10 (1.6%)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Architectonica sp.	10 (1.6%)	10 (1.2%)	-	-	-	-	-	-	-	10 (1.0%)	10 (1.8%)	-	-	10 (1.5%)	-	20 (1.8%)
Atlanta peroni	-	-	-	-	10 (1.6%)	-	-	-	-	-	10 (1.8%)	-	-	-	-	-
Bittium sp.1	40 (6.4%)	80 (10.0%)	-	-	30 (4.8%)	20 (8.0%)	70 (9.7%)	10 (1.8%)	120 (22.6%)	50 (5.1%)	20 (3.7%)	90 (14.5%)	110 (13.7%)	110 (16.9%)	30 (3.4%)	190 (17.5%)
Bittium sp.2	-	-	-	-	-	-	-	-	-	-	-	-	10 (1.2%)	-	-	-
Microdrillia niponica	-	-	-	-	-	-	-	-	-	10 (1.0%)	-	-	-	-	-	-
Tomopleura reevii	-	-	-	-	10 (1.6%)	-	-	20 (3.7%)	-	-	-	-	-	10 (1.5%)	10 (1.1%)	-
Bufonaria rana	-	10 (1.2%)	-	-	-	-	-	-	-	-	-	20 (3.2%)	-	-	10 (1.1%)	-
Calliostoma sp.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Calliostoma sp.2	-	-	-	-	-	-	20 (2.7%)	-	-	-	-	10 (1.6%)	20 (2.5%)	20 (3.0%)	-	10 (0.9%)
Semicassis sp.	10 (1.6%)	-	-	-	-	-	-	-	-	-	-	-	-	-	10 (1.1%)	-
Cavolinia globulosa	40 (6.4%)	30 (3.7%)	-	160 (30.7%)	10 (1.6%)	-	-	20 (3.7%)	240 (45.2%)	-	-	-	-	-	50 (5.8%)	20 (1.8%)
Diacavolinia longirostris	-	50 (6.2%)	30 (7.1%)	50 (9.6%)	30 (4.8%)	-	20 (2.7%)	90 (16.6%)	60 (11.3%)	10 (1.0%)	20 (3.7)	10 (1.6%)	30 (3.7%)	20 (3.0%)	70 (8.1%)	30 (2.7%)
Diacria trispinosa	20 (3.2%)	-	-	10 (1.9%)	-	-	-	-	-	-	-	-	-	-	-	-

Table 3.5 continued

Taxa	Station															
	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Gastropoda																
Paraclathurella celebensis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Glyphostoma carmen	10 (1.6%)	-	-	-	-	-	-	-	10 (1.8%)	-	-	-	10 (1.2%)	10 (1.5%)	-	-
Bathyconus comatosa	-	-	-	-	-	-	10 (1.3%)	-	-	20 (2.0%)	-	-	-	10 (1.5%)	-	10 (0.9%)
Vexillum gouldi	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Vexillum altisuturatum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Vexillum sagamiense	-	-	-	10 (1.9%)	-	-	-	-	-	-	-	-	-	-	10 (1.1%)	-
Vexillum sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	20 (2.3%)	20 (1.8%)
Adamnestia bizona	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Clavus fusconitens	-	10 (1.2%)	-	-	-	-	-	-	-	10 (1.0%)	-	-	-	-	10 (1.1%)	-
Latirus constrictus	-	-	-	-	-	-	-	-	-	10 (1.0%)	-	-	-	-	-	-
Atys sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10 (0.9%)
Paradrillia inconstans	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Paradrillia sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pseudoraphitoma bipyramidata	-	-	20 (4.7%)	-	-	-	-	-	-	-	-	-	-	-	-	-
Cythara sp.	-	-	-	-	-	-	-	-	-	10 (1.0%)	-	10 (1.6%)	-	-	-	-
Cryptospira strigata	-	-	-	20 (3.8%)	10 (1.6%)	-	-	10 (1.8%)	-	10 (1.0%)	-	10 (1.6%)	-	-	-	-

Table 3.5 continued

Taxa	Station															
	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Gastropoda																
Cryptospira fischeri	-	-	-	-	10 (1.6%)	-	-	-	-	10 (1.0%)	10 (1.8%)	-	-	-	-	-
Subcancilla amoena	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10 (0.9%)
Subcancilla sp.	-	-	-	-	-	-	-	-	-	10 (1.0%)	-	-	-	-	-	-
Nassarius euglyptus	-	10 (1.2%)	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nassarius dorsatus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nassaria pusilla	-	-	-	-	-	-	-	-	-	10 (1.0%)	-	-	10 (1.2%)	-	-	-
Nassarius sp.1	-	-	10 (2.3%)	-	-	-	-	-	-	-	10 (1.8%)	-	-	-	10 (1.1%)	-
Nassarius sp.2	-	10 (1.2%)	-	-	-	-	20 (2.7%)	-	-	10 (1.0%)	-	-	10 (1.2%)	-	-	-
Nassarius sp.3	20 (3.2%)	-	-	20 (3.8%)	-	-	-	-	-	10 (1.0%)	-	-	10 (1.2%)	-	10 1.1%	-
Neverita sp.	10 (1.6%)	-	-	20 (3.8%)	-	-	10 (1.3%)	10 (1.8%)	-	10 (1.0%)	-	-	-	30 (4.6%)	20 (2.3%)	10 (0.9%)
Olivella sp.	10 (1.6%)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Inquisitor sp.1	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-
Inquisitor sp.2	-	-	-	-	10 (1.6%)	-	-	-	-	-	-	-	-	10 1.5%	-	-
Pyramidella sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Turbonilla sp.	-	-	10 (2.3%)	-	-	-	10 (1.3%)	-	-	-	-	-	-	-	-	-
Reticutriton pfeifferianus	-	-	-	-	-	-	-	-	-	-	-	-	10 (1.2%)	-	-	-
Pyrunculus pyriformis	-	-	-	30 (5.7%)	-	-	-	-	-	-	-	-	-	-	-	-
Varicospira cancellata	-	-	10 (2.3%)	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 3.5 continued

Taxa	Station															
	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Gastropoda																
Ringicula sp.	-	-	-	10 (1.9%)	-	-	-	-	-	-	-	-	-	-	10 (1.1%)	-
Rissoina otohimeae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10 (1.1%)	-
Rissoina sp.	-	-	10 (2.3%)	-	-	-	-	-	40 (7.5%)	-	-	-	-	-	-	-
Zebinella herosae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dolomena sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Triphora sp.	20 (3.2%)	-	-	-	-	-	-	-	-	10 (1.0%)	-	-	-	-	-	-
Viriola corrugata	-	10 (1.2%)	-	-	-	-	-	-	-	10 (1.0%)	-	10 (1.6%)	-	-	-	-
Monilea callifera	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Gemmula ambara	20 (3.2%)	-	10 (2.3%)	20 (3.85%)	-	-	-	-	20 (3.7%)	-	-	-	-	-	-	-
turritella cingulifera	140 (22.5%)	70 (8.7%)	20 (4.7%)	10 (1.92%)	50 (8.0%)	30 (12.0%)	150 (20.8%)	20 (3.7%)	20 (3.7%)	220 (22.6%)	10 (1.85%)	70 (11.2%)	150 (18.7%)	50 (7.6%)	70 (8.1%)	290 (26.8%)
Vexillum epigonus	-	10 (1.2%)	10 (2.3%)	-	-	-	20 (2.7%)	-	-	10 (1.0%)	-	-	-	-	-	10 (0.9%)
Vexillum jackylenae	-		-	-	-	-	-	-	-	10 (1.0%)	-	-	-	10 (1.5%)	-	-
Vexillum scitulum	-	-	-	-	-	-	-	-	-	-	-	10 (1.6%)	-	-	-	-
Bivalvia																
Anadara craticulata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10 (0.9%)
Anadara rotundicostata	-	-	30 (7.1%)	-	30 (4.8%)	-	10 (1.3%)	10 (1.8%)	-	10 (1.0%)	20 (3.7%)	-	20 (2.5%)	20 (3.0%)	10 (1.1%)	-
Arca navicularis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 3.5 continued

Taxa	Station															
	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Bivalvia																
Striarca sp.	20 (3.2%)	-	-	10 (1.9%)	10 (1.6%)	-	-	-	10 (1.8%)	-	-	-	-	-	-	-
Ctenocardia virgo	-	-	10 (2.3%)	-	-	-	20 (2.7%)	10 (1.8%)	-	10 (1.0%)	10 (1.8%)	20 (3.2%)	20 (2.5%)	-	30 (3.4%)	20 (1.8%)
Frigidocardium sp.	-	-	-	-	-	-	10 (1.3%)	-	10 (1.8%)	-	-	-	10 (1.2%)	-	-	10 (0.9%)
Laevicardium multipunctatum	10 (1.6%)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cardilia semisulcata	-	-	-	-	-	-	-	-	-	-	-	10 (1.6%)	-	-	-	-
Arcturellina elegantula	-	30 (3.7%)	-	20 (3.8%)	-	-	70 (9.7%)	-	-	60 (6.1%)	10 (1.8%)	50 (8.0%)	30 (3.7%)	30 (4.6%)	-	40 (3.7%)
Corbula scaphoides	-	-	-	-	-	-	-	-	-	-	-	10 (1.6%)	-	-	-	10 (0.9%)
Meiocardia cumingi	-	10 (1.2%)	10 (2.3%)	-	20 (3.2%)	-	-	-	-	-	-	-	10 (1.2%)	-	-	10 (0.9%)
Glycymeris sp.	-	40 (5.00%)	-	-	-	40 (16.0%)	20 (2.7%)	-	-	30 (3.0%)	-	10 (1.6%)	50 (6.2%)	20 (3.0%)	-	30 (2.7%)
Limopsis sp.	-	180 (22.5%)	150 (35.7%)	60 (11.5%)	150 (24.1%)	30 (12.0%)	110 (15.2%)	210 (38.8%)	-	170 (17.5%)	220 (40.7%)	70 (11.2%)	90 (11.2%)	70 (10.7%)	240 (27.9%)	120 (11.1%)
Myadora sp.1	-	-	-	10 (1.9%)	-	-	-	-	-	-	-	10 (1.6%)	-	-	-	-
Myadora sp.2	-	-	-	-	-	-	-	-	-	-	-	10 (1.6%)	-	-	-	-
Saccella sp.	-	40 (5.0%)	-	-	10 (1.6%)	-	-	-	-	-	-	-	10 (1.2%)	-	-	-
Acila divaricata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Amusium pleuronectes	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Annachlamys striatula	10 (1.6%)	-	-	-	10 (1.6%)	-	-	-	-	-	10 (1.8%)	10 (1.6%)	20 (2.5%)	10 (1.5%)	10 (1.1%)	-

Table 3.5 continued

Taxa	Station															
	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Bivalvia																
Cryptopecten bullatus	-	-	-	-	-	-	-	-	-	10 (1.0%)	10 (1.8%)	10 (1.6%)	10 (1.2%)	10 (1.5%)	-	-
Mimachlamys cloacata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10 (0.9%)
Mimachlamys sanguinea	20 (3.2%)	-	-	-	20 (3.2%)	-	-	-	-	-	-	-	10 (1.2%)	10 (1.5%)	-	-
Ensiculus cultellus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Parvamussium pauciliratum	20 (3.2%)	-	-	-	10 (1.6%)	10 (4.0%)	10 (1.3%)	-	-	-	-	10 (1.6%)	10 (1.2%)	10 (1.5%)	10 (1.1%)	-
Gari lessoni	300 (48.3%)	10 (1.2%)	10 (2.3%)	-	20 (3.2%)	20 (8.0%)	10 (1.3%)	-	-	10 (1.0%)	30 (5.5%)	10 (1.6%)	-	-	10 (1.1%)	10 (0.9%)
Azorinus coarctatus	20 (3.2%)	10 (1.2%)	10 (2.3%)	-	20 (3.2%)	-	-	10 (1.8%)	-	-	10 (1.8%)	10 (1.6%)	10 (1.2%)	10 (1.5%)	20 (2.3%)	10 (0.9%)
Clathrotellina pretium	-	-	-	10 (1.9%)	-	-	-	-	-	10 (1.0%)	-	10 (1.6%)	-	-	-	10 (0.9%)
Tellina tokunagai	20 (3.2%)	20 (2.5%)	10 (2.3%)	-	10 (1.6%)	-	20 (2.7%)	20 (3.7%)	-	10 (1.0%)	30 (5.5%)	10 (1.6%)	10 (1.2%)	20 (3.0%)	-	20 (1.8%)
Dosinia laminata	20 (3.2%)	-	-	10 (1.9%)	30 (4.8%)	10 (4.0%)	-	-	-	-	-	-	-	-	-	-
Paphia semirugata	20 (3.2%)	10 (1.2%)	10 (2.3%)	10 (1.9%)	-	-	10 (1.3%)	-	-	10 (1.0%)	-	-	10 (1.2%)	-	-	-
Paphia sp.	-	-	-	-	-	-	10 (1.3%)	-	-	-	-	-	-	-	10 (1.1%)	-
Pitar citrinus	60 (9.6%)	40 (5.0%)	20 (4.7%)	20 (3.8%)	70 (11.2%)	60 (24.0%)	20 (2.7%)	40 (7.4%)	-	70 (7.2%)	40 (7.4%)	50 (8.0%)	50 (6.2%)	70 (10.7%)	130 (15.1%)	70 (6.4%)
Placamen calophyllum	10 (1.6%)	30 (3.7%)	20 (4.7%)	10 (1.9%)	10 (1.6%)	10 (4.0%)	-	-	-	10 (1.0%)	10 (1.8%)	-	10 (1.2%)	-	10 (1.1%)	10 (0.9%)
Timoclea subnodulosa	-	80 (10.0%)	10 (2.3%)	-	30 (4.8%)	20 (8.0%)	70 (9.7%)	60 (11.1%)	-	100 (10.3%)	50 (9.2%)	70 (11.2%)	50 (6.2%)	80 (12.3%)	30 (3.4%)	60 (5.5%)
Total	620	800	420	520	620	250	720	540	530	970	540	620	800	650	860	1080

3.3.3 Species Number, Diversity, Evenness, Richness, and Total Density

Shannon Diversity index value of gastropod and bivalve species in the study area was between 1.223 and 2.959 while the value of Simpsons Reciprocal index was in the range of 2.763 to 15.125. The highest value was recorded at station 5 while, the lowest was recorded at station 16. For the species evenness, the maximum value was obtained at station 8 and the lowest was obtained at station 13 with 0.938 and 0.650, respectively. The highest gastropod and bivalve species number was found in station 26, comprised of 33 species with richness value of 6.995. Meanwhile, the lowest richness value was recorded at station 16 (1.248) with only six species. The range of total density was between 250 ind./m^2 and 1940 ind./m^2. The highest was recorded at station 2 whereas the lowest was recorded at station 22. The community structure (species number, diversity, evenness, richness, and total density) of gastropod and bivalve in the study area was specified in Table 3.6.

Table 3.6: Species number, diversity, evenness, richness, and total density of gastropod and bivalve in the study area.

Station	Species Number	Shannon Diversity Index	Simpson's Reciprocal Index	Pielou's Index	Margalef Index	Total Density (ind./m^2)
1	19	2.116	5.203	0.718	3.868	1050
2	22	2.234	6.323	0.723	3.986	1940
3	16	2.291	7.557	0.826	3.507	720
4	22	2.524	8.624	0.816	4.159	1560
5	24	2.959	15.125	0.931	6.078	440
6	19	2.629	11.065	0.893	4.156	760
7	16	2.295	7.247	0.828	3.593	650
8	19	2.761	13.224	0.938	5.023	360
9	25	2.618	9.101	0.813	5.334	900
10	21	2.453	7.928	0.806	4.526	830
11	25	2.564	8.788	0.797	5.077	1130
12	8	1.593	3.917	0.766	1.839	450
13	11	1.559	3.139	0.650	2.569	490
14	22	2.557	8.952	0.827	4.655	910
15	18	2.341	7.287	0.810	4.152	600
16	6	1.223	2.763	0.682	1.248	550
17	25	2.88	11.791	0.895	5.815	620
18	23	2.696	10.390	0.860	5.021	800
19	20	2.482	6.485	0.828	5.083	420
20	20	2.513	7.511	0.839	4.809	520
21	24	2.767	10.333	0.817	5.573	620
22	10	2.137	7.353	0.928	2.796	250
23	22	2.625	9.708	0.849	4.910	720
24	14	2.034	4.893	0.771	3.259	540
25	9	1.609	3.587	0.732	2.015	530
26	33	2.757	9.215	0.789	6.995	970
27	19	2.279	5.152	0.774	4.512	540
28	26	2.845	12.645	0.873	6.057	620
29	28	2.844	11.594	0.853	6.162	800
30	23	2.762	11.835	0.881	5.270	650
31	26	2.606	8.022	0.800	5.612	860
32	28	2.582	7.776	0.775	5.767	1080

3.3.4 Correlation of Community Structure with Water Depth

The relationship between the distribution of gastropod and bivalve with the water depth was analysed using the Pearson correlation (Table 3.7). The depths of all the 32 stations were from 20 m to 200 m. The results showed the total density was negatively correlated with the depth of water (r = -0.371; p = 0.036). The r value indicates a weak relationship between them and the correlation was significant at the 0.05 level. The strength of the correlation coefficient value was shown in Table C1, Appendix C. The scattered plot of linear regression in Figure 3.4 showed the total density was significantly decreased with increasing water depth with R^2 value of 0.138.

Table 3.7: Pearson-linear correlation coefficient (r value) between community structure and environmental parameters.

Parameter		Species Number	Shannon Diversity Index	Simpson's Reciprocal Index	Pielou's Index	Margalef Index	Total Density
Depth	r	-.060	.102	.110	.263	.038	**-.371***
	p	.743	.579	.551	.145	.836	**.036**

*. Correlation is significant at the 0.05 level (2-tailed).

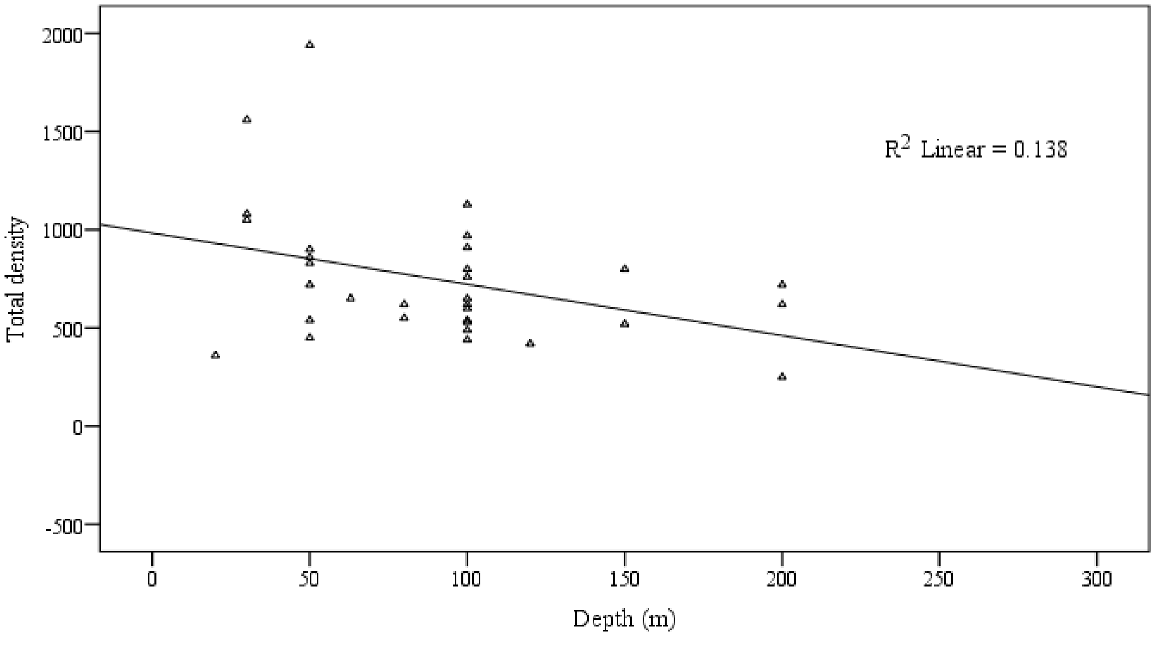


Figure 3.4: The scattered plot of linear regression between total density and water depth.

3.3.5 Cluster Analysis

Classification analysis using the Bray-Curtis similarity with group average linking method followed by an ordination through MDS was conducted on the gastropod and bivalve's abundance data (ind./m^2). The groupings in cluster analysis were displayed in the dendogram (Figure 3.5). The result was also confirmed by the two-dimensional (2D) ordination of similarity matrices which was displayed using the non-metric MDS (Figure 3.6). The cluster analysis grouped the sampling stations into 11 clusters at 50% similarity threshold. Station 1, 5, 15 and 17 were clearly separated from each other and formed four different clusters. Station 16, and 25 made up one cluster while, station 12, 13 and 20 formed a distinct group. Station 3 and 6 formed a cluster while, station 8 and 22 produced one cluster. Besides that, station 2 and 4 generates a group, whereas station 14, 19, 21, 24, 27, and 31 formed a group. Lastly, station 7, 9, 10, 11, 18, 23, 26, 28, 29, 30 and 32 produced the biggest cluster consisting nine stations.

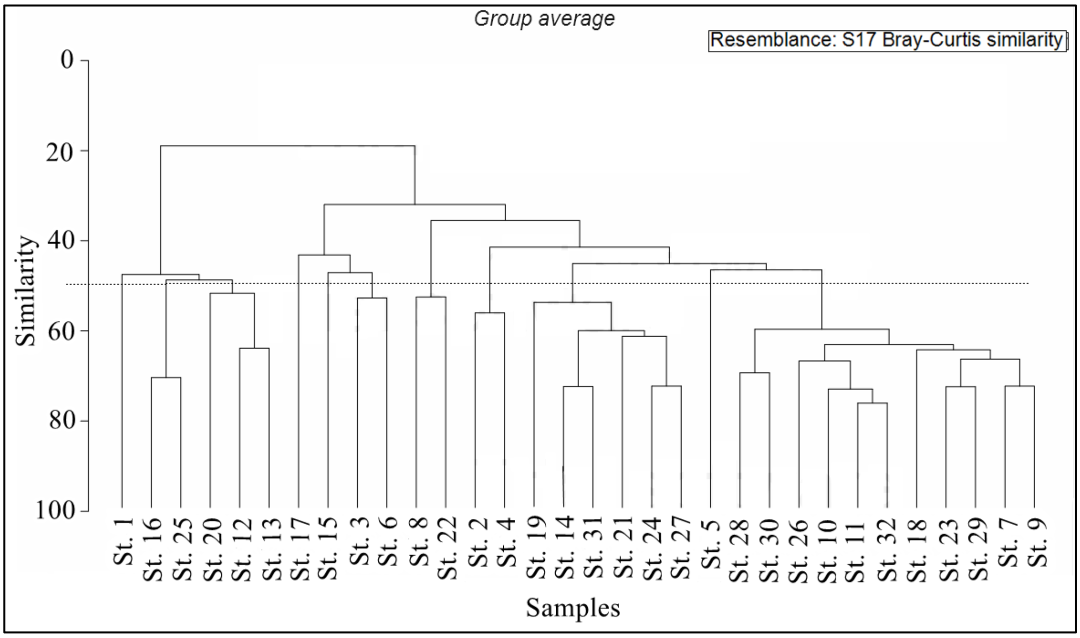


Figure 3.5: Dendogram produced by cluster analysis showing the percentage of similarity of gastropod and bivalve's abundance among all the stations at Sarawak EEZ based on Bray Curtis similarities.

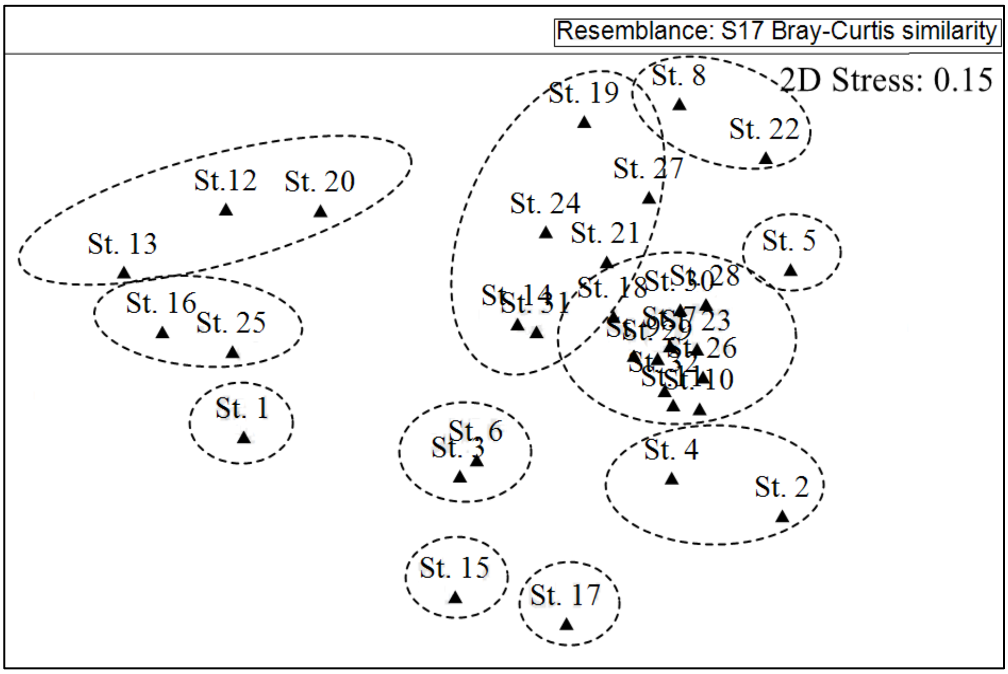


Figure 3.6: Multidimensional scaling (MDS) ordination (stress: 0.15) constructed based on the gastropod and bivalve's abundance among all the stations at Sarawak EEZ.

3.4 Discussion

3.4.1 Abundance of Gastropod and Bivalve

In this research, a total of 95 taxa of gastropod and bivalve were obtained with a total of 2,388 individuals. Of them, gastropod was 61 species while, bivalve was 34 species. Tan & Kastoro (2004) stated that Hasegawa *et al.* (2001) found a total of 309 gastropod and 118 bivalve species from Hainan Island, South China Sea. Furthermore, 91 species of gastropods and 43 species of bivalves were collected during a week-long expedition to the Anambas and Natuna Islands of Indonesia in the South China Sea (Tan & Kastoro, 2004). Besides that, a previous study on the abundance of macrobenthos which was conducted in South China Sea (Sarawak, Brunei and Sabah) about 20 years ago showed that gastropod and bivalves were found very few in number (Piamthipmanus, 1998).

A total of 95 species found in Sarawak EEZ in this study is comparable to other location of South China Sea which covered a large area. When comparing with earlier study which only recorded four mollusc species at Malaysia EEZ covering Sarawak waters conducted during 1996 to 1997, gastropod and bivalve recorded in this study are very high with huge increment. This suggests future studies can discover more species in Malaysia and ultimately help to record the biodiversity of mollusc in Malaysia.

The species number of gastropod was higher than bivalve and this is a common scenario in most of the mollusc research. However, the number of individuals of bivalve recorded was slightly higher than for gastropod. Gastropods and bivalves had quite different in term of environmental distributions (Gotshall & Miller, 2003), which could be affected their distribution at Sarawak EEZ. Some of the species was only identified to genus level. This is because some of the species are very similar within a genus, especially juvenile individuals. For example, gastropods such as *Nassarius* sp., *Ringicula* sp., and *Bittium* sp., while, bivalves such as *Myadora* sp., *Limopsis* sp., and *Paphia* sp. Zamprogno *et al.* (2013) also stated that young individuals of mollusc found in their study could not be identified to species level.

In the previous study at South China Sea (Sarawak, Brunei and Sabah) by Piamthipmanus (1998), about 92% of the survey area showed no difference in the abundance of molluscs. Gastropods such as *Zeuxis* sp. from family Nassariidae and *Terebellum* sp. from family Strombidae; and bivalves such as *Pitar* sp. from family Veneridae and *Azorinus* sp. from family Solecurtidae were obtained from the area (Piamthipmanus, 1998). In this study, species from family Nassariidae and Strombidae, and from genus *Azorinus,* and *Pitar* (one of the dominant species in this study) were also recorded.

Family Costellariidae recorded the highest species number of gastropod (7 species) in this study followed by the Nassariidae (6 gastropod species) and Veneridae (6 bivalve species). All the species found from the family Costellariidae are from genus *Vexillum*. Costellariidae is made up of about 150 species found in all tropical seas and they are primarily move about in the sand and others live buried in mud and sand (Tunnell, 2010). Besides that, Zhang & Zhang (2014) found the Indo-West Pacific region has the highest biodiversity of the family Nassariidae, with the genus *Nassarius* comprising 211 living species. Species of the family Nassariidae are mainly live in sandy or muddy sediments and they are widely distributed from the intertidal to the neritic zone, and even to deeper depths. During the Rumphius Biohistorical Expedition in 1990, 47 species of genus *Nassarius* were collected from Ambon, Indonesia, 41 species from the coasts of the Philippines, and 64 species were recorded from Vietnam (Zhang & Zhang, 2014). Veneridae is one of the largest families and most diverse within Bivalvia, being found in marine and estuarine environments. There are 40 species of the family recorded in Brazil (Rocha & Cascon, 2015). In Malaysia, 39 species from family Veneridae have been reported (Wong & Arshad, 2011). The high diversity within these families caused many species of them were also found in Malaysia EEZ of Sarawak waters.

3.4.2 Species Density of Gastropod and Bivalve

The range of total density of gastropod and bivalve at Sarawak EEZ was between 250 ind./m^2 to 1,940 ind./m^2. The highest was recorded at station 2 whereas the lowest was recorded at station 22. Their species density was about 10 ind./m^2 to 610 ind./m^2. Yasin & Razak (1998) specified that macrobenthos showed greater density in Malaysian waters during the pre-monsoon period with 2,500 individuals (at an average 67.6 ind./m^2) and the sampling after the monsoon has showed 620 individuals (16.8 ind./m^2). However, mollusc was observed in smaller quantities in the East Coast of Peninsular Malaysia. Additionally, Piamthipmanus (1998) reported that the abundance of mollusc was only 1 ind./m^2 on average and ranged from 0 to 20 ind./m^2 during the previous macrobenthos study at South China Sea (Sarawak, Brunei and Sabah) with the average abundance of macrobenthic fauna of 10 ind./m^2 to 167 ind./m^2. It indicates that gastropod and bivalve was occurred in low density during the survey conducted before.

Accordingly, this study showed a good result for molluscan distribution at Sarawak EEZ at recent time. In my opinion, even though the environmental data was not recorded, high density of molluscan at Sarawak EEZ could be due to sufficient food supply and stable environmental parameters. In most ecosystems, community structure emerges as a result of complex interaction between biotic and environmental variable. Shabdin *et al,* (2014a) also stated environmental factors such as nutrients and food availability are also important in structuring the macrofaunal community. Furthermore, the sediment characteristics are also assumed could perhaps be attributed to the higher density. This is because the mean grain size, fine sand, very fine sand, silts, and clay contents can affect the mollusc's distribution, density and diversity (Santos & Vanin, 2014).

The highest density of gastropod and bivalve was recorded by *Limopsis* sp., *Pitar citrinus*, and *Cavolinia globulosa*. *Limopsis* is one of the most wide-spread bivalve genera and at least forty extant and more than thirty extinct species of *Limopsis* are known (Whittle *et al.*, 2011). Bivalves in this genus, which are epibenthic suspension feeders, have a particular affinity to deep-sea habitats. In the southern high latitudes, seventeen *Limopsis* species were recorded up to 600 m (Whittle *et al.*, 2011). Its natural distribution at deep water promoted the high density of this species at Sarawak EEZ. Besides that, Munira (2011) found that 6.10% from the overall bivalve determined at Maluku, Indonesia was *P. citrinus.* Furthermore, as mentioned earlier, *Pitar* sp. has been found in the previous study at South China Sea comprises Sarawak EEZ. The high density of *Pitar* sp. in this study is applicable to its distribution earlier.

The gastropod, *C. globulosa* from the family Cavoliniidae is a tropical species inhabiting areas of 25 °C (optimal temperature) and 34 PSU (optimal salinity) (Rottman, 1976). According to Bhattacharjee (2000), *C. globulosa* is generally confined to the tropical belt of the Indo-Pacific region. It is also recorded from Bay of Bengal, eastern part of Indian Ocean and Arabian Sea. A total of three species from this family were found this study which are *C. globulosa, Diacavolinia longirostris,* and *Diacria trispinosa.* Rottman (1976) stated that during an Expedition at The Gulf of Thailand and the South China Sea in 1959-1961, all these three species were collected. This indicated the abundance of this species in South China Sea since a long time before. Moreover, the temperature and salinity recorded in this study suits the optimum temperature and salinity needed for *C. globulosa* and triggered the species to be found in high density.

3.4.3 Diversity of Gastropod and Bivalve

The value of the Simpsons Reciprocal diversity index of gastropod and bivalve found in this study was in the range of 2.763 to 15.125 whereas the Shannon Diversity index value was between 1.223 and 2.959. According to Ghosh & Biswas (2015) the diversity values showed a moderate status of ecosystem health at Sarawak EEZ. Table C2, Appendix C shows the relationship between the Shannon Diversity index and ecological level. The highest value was observed at station 5 while, the lowest was recorded at station 16 showing below moderate ecosystem status.

Jamil & Hadil (2012) stated the diversity of deep water fauna was found to be affected by factors such as water productivity and food supply. High diversity at station 5 is believed could be because of sufficient food source such as benthic micro-algae whereas the lowest value was observed at station 16 which could be connected with some disturbances. Examples of the disturbances might be resource depletion, inhibition of feeding, burial and removal of organisms, and exposure of infauna to predators. All of these events may cause the death of species, thus affecting the density and diversity of the communities (Santos & Vanin, 2014).

Previously, Shannon's Index of diversity for all samples of macrobenthos in the Gulf of Thailand and East Coast of Peninsular Malaysia ranging from 4.04 to 4.62 (Yasin & Razak, 1998) while in South China Sea (Sarawak, Brunei and Sabah) ranging from 2.95 to 3.56 (Piamthipmanus, 1998). However, both of the studies recorded very few species of mollusc. Based on the data of macrobenthos collected from the surveys of 4 cruises, which were conducted in 2004 at Daya Bay, South China Sea, the mean species diversity of macrobenthos was 2.06 (Feiyan *et al.,* 2008). Yet, the study covered all the macrobenthos present in the area. Therefore, the findings in this study were comparably very high than those studies as this research is specifically for gastropod and bivalve. The variation in species diversity in this study is because of spatial differences and also biological and physical dissimilarity between the stations. Some biological characteristics like longevity, reproduction strategy, depth of habitat, trophic level, and fishing pressure exert important influence in variation of frequency, succession and diversity of macrobiotic species (Simin *et al.*, 2012).

In addition, the maximum species evenness was recorded at station 8 with a value of 0.938. This indicates non-domination within the area by any specific species. A clear domination by any species would indicate non-stability in the benthic habitat. Station 13 was observed with lowest evenness value of 0.650 because of certain dominant species such as *Cavolinia globulosa* and *Diacavolinia longirostris*. Besides that, station 16 was also recorded with low evenness value because of the domination by *C. globulosa*. The highest species richness value was recorded at station 26 with 6.995 and the lowest was recorded at station 16 with 1.248. A survey of macrobenthos at Daya Bay, South China Sea resulted the mean richness and evenness value of 1.17 and 0.74, respectively (Feiyan *et al.,* 2008). According to Yasin & Razak (1998), the evenness value showed a range from 0.92 to 0.96 and less species richness was obtained because of the single replicate taken at each of the stations due to the tight time schedule followed during the sampling. This study indicates high species richness possibly because of balanced water conditions, and less predators and stress from surrounding. The provision of refuges from predation or physical stress has been shown to increase species abundance on tropical regions (Williams, 1994).

3.4.4 Relationship between Community Structure and Depth of Water

The total density was significantly correlated with the depth of water at EEZ of Sarawak waters, but it was a negative relationship. According to Naser (2011), depth affects the distribution of mollusc. Normally, in deep water environment, species and communities often change with increasing depth (Jamil & Hadil, 2012). Depth–diversity relationships have been addressed by many studies in the deep sea. For example, the diversity patterns of gastropod and bivalve at West Antarctica, from the South Shetland Islands to the Bellingshausen Sea were complex with no significant trends with depth ranging from 45 m to

3,304 m (Aldea *et al.*, 2008). In contrast, study at coastal water of Arabian Sea showed the macrofaunal abundance declined from shallower to deeper stations along the west coast of India (Ingole *et al.*, 2014). Degen *et al.* (2015) also stated the density of marine benthic macroinvertebrate generally decrease with increasing water depth and they proved it with their study in the Arctic deep sea, where negative relationship of macroinvertebrate with water depth was obtained. Besides that, Piamthimanus (1998) in the macrobenthos study at South China Sea, area Sarawak, Brunei and Sabah stated that the density of macrobenthic fauna tended to increase with decreasing of water depth. This study also supported the negative relationship of mollusc density with the water depth and confirmed the hypothesis tested in the present research.

One of the driving forces behind this pattern is the decrease in food input, depending on the regionally varying surface production and the assimilation efficiency in the water column. The low food concentration in the deep sea leads to a higher share of smaller organisms in the total community. This observation has been corroborated by more recent studies that found a decrease in mean body size with increasing water depth (Degen *et al.*, 2015). The high amount of sediment chlorophyll *a* can be found commonly near shore and shelf sediments due to its lower degradation in the water column. Conversely, high quality food will be consumed and elapsed before it reaches the deeper parts of the ocean floor and therefore less matter reaches the depths (Ingole *et al.*, 2014). Therefore, less density in the deeper area in this study can be related to this possibility. Besides this theory, food availability, substrate characteristics and hydrodynamic processes are also important factors structuring benthic communities (Degen *et al.*, 2015) and expected to affect the density of gastropod and bivalve at Sarawak EEZ. The other community structure of gastropod and bivalve did not show any significant relationship with the water parameters. The community structure seems to be less affected by the water quality maybe because of only ten stations were involved in the correlation study due to insufficient sampling time.

In the cluster analysis of similarity measure, where the most similar pairs of samples are first joined into clusters, high similarity in the abundance of gastropod and bivalve between stations was obtained. Similar habitats among the study area caused the stations to be clustered together. Derived multidimensional scaling (MDS) ordination reveals the same grouping of stations as in the cluster analysis with 0.15 stress value. A stress coefficient reflects the extent to which the rank order of distances between samples on the ordination agrees with the rank order of the similarity matrices. The stress values found in the MDS configuration is low, indicating good representation of the interrelationship between the gastropod and bivalve of each station.

3.5 Conclusions

A total of 95 taxa obtained in this research from Malaysia Exclusive Economic Zone of Sarawak waters shows Malaysia is rich in molluscan distribution and eventually probability of obtaining higher species in future studies is high. Many gastropod and bivalve species found have been recorded and published in previous studies at Sarawak. The diversity of gastropod and bivalve in the study area indicates a moderate ecosystem status due to the dominant species found in the samples. Meanwhile, species evenness values indicate the gastropod and bivalve were not evenly distributed at few stations. Species such as *Limopsis* sp., *Pitar citrinus*, *Cavolinia globulosa*, and *Turritella cingulifera* were found to be dominant in this study in term of abundance. The depth of water influenced the total density of gastropod and bivalve and it supported the hypothesis of this study. Based on the groupings formed by cluster and non-metric MDS analysis, similar habitat characteristics among the study area is believed to be the reason of high similarity in gastropod and bivalve abundance. The data on the abundance and distribution of gastropod and bivalve in this study will aid to the next EEZ macrobenthos survey and future monitoring study.

CHAPTER 4

GASTROPODS AND BIVALVES FROM SARAWAK INTERTIDAL

4.1 Introduction

Sarawak lies within the Indo-Malay-Philippine archipelago, which is part of the Indo-West Pacific region (Shabdin, 2014). Sarawak has a tropical rainforest climate. There are two monsoon seasons: the southwest monsoon, which is the dry season from April to September, and the northeast monsoon, which is the wet season from October to March (Morton & Blackmore, 2001). In Sarawak, mangrove forest covered 173,792 ha of the land which is suitable for mollusc habitat (Hamli *et al.*, 2012). Besides that, mudflats, sandy beaches and rocky shores occur along the coastal area of Sarawak (Shabdin, 2014). The muddy or sandy intertidal zones serve for a variety of micro ecosystems for benthic invertebrates (Gondal *et al.*, 2012).

Beaches are characteristic sites for human recreation (Dada *et al.*, 2012). The zone between the high and low tide marks is called the intertidal or littoral zone. Organisms in this zone are subject to exposure as the tide drops and submergence as the tide rises (Dame, 2012). Thus, animals in the intertidal area of the shore have to cope with being out of water at regular intervals (Gosling, 2004). Variations in biotic and abiotic characteristics promote various types of niches and habitats for macrofauna within the intertidal zone (Gondal *et al.*, 2012). There is much interest in the spatial and temporal patterns of distribution and activities of intertidal gastropods and bivalves due to strong direct and indirect effects of grazing (Zamprogno *et al.*, 2013). Three potential food sources make the intertidal beach a food-rich environment; zooplankton (brought by the substantial flow of water), various microalgae such as diatoms (since the beach provides a well-illuminated substratum for their growth), and detritus, especially seagrasses and algae deposited by waves (Ponder *et al.*, 2002).

Molluscs are widely distributed in marine assemblages and may be extremely abundant in subtidal and intertidal habitats (Zamprogno *et al.*, 2013). Differences in tidal height are of vital importance in the distribution of species (Williams, 1994). Although the rise and fall of the tides track a smooth curve, zonation in the intertidal region is often attributed to tides (Dame, 2012; Williams, 1994). The horizontal distribution (zonation) of organisms on rocky shores is based on three major tide levels: high-tide, mid-tide and low-tide. Bivalves inhabit at the middle and lower zones of the beach, while the high-tide level is characterized by organisms such as gastropods (Shabdin, 2014). Therefore, at the land-sea interface, tides have the potential to produce major effects on their distribution (Dame, 2012).

Furthermore, molluscs are found at all salinities including freshwater and hypersaline areas typical of tropical zones (Dame, 2012). They are able to inhabit in both sandy and sandy-loamy substrates with or without vegetation (Gondal *et al.*, 2012). Mudflats are located close to river mouths, are sheltered and receive less wave action (Shabdin, 2014) whereas the intertidal sandy beach is a physically rigorous environment because of wave action, shifting sediments and aerial exposure (Ponder *et al.*, 2002). The organisms inhabiting both habitats are exposed to high temperature and desiccation (Shabdin, 2014).

Factors that affect intertidal species are physical influences include water depth, sediment structure, salinity and hydrology; biological factors include predation, competition and recruitment; and human-induced factors include organic enrichment, chemical pollution and commercial fishing activity (Rolston & Dittmann, 2009). Interactions between species also affect benthic assemblages in tidal flats (Dittmann, 2000). Moreover, water inundation periods, driven by the combined effects of tides and wind can also determine the survival, abundance and distribution (Rolston & Dittmann, 2009). To be more specific in term of tidal level, upper limits are generally set by tolerance to additional temperature and aridity as the emersion times are longest, while lower limits are set primarily by biological factors such as predation and competition (Gosling, 2004). As a result of these influencing factors, macrobenthic invertebrate distribution often exhibits high spatial variability (Rolston & Dittmann, 2009). Most of the organisms are found at the low tide level where the environment is less extreme (Shabdin, 2014).

Studies on community structure of marine gastropod and bivalve in Sampadi Island, Lundu, Sarawak was conducted by Shabdin *et al.* (2014b). Furthermore, Shabdin & Rosniza, (2010) studied the distribution record of gastropod and bivalve at the east coast of Malaysia. Hamli *et al.* (2012) stated that there are few distribution records of mollusc in tropical regions and little is known of the edible mollusc in Sarawak. Previous studies on edible and molluscs community structure were focused on mangrove ecosystem (Shabdin *et al.*, 2014b) and selected divisions of Sarawak named Kuching, Sarikei, Mukah, Sibu, Bintulu, Miri, Limbang and Lawas (Hamli *et al.*, 2012). However, all the studies were conducted at different part of Sarawak. There is still no published information on the community structure of gastropod and bivalve at many intertidal locations of Sarawak until now. Marine-shelled mollusc is a massive group that definitely needs more than a handful of scientist to work on it (Wong & Arshad, 2011). In recent years, foreign scientists have been collecting and documenting the marine mollusc found in Malaysian waters even described a new species (Wong & Arshad, 2011).

The aim of this study is to determine the community structure of marine gastropod and bivalve, and its relationship with water quality at four locations which are Pandan beach, Lundu; Kabong beach, Kabong; Tanjung Batu beach, Bintulu; and Tusan beach, Miri. The findings of this study will be documented.

4.2 Methodology

4.2.1 Study Area

Sarawak is located between latitude 0° 50´ and 5° N, and longitude 109° 36´ and 115° 40´ E. Studies on community structures of gastropods and bivalves at Sarawak intertidal zone were conducted in four locations, namely Pandan beach, Lundu; Kabong beach, Kabong; Tanjung Batu beach, Bintulu; and Tusan beach, Miri. The samples from Kabong beach were collected on 26th February 2016 while, at Tanjung Batu beach, the sampling was carried out on 27th February 2016. Data collections at Tusan beach and Pandan Beach were conducted on 28th February 2016 and 1st March 2016, respectively. The samplings at all the locations were carried out during the low tides duration following the tide tables. The number of sampling stations varied between each location following the length of the intertidal habitat and the accessibility.

4.2.1.1 Pandan Beach

Pandan beach, Lundu is located in the Northwest of Kuching Division of Sarawak, Malaysia. The beach is long and wide and very gradually sloping into the South China Sea. Pandan beach has one of the most amazing coastal beach scenery and it is a tourist attraction spot. There is a small Malay fishing community that is a resident of the place. The habitat around the beach are rocky and sandy. The coastline is very tropical with tall coconut palms, soft and fine sand, and no pollution from nearby rivers or streams. A total of seven stations were chosen along the intertidal zone for this study (Figure 4.1). The coordinates of each station are shown in Table 4.1.

Table 4.1: Coordinates of all the stations at Pandan beach, Lundu.

Station	Coordinate
1	N 01° 45’ 45.5” E 109° 51’ 58.2”
2	N 01° 45’ 46.9” E 109° 51’ 54.0”
3	N 01° 45’ 48.2” E 109° 51’ 49.5”
4	N 01° 45’ 48.6” E 109° 51’ 48.0”
5	N 01° 45’ 49.4” E 109° 51’ 45.7”
6	N 01° 45’ 50.2” E 109° 51’ 43.1”
7	N 01° 45’ 50.7” E 109° 51’ 40.8”

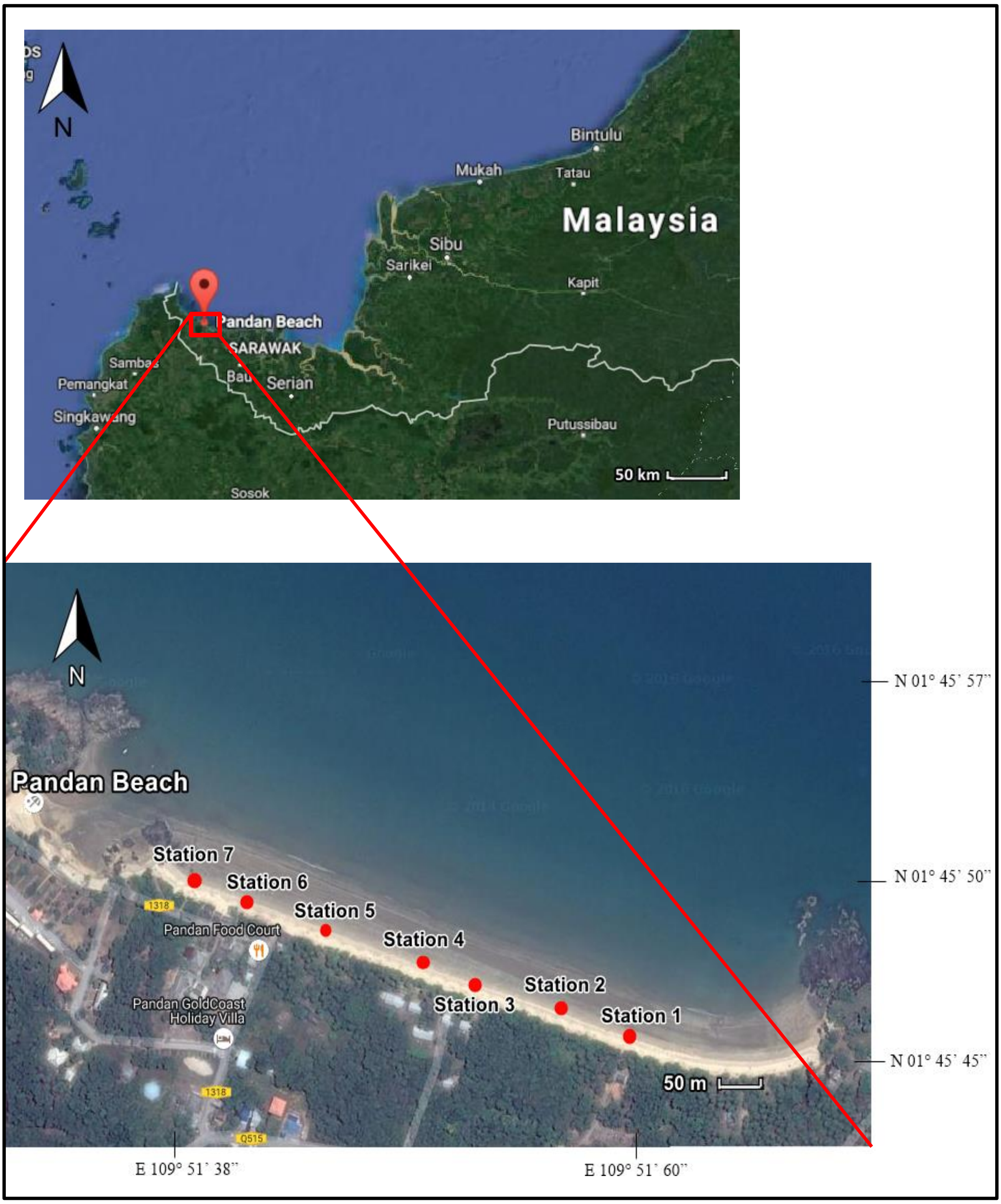


Figure 4.1: Map showing the location of sampling stations at Pandan Beach, Lundu.

4.2.1.2 Kabong Beach

Kabong beach or known as Alit beach is located within Roban and Kabong town which is about 80 km from Sarikei. Kabong has a long and clean beach, ideal for picnics, parties, and recreation which makes Kabong to have a great potential in the field of tourism. The coastal area is well known for its fisheries value and jellyfish will be caught seasonally. Four stations were chosen along the intertidal zone of Kabong beach (Figure 4.2). The coordinates of each station are shown in Table 4.2.

Table 4.2: Coordinates of each station at Kabong beach.

Station	Coordinate
1	N 01°55'50.7" E 111°09'11.7"
2	N 01°55'52.8" E 111°09'12.2"
3	N 01°55'54.6" E 111°09'13.4"
4	N 01°56'00.0" E 111°09'16.5"

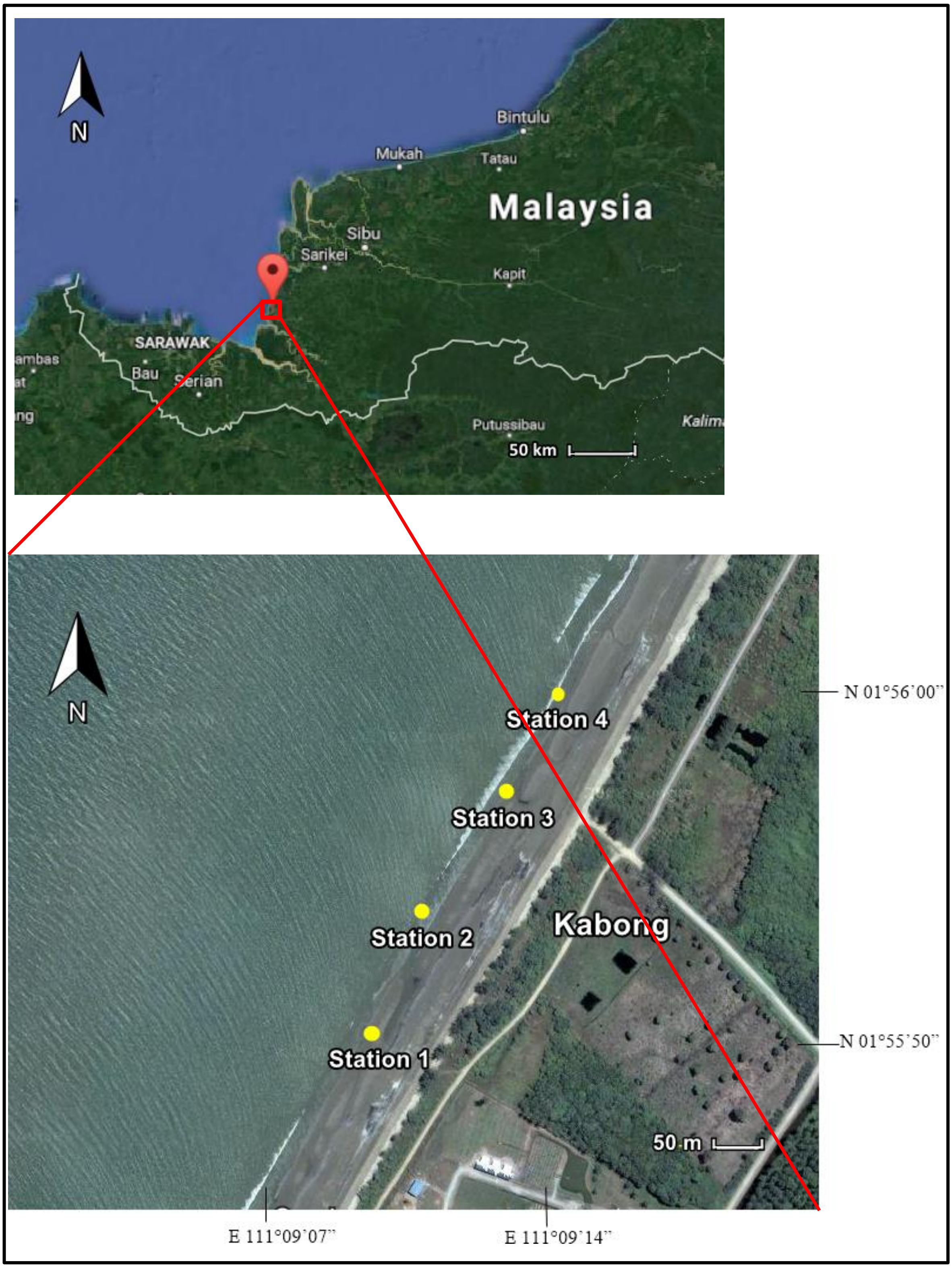


Figure 4.2: Map showing the location of sampling stations at Kabong Beach.

4.2.1.3 Tanjung Batu Beach

Tanjung Batu beach is situated at Bintulu. Bintulu is a coastal town in the central region of Sarawak. It is located 610 km northeast of Kuching, 216 km northeast of Sibu, and 200 km southwest of Miri. Originally, Bintulu is only a fishing village which is famous with its fisheries resources, but now it is emerging as an international city. Tanjung Batu beach is a local picnic and recreational spot located approximately 3 km from the town centre. The habitats around the beach are rocky and sandy. In order to conduct the research, four stations were selected along the intertidal zone (Figure 4.3). The coordinates of each stations are shown in Table 4.3.

Table 4.3: Coordinates of each station at Tanjung Batu beach.

Station	Coordinate
1	N 03°12'38.7" E 113°02'32.0"
2	N 03°12'41.0" E 113°02'34.9"
3	N 03° 12' 42.1" E 113° 02' 37.2"
4	N 03° 12' 44.8" E 113° 02' 39.1"

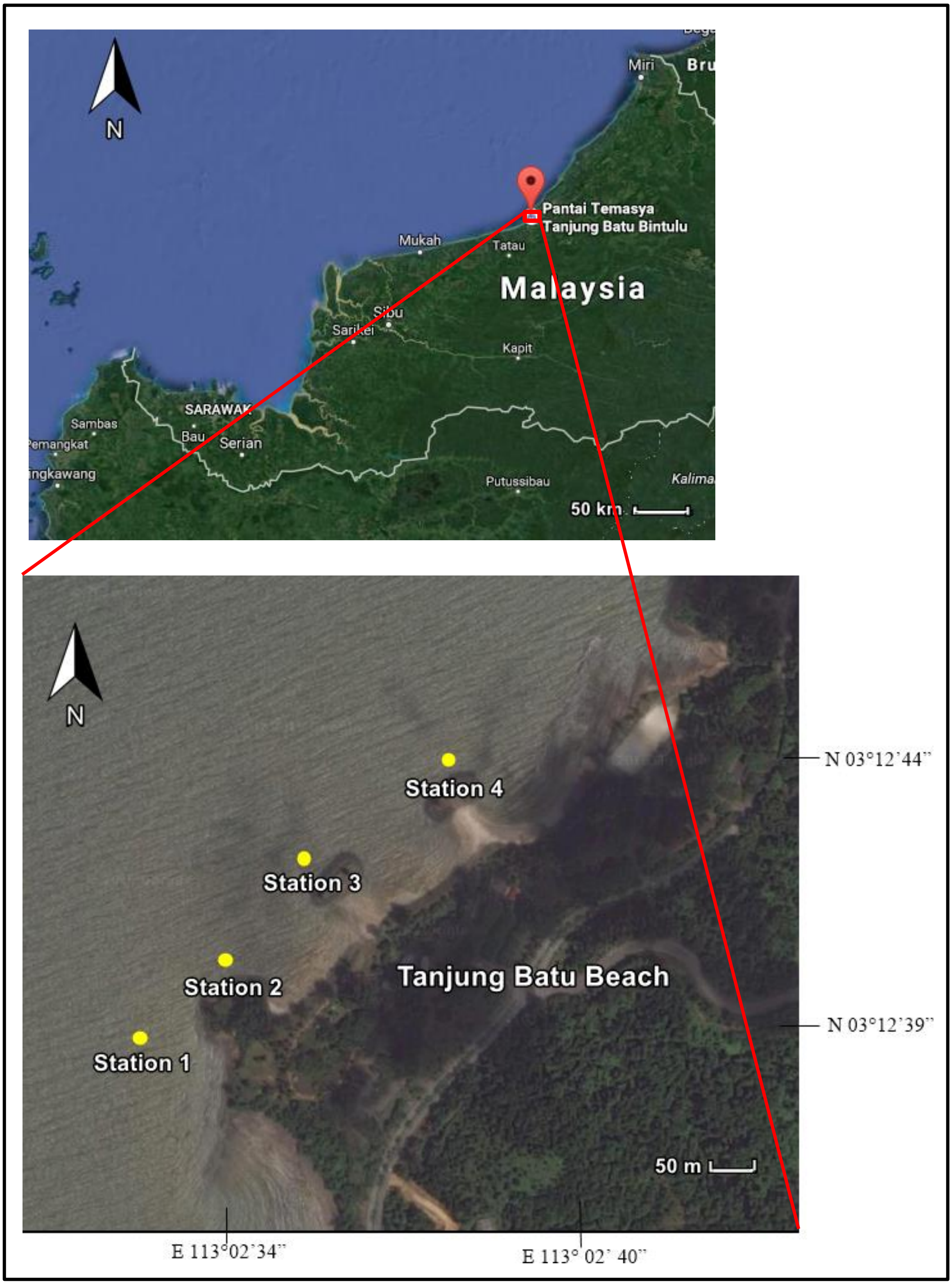


Figure 4.3: Map showing the location of sampling stations at Tanjung Batu Beach, Bintulu.

4.2.1.4 Tusan Beach

Tusan beach is found at Miri and located approximately 40 km from the city. Miri is a coastal city in northeastern Sarawak, located near to the border of Brunei. The city located 798 km northeast of Kuching and 329 km southwest of Kota Kinabalu. Tusan Beach has coral reefs, a waterfall, several cliff sides and a defining feature; a large cliff with a natural arch eroded through it. Ancient fossils are known to be found in this area, and natural rock layers on the cliff sides make it a geologist's playground. The habitat of the Tusan beach is rocky and sandy with a gentle slope towards the South China Sea. It is a long beach with white and smooth sand structure along the intertidal zone. Five stations were chosen along the intertidal zone (Figure 4.4). The coordinates of each station are shown in Table 4.4.

Table 4.4: Coordinates of each station at Tanjung Batu beach.

Station	Coordinate
1	N 04° 07' 39.1" E 113° 49' 10.0"
2	N 04° 07' 38.1" E 113° 49' 09.3"
3	N 04° 07' 37.4" E 113° 49' 08.5"
4	N 04° 07' 36.2" E 113° 49' 07.6"
5	N 04° 07' 32.3" E 113° 49' 05.0"

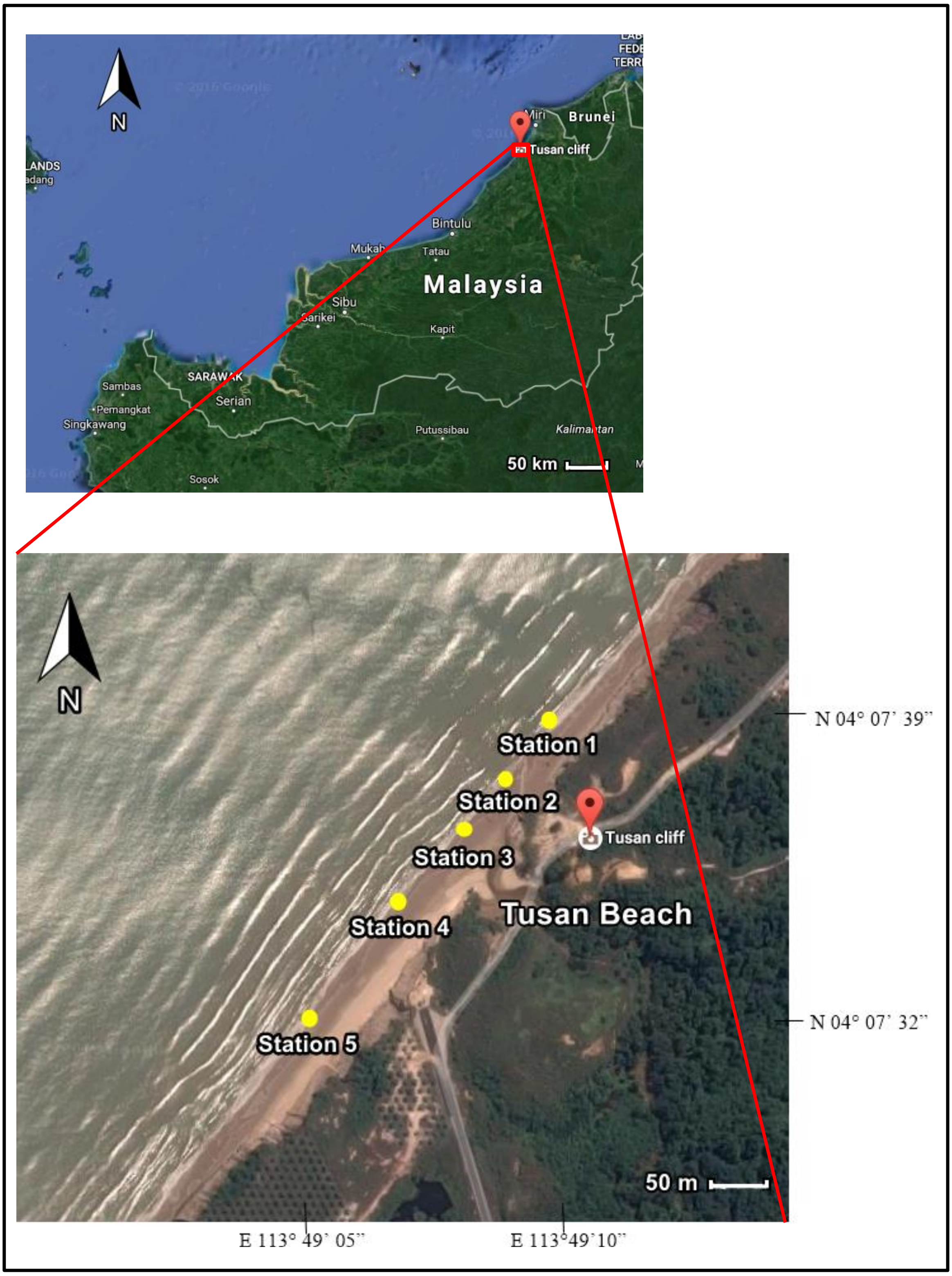


Figure 4.4: Map showing the location of sampling stations at Tusan Beach, Miri.

4.2.2 Physico-chemical of Water Parameters

The *in situ* physico-chemical parameters of water that were measured are pH, dissolved oxygen, salinity, turbidity, conductivity and temperature. The water parameters were measured in three replicates by using the water quality equipments such as, salinity (refractometer brand EXTECH instrument model RF20), turbidity (turbidity meter brand LT Lutron model TU-2016), pH (pH meter brand EXTECH instruments model SDL100), conductivity (conductivity meter brand LT Lutron model CD-4303), dissolved oxygen and temperature (dissolved oxygen meter brand EXTECH instrument model SDL150). The water parameters were measured at each station during low tide and all the water quality equipment were calibrated before use.

4.2.3 Field Sampling

4.2.3.1 Collection of Gastropod and Bivalve Samples

Marine gastropods and bivalves were collected from the bottom sediment using the Ekman grab sampler (Figure 4.5) during low tide at daytime. Ekman grab is most widely used and the opening area of the grab is 15 cm x 15 cm. It is usually operated by a handle and gives a perfect box-shaped sample. The collected materials were washed and sieved with 500 µm sieve using seawater. All collected benthic specimens were placed in a plastic bag and preserved in 70% ethanol. The specimens were labelled accordingly and stored in a cooler box. The samples were transferred to the laboratory for analysis. During the sampling, the coordinates of the sampling stations were recorded using the global positioning system (GPS) brand GARMIN model GPSmap 60CSx. The weather conditions were also observed.

Figure 4.5: Ekman grab (Tagliapietra & Sigovini, 2010).

4.2.3.2 Collection of Sediment Samples

For sediment samples, three replicates of surface sediment sample were collected at each station for the grain size analysis, total organic matter analysis and chlorophyll *a* analysis. The sediments were placed in labelled plastic bags and transported back to the laboratory for further analysis. During the field sampling, sediment samples for the total organic matter analysis and chlorophyll *a* analysis were immediately placed in the cooler box to prevent any degradation of organic matter.

4.2.4 Laboratory Analysis

4.2.4.1 Sorting and Counting

Refer 3.2.3.1

4.2.4.2 Identification of Gastropods and Bivalves

Refer 3.2.3.2

4.2.4.3 Grain Size Analysis

Firstly, the sediments were weighed using electronic balance brand A&D Company, model FX-3000i. Then, the sediments were sieved using 63 µm sieve on electronic shaker brand W.S. TYLER model RX-812-3. The retained sand on 63 µm sieve and silt and clay which passed through 63 µm sieve were weighed and recorded. The percentage of sand, clay and silt of all stations were calculated by using these formulae (Van Reeuwijk, 2002):

1) % of sand (> 63 µm) = $\frac{\text{weight of sand (g)}}{\text{weight of sediment (g)}} \times 100$

2) % of clay and silt (< 63 µm) = $\frac{\text{weight of clay and silt (g)}}{\text{weight of sediment (g)}} \times 100$

4.2.4.4 Total Organic Matter Analysis

The total organic matter (TOM) analysis was done by heating the sediment samples in the oven (drying oven 50L, brand Smith model A3018) at 60 °C for overnight to remove the water content from the sediments. Then, the sediments were weighed as initial weight. The weighed sediments in the crucible were put inside the furnace (brand Nabertherm GmbH model L 15/12/B180) with 500 °C temperature for 8 hours for the combustion of the organic matter. Then, the sediments were weighed as final weight to determine the weight loss. The temperature for combustion should be about 450 to 500^{0}C to avoid volatilizing bicarbonates. After 8 hours of combustion no important losses occur at 500^{0}C. Therefore, the loss of weight indicates the amount of total organic matter (TOM) in the samples. The equation involved is as follows:

$$F = \frac{(E-D)}{E} \times 100\%$$

Where:

F = Percentage (%) of total organic content

E = Crucible + Soil (60 °C, for 24 hours)

D = Crucible + Soil (500 °C, 8 hours)

4.2.4.5 Chlorophyll *a* Analysis

The chlorophyll *a* analysis was done using a modified method by Wasmund (1984). Firstly, a definite amount of sediment sample with known water content was placed into a mortar and homogenized by grinding. An amount of 5-10 ml of acetone was added to get a final concentration of 90% with the interstitial water. It was placed and cooled in the fridge overnight for more complete pigment extraction.

Then, the resulting suspension was transferred into a centrifuge tube and it was centrifuged at 4000 rpm for 30 minutes by using centrifuge brand Hettich type 1605, model Universal. The supernatant was decanted into a cuvette and the extinction at the wavelength was measured by using the spectrophotometer brand HACH, model DR 2800. The absorbance at 665 was measured before and after acidification. Acidification was done by adding one or two drops of 0.2 M HCl to the supernatant.

The water loss in the sediments was carried out by heating the other sets of sediments in the oven with a temperature of 60 °C for 24 hours. The sediments were weighed before heat as an initial weight and the weight after heat was recorded as the final weight. The data was used in the chlorophyll *a* calculation. Chlorophyll *a* was calculated from the equation given by Jeffrey & Humphrey (1975):

$$\text{Chlorophyll } a \text{ (mg/m}^3\text{)} = \frac{26.7\,(E_o - E_a) \times V}{V_s \times L}$$

E_o = absorbance before acidification at 665 nm

E_a = absorbance after acidification at 665 nm

V = volume of water content of the samples with acetone (100%) added

V_s = volume of sediment sample

L = path length (cm) of the spectrophotometer cell

4.2.5 Data Analysis

4.2.5.1 Analysis of Community Structure

Refer to Section 3.2.4.1

4.2.5.2 Statistical Analysis

Water parameters were tested for significant differences of means among the stations by using one-way analysis of variance (ANOVA) with significant set at $p < 0.05$. Pearson-linear correlation and linear regression were applied to determine the relationship of the environmental factors with the gastropod and bivalve's community structure. These statistical analyses were performed by using the Statistical Package for the Social Sciences (SPSS) software. An ordination of Principal Components Analysis (PCA) was conducted to summarize the relationship of environmental variables and to determine parameters that are indicative for each sampling station. The analysis was conducted using XLSTAT software.

Subsequently, the cluster analysis was performed using the Bray-Curtis similarity measure to investigate the similarities of gastropods and bivalve's abundance between the stations at spatial level. The relationship was based on the comparison of similarity matrices and was displayed using hierarchical agglomerative clustering technique (group average). Ordination using nonmetric multi-dimensional scaling (MDS) was performed to determine the variation of species abundance and to confirm the groups formed by the cluster. The cluster analysis was conducted using Plymouth Routines in Multivariate Ecological Research (PRIMER v7.0) software with the aid of Microsoft Excel 2010.

4.3 Results

4.3.1 Pandan Beach

4.3.1.1 Environmental Parameters

The environmental parameters involved in this study were dissolved oxygen (DO), pH, temperature, salinity, conductivity, turbidity, sand, silt and clay, total organic matter, and chlorophyll *a* content. Based on Table 4.5 and Figure 4.6, the mean values of DO were ranged from 6.97 mg/L to 7.27 mg/L. The lowest was recorded at station 1 and 4 while, the highest was recorded at station 6. The means between stations were significantly different ($p < 0.05$). For the pH of water, the lowest was recorded at station 3 which was 6.93 while, the highest was recorded at station 5 which was 8.04. The mean values of pH between stations were significantly different ($p < 0.05$).

The mean values of water temperature in all the stations were ranged from 28.76 °C to 30.90 °C. The highest was observed at station 4 whereas the lowest was obtained at station 7. The means between stations were significantly different ($p < 0.05$). On the other hand, salinity was ranged from 30.33 PSU to 32.67 PSU. Station 1 recorded the highest mean value while, station 4 recorded the lowest value. The mean values of salinity between stations were significantly different ($p < 0.05$).

Besides that, conductivity values between stations varied from 14.66 mS/cm to 18.65 mS/cm. The lowest value was recorded at station 5 while the highest was recorded at station 7. The mean values of conductivity between stations were not significantly different ($p > 0.05$). For the turbidity, the mean values were ranged from 20.36 NTU to 28.80 NTU. The highest mean value was observed at station 1 whereas the lowest mean value was recorded at station 7. The means between stations were significantly different ($p < 0.05$).

Table 4.5: Mean and standard deviation of environmental parameters at all the stations in Pandan beach.

Parameter/Station	1	2	3	4	5	6	7
Dissolved oxygen (mg/L)	6.97±0.12	6.98±0.07	7.02±0.11	6.97±0.06	7.23±0.15	7.27±0.15	7.20±0.10
pH	7.78±0.26	7.13±0.16	6.93±0.10	7.83±0.06	8.04±0.24	7.32±0.47	7.45±0.18
Temperature (°C)	29.90±0.35	30.53±0.31	29.97±0.55	30.90±1.28	29.17±0.25	29.13±0.25	28.76±0.22
Salinity (PSU)	32.67±0.58	32.33±0.58	31.00±1.00	30.33±0.58	31.33±0.58	31.67±0.58	31.00±1.00
Conductivity (mS/cm)	18.41±0.97	18.11±0.70	15.50±0.19	16.90±0.88	14.66±3.76	17.94±2.41	18.65±0.74
Turbidity (NTU)	28.80±0.26	25.44±0.99	27.88±1.29	25.63±2.28	21.58±1.87	21.61±1.21	20.36±1.25
Sand (%)	100.00±0.00	99.53±0.58	98.97±0.48	98.55±0.56	99.57±0.25	98.06±0.61	99.56±0.12
Silt and clay (%)	0.00±0.00	0.47±0.58	1.03±0.48	1.45±0.56	0.43±0.25	1.94±0.61	0.44±0.12
Total organic matter (%)	1.04±0.16	1.38±0.19	1.25±0.23	1.45±0.11	1.45±0.15	1.47±0.08	1.63±0.17
Chlorophyll *a* (mg/m^3)	0.12±0.01	0.15±0.01	0.14±0.04	0.13±0.06	0.19±0.01	0.21±0.01	0.16±0.05

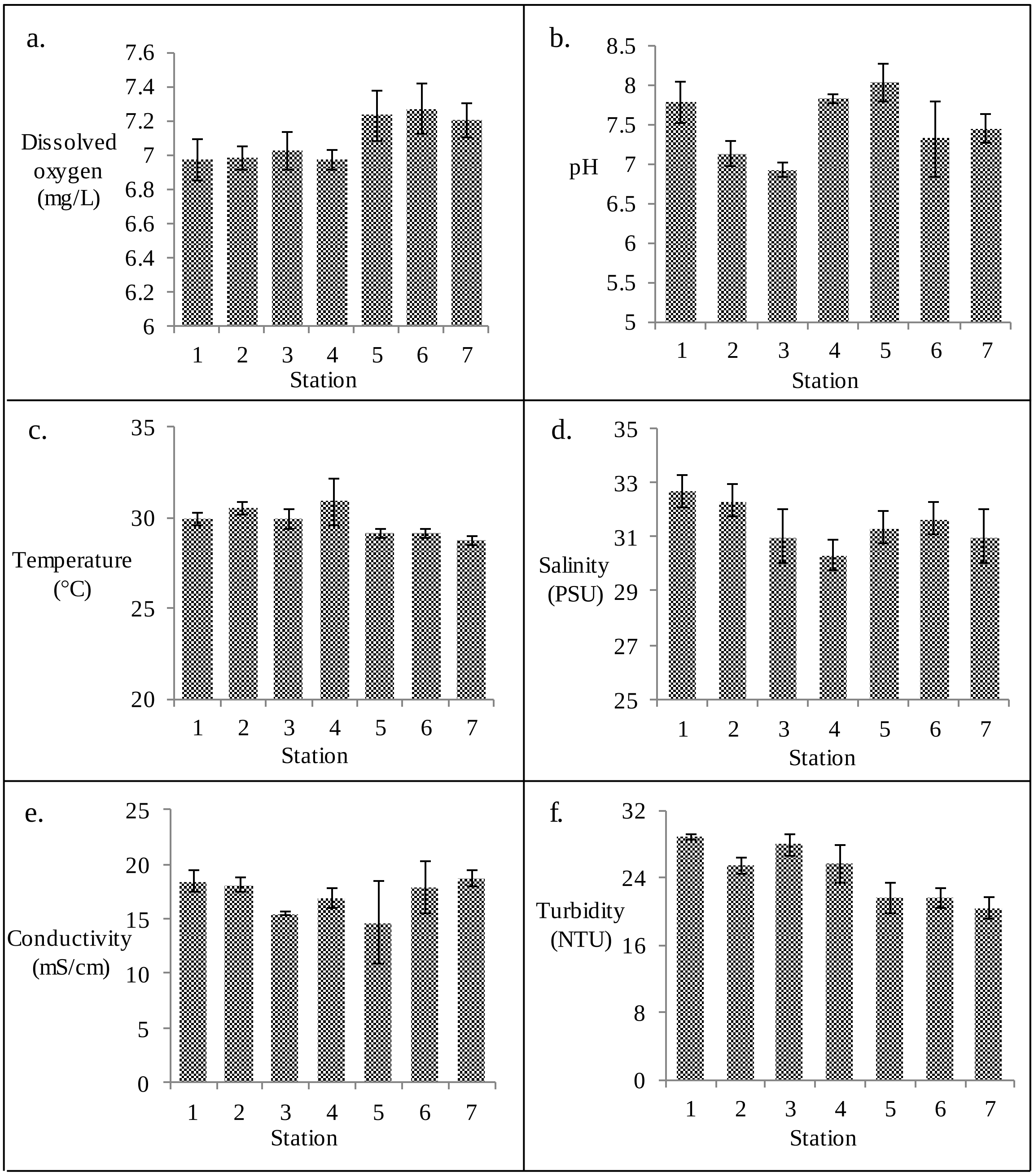


Figure 4.6: Water parameters of all the stations in Pandan beach. (**a.** dissolved oxygen, **b.** pH, **c.** temperature, **d.** salinity, **e.** conductivity, **f.** turbidity).

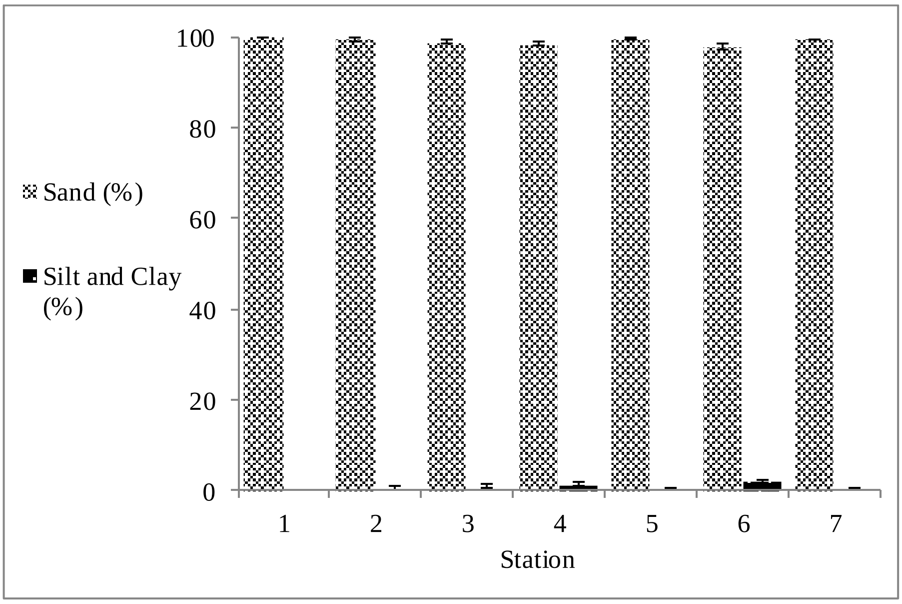


Figure 4.7: The percentage of sand, and silt and clay of all the stations in Pandan beach.

Sand dominated silt and clay in Pandan beach. All stations recorded more than 90% of sand where the highest was recorded at station 1 with 100% of sand. The lowest percentage of sand and highest percentage of silt and clay was observed at station 6 consist with 98.06% of sand and 1.94% of silt and clay, respectively. The means between stations were significantly different ($p < 0.05$). The trend of sand, and silt and clay composition was shown in Figure 4.7.

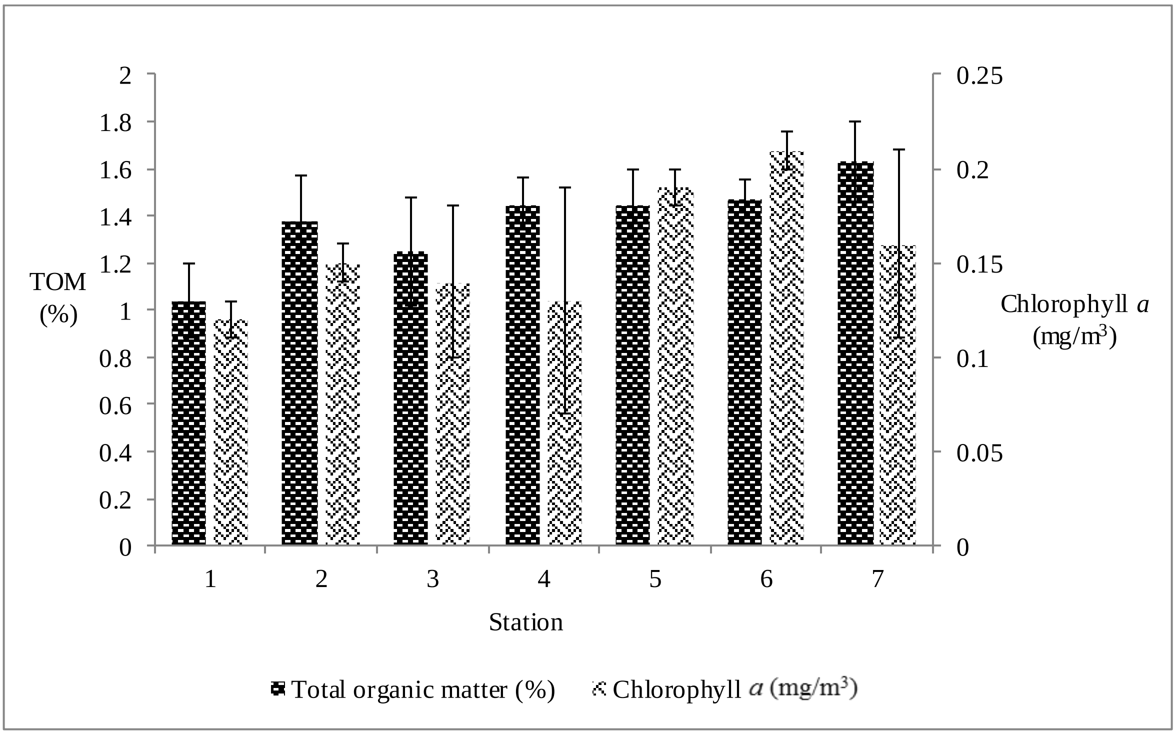


Figure 4.8: The total organic matter (%) and chlorophyll *a* content (mg/m^3) of the sediment in Pandan beach.

The total organic matter content in Pandan beach was between 1.04% to 1.63%. Even though the amount is small, significant difference in mean values between stations still exists ($p < 0.05$). The highest mean value was noted in station 7 while, the lowest was obtained at station 1. Station 4 and station 5 recorded the same mean value which was 1.45%.

For the chlorophyll *a* content, the mean value was ranged from 0.12 mg/m^3 to 0.21 mg/m^3. The highest mean value was recorded at station 6 followed by station 5. The lowest chlorophyll *a* content was recorded at station 1 where the least total organic matter content was discovered. The means between stations were significantly different ($p < 0.05$). The trend of chlorophyll *a* content and total organic matter content was shown in Figure 4.8.

4.3.1.2 Abundance of Gastropod and Bivalve

Study at Pandan beach recorded a total of 169 individuals of gastropod and 257 individuals of bivalve. Altogether, 426 individuals of gastropod and bivalve representing 26 species and 19 species, respectively were obtained in this study (Appendix B1). The gastropod recorded was from 17 families while, the bivalve obtained was from 8 families. Overall, 25 families were identified with a total of 45 species. From them 19 species of gastropod and 14 species of bivalve were identified to species level, whereas others were identified until genus level. Table 4.6 and 4.7 showed the species composition of gastropod and bivalve found in all the stations at Pandan beach.

Highly noticed species in Pandan beach was *Anadara granosa* from Bivalvia with a total of 107 individuals followed by *Turritella cingulifera* from Gastropoda with a total of 80 individuals. Appendix D displays the photos of *A. granosa* and *T. cingulifera*. Both species were recorded in all the seven stations. Gastropod such as *Bursa granularis, Austromitra canaliculata, Cassidula nucleus, Murex trapa, Nerita balteata, Oliva dubia, Latiromitra* sp., *Ringicula auriculata, Siphonaria* sp., *Margistrombus marginatus, M. septimus, Euterebra capensis,* and *E. fuscolutea* and bivalve such as *Donax* sp., *Placuna placenta, Azorinus scheepmakeri, Gafrarium* sp., and *Lioconcha* sp. were only found in one station.

Station 3 and station 5 recorded the highest number of gastropod individuals which was 47 individuals, each and followed by station 1 with 44 individuals. The highest number of bivalve's individuals was obtained at station 1 and station 3 with 54 individuals, separately and followed by station 5 with 48 individuals. Overall, highest number of gastropod and bivalve's individual was obtained at Station 3 with a total of 101 individuals accounted for 23.71% of the total individuals recorded at Pandan beach.

Table 4.6: Checklist of gastropod in Pandan Beach.

Taxa/Station	1	2	3	4	5	6	7
Architectonicidae							
Architectonica perdix	+					+	
Bursidae							
Bursa granularis	+						
Costellariidae							
Austromitra canaliculata			+				
Ellobiidae							
Cassidula nucleus		+					
Muricidae							
Murex trapa	+						
Neritidae							
Nerita balteata						+	
Newtoniellidae							
Cerithiella sp.		+	+		+		
Olivellidae							
Olivella fulgurata	+		+			+	
Olividae							
Oliva dubia			+				
Ptychatractidae							
Latiromitra sp.				+			
Ringiculidae							
Ringicula auriculata				+			
Siphonariidae							
Siphonaria sp.	+						
Strombidae							
Doxander vittatus		+	+	+			
Laevistrombus turturella			+	+	+		
Margistrombus marginatus	+						
Margistrombus septimus	+						
Margistrombus sp.	+			+			+
Terebridae							
Euterebra capensis					+		
Euterebra fuscolutea			+				
Trochidae							
Umbonium elegans	+				+		+
Umbonium vestarium	+		+		+		

Table 4.6 continued

Taxa/Station	1	2	3	4	5	6	7
Turritellidae							
Turritella cingulifera	+	+	+	+	+	+	+
Turritella sp. 1				+			
Turritella sp. 2			+		+	+	+
Turritella sp. 4		+					
Xenophoridae							
Onustus indicus	+		+	+	+		+
Total	12	5	11	8	8	5	5

Notes: (+) present; (-) absent

Table 4.7: Checklist of bivalve in Pandan Beach.

Taxa/Station	1	2	3	4	5	6	7
Arcidae							
Anadara sp. 1	+	+	+	+	+	+	
Anadara sp. 2	+	+					
Anadara sp. 3	+	+	+	+	+	+	+
Anadara sp. 4	+	+	+		+		
Anadara granosa	+	+	+	+	+	+	+
Arca navicularis	+		+				
Anadara nodifera			+		+		+
Cardiidae							
Acanthocardia tuberculata	+		+	+	+		
Lunulicardia hemicardia	+		+				+
Donacidae							
Donax semigranosum			+	+			
Donax sp.			+				
Donax variabilis	+		+				
Mactridae							
Mactrotoma angulifera	+		+				
Placunidae							
Placuna placenta				+			
Solecurtidae							
Azorinus scheepmakeri						+	
Tellinidae							
Loxoglypta subpallida	+	+			+	+	
Veneridae							
Gafrarium sp.			+				
Lioconcha sp.			+				
Samarangia quadrangularis	+						+
Total	12	6	14	6	7	5	5

Notes: (+) present; (-) absent

4.3.1.3 Species Density and Percentage

Highest density of gastropod and bivalve in Pandan beach was shown by *Turritella cingulifera* and *Anadara granosa* at station 5 with a density of 459.26 ind./m^2 and 429.63 ind./m^2, respectively (Table 4.8). Both the species made up 63.1% of the total density in station 5. The percentage values of gastropod and bivalve were calculated as the percentage of their density from the total density according to station. *A. granosa* has the highest percentage value with 44.7% of overall gastropod and bivalve reported at station 2.

At station 1 and station 3, the highest density was recorded by *T. cingulifera* with 311.11 ind./m^2 and 281.48 ind./m^2, respectively. It comprised 21.4% and 22.3% of the total density in the respective stations. The most density value at station 2, station 4, station 6, and station 7 was recorded by *A. granosa* with 251.85 ind./m^2, 296.30 ind./m^2, 88.89 ind./m^2, and 118.52 ind./m^2, correspondingly.

Table 4.8: Comparison of species density (ind./m^2) and percentage (%) of gastropod and bivalve in Pandan beach.

Taxa/Station	1	2	3	4	5	6	7
Gastropoda							
Architectonica perdix	14.81 (1.0%)	-	-	-	-	14.81 (4.3%)	-
Bursa granularis	14.81 (1.0%)	-	-	-	-	-	-
Austromitra canaliculata	-	-	59.26 (4.7%)	-	-	-	-
Cassidula nucleus	-	14.8 (2.6%)	-	-	-	-	-
Murex trapa	14.81 (1.0%)	-	-	-	-	-	-
Nerita balteata	-	-	-	-	-	14.81 (4.3%)	-
Cerithiella sp.	-	14.8 (2.6%)	14.81 (1.1%)	-	59.26 (4.2%)	-	-
Olivella fulgurata	59.26 (4.0%)	-	148.15 (11.7%)	-	-	29.63 (8.7%)	-
Oliva dubia	-	-	14.81 (1.1%)	-	-	-	-
Latiromitra sp.	-	-	-	14.81 (2.1%)	-	-	-
Ringicula auriculata	-	-	-	14.81 (2.1%)	-	-	-
Siphonaria sp.	14.81 (1.0%)	-	-	-	-	-	-
Doxander vittatus	-	14.81 (2.6%)	14.81 (1.1%)	14.81 (2.1%)	-	-	-
Laevistrombus turturella	-	-	14.81 (1.1%)	14.81 (2.1%)	14.81 (1.0%)	-	-
Margistrombus marginatus	29.63 (2.0%)	-	-	-	-	-	-
Margistrombus septimus	14.81 (1.0%)	-	-	-	-	-	-
Margistrombus sp.	88.89 (6.1%)	-	-	14.81 (2.1%)	-	-	29.63 (8.3%)

Table 4.8 continued

Taxa/Station	1	2	3	4	5	6	7
Gastropoda							
Euterebra capensis	-	-	-	-	14.81 (1.0%)	-	-
Euterebra fuscolutea	-	-	14.81 (1.1%)	-	-	-	-
Umbonium elegans	29.63 (2.0%)	-	-	-	14.81 (1.0%)	-	14.81 (4.1%)
Umbonium vestarium	29.63 (2.0%)	-	44.44 (3.5%)	-	29.63 (2.1%)	-	-
Turritella cingulifera	311.11 (21.4%)	14.81 (2.6%)	281.48 (22.3%)	44.44 (6.3%)	459.26 (32.6%)	14.81 (4.3%)	59.26 (16.6%)
Turritella sp. 1	-	-	-	14.81 (2.1%)	-	-	-
Turritella sp. 2	-	-	74.07 (5.8%)	-	88.89 (6.3%)	14.81 (4.3%)	29.63 (8.3%)
Turritella sp. 4	-	14.81 (2.6%)	-	-	-	-	-
Onustus indicus	29.63 (2.0%)	-	14.81 (1.1%)	14.81 (2.1%)	14.81 (1.0%)	-	14.81 (4.1%)
Bivalvia							
Anadara sp. 1	118.52 (8.1%)	74.07 (13.1%)	59.26 (4.7%)	118.52 (17.0%)	133.33 (9.4%)	74.07 (21.7%)	-
Anadara sp. 2	14.81 (1.0%)	14.81 (2.6%)	-	-	-	-	-
Anadara sp. 3	44.44 (3.0%)	14.81 (2.6%)	59.26 (4.7%)	88.89 (12.7%)	88.89 (6.3%)	59.26 (17.3%)	44.44 (12.5%)
Anadara sp. 4	148.15 (10.2%)	103.70 (18.4%)	251.85 (19.9%)	-	14.81 (1.0%)	-	-
Anadara granosa	237.04 (16.3%)	251.85 (44.7%)	162.96 (12.9%)	296.30 (42.5%)	429.63 (30.5%)	88.89 (26.0%)	118.52 (33.3%)
Arca navicularis	29.63 (2.0%)	-	44.44 (3.5%)	-	-	-	-

Table 4.8 continued

Taxa/Station	1	2	3	4	5	6	7
Bivalvia							
Anadara nodifera	-	-	29.63 (2.3%)	-	14.81 (1.0%)	-	14.81 (4.1%)
Acanthocardia tuberculata	103.70 (7.1%)	-	29.63 (2.3%)	14.81 (2.1%)	14.81 (1.0%)	-	-
Lunulicardia hemicardia	14.81 (1.0%)	-	14.81 (1.1%)	-	-	-	14.81 (4.1%)
Donax semigranosum	-	-	14.81 (1.1%)	14.81 (2.1%)	-	-	-
Donax sp.	-	-	29.63 (2.3%)	-	-	-	-
Donax variabilis	14.81 (1.0%)	-	29.63 (2.3%)	-	-	-	-
Mactrotoma angulifera	44.44 (3.0%)	-	29.63 (2.3%)	-	-	-	-
Placuna placenta	-	-	-	14.81 (2.1%)	-	-	-
Azorinus scheepmakeri	-	-	-	-	-	14.8 (4.3%)	-
Loxoglypta subpallida	14.81 (1.0%)	29.63 (5.2%)	-	-	14.81 (1.0%)	14.8(4.3%)	-
Gafrarium sp.	-	-	29.63 (2.3%)	-	-	-	-
Lioconcha sp.	-	-	14.81 (1.1%)	-	-	-	-
Samarangia quadrangularis	14.81 (1.0%)	-	-	-	-	-	14.81 (4.1%)
Total	1451.80	562.92	1261.39	696.25	1407.37	340.71	355.53

4.3.1.4 Species Number, Diversity, Evenness, Richness, and Total Density

The maximum species number of gastropod and bivalve at Pandan beach was recorded at station 3 with a total of 25 species and followed by station 1 with 24 species. The minimum species number was observed at station 6 and station 7 with 10 species, each. Species richness value was from 2.749 to 5.200 with the lowest recorded at station 2. For the species diversity, the Shannon Diversity index value was ranged from 1.763 to 2.703 while, the Simpson's Reciprocal index value was between 3.861 and 10.252. The lowest diversity was recorded at station 2 and the highest value was observed at station 3. Species evenness was ranged from 0.701 (station 5) to 0.876 (station 6).

Lastly, the total density of gastropod and bivalve was ranged from 340.71 ind./m^2 to 1451.80 ind./m^2. The most total density value was calculated at station 1 whereas, the least was found at station 6. The species number, diversity, evenness, richness, and total density of gastropod and bivalve in Pandan beach were shown in Table 4.9.

Table 4.9: Species number, diversity, evenness, richness, and total density of gastropod and bivalve in Pandan beach.

Community structure/Station	1	2	3	4	5	6	7
Species number	24	11	25	14	15	10	10
Species diversity (Shannon Diversity index)	2.632	1.763	2.703	1.923	1.898	2.017	2.001
Species Diversity (Simpson's Reciprocal index)	9.509	3.861	10.252	4.256	4.551	6.080	5.647
Species evenness	0.828	0.735	0.840	0.729	0.701	0.876	0.869
Species richness	5.016	2.749	5.200	3.376	3.074	2.870	2.832
Total density (ind./m^2)	1451.80	562.92	1261.39	696.25	1407.37	340.71	355.53

4.3.1.5 Correlation of Community Structure with Environmental Parameters

The result of Pearson correlation indicates that there are relationship between community structure of gastropod and bivalve and environmental parameters at Pandan beach (Table 4.10). For instance, species richness of gastropod and bivalve was strongly and positively correlated with the water turbidity (r = 0.818; p = 0.024). The correlation was significant (p < 0.05). Furthermore, the species richness was also indicated strong correlation with the total organic matter of the sediment (r = -0.835; p = 0.020). It was negatively correlated and the correlation was significant (p < 0.05). The other correlations among the community structure and environmental parameters were not significant. The strength of the correlation coefficient value was shown in Table C1, Appendix C.

Table 4.10: Pearson-linear correlation coefficient (r value) between community structure and environmental parameters in Pandan beach.

Parameter	Shannon Diversity index		Simpson's Reciprocal index		Pielou's index		Margalef index		Total density	
	r	p	r	p	r	p	r	p	r	p
Dissolved oxygen	-.336	.461	-.242	.601	.286	.534	-.524	.227	-.299	.515
pH	-.240	.605	-.322	.482	-.482	.274	-.152	.745	.342	.452
Temperature	.005	.991	-.091	.846	-.515	.237	.233	.615	.112	.811
Salinity	.177	.704	.218	.639	.103	.827	.147	.754	.212	.648
Conductivity	-.092	.845	-.046	.921	.495	.259	-.207	.656	-.590	.163
Turbidity	.678	.094	.606	.149	-.071	.880	**.818***	**.024**	.555	.196
Sand	.183	.694	.148	.752	-.205	.660	.228	.623	.499	.254
Silt and clay	-.183	.694	-.148	.752	.205	.660	-.228	.623	-.499	.254
Total organic matter	-.752	.051	-.707	.075	-.030	.949	**-.835***	**.020**	-.719	.069
Chlorophyll *a*	-.468	.289	-.369	.415	.114	.807	-.609	.147	-.346	.447

*. Correlation is significant at the 0.05 level (2-tailed).

Species richness was significantly increased with increasing turbidity with R^2 value of 0.670 and significantly decreased with increasing total organic matter with R^2 value of 0.696 (Figure 4.9 and Figure 4.10).

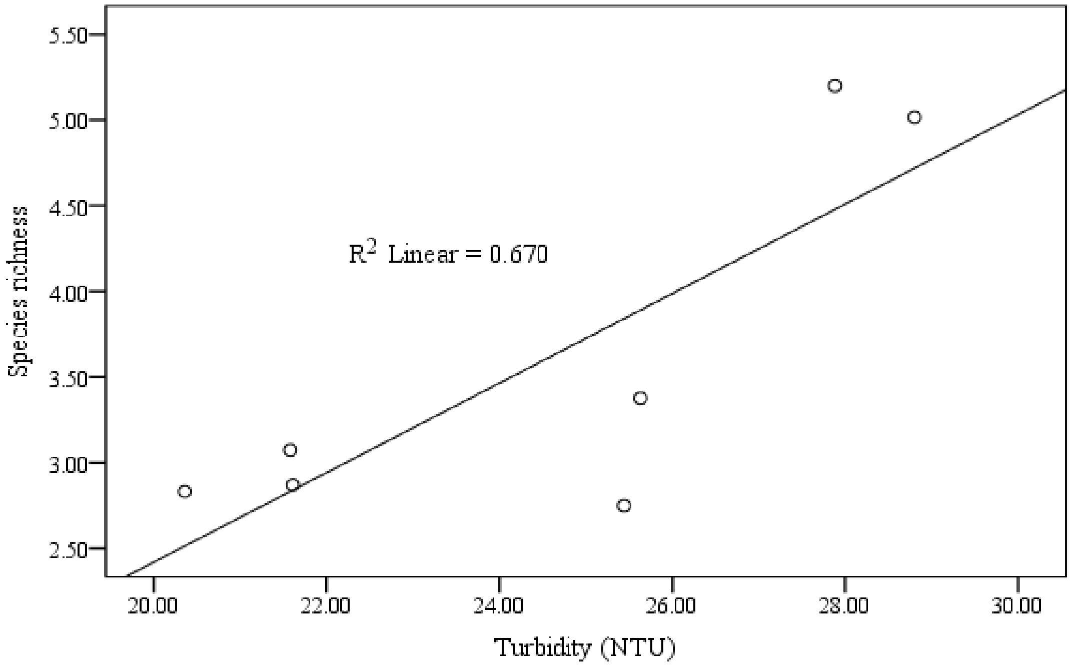


Figure 4.9: The scattered plot of linear regression between species richness and turbidity.

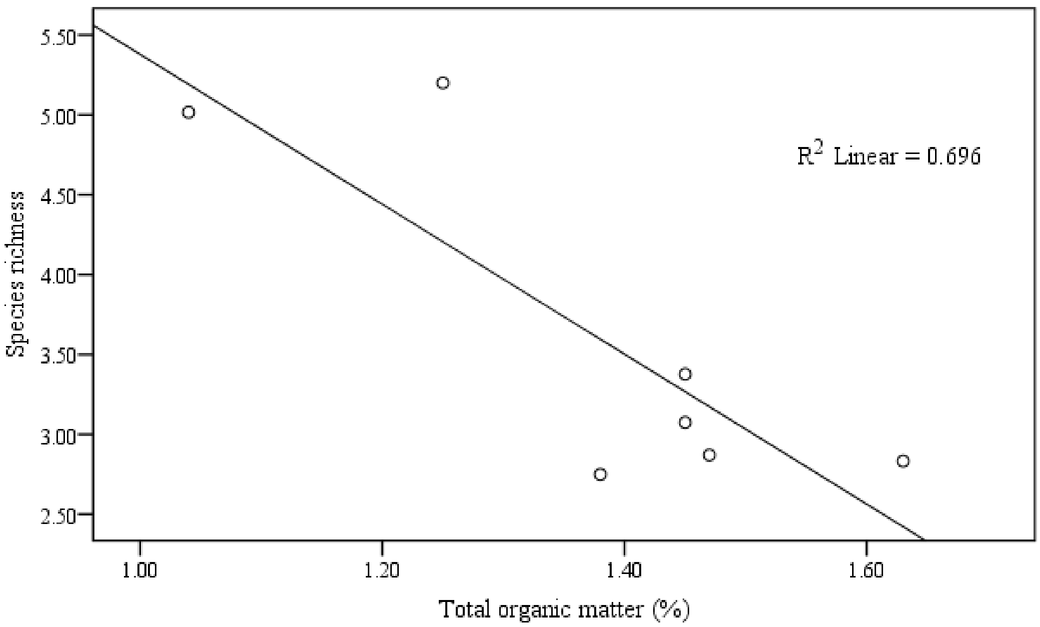


Figure 4.10: The scattered plot of linear regression between species richness and total organic matter.

4.3.1.6 Principal Component Analysis (PCA)

Result of PCA indicates that the variation in environmental variables is best explained by axis 1 and axis 2 with the total variance of 66.62% (Table 4.11). Axis 1 explained 43.77% of total variance. Meanwhile, axis 2 described 22.85% of variance. Axis 1 was mainly loaded by dissolved oxygen, temperature, turbidity, total organic matter and chlorophyll *a* content. On the other hand, axis 2 was mainly loaded with salinity, percentage of sand, and percentage of silt and clay. The biplot diagram (Figure 4.11) showed the environmental parameters that best describe each of the selected station.

Axis 1 was positively correlated with temperature and turbidity, while negatively correlated with dissolved oxygen, total organic matter and chlorophyll *a*. Axis 2 was positively correlated with the percentage of silt and clay and negatively correlated with salinity and percentage of sand. Station 1 was best described by high salinity and percentage of sand, whereas station 2 was distinguished by the turbidity of water. Station 3 and station 4 were characterised by high water temperature while at Station 5 and station 7, dissolved oxygen was predominant as demonstrated by the long arrows. Station 6 was described by high total organic matter, chlorophyll *a*, and percentage of silt and clay.

Table 4.11: Summary of Principal Component Analysis (PCA) for water quality at all sampling stations in Pandan beach.

Principal Component	Eigenvalues	Total Variance (%)	Cumulative (%)
F1	4.377	43.769	43.769
F2	2.285	22.850	66.620
F3	1.396	13.960	80.580
F4	0.935	9.350	89.930
F5	0.686	6.862	96.792
F6	0.321	3.208	100.000

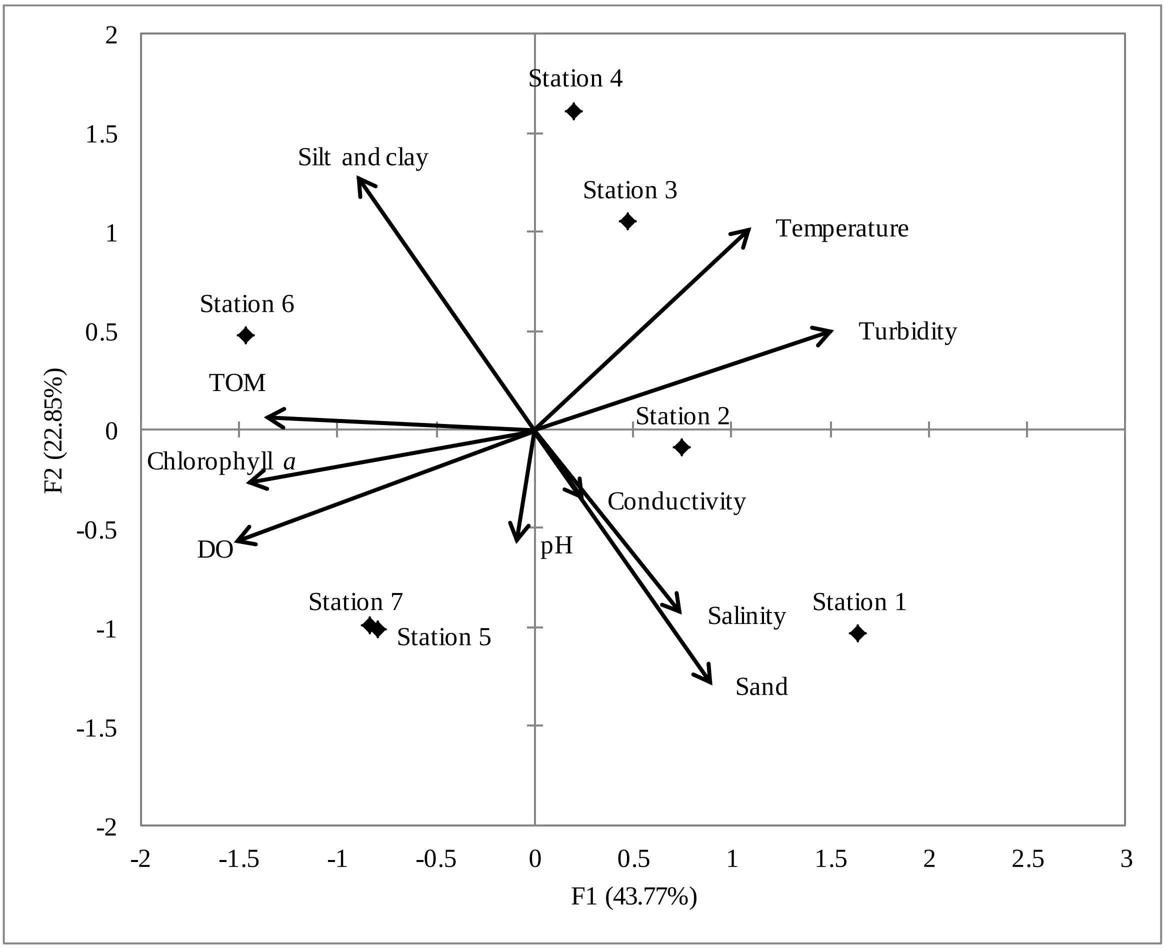


Figure 4.11: Biplot diagram showing variation of environmental parameters among all the stations in Pandan beach. Total variance explained by two axes is 66.62%.

4.3.1.7 Cluster Analysis

Hierarchical clustering technique (cluster analysis) using the Bray-Curtis similarity index with group average linking method was conducted on the gastropod and bivalve's abundance data for 45 species. The analysis grouped the sampling stations into four clusters at 50% similarity threshold. The groupings in the cluster analysis were also supported by the ordination of multidimensional scaling (MDS). Station 6 and station 7 separated from each other and formed two different clusters. Station 2 and station 4 formed a group with 60% similarity, while station 1, station 3, and station 5 formed a cluster with similarity greater than

50%. Figure 4.12 and Figure 4.13 display the dendogram produced in the hierarchical clustering and MDS ordination, respectively.

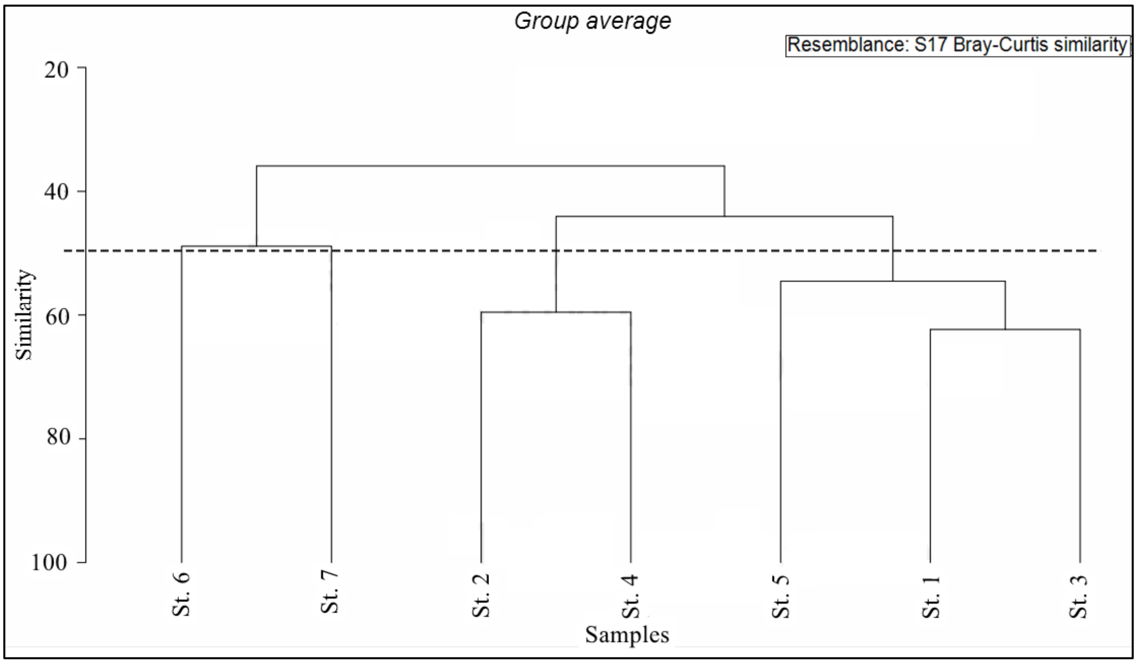


Figure 4.12: Dendogram produced in the cluster analysis showing the percentage of similarity between the intertidal stations of Pandan beach by using the gastropod and bivalve's abundance data based on Bray Curtis similarities (similarity threshold at 50%).

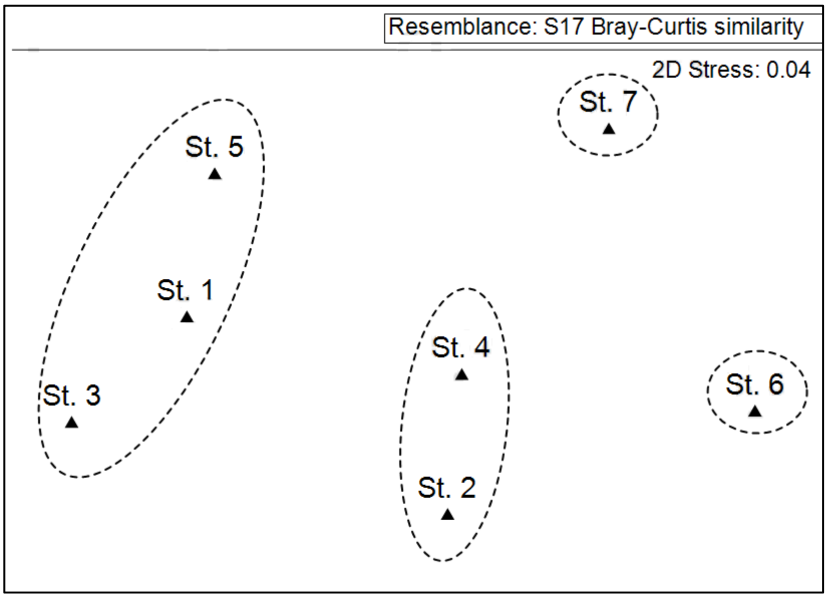


Figure 4.13: Multidimensional scaling (MDS) ordination (stress: 0.04) constructed based on the gastropod and bivalve's abundance in Pandan beach.

4.3.2 Kabong Beach

4.3.2.1 Environmental Parameters

From Table 4.12, the mean values of dissolved oxygen at Kabong beach were in the range of 6.07 mg/L to 6.73 mg/L. Even though the range is very small, there was a significant different in the mean values between stations ($p > 0.05$). The lowest and highest was recorded at station 3 and station 2, respectively. Besides that, the highest pH value was recorded at station 1 with 7.38 and followed by station 2 with 7.21. The least pH value was recorded at station 3 with 6.53. The means between stations were significantly different ($p < 0.05$).
The trend of water quality in the study area was shown in Figure 4.14.

Table 4.12: Mean and standard deviation of environmental parameters at all the stations in Kabong beach.

Parameter/Station	1	2	3	4
Dissolved oxygen (mg/L)	6.60±0.27	6.73±0.21	6.07±0.06	6.67±0.15
pH	7.38±0.02	7.21±0.12	6.52±0.39	7.04±0.05
Temperature (°C)	28.57±0.38	28.51±0.51	31.17±0.35	29.79±0.30
Salinity (PSU)	32.00±1.00	30.67±0.58	30.33±0.58	32.33±0.58
Conductivity (µS/cm)	107.00±1.00	105.00±2.65	103.30±0.95	106.70±2.52
Turbidity (NTU)	503.30±3.22	623.70±9.29	668.70±45.65	495.00±7.94
Sand (%)	82.03±1.59	86.98±1.24	91.91±3.01	88.45±1.03
Silt and clay (%)	17.97±1.59	13.02±1.24	8.09±3.01	11.55±1.03
Total organic matter (%)	2.79±0.03	1.81±0.16	2.79±0.16	3.02±0.19
Chlorophyll *a* (mg/m^3)	0.18±0.02	0.27±0.02	0.17±0.01	0.28±0.02

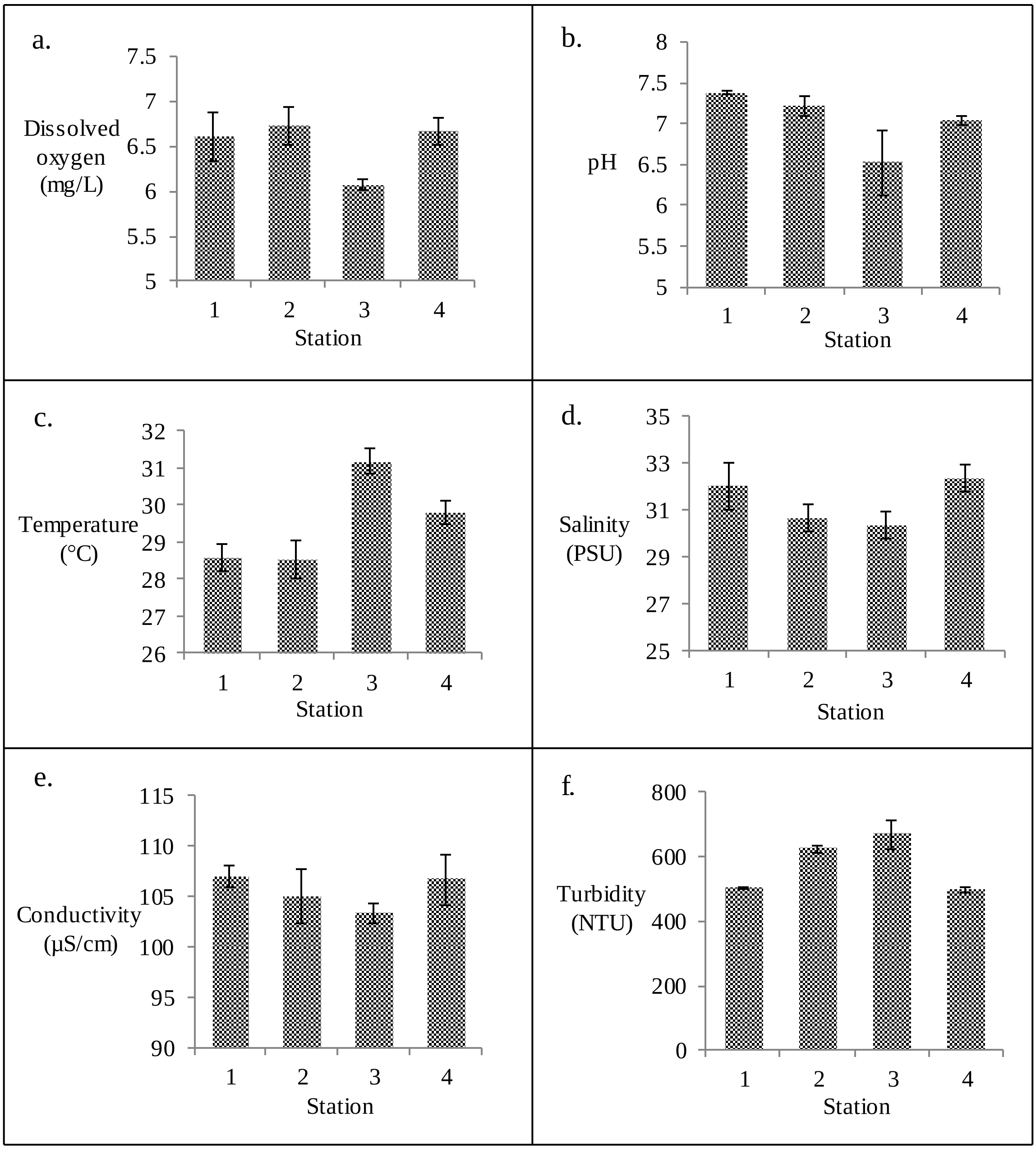


Figure 4.14: Water parameters of all the stations in Kabong beach. (**a.** dissolved oxygen, **b.** pH, **c.** temperature, **d.** salinity, **e.** conductivity, **f.** turbidity).

The water temperature at Kabong beach was between 28.51 °C and 31.17 °C. Station 2 recorded the lowest temperature value whereas, station 3 recorded the highest value. There was a significant different ($p < 0.05$) in mean values between stations. Besides that, salinity of water was in the range of 30.33 PSU to 32.33 PSU. The highest value was represented by station 4 and the lowest value was obtained from station 3. Station 1 recorded the second highest value (32.00 PSU) and followed by station 2 (30.67 PSU). The means of salinity between stations were significantly different ($p < 0.05$).

Besides that, conductivity was ranged from 103.30 µS/cm to 107.00 µS/cm. The maximum value was recorded at station 1, while, the minimum value was recorded at station 3. The means between stations were not significantly different ($p > 0.05$). On the other hand, the mean values of turbidity were in between 495.00 NTU to 668.70 NTU. There was a significant different ($p < 0.05$) in mean values of turbidity between stations. The most and least value was recorded at station 3 and station 4, respectively (Table 4.12 and Figure 4.14).

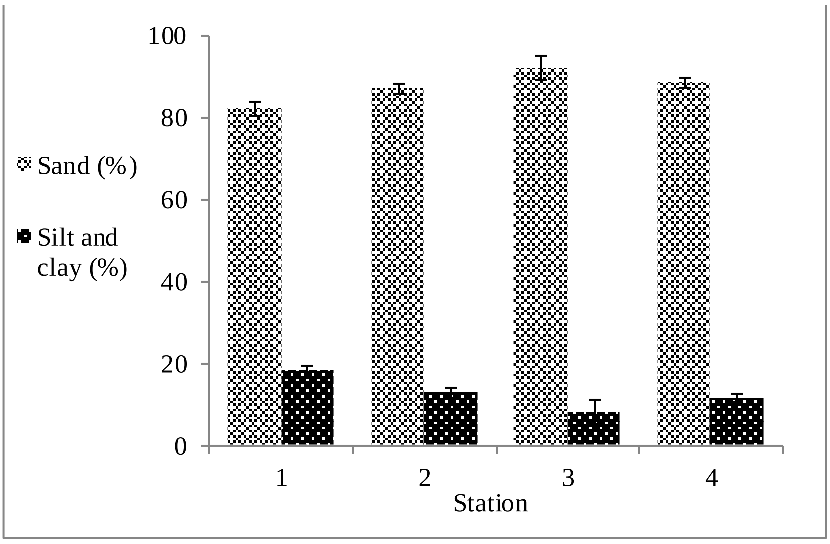


Figure 4.15: The percentage of sand, and silt and clay of all the stations in Kabong beach.

In the sediment grain size analysis, the percentage of sand was higher compared to the percentage of silt and clay (Figure 4.15). The maximum value was 91.91% which was found in station 3 meanwhile, the minimum value was 82.03% representing station 1. In contrast, the range of silt and clay was between 8.09% and 17.97%. The highest was obtained at station 1 whereas, the lowest recorded at station 3. The mean values of grain size percentage were significantly different ($p < 0.05$) among stations.

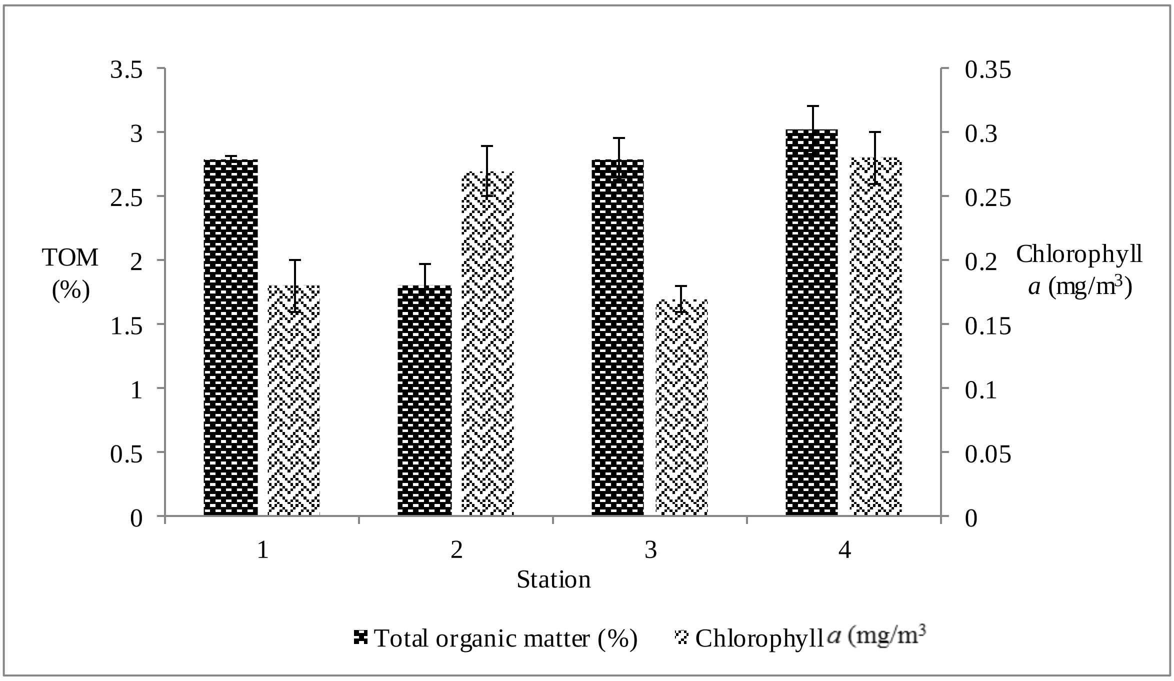


Figure 4.16: The total organic matter (%) and chlorophyll *a* content (mg/m^3) of the sediment in Kabong beach.

Based on Table 4.12 and Figure 4.16, the highest total organic matter content of sediment in Kabong beach was recorded at station 4 (3.02%) and followed by station 1 and station 3 with 2.79%. The lowest value was noted at station 2 with only 1.81%. The means between stations were significantly different ($p < 0.05$). Then, the highest chlorophyll *a* reading was observed at station 4 whereas, the lowest was observed at station 3. Chlorophyll *a* content was ranged from 0.17 mg/m^3 to 0.28 mg/m^3. There was a significant different in the mean values of chlorophyll *a* between stations ($p < 0.05$).

4.3.2.2 Abundance of Gastropod and Bivalve

Study at Kabong beach recorded 163 individuals of gastropod and bivalve representing 25 species and 12 species, respectively. From them, 83 individuals was gastropod while, 80 individuals was bivalve (Appendix B2). The gastropod was reported from 14 families while, the bivalve was obtained from 6 families. Overall, 20 families were identified with a total of 37 species. During the identification, 17 species of gastropod and 10 species of bivalve were identified until species level whereas, others were identified until genus level. Table 4.13 and 4.14 showed the species composition of gastropod and bivalve found in Kabong beach.

The most abundant species in Kabong beach was *Donax variabilis* from Bivalvia with total of 29 individuals (Appendix D). Family Donacidae represented 72.50% of total number of bivalve collected and 35.58% of overall individuals collected in the study area. They were found in all stations except at station 4. Station 1 recorded highest number of gastropod with 31 individuals, and followed by station 3 with 29 individuals. The highest number of bivalve's individuals was also obtained at station 1 and followed by station 3 with 33 and 30 individuals, respectively. Hence, highest number of gastropod and bivalve's individual was obtained at Station 1 with a total of 64 individuals representing 39.26% of the total individuals recorded at Kabong beach.

Table 4.13: Checklist of gastropod in Kabong Beach.

Taxa/Station	1	2	3	4
Architectonicidae				
Architectonica perdix	-	+	-	-
Cocculinidae				
Cocculina sp.	+	-	-	-
Cylichnidae				
Cylichna sibogae	+	-	-	-
Eulimidae				
Eulima bifascialis	+	-	+	-
Eulima sp.	+	-	-	-
Melanella sp.	-	-	+	-
Mangeliidae				
Pseudorhaphitoma sp.	+	-	-	-
Muricidae				
Thais blanfordi	-	+	-	-
Nassariidae				
Nassarius elegantissimus	+	+	+	-
Nassarius sp. 2	-	+	-	-
Nassarius sp. 3	+	-	+	-
Nassarius stolatus	-	+	+	-
Naticidae				
Natica tigrina	+	-	+	-
Neverita didyma	+	-	-	-
Tanea hilaris	-	+	+	+
Olivellidae				
Olivella fulgurata	+	+	-	-
Olividae				
Oliva multiplicata	+	-	-	-
Ringiculidae				
Ringicula auriculata	-	-	+	-
Ringicula doliaris	+	-	+	-
Terebridae				
Euterebra capensis	+	-	+	-
Trochidae				
Umbonium vestarium	+	+	+	-

Table 4.13 continued

Taxa/Station	1	2	3	4
Turritellidae				
Turritella cingulifera	+	-	+	+
Turritella duplicata	-	+	+	+
Turritella sp. 2	+	-	-	+
Turritella sp. 3	+	+	-	+
Total	17	10	13	5

Notes: (+) present; (-) absent

Table 4.14: Checklist of bivalve in Kabong Beach.

Taxa/Station	1	2	3	4
Arcidae				
Anadara globosa	-	-	-	+
Anadara granosa	+	-	-	-
Anadara rotundicostata	+	-	+	-
Donacidae				
Donax rugosus	+	+	+	-
Donax sp.	+	+	+	-
Donax variabilis	+	+	+	-
Pholadidae				
Pholas orientalis	-	+	-	-
Psammobiidae				
Hiatula adamsii	+	+	-	+
Tellinidae				
Loxoglypta subpallida	+	-	+	-
Veneridae				
Gafrarium sp.	+	+	+	-
Samarangia quadrangularis	+	-	+	-
Tivela mactroides	-	-	-	+
Total	9	6	7	3

Notes: (+) present; (-) absent

4.3.2.3 Species Density and Percentage

The density of gastropod and bivalve at Kabong beach was in the range of 14.81 ind/m^2 to 207.41 ind./m^2. Highest density was shown by *Donax* sp. and *D. variabilis* at station 3 and station 1, respectively. The least density value was same for all the stations but represented different percentage according to the total density by stations. The most density value at station 1 was recorded by *D. variabilis* representing 21.9% of the total density in that station. At station 2, again *D. variabilis* recorded the highest density with 20.0%, and at station 3, *Donax* sp. was found to be the highest (23.7%). Lastly, at station 4, *Turritella* sp. 2 and *Turritella* sp. 3 was noted to be the most. The species density and percentage values of gastropod and bivalve in Kabong beach are shown in Table 4.15.

Table 4.15: Comparison of species density (ind./m^2) and percentage (%) of gastropod and bivalve in Kabong beach.

Taxa/Station	1	2	3	4
Gastropoda				
Architectonica perdix	-	14.81 (3.3%)	-	-
Cocculina sp.	14.81 (1.5%)	-	-	-
Cylichna sibogae	14.81 (1.5%)	-	-	-
Eulima bifascialis	44.44 (4.7%)	-	59.26 (6.8%)	-
Eulima sp.	14.81 (1.5%)	-	-	-
Melanella sp.	-	-	14.81 (1.7%)	-
Pseudorhaphitoma sp.	14.81 (1.5%)	-	-	-
Thais blanfordi	-	14.81 (3.3%)	-	-
Nassarius elegantissimus	14.81 (1.5%)	14.81 (3.3%)	14.81 (1.7%)	-
Nassarius sp. 2	-	29.63 (6.6%)	-	-
Nassarius sp. 3	14.81 (1.5%)	-	59.26 (6.8%)	-
Nassarius stolatus	-	44.44 (10.0%)	29.63 (3.4%)	-
Natica tigrina	14.81 (1.5%)	-	14.81 (1.7%)	-
Neverita didyma	14.81 (1.5%)	-	-	-
Tanea hilaris	-	14.81 (3.3%)	14.81 (1.7%)	14.81 (10.0%)
Olivella fulgurata	59.26 (6.2%)	29.63 (6.6%)	-	-
Oliva multiplicata	14.81 (1.5%)	-	-	-
Ringicula auriculata	-	-	14.81 (1.7%)	-
Ringicula doliaris	14.81 (1.5%)	-	14.81 (1.7%)	-
Euterebra capensis	59.26 (6.2%)	-	14.81 (1.7%)	-
Umbonium vestarium	88.89 (9.4%)	44.44 (10.0%)	29.63 (3.4%)	-
Turritella cingulifera	29.63 (3.1%)	-	88.89 (3.4%)	14.81 (10.0%)
Turritella duplicata	-	14.81 (3.3%)	59.26 (6.8%)	14.81 (10.0%)

Table 4.15 continued

Taxa/Station	1	2	3	4
Gastropoda				
Turritella sp. 2	14.81 (1.5%)	-	-	29.63 (20.0%)
Turritella sp. 3	14.81 (1.5%)	14.81 (3.3%)	-	29.63 (20.0%)
Bivalvia				
Anadara globosa	-	-	-	14.81 (10.0%)
Anadara granosa	14.81 (1.5%)	-	-	-
Anadara rotundicostata	14.81 (1.5%)	-	14.81 (1.7%)	-
Donax rugosus	44.44 (4.7%)	14.81 (3.3%)	29.63 (3.4%)	-
Donax sp.	88.89 (9.4%)	44.44 (10.0%)	207.41 (23.7%)	-
Donax variabilis	207.41 (21.9%)	88.89 (20.0%)	133.33 (15.2%)	-
Pholas orientalis	-	14.81 (3.3%)	-	-
Hiatula adamsii	14.81 (1.5%)	14.81 (3.3%)	-	14.81 (10.0%)
Loxoglypta subpallida	29.63 (3.1%)	-	14.81 (1.7%)	-
Gafrarium sp.	44.44 (4.7%)	29.63 (6.6%)	14.81(1.7%)	-
Samarangia quadrangularis	29.63 (3.1%)	-	29.63 (3.4%)	-
Tivela mactroides	-	-	-	14.81 (10.0%)
Total	948.07	444.39	874.03	148.12

4.3.2.4 Species Number, Diversity, Evenness, Richness, and Total Density

The study showed that species number was recorded the most at station 1 with a total of 26 species. Second highest species number was found at station 3 with a total of 20 species. It was then followed by station 2 with 16 species and finally station 4 with 8 species. Species richness was in the range of 3.040 to 6.011. On the other hand, the value of species diversity using Shannon Diversity index was in the range of 2.025 to 2.853 and the value of species diversity using Simpson's Reciprocal index was in between 7.143 and 11.571. The highest was found at station 1 and the least was found at station 4.

Besides that, the maximum species evenness value was obtained at station 4 (0.974) and the minimum was observed at station 3 (0.854). Next, the total density of gastropod and bivalve was ranged from 148.12 ind./m^2 to 948.07 ind./m^2. The most density value was contributed by station 1 and the least value was represented by station 4. The species number, diversity, evenness, richness, and total density of gastropod and bivalve in Kabong beach were shown in Table 4.16.

Table 4.16: Species number, diversity, evenness, richness, and total density of gastropod and bivalve in Kabong beach.

Community structure/Station	1	2	3	4
Species number	26	16	20	8
Species Diversity (Shannon Diversity index)	2.853	2.575	2.558	2.025
Species diversity (Simpson's Reciprocal index)	11.571	10.714	8.995	7.143
Species evenness	0.876	0.929	0.854	0.974
Species richness	6.011	4.410	4.660	3.040
Total density (ind./m^2)	948.07	444.39	874.03	148.12

4.3.2.5 Correlation of Community Structure with Environmental Parameters

Pearson correlation between community structure of gastropod and bivalve and environmental parameters showed that there were two significant correlations indicated by the sediment chlorophyll *a* content. The chlorophyll *a* content was positively correlated with the species evenness of gastropod and bivalve with the correlation coefficient value of r = 0.956. Furthermore, the chlorophyll *a* content was negatively correlated with the total density of gastropod and bivalve (r = -0.956; p = 0.044). The correlations shown by chlorophyll *a* content were significant at the 0.05 level. The other correlations among environmental parameters and community structure were insignificant. Table 4.17 represented the correlation coefficient (r value) between each environmental parameters and community structure. The strength of the correlation coefficient value was shown in Table C1, Appendix C.

Table 4.17: Pearson-linear correlation coefficient (r value) between community structure and environmental parameters in Kabong beach.

Parameter	Shannon Diversity index		Simpson's Reciprocal index		Pielou's index		Margalef index		Total density	
	r	p	r	p	r	p	r	p	r	p
Dissolved oxygen	-.170	.830	.166	.834	.735	.265	-.171	.829	-.573	.427
pH	.266	.734	.537	.463	.345	.655	.306	.694	-.120	.880
Temperature	-.341	.659	-.632	.368	-.306	.694	-.322	.678	.111	.889
Salinity	-.340	.660	-.220	.780	.534	.466	-.153	.847	-.352	.648
Conductivity	-.116	.884	.078	.922	.504	.496	.033	.967	-.282	.718
Turbidity	.242	.758	.103	.897	-.499	.501	.061	.939	.299	.701
Sand	-.508	.492	-.678	.322	-.017	.983	-.593	.407	-.225	.775
Silt and clay	.508	.492	.678	.322	.017	.983	.593	.407	.225	.775
Total organic matter	-.323	.677	-.521	.479	-.060	.940	-.114	.886	.084	.916
Chlorophyll *a*	-.694	.306	-.412	.588	**.956***	**.044**	-.761	.239	**-.956***	**.044**

*. Correlation is significant at the 0.05 level (2-tailed).

The scattered plot of linear regression indicated the species evenness increases with increasing chlorophyll *a* content with R2 value of 0.915 (Figure 4.17). Meanwhile, the total density significantly decreased with increasing chlorophyll *a* content with R2 value of 0.914 (Figure 4.18).

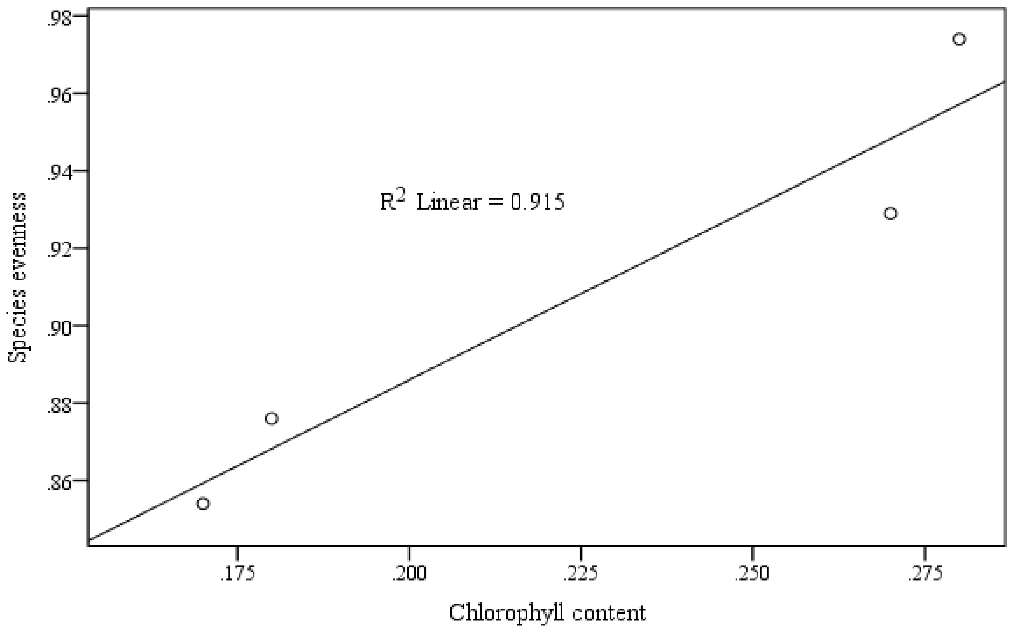


Figure 4.17: The scattered plot of linear regression between species evenness and chlorophyll *a*.

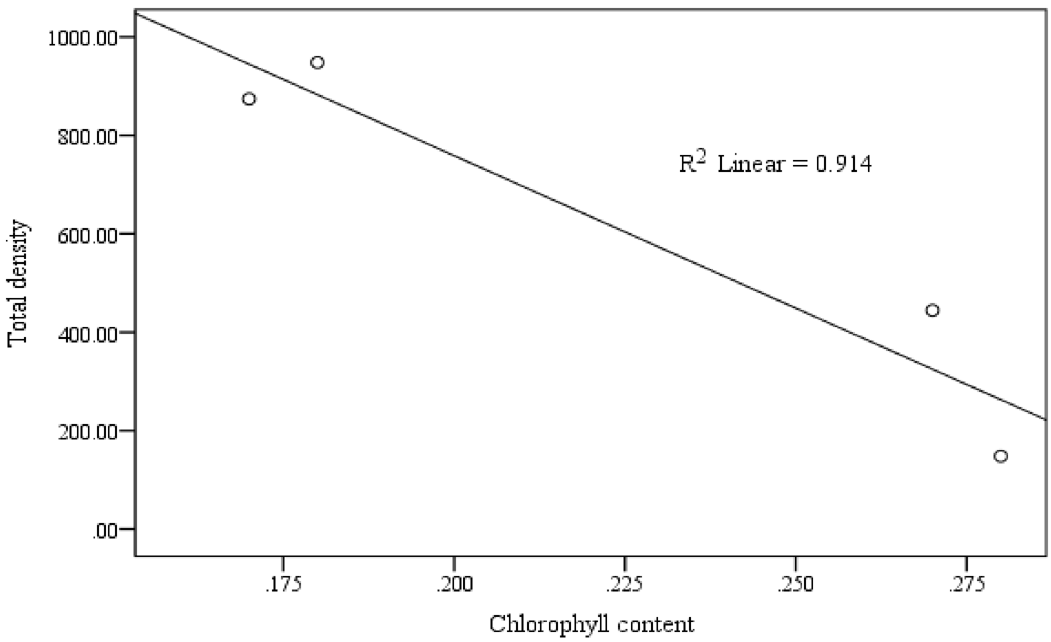


Figure 4.18: The scattered plot of linear regression between total density and chlorophyll *a*.

4.3.2.6 Principal Component Analysis (PCA)

Results of the PCA derived from the environmental variables showed that when the percentages of the total variances of axis 1 and axis 2 are accumulated, these two principal components made up of 85.97% of the total variance (Table 4.18). Axis 1 explained 63.90% and axis 2 with variance of 22.07%. Axis 1 was positively strongly correlated with dissolved oxygen, pH, salinity, conductivity, and percentage of silt and clay, while negatively strongly correlated with temperature, turbidity, and percentage of sand. On the other hand, axis 2 was strongly positively correlated with total organic matter.

Station 1 was dominated by salinity and conductivity whereas, station 2 was characterised by the presence of both turbidity and dissolved oxygen content. Station 3 was distinguished as areas with high percentage of sand and high temperature. High percentage of total organic matter and salinity were best represented by station 4. The biplot diagram (Figure 4.19) showed the environmental parameters that best describe each of the station in the study area.

Table 4.18: Summary of Principal Component Analysis (PCA) for water quality at all sampling stations in Kabong beach.

Principal Component	Eigenvalues	Total Variance (%)	Cumulative (%)
F1	6.390	63.897	63.897
F2	2.207	22.071	85.968
F3	1.403	14.032	100.000

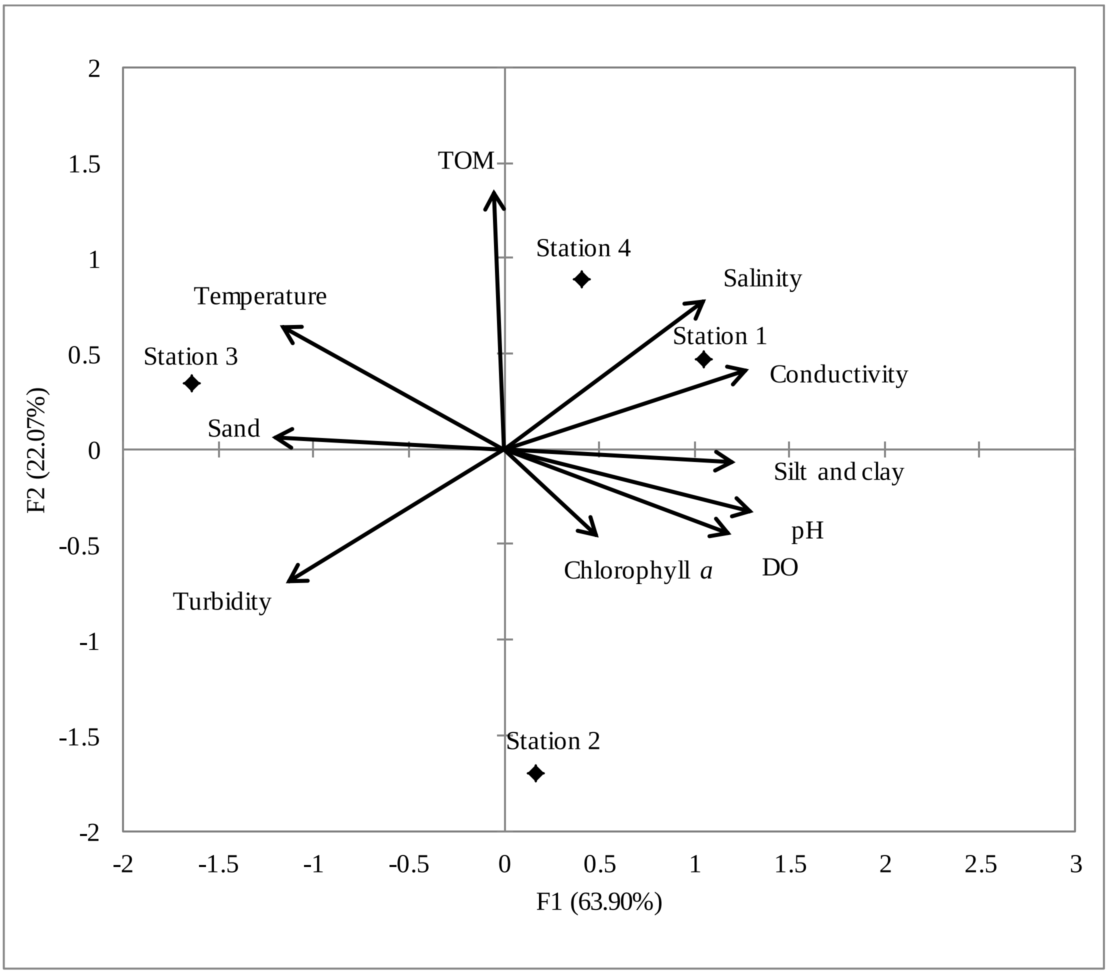


Figure 4.19: Biplot diagram showing variation environmental parameters among all the stations in Kabong beach. Total variance explained by two axes is 85.97%.

4.3.2.7 Cluster Analysis

Cluster analysis was conducted on the gastropod and bivalve's abundance data using the Bray-Curtis similarity index with group average linking method. The result showed that the sampling stations in Kabong beach were grouped into three clusters at 50% similarity threshold. In the MDS plot (Figure 4.21), it is found that all stations are separated conforming to the dendrogram. Station 2 and station 4 were classified as two different clusters, whereas station 1 and station 3 formed a separate group. The dendogram produced in the cluster analysis are shown in Figure 4.20.

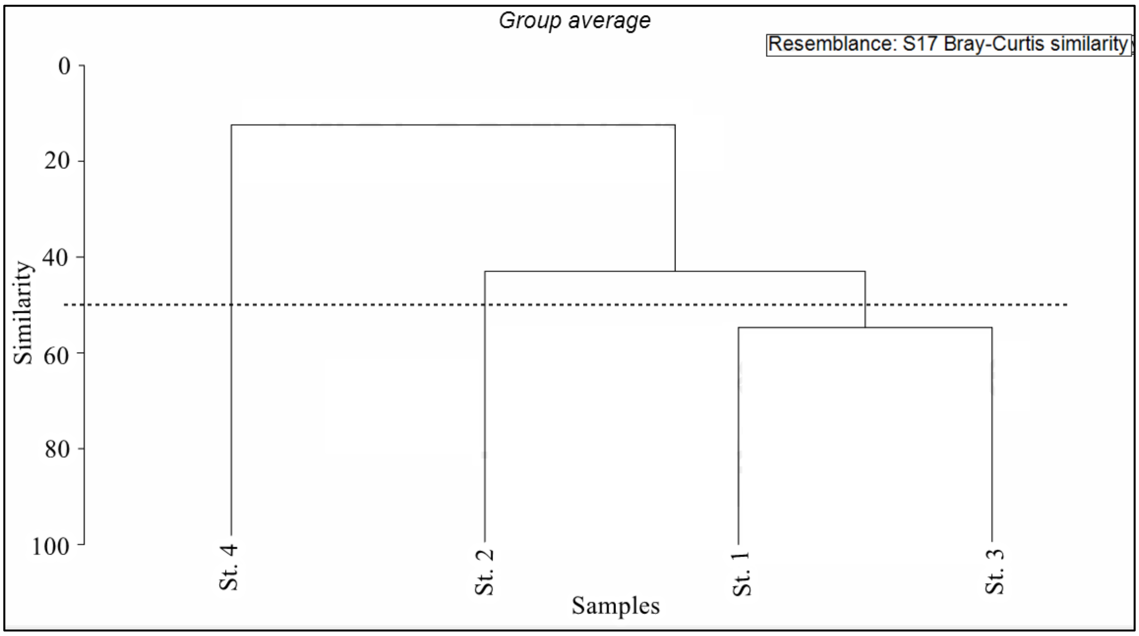


Figure 4.20: Dendogram produced in the cluster analysis showing the percentage of similarity between the intertidal stations of Kabong beach by using the gastropod and bivalve's abundance data based on Bray Curtis similarities (similarity threshold at 50%).

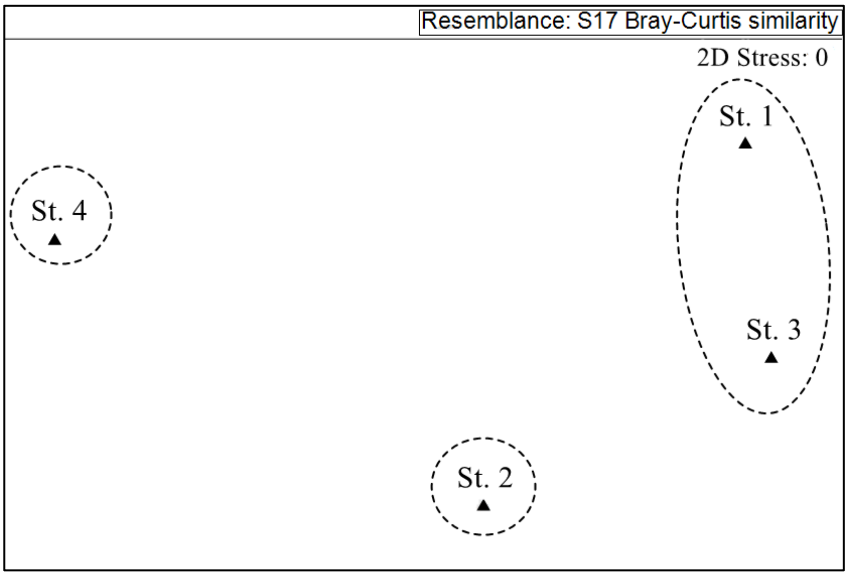


Figure 4.21: Multidimensional scaling (MDS) ordination (stress: 0) constructed based on the gastropod and bivalve's abundance in Kabong beach.

4.3.3 Tanjung Batu Beach

4.3.3.1 Environmental Parameters

The dissolved oxygen contents of water at Tanjung Batu beach were slightly varied from 5.07 mg/L to 6.53 mg/L (Table 4.19). The maximum reading was obtained at station 2 and the minimum reading was recorded at station 4. The means between stations were significantly different ($p < 0.05$). Meanwhile, the mean values of pH at the study are were in the range of 7.13 to 7.69. Station 1 recorded the highest value whereas, station 2 recorded the lowest value. There was a significant different ($p < 0.05$) in mean values between stations. Besides that, the maximum value of temperature was recorded at station 4 while, the minimum value was noted at station 2. The mean values of temperature among stations were from 27.63 °C to 30.47 °C and they were significantly different ($p < 0.05$).The trend of water quality in the study area was shown in Figure 4.22.

Table 4.19: Mean and standard deviation of environmental parameters at all the stations in Tanjung Batu beach.

Parameter/Station	1	2	3	4
Dissolved oxygen (mg/L)	5.83±0.31	6.53±0.72	6.43±0.31	5.07±0.40
pH	7.69±0.02	7.13±0.12	7.44±0.12	7.50±0.32
Temperature (°C)	28.13±0.40	27.63±0.55	28.87±0.15	30.47±0.32
Salinity (PSU)	32.33±0.58	32.33±1.53	30.67±0.58	32.33±0.58
Conductivity(mS/cm)	17.11±1.76	19.00±0.61	17.43±0.65	14.66±1.42
Turbidity (NTU)	55.33±1.16	58.33±2.08	78.67±8.39	59.67±1.53
Sand (%)	88.13±1.03	93.09±1.06	87.45±2.42	96.55±1.25
Silt and clay (%)	11.87±1.03	6.91±1.06	12.55±2.42	3.45±1.25
Total organic matter (%)	3.09±0.11	4.76±0.07	2.77±0.12	2.51±0.08
Chlorophyll *a* (mg/m^3)	0.32±0.04	0.30±0.01	0.24±0.02	0.21±0.01

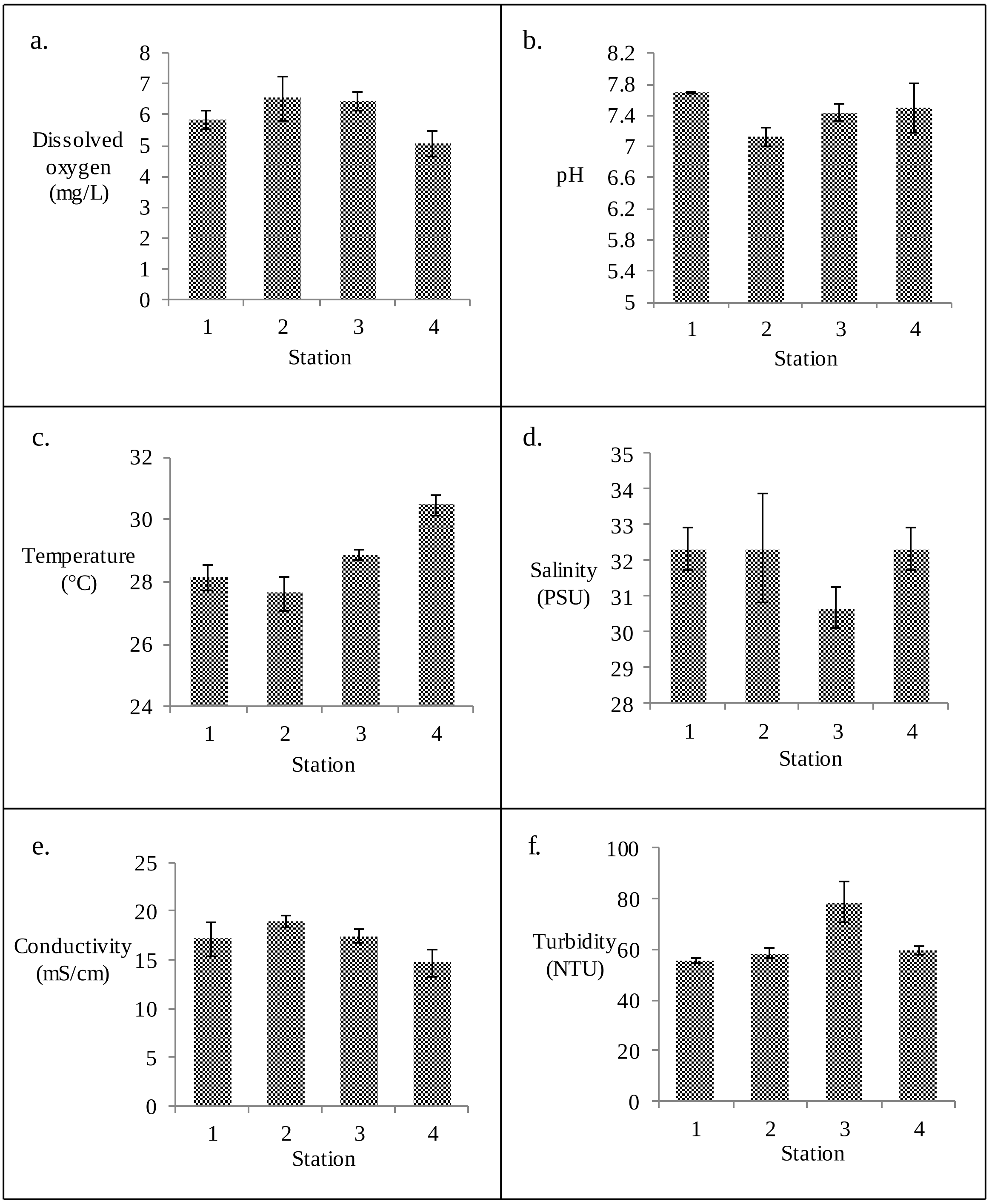


Figure 4.22: Water parameters of all the stations in Tanjung Batu beach. (**a.** dissolved oxygen, **b.** pH, **c.** temperature, **d.** salinity, **e.** conductivity, **f.** turbidity).

The mean value of salinity of the sea water at station 1, station 2, and station 4 was 32.33 PSU. Station 3 recorded a different mean value which was 30.67 PSU. There was no significant different ($p > 0.05$) in mean values among the stations. The conductivity of the water was from 14.66 mS/cm to 19.00 mS/cm. The least value was found at station 4 and the highest value was recorded at station 2. The means between stations were significantly different ($p < 0.05$). Next, water turbidity at the study area was in the range of 55.33 NTU to 78.67 NTU. The highest value was recorded at station 3 and the second highest value was recorded at station 4. The trend was then followed by station 2 and finally station 1 recorded the lowest value. The mean values between stations were significantly different ($p < 0.05$).

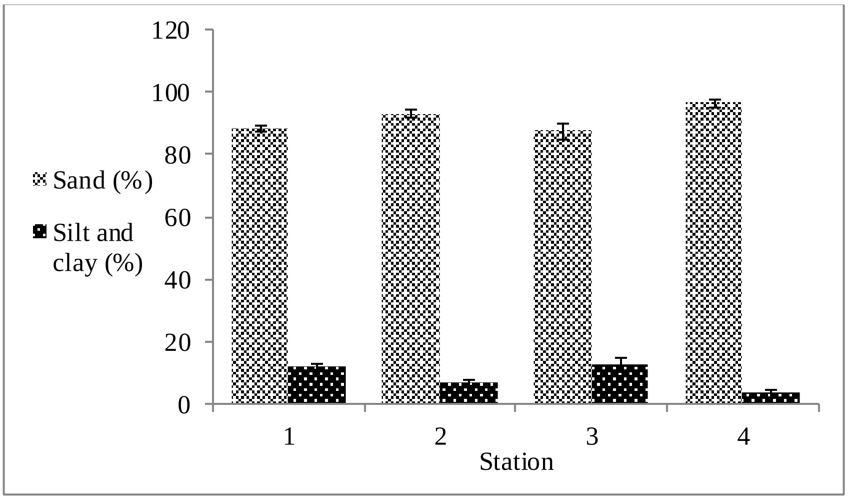


Figure 4.23: The percentage of sand, and silt and clay of all the stations in Tanjung Batu beach.

Based on Figure 4.23, the percentage of sand dominated the percentage of silt and clay at Tanjung Batu beach. The mean values between stations were significantly different ($p < 0.05$).The highest percentage of sand and lowest percentage of silt and clay was noted at station 4 with 96.55% and 3.45%, respectively. Meanwhile, the lowest percentage of sand and highest percentage of silt and clay was obtained at station 3 with 87.45% and 12.55%, respectively.

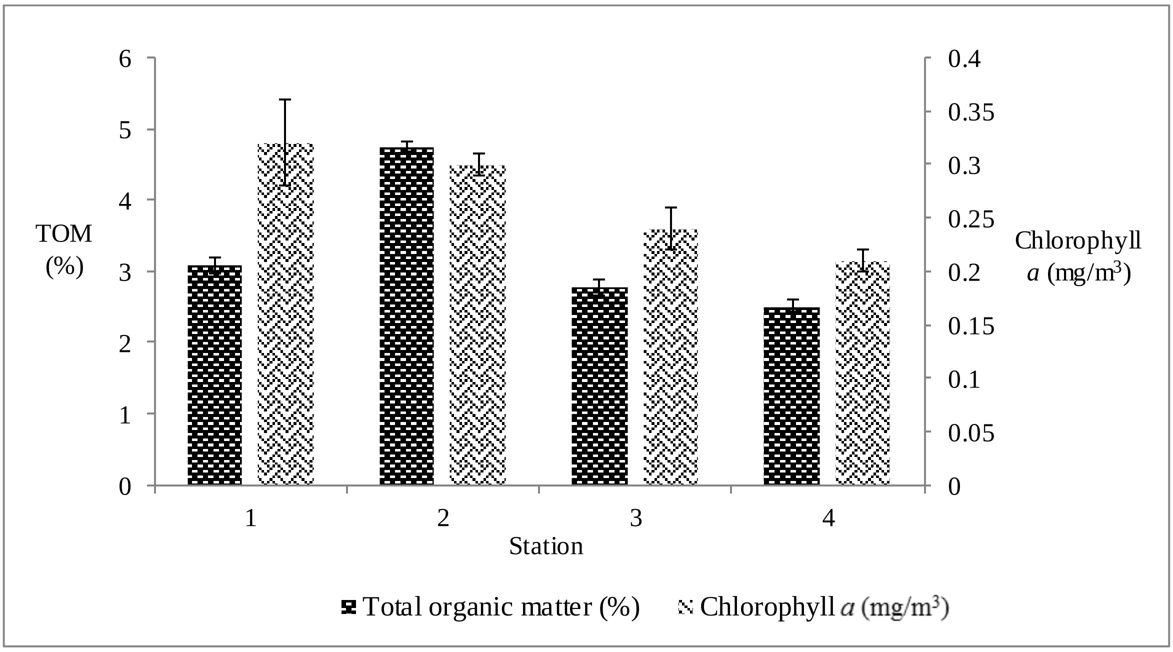


Figure 4.24: The total organic matter (%) and chlorophyll *a* content (mg/m^3) of the sediment in Tanjung Batu beach.

The total organic matter content of the sediment at Tanjung Batu beach was from 2.51% to 4.76%. The maximum value was found at station 2 and followed by station 1. The minimum value was found at station 4. The mean values between stations were significantly different ($p < 0.05$). In addition, the chlorophyll *a* content of the sediment was in the range of 0.21 mg/m^3 to 0.32 mg/m^3. The highest was recorded at station 1 while the lowest was recorded at station 4. The means among stations were significantly different ($p < 0.05$). The trend of total organic matter and chlorophyll *a* content of sediment at the study area were shown in Figure 4.24.

4.3.3.2 Abundance of Gastropod and Bivalve

In this study, a total of 22 individuals of gastropod and 11 individuals of bivalve were recorded. The total of 33 individuals belong to 13 species of gastropod and nine species of bivalve (Appendix B3). From them, seven species of gastropod and four species of bivalve were identified until species level and the rest were identified until genus level. Altogether, 22 species of gastropod and bivalve were found representing 12 families of gastropod and five families of bivalve. All the gastropod species found was from different families except *Eulima* sp. and *Melanella* sp. which were from same family. Table 4.20 and 4.21 represented the species composition of gastropod and bivalve found in Tanjung Batu beach.

Species such as *Diodora* sp., *Reishia jubilaea, Euterebra fuscolutea,* and *Trochus ochroleucus* from the class Gastropoda while, *Donax semigranosum* from the class Bivalvia were the most recorded in this study with three individuals each. They were found in at least two stations in the study area. Station 4 recorded highest number of gastropod and bivalve with eight and four individuals, respectively. Besides that, the least number of gastropod were from station 3 with only three individuals and the least number of bivalve was from station 1 and station 3 with two individuals, each. Overall, highest number of gastropod and bivalve's individual was obtained at Station 4 with a total of 12 individuals representing 36.36% of the total individuals recorded at Tanjung Batu beach.

Table 4.20: Checklist of gastropod in Tanjung Batu Beach.

Taxa/Station	1	2	3	4
Architectonicidae				
Architectonica perdix	-	-	-	+
Bursidae				
Bursa granularis	+	+	-	-
Eulimidae				
Eulima sp.	+	-	-	-
Melanella sp.	-	-	+	-
Fissurellidae				
Diodora sp.	-	+	-	+
Littorinidae				
Nodilittorina pyramidalis	-	-	-	+
Muricidae				
Reishia jubilaea	+	+	-	-
Nassariidae				
Nassarius sp. 1	+	-	-	-
Neritidae				
Nerita histrio	-	+	-	-
Rissoinidae				
Ailinzebina sp.	-	-	-	+
Siphonariidae				
Siphonaria sp.	-	-	-	+
Terebridae				
Euterebra fuscolutea	-	-	+	+
Trochidae				
Trochus ochroleucus	-	+	-	+
Total	4	5	2	7

Notes: (+) present; (-) absent

Table 4.21: Checklist of bivalve in Tanjung Batu Beach.

Taxa/Station	1	2	3	4
Arcidae				
Anadara sp. 5	-	-	-	+
Anadara sp. 6	-	-	-	+
Anadara sp. 7	-	+	-	-
Carditidae				
Cardites sp. 1	-	+	-	-
Cardites sp. 2	-	-	+	-
Donacidae				
Donax incarnatus	-	-	-	+
Donax semigranosum	+	-	+	+
Nuculanidae				
Nuculana confusa	-	+	-	-
Solecurtidae				
Azorinus scheepmakeri	+	-	-	-
Total	2	3	2	4

Notes: (+) present; (-) absent

4.3.3.3 Species Density and Percentage

From Table 4.22, the maximum species density at Tanjung Batu beach was 29.63 ind./m^2. It was recorded by *Reishia jubilaea* at station 1, *Diodora* sp. at station 2, , *Euterebra fuscolutea* at station 3, and *Trochus ochroleucus* at station 4 representing 28.6%, 22.2%, 40.0%, and 16.6% of total density in the respective stations. The minimum density value was 14.81 ind./m^2 recorded by all the species in at least one of the study station. The species density and percentage values of gastropod and bivalve in Tanjung Batu beach were shown in Table 4.7.

Table 4.22: Comparison of species density (ind./m^2) and percentage (%) of gastropod and bivalve in Tanjung Batu beach.

Taxa/Station	1	2	3	4
Gastropoda				
Architectonica perdix	-	-	-	14.81 (8.3%)
Bursa granularis	14.81 (14.3%)	14.81 (11.1%)	-	-
Eulima sp.	14.81 (14.3%)	-	-	-
Melanella sp.	-	-	14.81 (20.0%)	-
Diodora sp.	-	29.63 (22.2%)	-	14.81 (8.3%)
Nodilittorina pyramidalis	-	-	-	14.81 (8.3%)
Reishia jubilaea	29.63 (28.6%)	14.81 (11.1%)	-	-
Nassarius sp. 1	14.81 (14.3%)	-	-	-
Nerita histrio	-	14.81 (11.1%)	-	-
Ailinzebina sp.	-	-	-	14.81 (8.3%)
Siphonaria sp.	-	-	-	14.81 (8.3%)
Euterebra fuscolutea	-	-	29.63 (40.0%)	14.81 (8.3%)
Trochus ochroleucus	-	14.81 (11.1%)	-	29.63 (16.6%)
Bivalvia				
Anadara sp. 5	-	-	-	14.81 (8.3%)
Anadara sp. 6	-	-	-	14.81 (8.33%)
Anadara sp. 7	-	14.81 (11.1%)	-	-
Cardites sp. 1	-	14.81 (11.1%)	-	-
Cardites sp. 2	-	-	14.81 (20.0%)	-
Donax incarnatus	-	-	-	14.81 (8.3%)
Donax semigranosum	14.81 (14.3%)	-	14.81 (20.0%)	14.81 (8.3%)
Nuculana confusa	-	14.81 (11.1%)	-	-
Azorinus scheepmakeri	14.81 (14.3%)	-	-	-
Total	103.68	133.30	74.06	177.73

4.3.3.4 Species Number, Diversity, Evenness, Richness, and Total Density

The species diversity value of gastropod and bivalve in the study area using the Shannon Diversity index and Simpson's Reciprocal index was in the range of 1.332 to 2.369 and 3.571 to 10.286, respectively. The least value was recorded at station 3 and the most value was recorded at station 4. In addition, species evenness was from 0.961(station 3) to 0.988 (station 4). Meanwhile, species richness was in between 1.864 to 4.024. The species number was highest in the station 4 with 11 species and followed by station 2 with eight species. The lowest species number of gastropod and bivalve was obtained in station 3 with only three species. Highest total density was recorded in station 4 (177.7 ind./m^2) and the lowest was recorded in station 3 (74.06 ind./m^2). The species number, diversity, evenness, richness, and total density of gastropod and bivalve in Tanjung Batu beach were shown in Table 4.23.

Table 4.23: Species number, diversity, evenness, richness, and total density of gastropod and bivalve in Tanjung Batu beach.

Community structure/Station	1	2	3	4
Species number	6	8	4	11
Species diversity (Shannon Diversity index)	1.748	2.043	1.332	2.369
Species Diversity (Simpson's Reciprocal index)	5.444	7.364	3.571	10.286
Species evenness	0.976	0.983	0.961	0.988
Species richness	2.569	3.186	1.864	4.024
Total density (ind./m^2)	103.68	133.3	74.06	177.73

4.3.3.5 Correlation of Community Structure with Environmental Parameters

From Table 4.24, the correlation between community structure of gastropod and bivalve with environmental parameters in Tanjung Batu beach showed that they were correlated but most of the correlations were not significant ($p > 0.05$). The percentage of sand was positively strong correlated with Simpson's Reciprocal index ($r = 0.973$; $p = 0.027$). The percentage of sand was also formed a strong and positive relation with the species richness ($r = 0.966$; $p = 0.034$). Moreover, the percentage of sand showed strong and positive correlation with the total density of gastropod and bivalve ($r = 0.972$; $p = 0.028$). All these three correlations were significant ($p < 0.05$). In contrast, the percentage of silt and clay showed strong and negative correlation with Simpson's Reciprocal index, species richness, and total density of gastropod and bivalve. They were significantly correlated ($p < 0.05$). The strength of the correlation coefficient value was shown in Table C1, Appendix C.

Table 4.24: Pearson-linear correlation coefficient (r value) between community structure and environmental parameters in Tanjung Batu beach.

Parameter	Shannon Diversity index		Simpson's Reciprocal index		Pielou's index		Margalef index		Total density	
	r	p	r	p	r	p	r	p	r	p
Dissolved oxygen	-.655	.345	-.713	.287	-.581	.419	-.693	.307	-.710	.290
pH	-.176	.824	-.152	.848	-.177	.823	-.162	.838	-.154	.846
Temperature	.412	.588	.547	.453	.250	.750	.496	.504	.540	.460
Salinity	.818	.182	.720	.280	.908	.092	.760	.240	.726	.274
Conductivity	-.449	.551	-.553	.447	-.328	.672	-.514	.486	-.548	.452
Turbidity	-.710	.290	-.597	.403	-.823	.177	-.643	.357	-.604	.396
Sand	.946	.054	**.973***	**.027**	.878	.122	**.966***	**.034**	**.972***	**.028**
Silt and clay	-.946	.054	**-.973***	**.027**	-.878	.122	**-.966***	**.034**	**-.972***	**.028**
Total organic matter	.126	.874	.006	.994	.245	.755	.053	.947	.013	.987
Chlorophyll *a*	-.217	.783	-.373	.627	-.028	.972	-.313	.687	-.365	.635

*. Correlation is significant at the 0.05 level (2-tailed).

Simpson's Reciprocal index, species richness, and total density were significantly increased with increasing percentage of sand and decreasing percentage of silt and clay with R^2 value of 0.947, 0.932 and 0.945, respectively (Figure 4.25 to Figure 4.30).

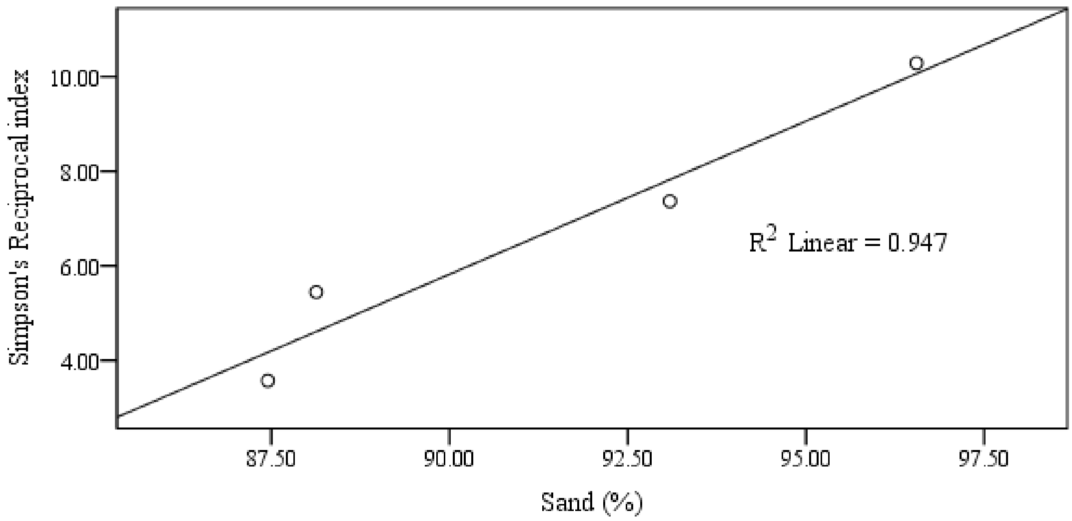


Figure 4.25: The scattered plot of linear regression between Simpson's Reciprocal index and percentage of sand.

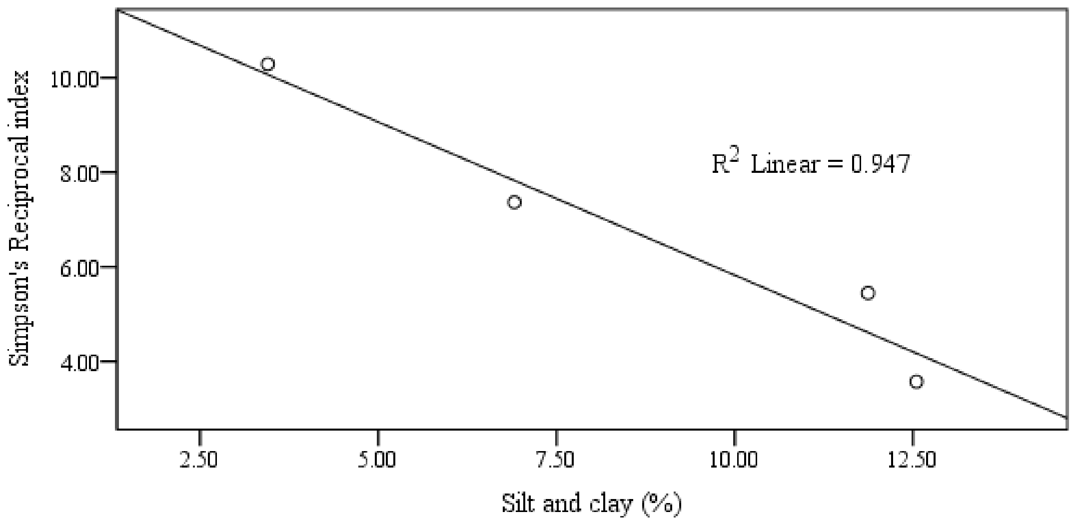


Figure 4.26: The scattered plot of linear regression between Simpson's Reciprocal index and percentage of silt and clay.

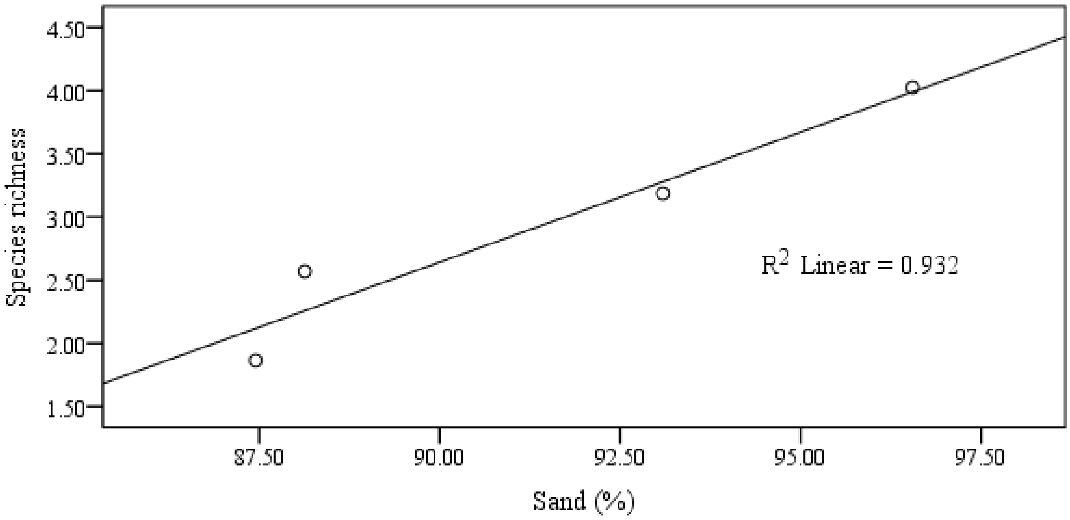


Figure 4.27: The scattered plot of linear regression between species richness and percentage of sand.

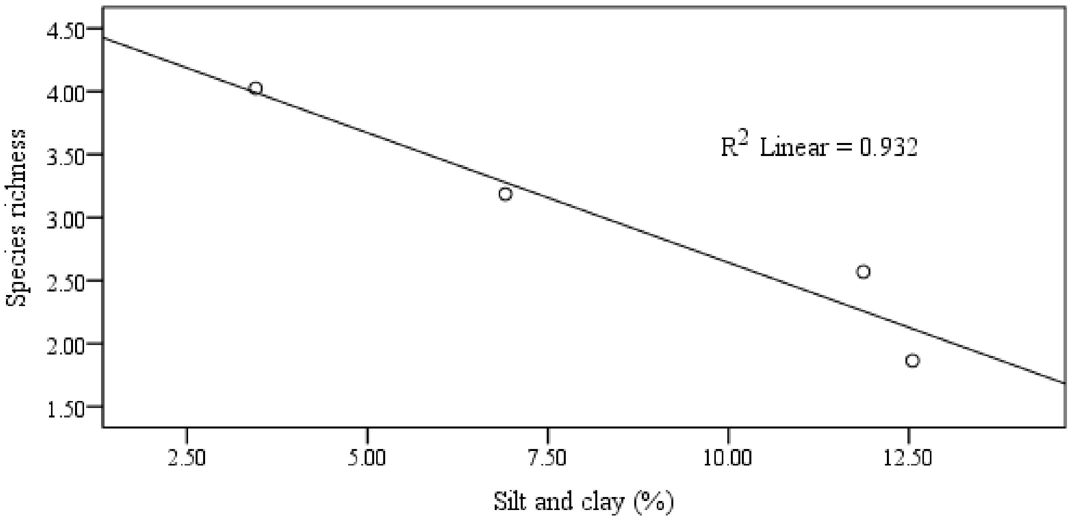


Figure 4.28: The scattered plot of linear regression between species richness and percentage of silt and clay.

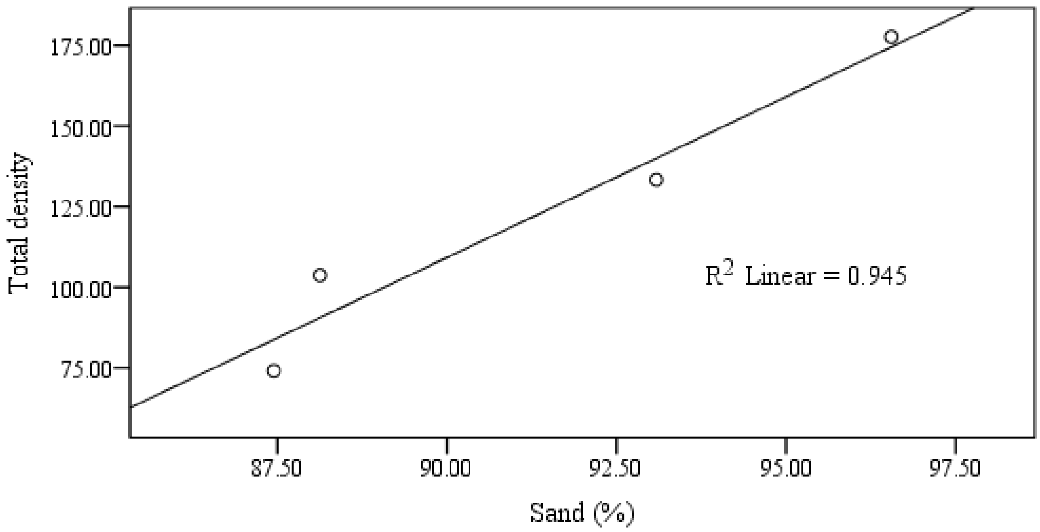


Figure 4.29: The scattered plot of linear regression between total density and percentage of sand.

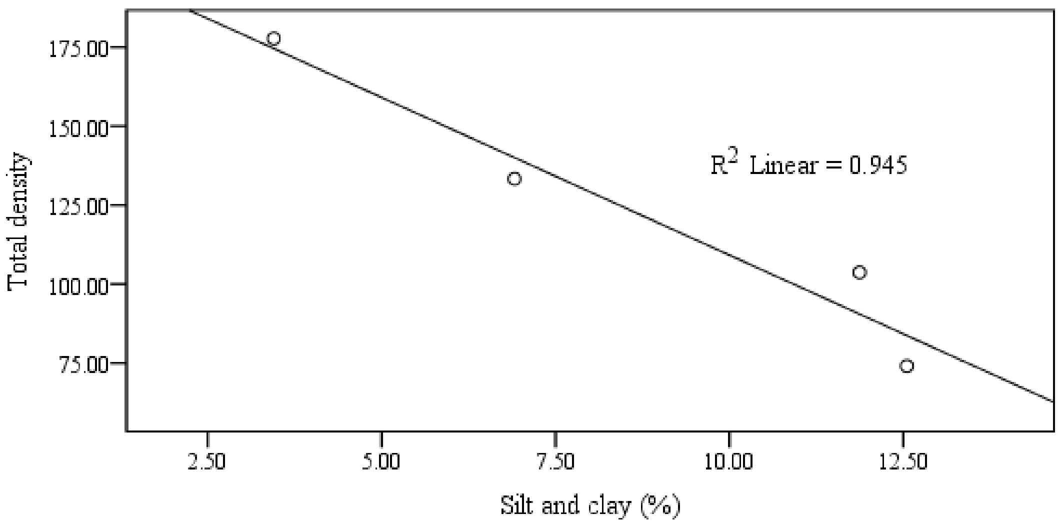


Figure 4.30: The scattered plot of linear regression between total density and percentage of silt and clay.

4.3.3.6 Principal Component Analysis (PCA)

Result of PCA showed that the variation of environmental variables is best explained by axis 1 and axis 2 with a total variance of 81.28% (Table 4.25). Axis 1 clarified 48.65% of total variance mainly loaded by dissolved oxygen, temperature, conductivity, total organic matter, and chlorophyll *a*. At the same time, axis 2 with variance of 32.64% was mainly loaded by silt and clay, sand, salinity, and turbidity. Axis 1 was positively strong correlated with dissolved oxygen, conductivity, total organic matter, and chlorophyll *a*, while negatively strong correlated with temperature. On the other hand, axis 2 was positively correlated with salinity and sand while, negatively correlated with turbidity and silt and clay. Station 1 was distinguished with the presence of dissolved oxygen, conductivity and chlorophyll *a*. High total organic matter content was the best representative of station 2. The station was also described by high salinity. Station 3 was characterised with high turbidity and the presence of silt and clay. Finally, station 4 was explained by high temperature and sand. The biplot diagram (Figure 4.31) showed the water quality parameters that best describe each of the selected stations.

Table 4.25: Summary of Principal Component Analysis (PCA) for water quality at all sampling stations in Tanjung Batu beach.

Principal Component	Eigenvalues	Total Variance (%)	Cumulative (%)
F1	4.864	48.644	48.644
F2	3.264	32.636	81.280
F3	1.872	18.720	100.000

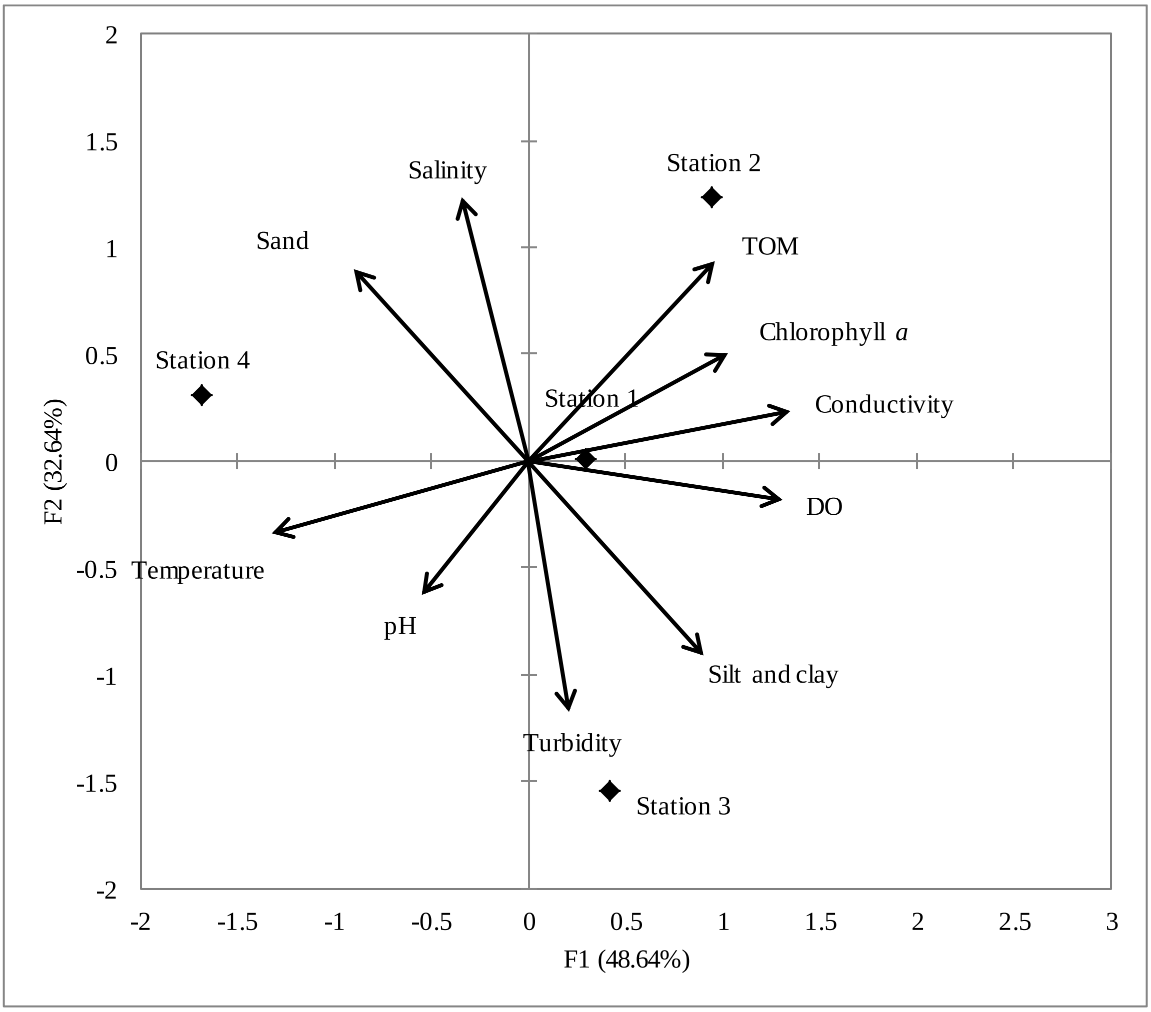


Figure 4.31: Biplot diagram showing variation of environmental parameters among all the stations in Tanjung Batu beach. Total variance explained by two axes is 81.28%.

4.3.3.7 Cluster Analysis

Classification analyses (using Bray-Curtis similarity) followed by an ordination through MDS on gastropod and bivalve's abundance data were undertaken. The dendogram produced in the cluster analysis showed that all the four sampling stations (station 1, station 2, station 3, and station 4) were divided into four separate clusters at 50% similarity threshold (Figure 4.32). The plotting in MDS ordination with 0 stress value indicates good relationship and supported the groupings formed in the cluster analysis (Figure 4.33). Cluster with more than one station can only be seen at similarity value less than 30%. Two clusters with Station

1 and station 2 in the first cluster and station 3 and station 4 in the second cluster were formed at similarity value in between 20% and 30%.

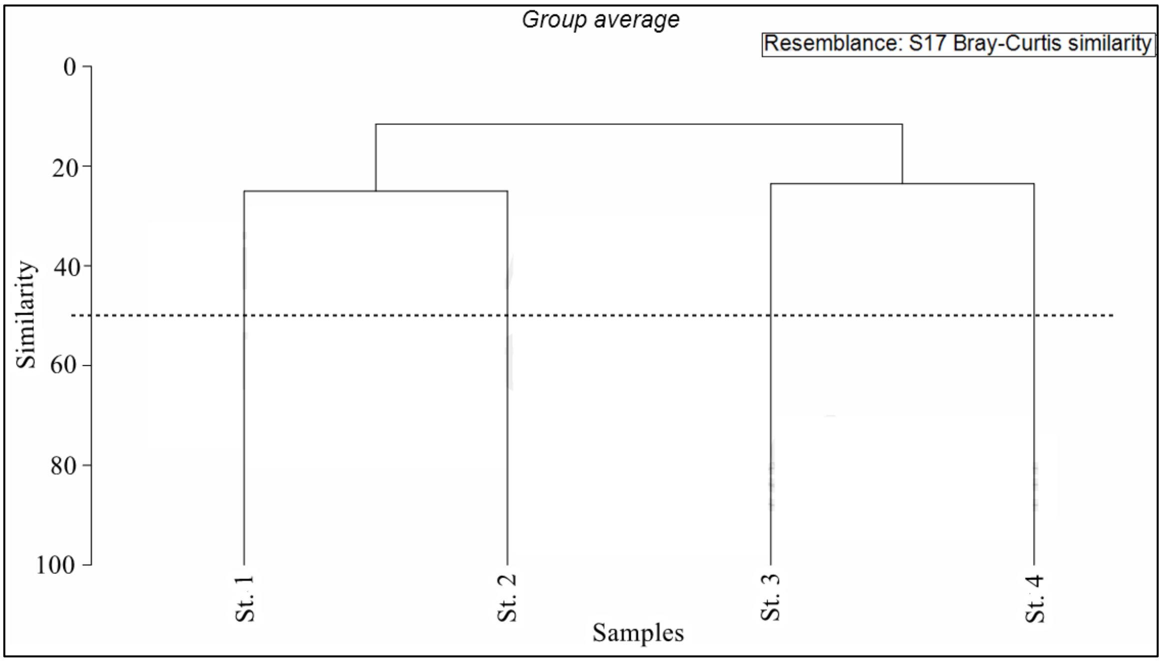


Figure 4.32: Dendogram produced in the cluster analysis showing the percentage of similarity between the intertidal stations of Tanjung Batu beach by using the gastropod and bivalve's abundance data based on Bray Curtis similarities (similarity threshold at 50%).

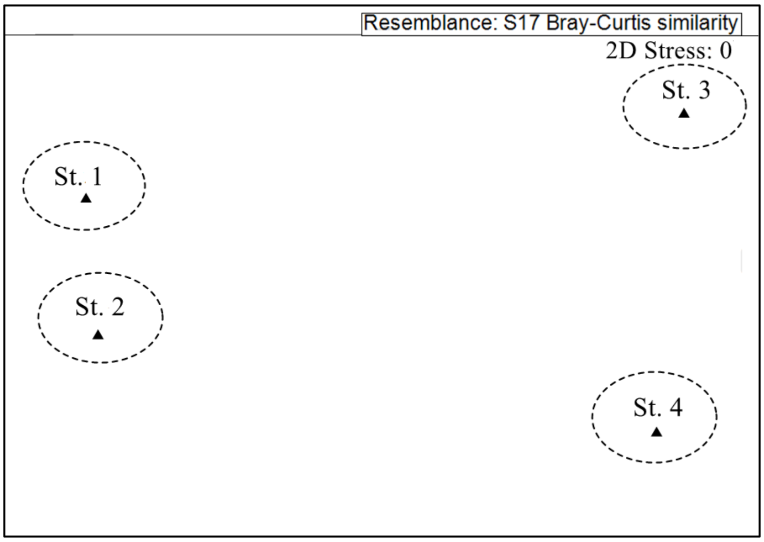


Figure 4.33: Multidimensional scaling (MDS) ordination (stress: 0) constructed based on the gastropod and bivalve's abundance in Tanjung Batu beach.

4.3.4 Tusan Beach

4.3.4.1 Environmental Parameters

Table 4.26 showed that the dissolved oxygen content in the study area was from 5.57 mg/L to 5.80 mg/L. The minimum value was recorded at station 5 whereas the maximum value was recorded at station 4. The means between stations were not significantly different ($p > 0.05$). Besides that, the pH of water was in the range of 7.10 to 7.83. The lowest value was obtained at station 5 and the highest value was observed at station 4. The values among stations were significantly different ($p < 0.05$). On the other hand, the lowest reading of temperature was noted at station 1 and the highest reading was noted at station 4 with 29.47 °C and 32.00 °C, respectively. There was no significant different ($p > 0.05$) in the mean values of temperature among the stations. The trend of water quality in the study area was shown in Figure 4.34.

Table 4.26: Mean and standard deviation of environmental parameters at all the stations in Tusan beach.

Parameter/Station	1	2	3	4	5
Dissolved oxygen (mg/L)	5.70±0.10	5.63±0.15	5.70±0.27	5.80±0.10	5.57±0.49
pH	7.69±0.08	7.53±0.15	7.59±0.26	7.83±0.15	7.10±0.27
Temperature (°C)	29.47±0.85	30.70±0.27	29.93±0.51	32.00±1.73	30.67±0.81
Salinity (PSU)	32.33±1.16	34.67±0.58	33.67±0.58	33.67±1.16	32.67±0.58
Conductivity (mS/cm)	17.12±0.37	17.88±1.02	17.07±0.91	18.20±1.09	17.13±0.21
Turbidity (NTU)	112.70±2.08	115.70±2.08	113.30±2.08	115.00±2.65	115.70±3.01
Sand (%)	94.83±1.64	96.35±1.60	100.00±0.00	99.36±0.28	95.73±1.60
Silt and clay (%)	5.17±1.64	3.65±1.60	0.00±0.00	0.64±0.28	4.27±1.60
Total organic matter (%)	2.31±0.16	2.47±0.04	2.39±0.03	1.19±0.12	1.40±0.06
Chlorophyll *a* (mg/m^3)	0.20±0.02	0.14±0.02	0.20±0.02	0.23±0.03	0.17±0.02

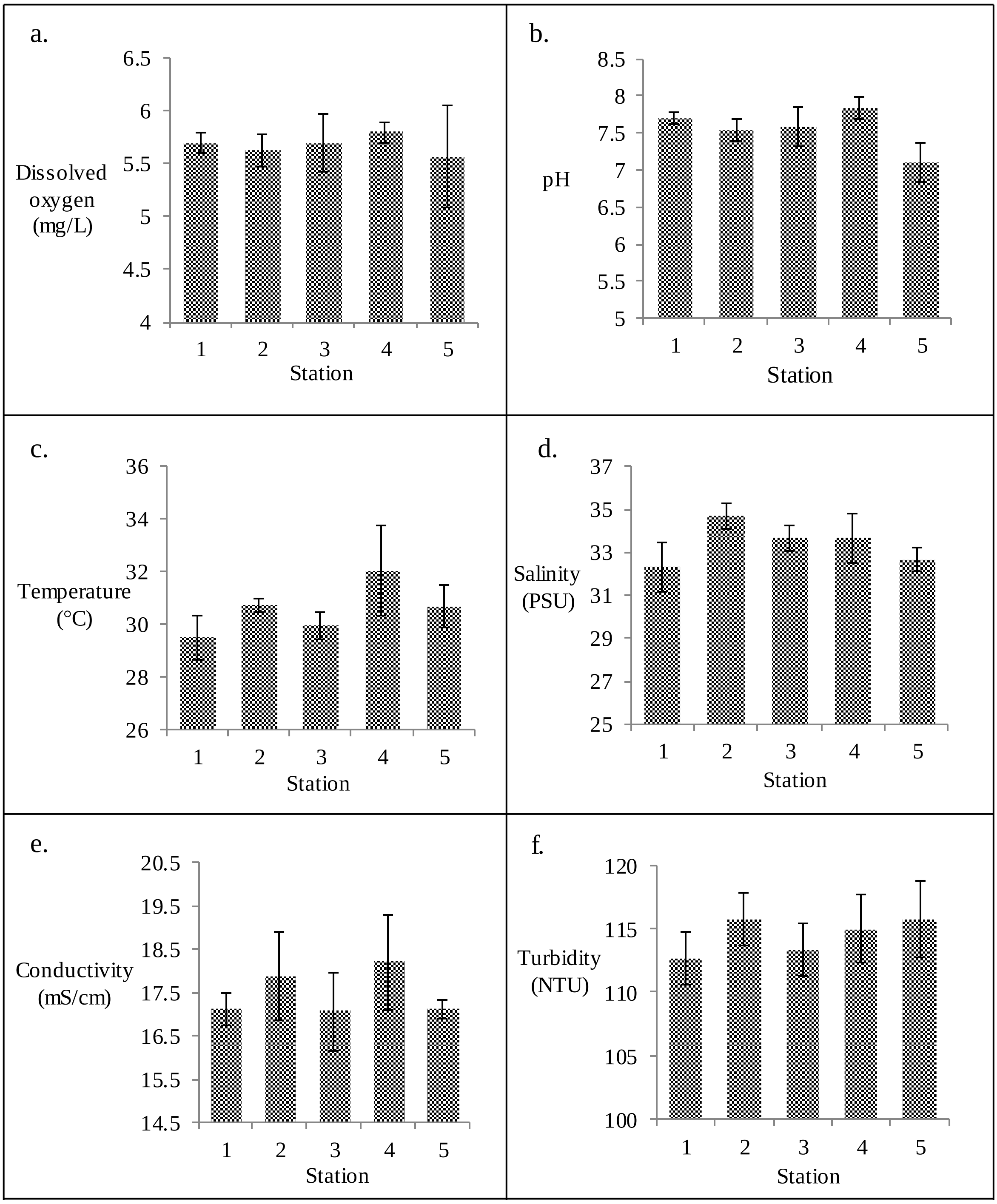


Figure 4.34: Water parameters of all the stations in Tusan beach. (**a.** dissolved oxygen, **b.** pH, **c.** temperature, **d.** salinity, **e.** conductivity, **f.** turbidity).

The salinity of water was highest at station 2 with a value of 34.67 PSU and followed by station 3 and station 4 with a mean value of 33.67 PSU, separately. The least value was 32.33 PSU which was recorded at station 1. The means between stations were significantly different ($p < 0.05$). The range of conductivity means values at the study area were from 17.07 mS/cm to 18.20 mS/cm. The maximum value was recorded at station 4 and the minimum value was determined at station 3. The mean values between stations were not significantly different ($p > 0.05$). Besides that, the mean value of turbidity was highest at station 2 and station 5 with 115.70 NTU and lowest at station 1 with 112.70 NTU. There was no significant different in the means of turbidity between stations ($p > 0.05$).

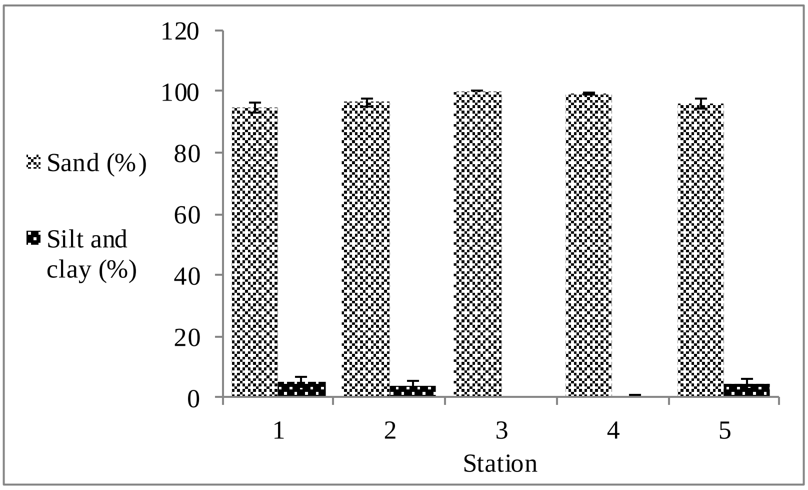


Figure 4.35: The percentage of sand, and silt and clay of all the stations in Tusan beach.

The percentage of sand was higher than the percentage of silt and clay in all the stations at Tanjung Batu beach (Figure 4.35). The highest percentage of sand and lowest percentage of silt and clay was noted at station 3 with 100% and 0%, respectively. Meanwhile, the lowest percentage of sand and highest percentage of silt and clay was obtained at station 1 with 94.83% and 5.17%, respectively. The mean values between stations were significantly different ($p < 0.05$).

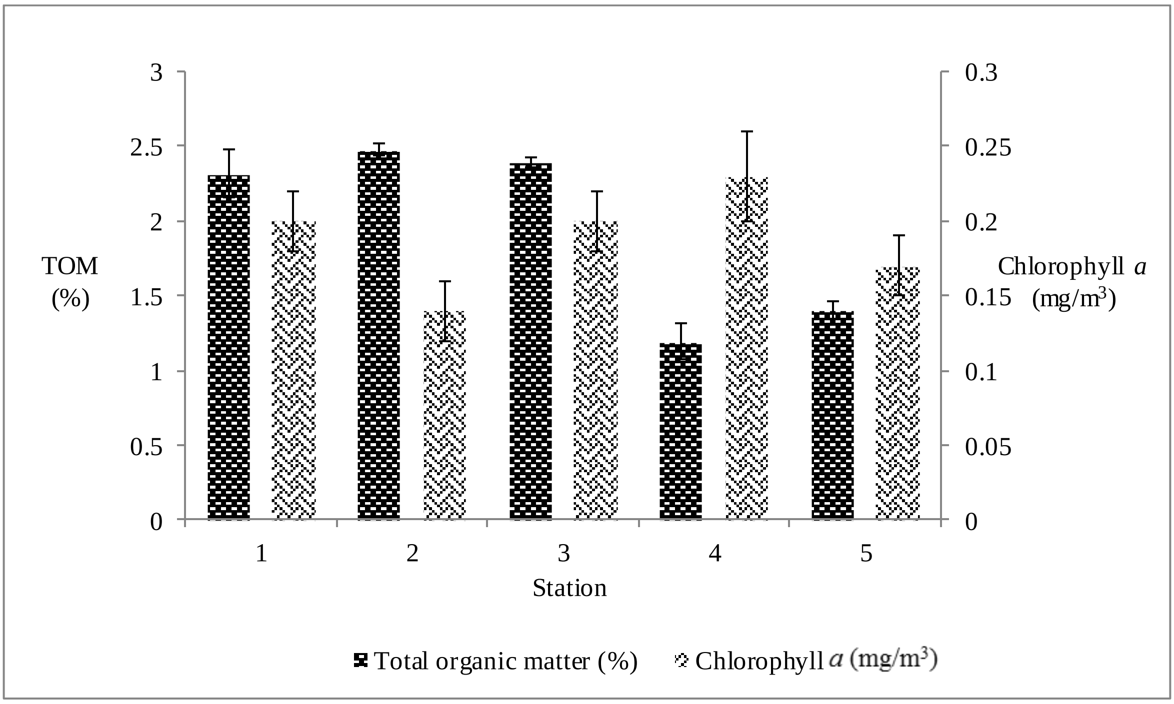


Figure 4.36: The total organic matter (%) and chlorophyll *a* content (mg/m^3) of the sediment in Tusan beach.

Based on Figure 4.36, the total organic matter content of the sediment at Tusan Batu beach was ranged from 1.19% to 2.47%. The highest value was found at station 2 and the lowest value was observed at station 4. On the other hand, the chlorophyll *a* content of the sediment was from 0.14 mg/m^3 to 0.23 mg/m^3. The maximum value was recorded at station 4 and followed by station 1 and station 3. The minimum value was recorded at station 2. The mean values of total organic matter and chlorophyll *a* content between stations were significantly different ($p < 0.05$).

4.3.4.2 Abundance of Gastropod and Bivalve

Study at Tusan beach recorded 16 individuals of gastropod and 43 individuals of bivalve with a total of 59 individuals. The gastropod recorded was from six species representing six families while, the bivalve obtained was from 11 species representing eight families (Appendix B4). From them, three species of gastropod and ten species of bivalve were identified until species level whereas, others were identified until genus level. Overall, 14 families of gastropod and bivalve were identified with a total of 17 species. Table 4.27 and 4.28 showed the species composition of gastropod and bivalve found in Tusan beach.

The most abundant species in the study area was *Megacardita turgida* from class Bivalvia with a total of 12 individuals (Appendix D). The species accounts for 27.91% from total individuals of bivalve obtained and it was found in all station except at station 5. Meanwhile, the least species found was *Turricula* sp. from class Gastropoda, and *Anadara* sp. 1, *Loxoglypta subpallida,* and *Circe scripta* from class Bivalvia. Only one individual was recorded from each of the species.

Table 4.27: Checklist of gastropod in Tusan Beach.

Taxa/Station	1	2	3	4	5
Architectonicidae *Architectonica perdix*	-	-	-	+	+
Clavatulidae *Turricula* sp.	-	-	-	+	-
Nassariidae *Nassarius* sp. 1	+	+	-	+	-
Naticidae *Tanea hilaris*	-	-	+	+	+
Turritellidae *Turritella* sp. 3	-	-	+	+	-
Xenophoridae *Onustus indicus*	-	+	-	+	-
Total	1	2	2	6	2

Notes: (+) present; (-) absent

Table 4.28: Checklist of bivalve in Tusan Beach.

Taxa/Station	1	2	3	4	5
Arcidae *Anadara* sp. 1	-	-	-	+	-
Arcticidae *Arctica islandica*	+	-	+	-	-
Carditidae *Megacardita turgida*	+	+	+	+	-
Donacidae *Donax rugosus*	+	+	+	-	+
Donax sp.	-	-	-	+	+
Donax variabilis	+	+	+	-	-
Glycymerididae *Glycymeris reevei*	+	-	-	+	-
Solecurtidae *Azorinus scheepmakeri*	-	+	-	+	-
Tellinidae *Loxoglypta subpallida*	-	-	-	+	-
Veneridae *Circe scripta*	-	-	-	+	-
Tivela mactroides	+	-	-	-	+
Total	6	4	4	7	3

Notes: (+) present; (-) absent

4.3.4.3 Species Density and Percentage

From Table 4.29, the maximum species density at Tusan beach was 74.07 ind./m^2 which was recorded by *Megacardita turgida* at station 4 and *Donax variabilis* at station 1 representing 26.3% and 35.7% of total density in the respective stations. The percentage values below the density are based on the composition of gastropod and bivalve in each station calculated from the total density by station. Besides that, the maximum density recorded at station 2 was 44.44 ind./m^2 recorded by *M. turgida* and *D. variabilis*. At station 3 and station 5, the maximum density value was only 29.63 ind./m^2. The minimum density value in this study was 14.81 ind./m^2 which was recorded by most the species in at least one of the stations. The species density and percentage values of gastropod and bivalve in Tusan Batu beach were shown in Table 4.29.

Table 4.29: Comparison of species density (ind./m^2) and percentage (%) of gastropod and bivalve in Tusan beach.

Taxa/Station	1	2	3	4	5
Gastropoda					
Architectonica perdix	-	-	-	14.81 (5.2%)	29.63 (33.3%)
Turricula sp.	-	-	-	14.81 (5.2%)	-
Nassarius sp. 1	14.81 (7.1%)	14.81 (9.1%)	-	14.81 (5.2%)	-
Tanea hilaris	-	-	29.63 (22.2%)	14.81 (5.2%)	14.81 (16.6%)
Turritella sp. 3	-	-	14.81 (11.1%)	29.63 (10.5%)	-
Onustus indicus	-	14.81 (9.1%)	-	14.81 (5.2%)	-
Bivalvia					
Anadara sp. 1	-	-	-	14.81 (5.2%)	-
Arctica islandica	14.81 (7.1%)	-	14.81 (11.1%)	-	-
Megacardita turgida	29.63 (14.3%)	44.44 (27.3%)	29.63 (22.2%)	74.07 (26.3%)	-
Donax rugosus	14.81 (7.1%)	29.63 (18.2%)	14.81 (11.1%)	-	14.81 (16.6%)
Donax sp.	-	-	-	14.81 (5.2%)	14.81 (16.6%)
Donax variabilis	74.07 (35.7%)	44.44 (27.2%)	29.63 (22.2%)	-	-
Glycymeris reevei	29.63 (14.3%)	-	-	14.81 (5.2%)	-
Azorinus scheepmakeri	-	14.81 (9.1%)	-	29.63 (10.5%)	-
Loxoglypta subpallida	-	-	-	14.81 (5.2%)	-
Circe scripta	-	-	-	14.81 (5.2%)	-
Tivela mactroides	29.63 (14.3%)	-	-	-	14.81 (16.6%)
Total	207.39	162.94	133.32	281.43	88.87

4.3.4.4 Species Number, Diversity, Evenness, and Total Density

Based on Table 4.30, the species number of gastropod and bivalve was highest at station 4 with a total of 13 species. Second highest species number was found at station 1 with a total of seven species and followed by station 2 and station 3 with six species, each. Lastly, the least species number was found at station 5 with only five species. Species richness was in the range of 2.085 (station 2) to 4.075 (station 4). Shannon Diversity index value was in the range of 1.561 to 2.375. In addition, the value of Simpson's Reciprocal index was in between 4.500 and 8.395. The highest species diversity was found at station 4 and the least was found at station 5. Besides that, the species evenness was from 0.908 to 0.970. The minimum species evenness value was observed at station 1 and the maximum value was noted at station 5. The total density of gastropod and bivalve was ranged from 88.87 ind./m^2 to 281.43 ind./m^2. The highest density value was shown by station 4 and the least value was represented by station 5.

Table 4.30: Species number, diversity, evenness, richness, and total density of gastropod and bivalve in Tusan beach.

Community parameter/Station	1	2	3	4	5
Species number	7	6	6	13	5
Species diversity (Shannon Diversity index)	1.767	1.673	1.735	2.375	1.561
Species Diversity (Simpson's Reciprocal index)	4.900	4.840	5.400	8.395	4.500
Species evenness	0.908	0.934	0.968	0.926	0.970
Species richness	2.274	2.085	2.276	4.075	2.232
Total density (ind./m^2)	207.39	162.94	133.32	281.43	88.87

4.3.4.5 Correlation of Community Structure with Environmental Parameters

Pearson correlation between community structure of gastropod and bivalve and environmental parameters showed that Shannon Diversity index was strongly correlated with the dissolved oxygen of water ($r = 0.905$; $p = 0.034$). The correlation was positive and significant at $p = 0.05$ level. Besides that, the total density was strongly correlated with the dissolved oxygen and pH of water at $r = 0.892$ and $r = 0.885$, respectively. The correlations were also positive and significant ($p < 0.05$).The other correlations among the community structure and environmental parameters were insignificant. Table 4.31 displayed the correlation coefficient between community structure of gastropod and bivalve and environmental parameters. The strength of the correlation coefficient value was shown in Table C1, Appendix C.

Table 4.31: Pearson-linear correlation coefficient (r value) between community structure and environmental parameters in Tusan beach.

Parameter	Shannon Diversity index		Simpson's Reciprocal index		Pielou's index		Margalef index		Total density	
	r	p	r	p	r	p	r	p	r	p
Dissolved oxygen	**.905***	**.034**	.867	.057	-.509	.381	.799	.105	**.892***	**.042**
pH	.753	.142	.678	.208	-.693	.194	.577	.308	**.885***	**.046**
Temperature	.703	.185	.767	.131	-.004	.995	.802	.103	.470	.424
Salinity	.157	.801	.218	.724	.085	.892	.089	.887	.111	.859
Conductivity	.726	.165	.728	.163	-.404	.500	.706	.183	.696	.192
Turbidity	-.007	.991	.075	.905	.303	.620	.140	.823	-.177	.776
Sand	.545	.343	.644	.240	.341	.574	.527	.361	.257	.676
Silt and clay	-.545	.343	-.644	.240	-.341	.574	-.527	.361	-.257	.676
Total organic matter	-.533	.356	-.584	.302	-.125	.842	-.714	.176	-.260	.673
Chlorophyll *a*	.765	.132	.748	.146	-.240	.698	.749	.145	.644	.241

*. Correlation is significant at the 0.05 level (2-tailed).

The scattered plot of linear regression in Figure 4.37 and Figure 4.38 displayed the species diversity and total density of gastropod and bivalve were significantly went up with increasing dissolved oxygen at the study area with R^2 value of 0.820 and 0.795, respectively. Besides that, the total density was also enlarged with increasing pH with R^2 value of 0.783 (Figure 4.39).

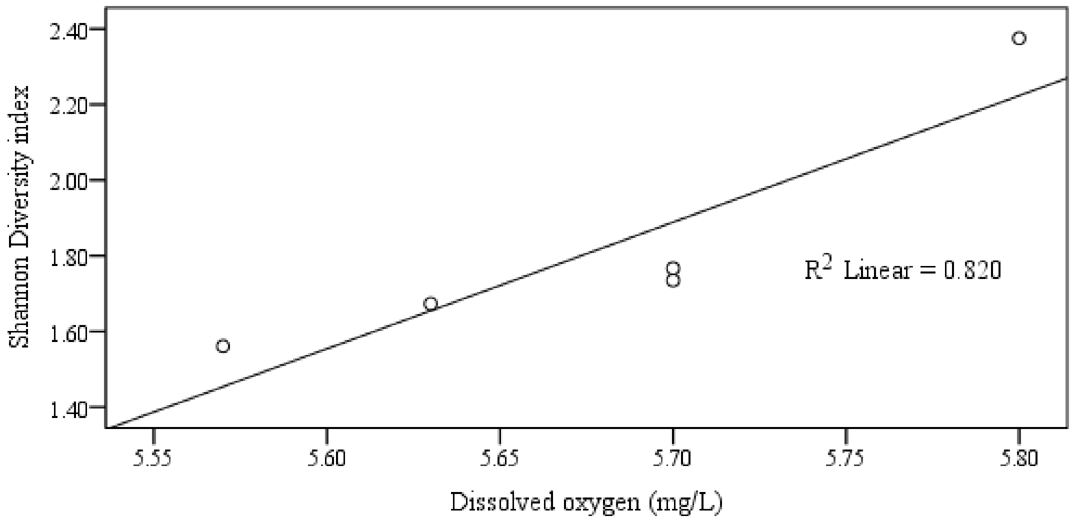


Figure 4.37: The scattered plot of linear regression between species diversity and dissolved oxygen.

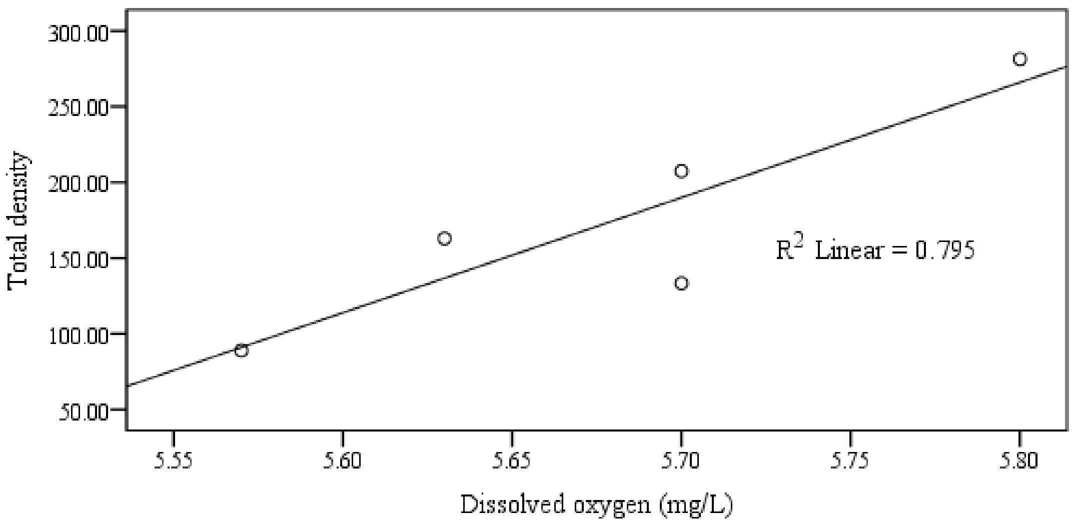


Figure 4.38: The scattered plot of linear regression between total density and dissolved oxygen.

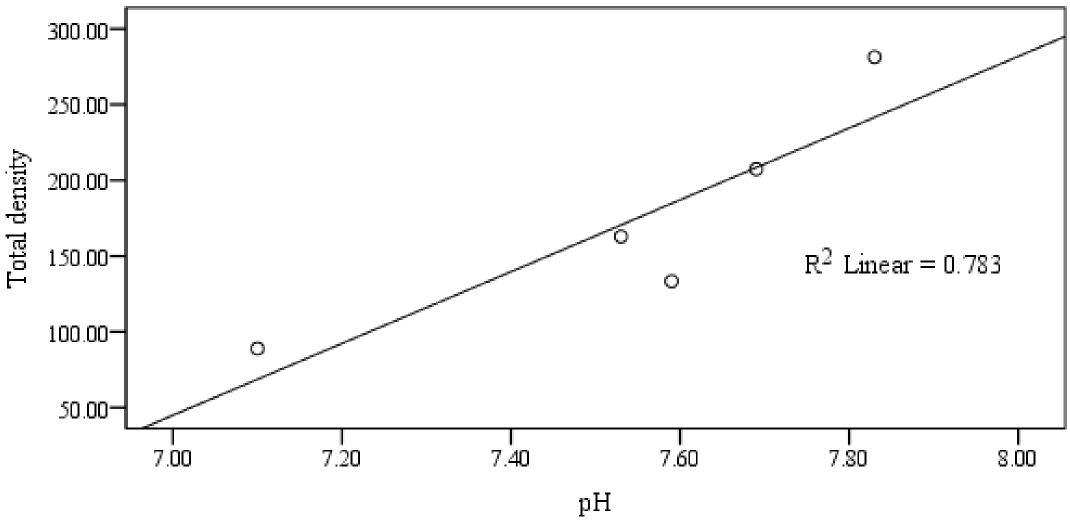


Figure 4.39: The scattered plot of linear regression between total density and pH.

4.3.4.6 Principal Component Analysis (PCA)

Result of PCA indicates that variation of environmental variables is best explained by Axis 1 and 2 (Table 4.32). The percentages of the total variances of these two principal components account for 71.95%. Axis 1 explained 43.56% of total variance and axis 2 described 28.39% of total variance. Axis 1 was positively strong correlated with DO, pH, temperature, conductivity, sand, and chlorophyll *a* while, negatively strong correlated with silt and clay. Axis 2 was positively strong correlated with turbidity.

The biplot diagram (Figure 4.40) presented the water quality parameters that best describe each of the selected stations. Station 1 was described by both chlorophyll *a*, and silt and clay. Station 2 and 5 are characterised by high turbidity and also the presence of silt and clay. At station 3, high sediment chlorophyll *a* content was present while at station 4, sand, conductivity, temperature, DO, pH and chlorophyll *a* were predominant.

Table 4.32: Summary of Principal Component Analysis (PCA) for water quality at all sampling stations in Tusan beach.

Principal Component	Eigenvalues	Total Variance (%)	Cumulative (%)
F1	4.356	43.561	43.561
F2	2.839	28.386	71.947
F3	1.722	17.223	89.170
F4	1.083	10.830	100.000

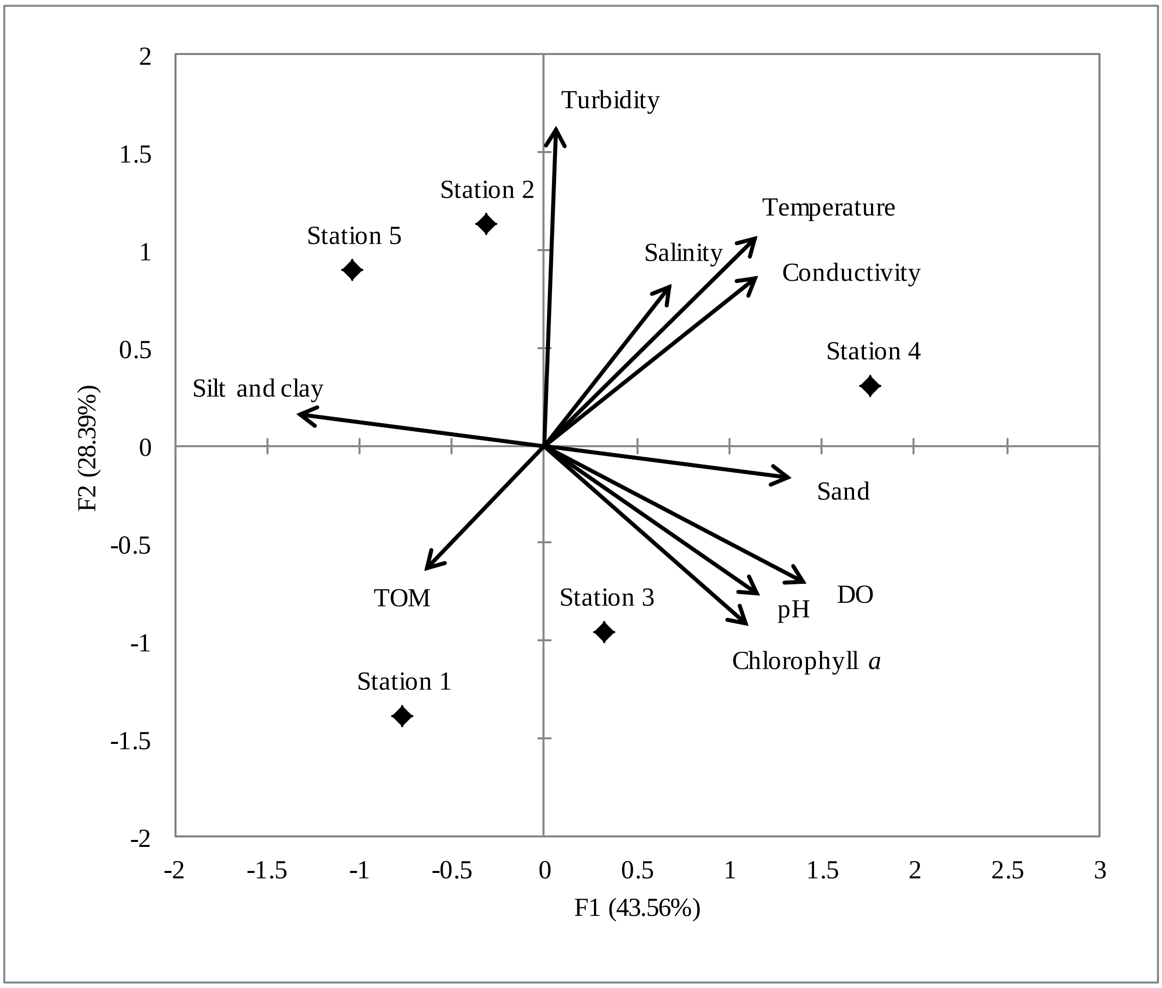


Figure 4.40: Biplot diagram showing variation of environmental parameters among all the stations in Tusan beach. Total variance explained by two axes is 71.95%.

4.3.4.7 Cluster Analysis

Classification analysis using Bray-Curtis similarity with group average linking method followed by an ordination through MDS was conducted on the gastropod and bivalve's adundance data for 17 species. The similarities between all the sampling stations in Tusan beach were displayed by the dendogram produced in the analysis (Figure 4.41). The analysis grouped the sampling stations into three clusters at 50% similarity threshold. The 2 dimensional (2D) ordination of MDS supported the assemblages formed in cluster analysis (Figure 4.42). Station 4 and station 5 detached from each other and formed two different clusters. Meanwhile, station 1, station 2 and station 3 formed a dissimilar group. The study showed that station 1 and station 2 were the most similar compared to others.

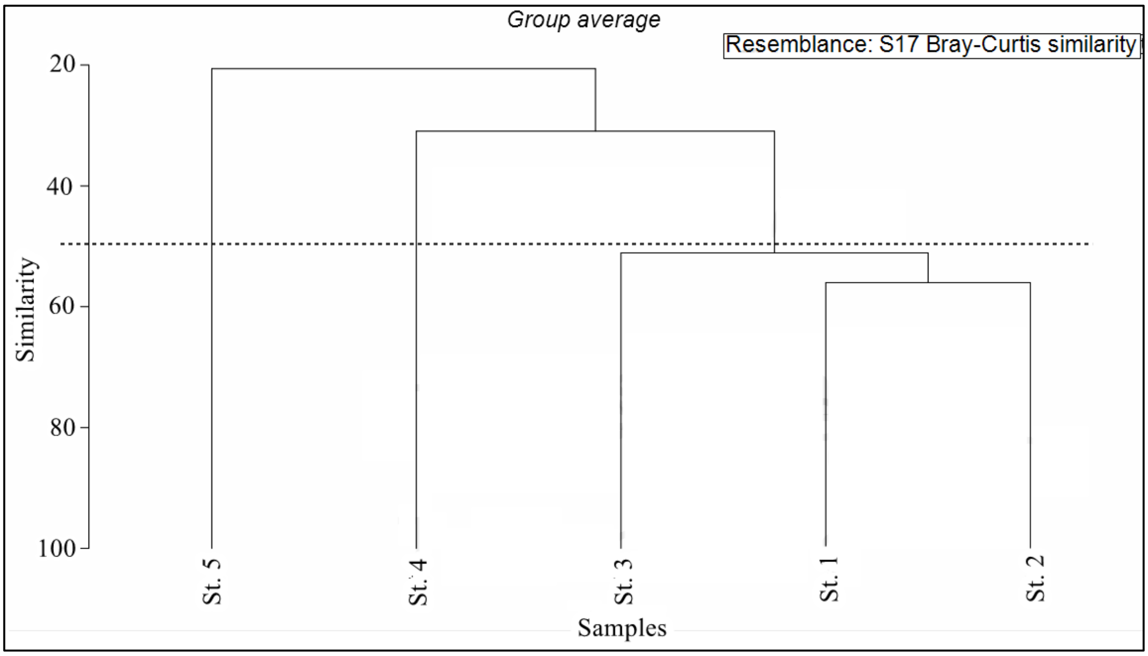


Figure 4.41: Dendogram produced in the cluster analysis showing the percentage of similarity between the intertidal stations of Tusan beach by using the gastropod and bivalve's abundance data based on Bray Curtis similarities (similarity threshold at 50%).

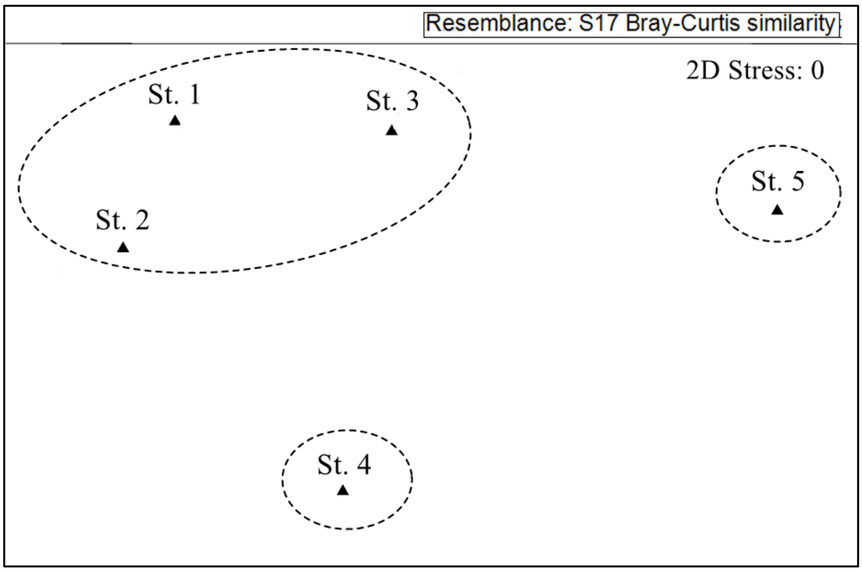


Figure 4.42: Multidimensional scaling (MDS) ordination (stress: 0) constructed based on the gastropod and bivalve's abundance in Tusan beach.

4.4 Discussion

4.4.1 Abundance of Gastropod and Bivalve

In this study, 26 species of gastropod and 19 species of bivalve were found at Pandan Beach. A total of 25 species of gastropod and 12 species of bivalve were obtained at Kabong Beach. Study at Tanjung Batu Beach recorded 13 species of gastropod and nine species of bivalve while, at Tusan Beach, six species of gastropod and 11 species of bivalve were recorded. Some of the gastropod and bivalve species were found at more than 1 study area. Overall, a total of 88 different species of gastropods (52) and bivalves (36) were obtained. Referring to previous studies at the Borneo Island, about 125 gastropod and 43 bivalve species were recorded from Darvel Bay off southeast Sabah, Borneo (Tan & Kastoro, 2004). Shabdin (2014) stated that a total of 78 species of gastropods and 31 species of bivalves were recorded in Sarawak.

Besides that, a total of 29 species of edible molluscs from 16 families, 15 bivalves and 14 gastropods were recorded from eight divisions of Sarawak (Hamli *et al.*, 2012). A research done in east coast Malaysia recorded 37 gastropod species and 26 bivalve species and from them, 27 gastropod species and 11 bivalve species have been recorded in Sarawak coastal water (Shabdin & Rosniza, 2010). Previously, 33 species of gastropods and seven species of bivalves are recorded from Sampadi Island located in Lundu, Sarawak (Shabdin *et al*., 2014b). In Bruit Island, Sarawak, a total of 624 individuals of gastropod (603) and bivalve (21) were collected within all stations, representing six families and 15 species of gastropod and one family and one species of bivalve (Azzahra, 2015).

When comparing with the other molluscan distribution study in Sarawak, the number of species obtained in this study is relevant with slightly higher value. Different number of mollusc species recorded in each study might be due the different condition of the study habitats and different sampling methods employed. This is because Sarawak intertidal habitats are characterize by sandy beach, mudflats, and rocky shores. Mostly, different species can be seen to dominate dissimilar habitat by adapting to the environment they lives in. Furthermore, sampling of mollusc have many method such as, grab sampler, dredges, box-corers, hand nets (Tagliapietra & Sigovini, 2010). For example, Shabdin *et al*. (2014b) and Azzahra (2015) used line transect method using quadrate. Different methods will have different sampling efficiency and thus will affect the results.

The total number of species obtained in this study is also considered high because only a small area was covered in each location with less habitat diversity. The sampling period was also short. High energy habitats, such as sandy areas supported a high abundance of molluscs (Mustaffa *et al*., 2013). It is believed that the gastropod and bivalve live in the area are not disturbed by the people from the surrounding mainland area. Furthermore, it seems that seasonal pattern in the Southeast Asia such as monsoonal rainfall provide nutrients enriched environment for these filter feeder organisms which eventually help to increase the number of mollusc diversity in this area (Hamli *et al.*, 2012).

All locations show the highest species number of gastropods than bivalves except at Tusan Beach, where the total species number of bivalves was higher than that of gastropods. Previous mollusc's studies in Sarawak also revealed a lower availability of bivalves compared to gastropods. The number of bivalve species is found to be low because this study only covers the intertidal zone where the organisms subject to exposure as the tide drops. Since suspension-feeding is a common method of food collection for bivalve, they need to be submerged in water almost all the times for filtering the food from it. The occurrence of suspension feeders is restricted to the lower intertidal because suspension feeders can only feed at high tide, they cannot exist where submergence is short and are therefore negatively correlated with the intertidal gradient from high to low tide levels (Dittmann, 2000). This is because suspension-feeding bivalves require sufficient water motion to bring in new supplies of suspended food and take away waste. Therefore, at the land-sea interface, tides have the potential to produce major effects on system dominated by bivalves (Dame, 2012). Gosling (2004) stated that the animals in the intertidal area of the shore have to cope with being out of water at regular intervals.

In addition, exposure to wave action is another factor that influences bivalve distribution and abundance as specified by Gosling (2004). High wave energy at Sarawak intertidal zone may be one of the subjects for the low bivalve composition found in this study. Generally, benthic molluscs are sedentary organisms and able to respond to any physiochemical disturbance in their habitat. It has been hypothesized that disturbances, such as wind stress, that decrease the stability of the sediment, result in assemblages that are dominated by deposit feeders and in which filter feeders have proportionally small abundances (Bishop, 2006). This is because turbidity from wave actions and sediment changes might affect benthic molluscs' population (Mustaffa *et al.,* 2013). For instance, high wave energy which increases the water turbidity will affect the feeding mechanism of suspension feeders. Gastropods with a variety of feeding methods can still dominate the high wave environment.

Furthermore, high numbers of gastropod species are found because they are the most diverse within the phylum Mollusca representing more than half of them. (Gosling, 2004; Ponder *et al.,* 2002; Zamprogno *et al.,* 2013). Moreover, gastropod was highest in this study because of their own lifestyle where food can be grazed on the surface of rocks and sediments even though the areas are not covered by the seawater at all times. Besides that, gastropods are more active compared to bivalves (Irma & Sofyatuddin, 2012). They can move up and down following the tides whereas, all bivalves are nearly sedentary. Due to mobile characteristics of gastropods, this probably caused their high abundance and distribution.

In this study, the highest species number of gastropod and bivalve was found at Pandan beach, where the highest number of sampling stations selected. More stations were chosen at Pandan beach because the long intertidal habitat with easily assessable environment condition favors the sampling. Rationally, the difference in the number of sampling stations played an important role in the species obtained. When the sampling covered large area with more stations that others, the probabilities to yield more species is high. The lowest species number was recorded at Tusan beach. When comparing the habitat between Pandan beach and Tusan beach, even though both the locations are with sandy and rocky shores, Tusan beach with its natural rock layers on the cliff sides have boulder formations along the beach. Rock pools on Sarawak's rocky shore support minimal flora and fauna due to a high fluctuation of salinity, temperature and dissolved oxygen (Shabdin, 2014). Also, in general, species density, diversity and number of species increase as exposure to wave action declines (Ong & Krishnan, 1995).

Thus, these factors can also be the reasons for the difference in the species abundance between the study areas.

In this study, Bivalvia that commonly found was *Donax* sp. from family Donacidae in Pandan beach, Kabong beach, and Tusan beach. The highest abundance was recorded in Kabong beach with a total density of 340.74 ind./m^2. On the other hand, gastropod species that was found in all the location is *Architectonica perdix* from family Architectonicidae but its abundance was very low with only 29.63 ind./m^2 as a maximum reading. Species from genus *Nassarius* and *Turritella* were also commonly found. Pictures of *Donax* sp. and *A. perdix* are shown in Appendix D.

Shabdin & Rosniza (2010) have recorded the presence of all these species in Sarawak coastal water. Wong & Arshad (2011) also stated that they were found in Malaysia before this. They live on sandy bottoms and widely distributed in the intertidal habitat. Besides that, *A. perdix* and *Nassarius* sp. were recorded during a research conducted in the northern Beibu Gulf of China (Yan *et al,* 2006). *Nassarius* species is known to be the most abundant at the intertidal zone (Gondal *et al.*, 2012). Moreover, one of the common snails of the intertidal areas in Mersing, Johor is the mud snail from the family Nassaridae (Cob *et al.,* 2012). Furthermore, species from genus *Nassarius* accounts for 15.27% of total gastropod found in the study conducted at Merambong Shoal, Johor Straits, Malaysia (Mustaffa *et al.*, 2013).

Generally, all locations recorded different dominant species of gastropod and bivalve. The distribution pattern of gastropod and bivalves at the intertidal of Sarawak was varied from place to place. A study at Tamil Nadu coast shows that temporal and spatial changes in bivalves and gastropods population and distribution pattern seems to be fully governed by the physico-chemical and hydrobiological characteristics of the environment (Thilagavathi *et al.,* 2013). Intertidal fauna at the study area have to cope with harsh environmental conditions marked by high salinity, increased evaporation, wide seasonal temperature fluctuations, and different degrees of tidal amplitudes. The wide spatial difference between the study area with different physical and biological characters were the major aspect for the differences in species obtained between locations.

4.4.2 Species Density of Gastropod and Bivalve

4.4.2.1 Pandan Beach

The total density of gastropod and bivalve was ranged from 340.71 ind./m^2 to 1451.80 ind./m^2. The most total density value was calculated at station 1 where *Anadara granosa* seems to be the most dominant with 237.04 ind./m^2. An assessment of community composition of the dominant species have been carried out in two intertidal areas of Malaysian mudflat and the outcome revealed bivalve mollusc *A. granosa* was dominated the overall composition (Broom, 1982). Highest density of this species might due to higher availability of food, stable environment, and less competition among species.

However, highest density of gastropod and bivalve in Pandan beach was shown by *Turritella cingulifera* and *A. granosa* at station 5 with the density of 459.26 ind./m^2 and 429.63 ind./m^2, respectively. At station 1 and station 3, the highest density was recorded by *T. cingulifera* whereas, the most density value at station 2, station 4, station 6, and station 7 was recorded by *A. granosa*. Bivalve molluscs in the family Arcidae are of considerable importance especially in the Indo-Pacific region. However, probably the most important species in this family, in terms of quantity landed annually, is *Anadara granosa* (Broom, 1983). This species was commonly found during a research conducted on edible mollusc in Kuching area (Hamli *et al.*, 2012). *T. cingulifera* also have been documented in Malaysia in previous studies. *T. cingulifera* mostly can be discovered at sandy beaches and rocky shores (Sanpanich & Duangdee, 2013). In a mollusc distribution study involving three sampling stations at Merambong Shoal, Johor Straits, *Turritella* sp. was observed at two stations (Mustaffa *et al.*, 2013). Its present was also recorded at east coast of the Gulf of Thailand (Sanpanich & Duangdee, 2013).

4.4.2.2. Kabong Beach

The total density of gastropod and bivalve was ranged from 148.12 ind./m^2 to 948.07 ind./m^2. The most density value was contributed by station 1 and the least value was represented by station 4. Even so, the environmental parameters between these two stations are very similar. In suggestion, the least density at station 4 occured because of human disturbance during sampling as station 4 was sampled at last. Gastropods with its mobility characters tend to escape when they detect such disturbances.

The species density of gastropod and bivalve at Kabong beach was in the range of 14.81 ind/m^2 to 207.41 ind./m^2. Highest density was shown by *Donax* sp. and *D. variabilis.* The most density value at station 1, station 2 and station 3 was recorded by *Donax* species. In contrast, at station 4, *Turritella* species was noted to be the most. The family Donacidae is a large family of about 100 recognised species found worldwide. These clams generally live shallowly-buried just under the surface of wave-swept parts of beaches in the intertidal zone (Tan & Martyn, 2013). Cob *et al.* (2012) stated Morris & Purchon (1981) in their extensive research on Malaysian bivalves, documented seven species of Donacidae in Malaysian coastal waters. Besides that, *Donax* species was recorded in a study within the intertidal of Teluk Penyabong and Teluk Gorek, Mersing, Johor, Malaysia (Cob *et al.,* 2012). In Singapore, *Donax* species are abundant in some places where they occur (Tan & Martyn, 2013).

4.4.2.3 Tanjung Batu Beach

Highest total density at Tanjung Batu beach was recorded in station 4 (177.7 ind./m^2) and the lowest was recorded in station 3 (74.06 ind./m^2). High salinity and less turbidity value at station 4 compared to station 3 was expected to be one of the cause. In fact, variation in water parameters such as salinity, temperature, and turbidity in the water-sediment interface are very important in structuring the benthic community (Fletcher *et al*., 2011).

The maximum species density was 29.63 ind./m^2. It was recorded by *Reishia jubilaea* at station 1, *Diodora* sp. at station 2, *Euterebra fuscolutea* at station 3, and *Trochus ochroleucus* at station 4. However, the density value shows that their abundances are low with only few individuals. *R. jubilaea* from the family Muricidae is dominant on tropical rocky seashores primarily in the intertidal and shallow subtidal zones and plays an important ecological role in the structuring of littoral communities. Genus *Reishia* has often been confused with *Thais* but they are best recognized as different genera (Claremont *et al*., 2013). The species from this family is of worldwide, predominantly tropical distribution, and many species are common and easily obtainable; and thus they are often used in evolutionary and ecological studies (Claremont *et al*., 2013). Species from genus *Diodora* usually distributed at sandy habitats (Beasley *et al*., 2005). Therefore, sandy beach at Tanjung Batu beach promotes the survival of this species. Before this, *Diodora* sp. was found at intertidal zone of Ajuruteua, Brazil (Beasley *et al*., 2005).

E. fuscolutea from the family Terebridae has been recorded in Philippines. The Terebridae is a diverse family of medium to large-sized marine gastropods distributed throughout most tropical and subtropical oceans (Castelin *et al*., 2012). Ramakrishna *et al*. (2010) stated that *Trochus* live chiefly on bottom deposits and fresh algal vegetation. It inhabits the intertidal and shallow subtidal zones and it is abundant on open coasts exposed to rough weather. These species found in the tropical and subtropical waters (Ramakrishna *et al.*, 2010). *Diodora* sp., *Throchus* sp. and *Reishia* sp. were observed at sandy beaches and rocky shores in east coast of the Gulf of Thailand (Sanpanich & Duangdee, 2013).

4.4.2.4 Tusan Beach

The total density of gastropod and bivalve at Tusan beach was ranged from 88.87 ind./m^2 to 281.43 ind./m^2. The highest value was recorded at station 4 whereas, the lowest was found at station 5. Station 4 was observed with highest species number and species diversity which eventually increase the total organisms obtained in that station. In contrast, the minimum species number and species diversity were noted in station 5 with minimum number of individuals. The study showed that the value of total density is related with the species number and species diversity in certain cases.

Donax variabilis, a commonly found intertidal species, recorded a density value of 74.07 ind./m^2 at station 1. Many intertidal study recorded the present of *Donax* species in both east and west Malaysia. In addition, *Donax* sp. was frequently found in the sandy beaches of the Gulf of Tehuantepec, Mexico (Jara *et al.*, 2009) and Pacific coast of Colombia (Fletcher *et al.*, 2011). Furthermore, macrobenthic study at the Kalbadevi Bay along the west coast of India has been recorded 25-50 ind./m^2 of *Donax* species (Sivadas *et al.*, 2013).

4.4.3 Diversity of Gastropod and Bivalve

Highest Shannon Diversity index value in Pandan beach was recorded at station 3 (2.703) while, the lowest was obtained at station 2 (1.763). In Kabong beach, the value of species diversity was in the range of 2.025 to 2.853. The highest was found at station 1 and the least was found at station 4. Besides that, the species diversity value at Tanjung Batu was in the range of 1.332 to 2.369. The least value was recorded at station 3 and the most value was recorded at station 4. Lastly, at Tusan beach, species diversity was in the range of 1.561 to 2.375. The highest species diversity was found at station 4 and the least was found at station 5.

Hill (1973) stated when the size of the sample is increased, the diversity, will also increase almost without limit. It was noticed that stations with high species diversity in this study was also having a high species number. For example, the highest species number found in this intertidal study was in station 1 of Kabong beach and the highest species diversity was also discovered there. Therefore, an area with greater diversity yield more species, and there would be a higher proportion of rare varieties (Hurlbert, 1971). Low number of species recorded might be one of the reasons for low diversity since species number can influence the species diversity (Shabdin *et al.*, 2014a). The competitions among species and the availability of food are also assumed to influence the low species diversity in the area.

According to the relationship between the diversity value and ecological level (Appendix C, Table C2); Pandan beach, Tanjung Batu beach, and Tusan beach are in poor to moderate ecosystem status, while Kabong beach is in moderate status. Yet, the study shows that species diversity only slightly varies among all the station in a study area and nearly similar between locations. The results of the study in the coasts of the Kathiawar Peninsula, India indicated that there were no spatial variations in the species diversity of major macrofaunal phyla. This is possibly due to the fact that the shores studied are situated along the same continuous coastline and share common coast characteristics (Bhadja *et al.*, 2014).

Since all the stations within a location are near to each other, it is believed that they shared the same intertidal characteristics.

A study on the community structure of gastropod and bivalve conducted by Azzahra (2015) in Bruit Island, Sarawak, recorded the highest diversity index value of 1.69 at the intertidal sandy beach habitat. Further, the diversity values range between 1.12 and 1.78 at Sampadi Island, Lundu (Shabdin *et al.,* 2014b). In this study, even though the diversity values are not representing good ecosystem status, the maximum diversity value in this study is greater than the maximum diversity value obtained at Bruit Island and Sampadi Island of Sarawak. Typically, the distribution and aggregations pattern of marine gastropod and bivalve were determined by the physical and biological factor such as water movement, competition, seasonality, reproduction and recruitment. Additionally, environmental factors such as the degree of exposure to wave action, duration of exposure and the immersion by seawater and the sea temperatures also possibly influenced the species diversity (Shabdin *et al.,* 2014b). Hence, the diversity pattern of gastropod and bivalve, and the ecosystem status at all the places can be related to dissimilarity in physical and biological factor.

Species evenness at Pandan beach and Kabong beach was ranged from 0.701 (station 5) to 0.876 (station 6) and 0.854 (station 3) to 0.974 (station 4), respectively. In Tanjung Batu beach, species evenness was from 0.961 (station 3) to 0.988 (station 4) whereas, in Tusan beach, the species evenness was from 0.908 (station 1) to 0.970 (station 5). Since, species evenness reflects the distribution of abundance of the species (Hill, 1973; Hurlbert, 1971), in this intertidal study, all the stations with high evenness value shows that the individuals of gastropod and bivalve in each species are evenly distributed without many differences in the number of individuals between species compared with other stations.

For species richness, the maximum value in Pandan beach was 5.200 recorded at station 3 and the minimum value was 2.749 obtained at station 2. At Kabong beach, species richness was in the range of 3.040 to 6.011 where the highest was recorded at station 1 and the lowest was recorded at station 4. Meanwhile, species richness at Tanjung Batu beach was in between 1.864 (station 3) to 4.024 (station 4). Finally, the reading for species richness at Tusan beach was in the range of 2.085 (station 2) to 4.075 (station 4). Low species number maybe because of low species diversity in the respective station as species diversity and species richness are interconnected.

Besides that, higher species richness in this study reflected higher species number obtained in the corresponding stations. This is because the species richness index calculates the total number the different taxa/species found found in the area or system under investigation (Hill, 1973; Hurlbert, 1971; Milroy, 2015; Treuting, 2012). Furthermore, high species richness recorded at some of the study sites might be due to stable environmental factors that play an important role in faunal distribution in coasts (Bhadja *et al.*, 2014). In addition, the higher the species richness, the more it is associated with clean water conditions (Treuting, 2012). Pandan beach and Kabong beach were noted with a slightly higher value of species richness compared to the other study locations. The dissolved oxygen content values were above 6 mg/L at both the locations. High dissolved oxygen content in these places compared to others might be one of the causing factors.

4.4.4 Relationship between Community Structure and Environmental Parameters

Physico-chemical parameters are determining factors in community structure of molluscs (Bhadja *et al.*, 2014). At Pandan beach, species richness of gastropod and bivalve was strongly and positively correlated with water turbidity ($r = 0.818$; $p = 0.024$). The correlation was significant ($p < 0.05$). Alin *et al.* (1999) stated the faunal data in their molluscs study showed that species richness and density correlated negatively with turbidity. Most bivalves cannot tolerate high turbidity. As filter-feeders, sediments and organic matter prevent them from feeding. In certain case, filter feeders' filtering mechanisms may be blocked by sediment. However, high turbidity is not detrimental to all bivalves (Gosling, 2004). For example, evidence from both laboratory and field trials show that certain bivalves grow well in environments with a high sediment load. This is because they are extremely efficient in selectively rejecting sediment particles so that only a small fraction of filtered algae is lost in pseudofaeces (Gosling, 2004). The maximum species richness in this study was obtained at station 3 where the second highest turbidity value was determined. Nevertheless, the turbidity value at Pandan beach was only in between 20.36 NTU to 28.80 NTU at all the stations and the habitat is also sandy. Growth in bivalves is in fact better over sand than over mud due to excessive turbidity over muddy bottoms (Gosling, 2004).

A study done at Cincinnati Arch reported that bivalves were significantly associated with high turbidity, both in species richness and abundance (Gotshall & Miller, 2003). Bivalves were most dominant in deep subtidal, with high levels of turbidity whereas, gastropods were not significant with respect to either measure of dominance, with slightly greater species richness in turbid settings and greater abundance in cleaner ones (Gotshall & Miller, 2003). Relationship between species richness and turbidity in this study shows that they are positively related and the turbidity does not deleteriously affect the distribution of gastropod and bivalve.

Furthermore, species richness also indicated a strong correlation with the total organic matter of the sediment ($r = -0.835$; $p = 0.020$). It was negatively correlated and the correlation was significant ($p < 0.05$). Organic matter is a primary source of food for benthic organisms, and is therefore an important structuring factor in the composition of the benthic fauna (Trannum *et al.,* 2006). However, negative correlation indicates that the organic matter content at Pandan beach does not contribute to the high species richness in the study. Nevertheless, very low amount of total organic matter was found throughout the study with only 1.04% to 1.63%. This might be because all the stations recorded more than 98% of sand. In general, the proportion of organic matter is higher at the mudflat site than at the muddy sand and sandflat sites (Dittmann, 2000). The low amount of organic content in the study area is believed not to be the only factor contributing in the species richness value.

The relationship between environmental parameters and community structure of gastropod and bivalve at Kabong beach showed that sediment chlorophyll *a* content was positively correlated with the species evenness of gastropod and bivalve with the correlation coefficient value of $r = 0.956$. The correlation was significant ($p < 0.05$). Station 4 which recorded the highest species evenness, recorded the highest sediment chlorophyll *a* content (0.28 mg/m^3). The vertical distribution of benthic chlorophyll is the net effect of the opposing actions of migration to the sediment surface of motile organisms and mixing, which tends to produce a uniform distribution in the surface layer (Wazniak, 2004). Higher even distribution of species at Station 4 might be due to higher chlorophyll *a* content.

Moreover, the chlorophyll *a* content was negatively correlated with the total density of gastropod and bivalve ($r = -0.956$, $p = 0.044$). The correlation was significant at the 0.05 level. The highest total density was seen at station 1 with 0.18 mg/m^3 chlorophyll *a* content. The minimum total density was recorded at station 4 where the highest chlorophyll *a* content (0.28 mg/m^3) was obtained. However, the small difference in the cholorophyll *a* content is not assumed to determine the total density. Based on an intertidal benthic community study at the west coast of peninsular Malaysia, concentration of benthic chlorophyll *a* shows no obvious signs of a seasonal fluctuation and the seasonality of the primary consumers are not thought to be related to food abundance (Broom, 1982). Therefore, lowest species richness and species diversity at station 4 expected to contribute more in the lowest total density at the station.

Study at Tanjung Batu revealed that the percentage of sand was positively correlated with Simpson's Reciprocal index ($r = 0.973$, $p = 0.027$) , species richness ($r = 0.966$, $p = 0.034$) and the total density ($r = 0.972$, $p = 0.028$) of gastropod and bivalve. In contrast, the percentage of silt and clay showed strong negative correlation with Simpson's Reciprocal index, species richness, and total density of gastropod and bivalve. The correlations among them were significant ($p < 0.05$). The highest percentage of sand (96.55%) was found at station 4, where the highest species diversity, evenness, richness, and total density was obtained. Yet, sand was dominated silt and clay at all the stations in the study area with more than 80%. Mostly, intertidal areas of Sarawak are sandy. For instance, the intertidal area of Sampadi Island showed more than 98% sand (Shabdin *et al*., 2014a).

The most important factors determining the structure of these tropical benthic assemblages are sedimentological variables (Fletcher *et al*., 2011). The density of mollusc was positively correlated with sand (coarse, medium and fine sand), and was negatively related to very fine sand and silt at Ubatuba Bay, Southeastern Brazilian Coast (Santos and Vanin, 2014). According to Degraer *et al.* (2007), in his study, a preference for increasing median grain size was detected in the distribution of macrobenthos community structure. Furthermore, Fletcher *et al*. (2011) stated that high species richness of the submerged bottoms can be explained by the predominance of hard substrates such as rocks, gravel and coarse sand. Whereas, species richness is lower in areas with predominance of soft bottoms such as fine sand, slime, and clays (Fletcher *et al.*, 2011). However, different factors are effective on density, distribution, composition and diversity of benthic animals (Babahmadi *et al.*, 2013). Station 4 was also recorded with highest DO and chlorophyll *a* content which are very important in mollusc distribution. Besides the abiotic variables, biological factors such as predation must be important regulators of the abundance and exercise an influence on the distribution and density of species in the study area (Santos & Vanin, 2014).

Pearson correlation between community structure of gastropod and bivalve and environmental parameters in Tusan beach showed that the Shannon Diversity index and total density were strongly and positively correlated with the dissolved oxygen of water. High species diversity and total density was found at station 4 which recorded the high dissolved oxygen content. Santos & Vanin (2014) found the density of mollusc was positively correlated with dissolved oxygen at Ubatuba Bay, Southeastern Brazilian Coast. Dissolved oxygen also showed positive correlations with density at Sampadi Island (Shabdin *et al.*, 2014a). Dissolved oxygen is very important for the survival of molluscs as when the dissolved oxygen levels decrease, it becomes harder for animals to get the oxygen they need.

Besides that, the total density of gastropod and bivalve was positively correlated with the pH of water. Higher total density was obtained at station 4, where the higher pH value was observed. According to Sharma *et al.* (2013), acidic pH is unfavourable to the occurrence of molluscs and generally, pH of water provides a positive relationship with gastropods and bivalves. The natural pH levels, to which marine organisms have evolved is in the range between 7.6 and 8.4 and pH levels below those occurring naturally in the sea are deleterious to certain mollusc species. For example, growth suppression, tissue weight loss, reduced shell size, shell dissolution and suppressed feeding activity occurred at $pH < 7$ (Bamber, 1990).

Remarkably, in the presence of predators, organisms appeared unable to increase shell thickness at low pH, a physiological trait employed by the species under ambient pH conditions for improved protection. A decrease in shell resistance due to increased dissolution might increase the predation pressure on these organisms (Gazeau *et al.*, 2013). Garg *et al.* (2009) found that the values of the coefficient of correlation indicate that there is a moderate positive correlation between the gastropods and pH in Ramsagar reservoir, India. Moreover, pH is thought to exert strong influence on the abundance and structure of gastropod at Port Swettenham, Malaysia (Lee, 2008). Therefore, pH is also one of the important water parameters, which plays an important part in the distribution of gastropod and bivalve in this study.

The multivariate analysis technique was used to analysis data corresponding to a large number of variables to produce easily interpretable results (Mazlum *et al.*, 1999). In this multivariate analysis study, principal component analysis was employed to investigate the factors which caused variations in the observed water quality data at Sarawak intertidal. Axis 1 and axis 2 represented more than 60% of the total variance in all the locations, which means that the majority of the variance of the original data has been accounted for by these extracted components. The first two components in this study produced eigenvalues more than 1 showing good result. Many social scientists use the rule that eigenvalues less than 1 may be disregarded when analyzing a correlation matrix where the sum of the eigenvalues is equal to the number of variables (Mazlum *et al.,* 1999). Since most the communalities are larger than 0.7 in this case, it may be assumed that the variables were described to an acceptable level.

4.5 Conclusions

Overall, 88 taxa was recorded at Sarawak intertidal covering 20 stations. Some of the species were found in more than one study area. The species number of gastropod was higher than bivalve due to the exposure of the organisms during low tides. *Donax* sp. and *Architectonica perdix* were commonly found, while *Turitella cingulifera* and *Anadara granosa* were noted in high density. The most abundant species in Pandan beach was *A. granosa* from the class Bivalvia followed by *T. cingulifera* from the class Gastropoda. The dominant species in Kabong beach was bivalve, *Donax variabilis*. At Tanjung Batu beach, the most recorded species were *Diodora* sp., *Reishia jubilaea, Euterebra fuscolutea,* and *Trochus ochroleucus* from Gastropoda while, *Donax semigranosum* from Bivalvia. Finally, at Tusan beach, *Megacardita turgida* was the highest found species.

From the present study, it could be concluded that turbidity, pH, dissolved oxygen, total organic matter, chlorophyll *a*, and sediment particle size influenced the gastropod and bivalve assemblages in the study area. The relationship between the environmental parameters and the community structure of gastropod and bivalve confirmed the hypothesis being studied. The diversity and distribution pattern of gastropod and bivalve in this study provide baseline information on the dominant species found in Sarawak intertidal zone.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

This study recorded a total of 95 taxa and 88 taxa of gastropod and bivalve from Malaysia EEZ of Sarawak waters and Sarawak intertidal, respectively. At EEZ, *Turritella cingulifera, Diacavolinia longirostris*, *Limopsis* sp., and *Pitar citrinus* were the dominant species while, *Architectonica perdix* and *Donax* sp. species were commonly found in the intertidal study. The number of species discovered in this study is higher than previous study at Sarawak. Most of the gastropod and bivalve species found at Sarawak EEZ are different from those obtained at Sarawak intertidal with few organisms from same genera. This is because of the difference in the intertidal and sublittoral characteristics as the EEZ are away from the shoreline. More species number, species density and number of individuals of gastropod and bivalve were documented at Sarawak EEZ compared to the intertidal locations. When comparing the species diversity between the EEZ and intertidal study, both the study presented poor to moderate ecosystem status due to dominant species recorded.

The distribution of gastropod and bivalve at Sarawak EEZ was affected by the depth of water. Decrease of food input following the depth is assumed to be one of the driving forces. For the intertidal study, species richness of gastropod and bivalve was influenced by the turbidity and total organic matter at Pandan beach. Study at Kabong beach showed that chlorophyll *a* content influenced the species evenness and total density of gastropod and bivalve. At Tanjung Batu beach, species richness and total density showed positive response on sand particles compared to silt and clay. Lastly, study at Tusan beach resulted that dissolved oxygen and pH influenced the diversity and density of the organisms. Thus, environmental parameters are determining factors in the distribution of gastropod and bivalve.

The water parameters measured in this research were temperature, pH, salinity, dissolved oxygen, turbidity, and conductivity. Additional parameters such as TSS, BOD, nutrient and heavy metal analysis need to be employed in future monitoring studies to find their relationship with the species distribution of gastropod and bivalve. Furthermore, sediment characteristics such as TOM, chlorophyll *a*, percentage of sand, silt, and clay were only observed at Sarawak intertidal and not recorded at Sarawak EEZ in order to manage the time constraints. Therefore, better sampling schedules should be prepared in the next survey.

Overall, the results of this study supported the hypotheses tested. The recorded data on the community structure of the gastropods and bivalves in Sarawak intertidal and EEZ can be used as a baseline data for future management survey in the area. There are still many areas in Sarawak without any documented mollusc's distribution data. Thus, more studies regarding the gastropod and bivalve are needed to record the species occurs at Sarawak. Besides that, future studies are also necessary to observe the variation and changes of molluscan distribution over time. The biodiversity at Sarawak should be conserved and managed properly for the benefit of our ecosystem.

REFERENCES

A Guide for the Identification of the Snail Intermediate Hosts of Schistosomiasis in the Americas. (1968). Washington: Pan American Health Organization.

Abbaspour, R., Hedayatifard, M., Sabet, H.R.A., Hassanzadeh, H. & Karimi, J.M. (2013). Bioassessment of Macrobenthic Fauna of the Cheshmeh Kileh River, Northern Iran. *Journal of Agriculture and Environment Science*, *13*(6), 747-753.

Aldea, C., Olabarria, C. & Troncoso, J.S. (2008). Bathymetric Zonation and Diversity Gradient of Gastropods and Bivalves in West Antarctica from the South Shetland Islands to the Bellingshausen Sea. *Deep-Sea Research I*, *55*, 350-368.

Alin,S.R., Cohen, A.S., Bills, R., Gashagaza, M.M., Michel, E., Tiercelin, J., Marten, K., Coveliers, P., Mboko, S.K., West, K., Soreghan, M., Kimbadi, S. & Ntakimazi, G. (1999). Effects of Landscape Disturbance on Animal Communities in Lake Tanganyika, East Africa. *Conservation Biology*, *13*(5), 1017-1033.

Ashton, E.C. (1999). *Biodiversity and Community Ecology of Mangrove Plants, Molluscs and Crustaceans in Two Mangrove Forests in Peninsular Malaysia in Relation to Local Management Practices.* A thesis submitted for the degree of Doctor of Philosophy. University of York, UK.

Ashton, E.C., Macintosh, D.J. & Hogarth, P.J. (2003). Diversity and Community Ecology of Crab and Molluscan Macrofauna in the Sematan Mangrove Forest, Sarawak. *Journal of Tropical Ecology*, *19*(2), 127-142.

Azzahra, A.K. (2015). *The Gastropod and Bivalve of Bruit Island, Sarawak*. Unpublished Final Year Project Report. Faculty of Resource Science and Technology, Universiti Malaysia Sarawak.

Babahmadi, R.R., Rouzbahani, M.M. & Ghatrami, E.R. (2013). Reviews of Diversity, Density and Frequency of Macro Benthos on Karun River in both Cold and Warm Seasons, (Khuzestan Province). *Researcher, 5*(10), 68-74.

Bamber, R.N. (1990). The Effects of Acidic Seawater on Three Species of Lamellibranch Mollusc. *Jounal of Experimental Marine Biology and Ecology, 143*, 181-191.

Beasley, C.R., Fernandes, C. M., Gomes, C.P., Lima, S.M. & Tagliaro, C.H. (2005). Molluscan Diversity and Abundance among Coastal Habitats of Northern Brazil. *Ecotropica , 11*, 9-20.

Bedini, R., Canali, M.G. & Cappagli, M. (2003). Analysis of Macrobenthic Community Structure in Relation to Different Environmental Conditions in Three Harbours in the North Tyrrhenian Sea. *Mediterranean Marine Science, 4*(2), 83-97.

Bernard, F.R., Cai, Y.Y. & Morton, B. (1993). *Catalogue of the Living Marine Bivalve Molluscs of China*. Hong Kong: Hong Kong University Press.

Bhadja, P., Poriya, P. & Kundu, R. (2014). Community Structure and Distribution Pattern of Intertidal Invertebrate Macrofauna at Some Anthropogenically Influenced Coasts of Kathiawar Peninsula (India). *Advances in Ecology*, 2014, Article ID 547395. doi:org/10.1155/2014/547395

Bhattacharjee, D. (2000). Taxonomy Study for Pteropods from the Seabed Sediments in the Carlsberg Ridge and its Significance. *Journal of the Palaeontological Society of India, 40*, 79-89.

Biasi, A.M. & Ranieri, S. (2006). Seabed Morphology, Sediment Grain Size, and Microbenthic Communities in a Fished Area and an Area Unaffected By Fishing in the Central Adriatic (Italy). *Acta Adriatica, 47*(2), 183-193.

Bishop, M.J. (2006). A posteriori Evaluation of Strategies of Management: The Effectiveness of No-Wash Zones in Minimizing the Impacts of Boat-Wash on Macrobenthic Infauna. *Environmental Management*, *34*(1), 140-149.

Boonyapiwat, S. (1997). Distribution, Abundance and Species Composition of Phytoplankton in the South China Sea, Area I: Gulf of Thailand and East Coast of Peninsular Malaysia. Proceedings of the SEAFDEC First Technical Seminar on Fishery Resources, Bangkok, Thailand, 111-133**.**

Brandt, A., Linse, K. & Schuller, M. (2009). Bathymetric Distribution Patterns of Southern Ocean Macrofaunal Taxa: Bivalvia, Gastropoda, Isopoda and Polychaeta. *Deep-Sea Research I, 56*, 2013-2025.

Broom, M.J. (1982). Structure and Seasonality in a Malaysian Mudflat Community. *Estuarine, Coastal and Shelf Science*, *15*, 135-150.

Broom, M.J. (1983). Gonad Development and Spawning in *Anadara granosa* (Bivalvia: Arcidae) *Aquaculture, 30*, 211-219.

Cannicci, S., Burrows, D., Fratini, S., Smith, T.J., Offenberg, J. & Guebas, F.D. (2008). Faunal Impact on Vegetation Structure and Ecosystem Function in Mangrove Forests: A Review. *Aquatic Botany*, *89*, 186-200.

Castelin, M., Puillandre, N., Kantor, Y.I., Modica, M.V., Terryn, Y., Cruaud, C., Bouchet, P. & Holford, M. (2012). Macroevolution of Venom Apparatus Innovations in Auger Snails (Gastropoda; Conoidea; Terebridae). *Molecular Phylogenetics and Evolution, 64*, 21-44.

Chase, R. (2002). *Behavior and Its Neural Control in Gastropod Molluscs*. United States of America: Oxford University Press.

Chen, G.C., Ye, Y. & Lu, C.Y. (2007). Changes of Macro-Benthic Faunal Community with Stand Age of Rehabilitated Kandelia Candel Mangrove in Jiulongjiang Estuary, China. *Ecological Engineering*, *31*, 215-224.

Claremont, M., Vermeij, G.J., Williams, S.T. & Reid, D.G. (2013). Global Phylogeny and New Classification of the Rapaninae (Gastropoda: Muricidae), Dominant Molluscan Predators on Tropical Rocky Seashores. *Molecular Phylogenetics and Evolution*, *66*, 91-102.

Cob, Z.C., Samat, A., Muda, W.M.L.W. & Mazlan A.G. (2012). Preliminary Checklist of Marine Invertebrate Fauna within the Intertidal of Teluk Penyabong and Teluk Gorek, Mersing, Johor, Malaysia. *Journal of Tropical Marine Ecosystem*, *1*, 1-14.

Dada, A.C., Asmat, A., Gires, U., Heng, L.Y. & Deborah, B.O. (2012). Bacteriological Monitoring and Sustainable Management of Beach Water Quality in Malaysia: Problems and Prospects. *Global Journal of Health Science*, *4*(3), 126-138.

Dame, R.F. (2012). *Ecology of Marine Bivalves: An Ecosystem Approach* (2nd ed.). New York: CRC Press.

Degen, R., Vedenin, A., Gusky, M., Boetius, A. & Brey, T. (2015). Patterns and Trends of Macrobenthic Abundance, Biomass and Production in the Deep Arctic Ocean. *Polar Research*, 34, Article ID 24008. http://dx.doi.org/10.3402/polar.v34.24008

Degraer, S., Verfaillie, E., Willems, W., Adriaens, E., Vincx, M. & Lancker, V. (2007). Habitat Suitability Modelling As a Mapping Tool for Microbenthic Communities: An Example from the Belgian Part of the North Sea. *Continental Shelf Research*. doi:10.1016/j.csr.2007.09.001

Deliman, D. G. (1979). *Evaluation of Present Chemical Standards in Relationship to In Situ Marine Water Quality Measurements.* United States: Office of Energy, Minerals, and Industry, Office of Research and Development, U.S. Environmental Protection Agency.

Dittmann, S. (2000). Zonation of Benthic Communities in a Tropical Tidal Flat of North-East Australia. *Journal of Sea Research*, *43*, 33-51.

Dolorosa, R.G. & Picardal, R.M. (2014). The Molluscan Fauna (Gastropods and Bivalves) and Notes on Environmental Conditions of Two Adjoining Protected Bays in Puerto Princesa City, Palawan, Philippines. *Journal of Entomology and Zoology Studies*, *2*(5), 72-90.

Dong, Z., Liu, D. & Keesing, J.K. (2010). Jellyfish Blooms in China: Dominant Species, Causes and Consequences. *Marine Pollution Bulletin*, *60*, 954-963.

Feiyan, D., Xuehui, W., Chunhou, L., Hanhua, Z. & Xiaoping, J. (2008). Study on Species Diversity of Macrobenthos in Daya Bay, South China Sea. *South China Fisheries Science*, *4*(6), 33-41.

Fletcher, C.E.G., Kintz, J.R.C., Ladino, L.M.M. & Cortes, F.A. (2011). Benthic Macrofauna Associated with Submerged Bottoms of a Tectonic Estuary in Tropical Eastern Pacific. *Journal of Marine Biology*, 2011, Article ID 193759. doi:10.1155/2011/193759

Foster, J. & Whiteley, N. (2002). *Fish and Shellfish Identification*. Seafish Open Tech Project. Retrieved from http://www.seafish.org/media/publications/fish_and_shellfish_identification.pdf

Garg, R.K., Rao, R.J. & Saksena, D.N. (2009). Correlation of Molluscan Diversity with Physicochemical Characteristics of Water of Ramsagar Reservoir, India. *International Journal of Biodiversity and Conservation, 1*(6), 202-207.

Gasim, M.B., Ismail, B.S., Toriman, E., Mir, S.I. & Chek, T.C. (2007). A Physico-Chemical Assessment of the Bebar River, Pahang, Malaysia. *Global Journal of Environmental Research*, *1*(1), 7-11.

Gazeau, F., Parker, L.M., Comeau, S., Gattuso, J.P., O'Connor, W.A., Martin, S., Portner, H.O. & Ross, P.M. (2013). Impacts of Ocean Acidification on Marine Shelled Molluscs. *Marine Biology*, *160*, 2207-2245.

Georgiev, D., Kostov, D. & Vladova, D. (2009). Molluscs (Mollusca: Gastropoda, Bivalvia) From the Azmashka Mound, Upper Trakia Plain, South Bulgaria. *Trakia Journal of Sciences*, *7*(2), 74-79.

Ghasemi, A.F. & Kamali, M. (2014). Benthic Macroinvertebrates along the Haraz Downstream in Southern Caspian Sea Basin: In Gradient of the Physicochemical Parameters. *International Journal of Zoology*, 2014, Article ID 145430. doi.org/10.1155/2014/145430

Ghosh, D. & Biswas, J.K. (2015). Macroinvertebrate diversity indices: A quantitative bioassessment of ecological health status of an oxbow lake in Eastern India. *Journal of Advances in Environmental Health Research*, *3*(2), 78-90.

Giller, P.S. (2012). *Community Structure and the Niche*. United States: Springer Science & Business Media.

Gondal, M.A., Saher, N.U. & Qurechi, N.A. (2012). Diversity and Biomass Distribution of Intertidal Fauna in Sonmiani Bay (Miani Hor), Balochistan (Pakistan). *Journal of Biology Science*, *4*(1), 219-234.

Gosling, E. (2004). *Bivalve Molluscs: Biology, Ecology and Culture*. Great Britain: Blackwell Publishing.

Gosling, E. (2015). *Marine Bivalve Molluscs* (2nd ed.). Pondicherry: John Wiley & Sons, Ltd.

Gottshall, P.M.N. & Miller, A.I. (2003). Comparative Taxonomic Richness and Abundance of Late Ordovician Gastropods and Bivalves in Mollusc-rich Strata of the Cincinnati Arch. *Palaios*, *18*(6), 559-571.

Gray, J.S., Clarke, K.R., Warwick, R.M. & Hobbs, G. (1990). Detection of Initial Effects of Pollution on Marine Benthos: An Example from the Ekofisk and Eldfisk Oilfields, North Sea. *Marine Ecology Progress Series*, *66*, 285-299.

Hamli, H., Idris, M.H., Abu Hena, M.K. & Wong, S.K. (2012). Diversity of Edible Mollusc (Gastropoda and Bivalvia) at Selected Divison of Sarawak, Malaysia. *International Journal on Advanced Science Engineering Information Technology, 2*(4), 5-7.

Handbook for Sampling and Sample Preservation of Water and Wastewater, Volume 1. (1982). California: U.S. Environmental Protection Agency, Office of Research and Development, Environmental Monitoring and Support Laboratory.

Heip, C. (1974). A New Index Measuring Evenness. *Journal of the Marine Biological Association, 54*, 555-557.

Higgins, R.P. & Thiel, H. (1988). *Introduction to the Study of Meiofauna*. Washington: Smithsonian Institution Press.

Hill, M. O. (1973). Diversity and Evenness: A Unifying Notation and Its Consequences. *Ecology, 54*, 427-432.

Hoey, G.V., Degraer, S. & Vincx, M. (2004). Macrobenthic Community Structure of Soft-Bottom Sediments at the Belgian Continental Shelf. *Estuarine, Coastal and Shelf Science*. doi:10.1016/j.ecss.2003.11.005

Hu, J., Kawamura, H., Hong, H. & Qi, Y. (2000). A Review on the Currents in the South China Sea: Seasonal Circulation, South China Sea Warm Current and Kuroshio Intrusion. *Journal of Oceanography, 55*, 607-624.

Hurlbert, S.H. (1971). The Nonconcept of Species Diversity: A Critique and Alternative Parameters. *Ecology*, *52*(4), 577-586.

Hutchings, J. A. & Haedrich, R. L. (1984). Growth and Population Structure in Two Species of Bivalves (Nuculanidae) from the Deep Sea. *Marine Ecology Progress Series*, 135-142.

Idris, M.H., Arshad, A., Bujang, J.S., Ghaffar, M.A. & Daud, S.K. (2008). Biodiversity and Distribution of Pen Shells (Bivalvia: Pinnidae) from the Seagrass Beds of Sungai Pulai, Peninsular Malaysia. *Research Journal of Fisheries and Hydrobiology*, *3*(2), 54-62.

Ingole, B.S., Gaonkar, U.V., Deshmukh, A., Mukherjee, I., Sivadas, S.K. & Gophane, A. (2014). Macrobenthic Community Structure of Coastal Arabian Sea during the Fall Intermonsoon. *Indian Journal of Geo-Marine Sciences*, *4*, 646-654.

Irma, D. & Sofyatuddin, K. (2012). Diversity of Gastropods and Bivalves in Mangrove Ecosystem Rehabilitation Areas in Aceh Besar and Banda Aceh Districts, Indonesia. *Aquaculture, Aquarium, Conservation & Legislation International Journal of the Bioflux Society*, *5*(2), 55-59.

Jackson, B.C.J. (2008). *Assessing Species Composition in Second Growth and Old Growth Rich Coves of the Southern Appalachians.* A thesis submitted for the degree of Doctor of Philosophy. Graduate Faculty of North Carolina State University, Raleigh, North California.

Jamil, M. & Hadil, R. (2012). Deepwater (150-500m) Demersal Resources Exploration in the Exclusive Economic Zone of Malaysia Using Beam Trawl. *Malaysian Fisheries Journal*, *11*, 42-79.

Jara, E.R., Caravantes, C.M.N., Villa, C.M.G. & Uriarte, E.L. (2009). Bivalves and Gastropods of the Gulf of Tehuantepec, Mexico: A Checklist of Species with Notes on Their Habitat and Local Distribution. *Journal of Marine Biology*, 2009, Article ID 17680. doi:10.1155/2009/17680

Jean, A. (1971). *Publication Seashells of the Texas Coast, The Elma Dill Russel Spencer Foundation Series*. Austin: University of Texas Press.

Jeffery, S.W. & Humphrey, G.F. (1975). New Spectrophotometric Equations for Determining Chlorophylls *a*, b, c1, and c2 in Higher Plants, Algae and Natural Phytoplankton. *Biochemie und Physiologie der Pflanzen*, *167*, 191-194.

Kumar, R., Nesemann, H., Sharma, G., Tseng, L.C., Prabhakar, A.K. & Roy, S.P. (2013). Community Structure of Microbenthic Invertebrates in the River Ganga in Bihar, India. *Aquatic Ecosystem Health and Management*, *16*(4), 385-394.

Lee, S.Y. (2008). Mangrove Macrobenthos: Assemblages, Services, and Linkages. *Journal of Sea Research*, *59*, 16-29.

Link, J.S., Grisworld, C.A., Methratta,E.T. & Gunnard, J. (2006). Documentation for the Energy Modeling and Analysis eXercise (EMAX). *Northeast Fisheries Science Center Reference Document 06-15*.

Ludwig, J.A. & J. F. Reynolds (1988). *Statistical Ecology: A Primer on Methods and Computing*. United States: Wiley-Interscience Publication.

Machado, P.M., Sa, F. S., Rezende, C.E. & Zalmon, I.R. (2013). Artificial Reef Impact on Microbenthic Community on South-Eastern Brazil Coast. *Marine Biodiversity Records*, *6*, 1-9.

Margalef, D.R. (1958). Informational Theory in Ecology. *General System*, *3*, 36-71.

Mazlum, N., Ozer, A. & Mazlum, S. (1999). Interpretation of Water Quality Data by Principal Components Analysis. *Tropical Journal of Engineering and Environmental Science*, *23*, 19-26.

Mclean, R. (1983). Gastropod Shells: A Dynamic Resource that Helps Shape Benthic Community Structure. *Journal of Experimental Marine Biology Ecology*, *69*, 151-174.

Millero, F.J. (2010). History of the Equation of State of Seawater. *Oceanography, 23*(3), 18-33.

Milroy, S.P. (2015). *Field Methods in Marine Science: From Measurements to Models*. United States: Garland Science.

Morton, B. (1996). The Subsidiary Impacts of Dredging (and Trawling) on a Subtidal Benthic Molluscan Community in the Southern Waters of Hong Kong. *Marine Pollution Bulletin*, *32*(10), 701-710.

Morton, B. & Blackmore, G. (2001). South China Sea. *Marine Pollution Bulletin, 42*(12), 1236-1263.

Munira. (2011). Beberapa Aspek Ekologi Bivalvia di Daerah Pasang Surut Waling Besar Kepulauan Banda, Maluku. *Bimafika*, *3*, 259-265.

Mustaffa, A., Ahmad, O., Vongpanich, V., Talib, A. & Yahya, K. (2013). *Benthic Mollusc Assemblages in Subtidal Coastal Waters of Penang National Park, Malaysia.* Proceedings of the 3rd Annual International Conference. Syiah Kuala University, Banda Aceh.

Naser, H. (2011). Human Impacts on Marine Biodiversity: Macrobenthos in Bahrain, Arabian Gulf. *The Importance of Biological Interactions in the Study of Biodiversity*. Retrieved from http://www.intechopen.com/books/the-importance-of-biologicalinteractions-in-the-study-of-biodiversity/human-impacts-on-marine-biodiversity-macrobenthos-in-bahrainarabian-gulf

Nowak, J. & Kozlowski, M. (2013). *Mussels: Ecology, Life Habits and Control*. New York: Nova Publishers.

Ong, B. & Krishnan, S. (1995). Changes in the Macrobenthos Community of a Sand Flat after Erosion. *Estuarine, Coastal and Shelf Science*, *40*, 21-33.

Peres, L.A. & Mantelatto, F.L. (2010). Epibiont Occurance on Gastropod Shells Used By the Hermit Crab *Loxopagurus Loxochelis* (Anomura: Diogenidae) On the Northern Coast Of Sao Paulo, Brazil. *Zoologia, 27*(2), 222-227.

Piamthipmanus, M. (1998). Temporal Changes in the Abundance of Macrobenthos in the South China Sea, Area II: Sarawak, Brunei and Sabah. *Department of Fisheries*, 323-337.

Ponder, W., Hutchings, P. & Chapman, R. (2002). *Overview of the Conservation of Australian Marine Invertebrates.* A Report for Environment Australia. Australian Museum, Sydney.

Ramakrishna, Raghunathan, C. & Sivaperuman, C. (2010). Status Survey on *Trochus niloticus* (Linnaeus, 1767) in Andaman and Nicobar Islands. *Status Survey of Endangered Species*, 1-80.

Ray, A.K. (2008). *Fossils in Earth Sciences*. New Delhi: PHI Learning Private Limited.

Rocha, V.P. & Cascon, H.M. (2015). Distribution patterns inference of the family Veneridae (Mollusca, Bivalvia) in Brazil through secondary database. *Neotropical Biology and Conservation, 10*(3), 123-131.

Rolston, A. & Dittmann, S. (2009). *The Distribution and Abundance of Macrobenthic Invertebrates in the Murray Mouth and Coorong Lagoons 2006 to 2008.* CSIRO: Water for a Healthy Country National Research Flagship.

Rosenberg, D.M. & Resh, V.H. (1993). *Freshwater Biomonitoring and Benthic Macroinvertebates*. New York: Chapman & Hall.

Rottman, M. (1976). *Euthecosomatous Pteropods (Mollusca) in the Gulf of Thailand and the South China Sea: Seasonal Distribution and Species Associations*. Naga Report, 6(4). Retrieved from http://escholarship.org/uc/item/8dr9f3ht

Ryu, S.H., Jang, K.H., Choi, E.H., Kim, S.K., Song, S.J., Cho, H.J., Ryu, J.S., Kim, Y.M., Sagong, J., Lee, J.H., Yeo, M.Y., Bahn, S.Y., Kim, H.M., Lee, G.S., Lee, D.H., Choo, Y.S., Pak, J.H., Pak, J.S., Ryu, J.S., Kim, J.S. & Hwang, U.W. (2012). Biodiversity of Marine Invertebrates on Rocky Shores of Dokdo, Korea. *Zoological Studies*, *51*(5), 710-726.

Salgeback, J. (2006). *Functional Morphology of Gastropods and Bivalves.* Acta Universitatis Upsaliensis. Digital Comprehensive Summaries of Uppsala Dissertations from the Faculty of Science and Technology 257. Uppsala. ISBN 91-554-6764-4.

Salleh, A.M., Desa, M.M. & Tuit, R.M. (2013). The Relationship between the Learning Ecology System and Students' Engagement: A Case Study in Selangor. *Asian Social Science*, *9*(12), 110-117.

Sanpanich, K. & Duangdee, T. (2013). The Biodiversity of Marine Gastropods of Thailand in the Late Decade. *Malaysian Journal of Science, 32*, 47-64.

Santos, M.F.L. & Vanin, A.M.S.P. (2004). Structure and Dynamics of The Macrobenthic Communities of Ubatuba Bay, Southeastern Brazilian Coast. *Brazilian Journal of Oceanography*, *52*(1), 59-73.

Shabdin M. L. & Rosniza, R. (2010). *Kekunci Siput dan Kerang-Kerangan Perairan Pantai Malaysia Timur.* Kuala Terengganu: Penerbit UMT.

Shabdin, M.L. (2014). Sarawak Coastal Biodiversity: A Current Status. *Kuroshio Science*, *8*(1), 71-84.

Shabdin, M.L., Abdullah, A.A.F.A. & Rahim, S.A.A. (2014b). *Marine Gastropod and Bivalves of Sampadi Island, Lundu, Sarawak*. Paper presented at Aquatic Science Colloqium, Universiti Malaysia Sarawak. Retrieved from https://www.researchgate.net/publication/269395974

Shabdin, M.L., Taufek, Z.M. & Salleh, N.M.M. (2014a). *Macrofauna Community Structure on Seagrass Meadows of Sampadi Island, Lundu, Sarawak*. Paper presented at Aquatic Science Colloqium, Universiti Malaysia Sarawak. Retrieved from http://www.researchgate.net/publication/269395898

Sharma, K.K., Bangotra, K. & Saini, M. (2013). Diversity and Distribution of Mollusca in Relation to the Physico-Chemical Profile of Gho-Manhasan Stream, Jammu (J & K). *International Journal of Biodiversity and Conservation*, *5*(4), 240-249.

Shaw, P.T. (1991). The Seasonal Variation of the Intrusion of the Philippine Sea Water into the South China Sea. *Journal of Geophysical Research*, *96*(C1), 821-827.

Simin, D.M., Bagher, N.S.M., Jasem, G.M., Najmeh, J. & Emad, K. (2012). Application of Abundance Biomass Curve in Ecological Health Assessment of Khure-Mussa (Northwest of the Persian Gulf). *Journal of the Persian Gulf*, *3*(7), 1-10.

Sivadas S. K., Ingole, B. S. & Fernandes, C. E. G. (2013). Environmental Gradient Favours Functionally Diverse Macrobenthic Community in a Placer Rich Tropical Bay. *The Scientific World Journal,* 2013, Article ID 750580. doi.org/10.1155/2013/750580

Sturm, C.F., Pearce, T.A. & Valdés, A. (2006). *The Mollusks: A Guide to Their Study, Collection, and Preservation*. Pittsburgh: American Malacological Society.

Tan, K.S. & Kastoro, W.W. (2004). A Small Collection of Gastropods and Bivalves from the Anambas and Natuna Islands, South China Sea. *The Raffles Bulletin of Zoology*, *11*, 47-54.

Tan, K.S., Moneva, C.S.O., Barazona, C.A., Coronel, K.H.I. & Demayo, C.G. (2015). Qualitative and Quantitative Characterization of Some Common Bivalves: *Polymesoda bengalensis, Codakia tigerina* and *Anodontia edentula*. *Advances in Environmental Biology, 9*(19), 114-122.

Tan, S.K. & Martyn, E.Y.L. (2013). Singapore Mollusca: 3. the Family Donacidae (Bivalvia: Veneroida: Tellinoidea). *Nature in Singapore*, *6*, 257-263.

Tangliapietra, D. & Sigovini, M. (2010). Benthic Fauna: Collection and Identification of Macrobenthic Invertebrates. *NEAR Curriculum in Natural Environmental Science*, *88*, 253-261. ISBN 2–940153–87–6.

The Mac Donald Encyclopedia of Shell. (1982). Great Britain: Mac Donald and Company.

Thilagavathi, B., Varadharajan, D., Babu, A., Manoharan, J., Vijayalakshmi, S., & Balasubramanian, T. (2013). Distribution and Diversity of Macrobenthos in Different Mangrove Ecosystems of Tamil Nadu Coast, India. *Journal of Aquaculture Research and Development*, *4*(6). doi:10.4172/2155-9546.1000199

Thrush, S.F., Hewitt, J.E., Cummings, V.J., Dayton, P.K., Cryer, M., Turrner, S.J., Funnell, G.A., Budd, R.G., Milburn, C.J. & Wilkinson, M.R. (1998). Disturbance of the Marine Benthic Habitat by Commercial Fishing: Impacts at the Scale of the Fishery. *Ecological Applications*, *8*(3), 866-879.

Tilman, D. (1982). *Resource Competition and Community Structure*. United States: Princeton University Press.

Trannum, H.C., Brakstad, F. & Neff, J. (2006). *Sediment Characterization and Parameter Estimation* (No. APN-411.3119). ERMS Task 3, Akvaplan-niva Report. Retrieved from https://www.sintef.no/globalassets/project/erms/reports/erms-report-no-12

Treuting, C. (2012). *Macroinvertebrates.* A thesis submitted for the degree of Master. Rochester Institute of Technology, Rochester.

Tunnell, J.W. (2010). *Encyclopedia of Texas Seashells: Identification, Ecology, Distribution, and History*. College Station: Texas A & M University Press.

United Nations Convention on the Law of the Sea 1982. Retrieved from http://www.un.org/ depts/los

Van Reeuwijk L.P. (2002). *Procedures for soil analysis* (6th ed.). Technical Paper No.9, Wageningen: International Soil Reference and Information Centre.

Venkatesan, V. & Mohamed, K.S. (2015a). Gastropod Classification and Taxonomy. *Central Marine Fisheries Research Institute*, 38-41.

Venkatesan, V. & Mohamed, K.S. (2015b). Bivalve Classification and Taxonomy. *Central Marine Fisheries Research Institute*, 42-48.

Ward, J. E. MacDonald, B. A. & Thompson, R. J. (1993). Mechanisms of Suspension Feeding in Bivalves: Resolution of Current Controversies by Means of Endoscopy. *Limnology and Oceanography*, *38*(2), 265-272.

Ware, S.J. & Kenny, A.J. (2011). *Guidelines for the Conduct of Benthic Studies at Marine Aggregate Extraction Sites* (2nd ed.). Marine Aggregate Levy Sustainability Fund.

Warwick, R.M. (1988). Analysis of Community Attributes of the Macrobenthos of Frierfjord/Langesundfjord at Taxonomic Levels Higher than Species. *Marine Ecology Progress Series*, *46*, 167-170.

Wasmund, N. (1984). Production and Distribution of the Microphytobenthos in the Sediment of Lake Mikolajskie. *Internatinale Revue der Gesamten Hydrobiology und Hydrographie*, *69*(2), 215-229.

Wazniak, C. (2004). Benthic Chlorophyll Measurements in the Maryland Coastal Bays. *Maryland's Coastal Bays: Ecosystem Health Assessment*, *4*, 66-72.

Whittle, R.J., Linse, K. & Griffiths, H.J. (2011). The Fossil Record of Limopsis (Bivalvia: Limopsidae) in Antarctica and the Southern High Latitudes. *Palaeontology*, *54*(4), 935-952.

Wigley, R.L. (1967). Comparative Efficiencies of Van Veen and Smith-McIntyre Grab Samplers as Revealed by Motion Pictures. *Ecology*, *48*(1), 168-169.

Williams, G.A. (1993). Seasonal Variation in Algal Species Richness and Abundance in the Presence of Molluscan Herbivores on a Tropical Rocky Shore. *Journal of Experimental Marine Biology Ecology*, *167*, 261-275.

Williams, G.A. (1994). The Relationship between Shade and Molluscan Grazing in Structuring Communities on a Moderately-Exposed Tropical Rocky Shore. *Journal of Experimental Marine Biology Ecology*, *178*, 79-95.

Wong, N.L.W.S. & Arshad, A. (2011). A Brief Review on Marine Shelled Mollusca (Gastropoda and Bivalvia) Record in Malaysia. *Journal of Fisheries and Aquatic Sciences*, *6*(7), 669-699.

Yan, T., Yan, W., Dong, Y., Wang, H., Yan, Y. & Liang, G. (2006). Marine Fouling of Offshore Installations in the Northern Beibu Gulf of China. *International Biodeterioration and Biodegradation*, *58*, 99-105.

Yang, W., Kashani, N., Li, X.W., Zhang, G.P. & Meyers, M.A. (2010). Structural Characterization and Mechanical Behavior of a Bivalve Shell (*Saxidomus purpuratus*). *Materials Science and Engineering C*. doi:10.1016/j.msec.2010.10.003

Yasin, A.H. & Razak, S.A. (1998). Distribution of Macrobenthos in the South China Sea, Area I: Gulf of Thailand and East Coast of Peninsular Malaysia. *Marine Fishery Resources Development and Management Department*, 285-293.

Zamprogno, G.C., Costa, M.B., Barbiero, D.C., Ferreira, B.S. & Souza, F.T.V.M. (2013). Gastropod Communities Associated with Ulva Spp. in the Littoral Zone in Southeast Brazil. *Latin American Journal of Aquatic Research*, *41*(5), 968-978.

Zhang, J. & Zhang, S. (2014). A New Species of *Nassarius* (Gastropoda: Nassariidae) from the China Seas. *Raffles Bulletin of Zoology*, *62,* 610-614.

Zhaohui, W., Jiangang, Z., Yujuan, Z. & Yu, C. (2009). Phytoplankton Community Structure and Environmental Parameters in Aquaculture Areas of Daya Bay, South China Sea. *Journal of Environmental Sciences, 21*, 1268-1275.

Zhou, F., Guo, H., Liu,Y. & Jiang, Y. (2007). Chemometrics Data Analysis of Marine Water Quality and Source Identification in Southern Hong Kong. *Marine Pollution Bulletin, 54*, 745-756.

APPENDICES

APPENDIX A

Table A1: Number of individuals of gastropod from Malaysia EEZ of Sarawak waters.

Taxa/Station	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Gastropoda																																
Acteon dancei	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Architectonica sp.	-	1	1	1	2	2	-	-	1	-	-	-	-	-	-	-	1	1	-	-	-	-	-	-	-	1	1	-	-	1	-	2
Atlanta peroni	2	-	-	-	-	-	-	1	-	-	-	-	1	-	-	-	-	-	-	-	1	-	-	-	-	-	1	-	-	-	-	-
Bittium sp.1	-	14	3	9	7	8	11	2	12	18	23	-	-	2	-	6	4	8	-	-	3	2	7	1	12	5	2	9	11	11	3	19
Bittium sp.2	6	-	-	-	1	-	-	-	-	-	3	-	-	-	13	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-
Microdrillia niponica	1	-	1	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
Tomopleura reevii	-	2	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	1	-	-	2	-	-	-	-	-	1	1	-
Bufonaria rana	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	2	-	-	1	-
Calliostoma sp.1	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Calliostoma sp.2	-	-	-	-	2	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	1	2	2	-	1
Semicassis sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-
Cavolinia globulosa	35	-	7	-	-	5	1	-	1	2	-	14	13	4	4	27	4	3	-	16	1	-	-	2	24	-	-	-	-	-	5	2
Diacavolinia longirostris	26	-	8	11	1	12	-	2	5	2	2	16	24	13	3	18	-	5	3	5	3	-	2	9	6	1	2	1	3	2	7	3
Diacria trispinosa	2	-	-	-	-	-	-	-	-	-	-	3	1	-	-	-	2	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
Paraclathurella celebensis	-	1	-	-	-	-	-	1	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Glyphostoma carmen	-	-	-	-	1	1	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	1	-	-	-	1	1	-	-
Bathyconus comatosa	-	-	-	-	1	-	1	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	2	-	-	-	1	-	1
Vexillum gouldi	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table A1 continued

Taxa/Station	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Gastropoda																																
Vexillum altisuturatum	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Vexillum epigonus	-	-	-	-	-	-	-	-	1	-	1	-	-	-	-	-	-	1	1	-	-	-	2	-	-	1	-	-	-	-	-	1
Vexillum jackylenae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	1	-	-	-	1	-	-
Vexillum scitulum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-
Vexillum sagamiense	1	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	1	-
Vexillum sp.	-	1	-	-	-	-	-	1	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	2
Adamnestia bizona	1	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Clavus fusconitens	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	1	-	-	-	-	1	-
Latirus constrictus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
Atys sp.	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Paradrillia inconstans	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Paradrillia sp.	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pseudoraphitoma bipyramidata	1	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-
Cythara sp.	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1	-	-	-	-
Cryptospira strigata	2	-	-	-	-	2	-	1	-	-	-	-	-	1	-	-	-	-	-	2	1	-	-	1	-	1	-	1	-	-	-	-
Cryptospira fischeri	-	1	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	1	1	-	-	-	-	-
Subcancilla amoena	-	-	-	-	-	1	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Subcancilla sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
Nassarius euglyptus	-	-	1	7	-	-	-	-	-	-	-	-	-	1	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nassarius dorsatus	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nassaria pusilla	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	1	-	-	-
Nassarius sp.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	1	-	-	-	1	-

Table A1 continued

Taxa/Station	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Gastropoda																																
Nassarius sp.2	-	-	-	-	1	-	-	-	-	-	-	-	-	1	-	-	-	1	-	-	-	-	2	-	-	1	-	-	1	-	-	-
Nassarius sp.3	-	-	-	-	-	6	-	-	-	-	1	-	-	-	-	-	2	-	-	2	-	-	-	-	-	1	-	-	1	-	1	-
Neverita sp.	1	1	1	-	2	-	-	-	3	-	1	-	-	2	1	-	1	-	-	2	-	-	1	1	-	1	-	-	-	3	2	1
Olivella sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Inquisitor sp.1	1	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-
Inquisitor sp.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	1	-	-
Pyramidella sp.	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Turbonilla sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	1	-	-	-	-	-	-	-	-	-
Reticutriton pfeifferianus	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-
Pyrunculus pyriformis	3	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-
Varicospira cancellata	-	1	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
Ringicula sp.	-	-	-	-	-	1	-	-	-	-	-	-	-	1	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	1	-
Rissoina otohimeae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-
Rissoina sp.	-	-	-	-	-	-	-	-	-	-	-	-	2	1	-	1	-	-	1	-	-	-	-	-	4	-	-	-	-	-	-	-
Zebinella herosae	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dolomena sp.	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Triphora sp.	-	-	-	-	-	3	-	-	-	-	1	-	-	-	1	-	2	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
Viriola corrugata	-	-	1	1	-	-	-	-	-	1	2	-	-	-	-	-	-	1	-	-	-	-	-	-	-	1	-	1	-	-	-	-
Monilea callifera	-	-	-	-	1	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Gemmula ambara	-	-	-	-	1	-	1	-	-	-	-	-	-	-	2	-	2	-	1	2	-	-	-	-	2	-	-	-	-	-	-	-
Turritella fascialis	8	13	14	12	4	12	13	2	14	17	21	-	-	7	8	-	14	7	2	1	5	3	15	2	2	22	1	7	15	5	7	29
Total	94	36	37	42	25	53	28	14	43	43	59	36	44	35	35	52	36	30	13	36	17	5	33	18	51	46	9	24	37	29	35	63

Table A2: Number of individuals of bivalve from Malaysia EEZ of Sarawak waters.

Taxa/Station	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Bivalvia																																
Anadara craticulata	-	3	-	8	1	-	2	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Anadara rotundicostata	-	-	4	-	-	-	1	-	1	-	3	-	-	4	1	-	-	-	3	-	3	-	1	1	-	1	2	-	2	2	1	-
Arca navicularis	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Striarca sp.	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	2	-	-	1	1	-	-	-	1	-	-	-	-	-	-	-
Ctenocardia virgo	-	-	-	1	-	-	-	-	1	2	1	-	-	-	-	-	-	-	1	-	-	-	2	1	-	1	1	2	2	-	3	2
Frigidocardium sp.	-	-	9	-	-	-	2	3	-	1	-	-	-	-	-	2	-	-	-	-	-	-	1	-	1	-	-	-	1	-	-	1
Laevicardium multipunctatum	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cardilia semisulcata	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-
Arcturellina elegantula	-	28	-	8	1	-	-	1	2	4	5	-	3	2	-	-	-	3	-	2	-	-	7	-	-	6	1	5	3	3	-	4
Corbula scaphoides	-	-	-	2	-	-	-	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	1
Meiocardia cumingi	-	-	-	-	-	-	-	-	-	1	1	-	-	1	1	-	-	1	1	-	2	-	-	-	-	-	-	-	1	-	-	1
Glycymeris sp.	-	4	-	7	2	-	4	2	4	3	5	-	-	-	-	-	-	4	-	-	-	4	2	-	-	3	-	1	5	2	-	3
Limopsis martini	-	61	-	26	3	-	15	5	20	6	15	7	-	20	-	-	-	18	15	6	15	3	11	21	-	17	22	7	9	7	24	12
Myadora sp.1	2	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	1	-	-	-	-
Myadora sp.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-
Saccella sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	-	-	1	-	-	-	-	-	-	-	1	-	-	-
Acila divaricata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Amusium pleuronectes	-	-	-	-	-	1	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Annachlamys striatula	-	-	-	3	-	-	-	-	-	1	-	1	-	-	-	-	1	-	-	-	1	-	-	-	-	-	1	1	2	1	1	-
Cryptopecten bullatus	-	3	-	4	-	-	-	3	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	1	1	1	1	1	-	-
Mimachlamys cloacata	-	1	-	1	1	-	1	-	-	1	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1

Table A2 continued

Taxa/Station	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Bivalvia																																
Mimachlamys sanguinea	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	2	-	-	-	-	-	-	-	1	1	-	-
Ensiculus cultellus	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Parvamussium pauciliratum	-	1	2	3	2	3	-	1	1	-	1	-	-	-	1	-	2	-	-	-	1	1	1	-	-	-	-	1	1	1	1	-
Gari lessoni	-	15	-	2	-	2	-	-	1	-	2	-	-	-	-	-	3	1	1	-	2	2	1	-	-	1	3	1	-	-	1	1
Azorinus coarctatus	-	-	2	-	-	5	3	-	1	-	1	-	-	6	5	-	2	1	1	-	2	-	-	1	-	-	1	1	1	1	2	1
Clathrotellina pretium	-	-	-	-	1	-	-	-	-	1	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	1	-	1	-	-	-	1
Tellina tokunagai	-	-	-	-	-	2	3	-	2	-	-	-	-	-	-	-	2	2	1	-	1	-	2	2	-	1	3	1	1	2	-	2
Dosinia laminata	-	-	-	-	1	3	-	-	-	1	1	-	-	1	-	-	2	-	-	1	3	1	-	-	-	-	-	-	-	-	-	-
Paphia semirugata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	1	1	1	-	-	1	-	-	1	-	-	1	-	-	-
Paphia sp.	-	-	-	-	-	1	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	1	-
Pitar citrinus	9	18	16	38	2	6	4	5	7	5	9	-	-	14	14	-	6	4	2	2	7	6	2	4	-	7	4	5	5	7	13	7
Placamen calophyllum	-	1	1	1	1	-	-	-	1	-	-	-	-	3	-	-	1	3	2	1	1	1	-	-	-	1	1	-	1	-	1	1
Timoclea subnodulosa	-	22	-	9	4	-	2	1	5	12	9	-	-	3	-	-	-	8	1	-	3	2	7	6	-	10	5	7	5	8	3	6
Total	11	158	35	114	19	23	37	22	47	40	54	9	5	56	25	3	26	50	29	16	45	20	39	36	2	51	45	38	43	36	51	45

APPENDIX B1

Table B1: Number of individuals of gastropod at Pandan beach.

Taxa/Station	1	2	3	4	5	6	7
Gastropoda							
Architectonica perdix	1	-	-	-	-	1	-
Bursa granularis	1	-	-	-	-	-	-
Austromitra canaliculata	-	-	4	-	-	-	-
Cassidula nucleus	-	1	-	-	-	-	-
Murex trapa	1	-	-	-	-	-	-
Nerita balteata	-	-	-	-	-	1	-
Cerithiella sp.	-	1	1	-	4	-	-
Olivella fulgurata	4	-	10	-	-	2	-
Oliva dubia	-	-	1	-	-	-	-
Latiromitra sp.	-	-	-	1	-	-	-
Ringicula auriculata	-	-	-	1	-	-	-
Siphonaria sp.	1	-	-	-	-	-	-
Doxander vittatus	-	1	1	1	-	-	-
Laevistrombus turturella	-	-	1	1	1	-	-
Margistrombus marginatus	2	-	-	-	-	-	-
Margistrombus septimus	1	-	-	-	-	-	-
Margistrombus sp.	6	-	-	1	-	-	2
Euterebra capensis	-	-	-	-	1	-	-
Euterebra fuscolutea	-	-	1	-	-	-	-
Umbonium elegans	2	-	-	-	1	-	1
Umbonium vestarium	2	-	3	-	2	-	-
Turritella cingulifera	21	1	19	3	31	1	4
Turritella sp. 1	-	-	-	1	-	-	-
Turritella sp. 2	-	-	5	-	6	1	2
Turritella sp. 4	-	1	-	-	-	-	-
Onustus indicus	2	-	1	1	1	-	1
Total	44	5	47	10	47	6	10

Table B2: Number of individuals of bivalve at Pandan beach.

Taxa/Station	1	2	3	4	5	6	7
Bivalvia							
Anadara granosa	16	17	11	20	29	6	8
Anadara nodifera	-	-	2	-	1	-	1
Anadara sp. 1	8	5	4	8	9	5	-
Anadara sp. 2	1	1	-	-	-	-	-
Anadara sp. 3	3	1	4	6	6	4	3
Anadara sp. 4	10	7	17	-	1	-	-
Arca navicularis	2	-	3	-	-	-	-
Acanthocardia tuberculata	7	-	2	1	1	-	-
Lunulicardia hemicardia	1	-	1	-	-	-	1
Donax semigranosum	-	-	1	1	-	-	-
Donax sp.	-	-	2	-	-	-	-
Donax variabilis	1	-	2	-	-	-	-
Mactrotoma angulifera	3	-	2	-	-	-	-
Placuna placenta	-	-	-	1	-	-	-
Azorinus scheepmakeri	-	-	-	-	-	1	-
Loxoglypta subpallida	1	2	-	-	1	1	-
Gafrarium sp.	-	-	2	-	-	-	-
Lioconcha sp.	-	-	1	-	-	-	-
Samarangia quadrangularis	1	-	-	-	-	-	1
Total	54	33	54	37	48	17	14

APPENDIX B2

Table B3: Number of individuals of gastropod at Kabong beach.

Taxa/Station	1	2	3	4
Gastropoda				
Architectonica perdix	-	1	-	-
Cocculina sp.	1	-	-	-
Cylichna sibogae	1	-	-	-
Eulima bifascialis	3	-	4	-
Eulima sp.	1	-	-	-
Melanella sp.	-	-	1	-
Pseudorhaphitoma sp.	1	-	-	-
Thais blanfordi	-	1	-	-
Nassarius elegantissimus	1	1	1	-
Nassarius sp. 2	-	2	-	-
Nassarius sp. 3	1	-	4	-
Nassarius stolatus	-	3	2	-
Natica tigrina	1	-	1	-
Neverita didyma	1	-	-	-
Tanea hilaris	-	1	1	1
Olivella fulgurata	4	2	-	-
Oliva multiplicata	1	-	-	-
Ringicula auriculata	-	-	1	-
Ringicula doliaris	1	-	1	-
Euterebra capensis	4	-	1	-
Umbonium vestarium	6	3	2	-
Turritella duplicata	-	1	4	1
Turritella cingulifera	2	-	6	1
Turritella sp. 2	1	-	-	2
Turritella sp. 3	1	1	-	2
Total	31	16	29	7

Table B4: Number of individuals of bivalve at Kabong beach.

Taxa/Station	1	2	3	4
Bivalvia				
Anadara granosa	1	-	-	-
Anadara globosa	-	-	-	1
Anadara rotundicostata	1	-	1	-
Donax rugosus	3	1	2	-
Donax sp.	6	3	14	-
Donax variabilis	14	6	9	-
Pholas orientalis	-	1	-	-
Hiatula adamsii	1	1	-	1
Loxoglypta subpallida	2	-	1	-
Gafrarium sp.	3	2	1	-
Samarangia quadrangularis	2	-	2	-
Tivela mactroides	-	-	-	1
Total	33	14	30	3

APPENDIX B3

Table B5: Number of individuals of gastropod at Tanjung Batu beach.

Taxa/Station	1	2	3	4
Gastropoda				
Architectonica perdix	-	-	-	1
Bursa granularis	1	1	-	-
Eulima sp.	1	-	-	-
Melanella sp.	-	-	1	-
Diodora sp.	-	2	-	1
Nodilittorina pyramidalis	-	-	-	1
Reishia jubilaea	2	1	-	-
Nassarius sp. 1	1	-	-	-
Nerita histrio	-	1	-	-
Ailinzebina sp.	-	-	-	1
Siphonaria sp.	-	-	-	1
Euterebra fuscolutea	-	-	2	1
Trochus ochroleucus	-	1	-	2
Total	5	6	3	8

Table B6: Number of individuals of bivalve at Tanjung Batu beach.

Taxa/Station	1	2	3	4
Bivalvia				
Anadara sp. 6	-	-	-	1
Anadara sp. 7	-	1	-	-
Anadara sp. 5	-	-	-	1
Cardites sp. 1	-	1	-	-
Cardites sp. 2	-	-	1	-
Donax incarnatus	-	-	-	1
Donax semigranosum	1	-	1	1
Nuculana confusa	-	1	-	-
Azorinus scheepmakeri	1	-	-	-
Total	2	3	2	4

APPENDIX B4

Table B7: Number of individuals of gastropod at Tusan beach.

Taxa/Station	1	2	3	4	5
Gastropoda					
Architectonica perdix	-	-	-	1	2
Turricula sp.	-	-	-	1	-
Nassarius sp. 1	1	1	-	1	-
Tanea hilaris	-	-	2	1	1
Turritella sp. 3	-	-	1	2	-
Onustus indicus	-	1	-	1	-
Total	1	2	3	7	3

Table B8: Number of individuals of bivalve at Tusan beach.

Taxa/Station	1	2	3	4	5
Bivalvia					
Anadara sp. 1	-	-	-	1	-
Arctica islandica	1	-	1	-	-
Megacardita turgida	2	3	2	5	-
Donax rugosus	1	2	1	-	1
Donax sp.	-	-	-	1	1
Donax variabilis	5	3	2	-	-
Glycymeris reevei	2	-	-	1	-
Azorinus scheepmakeri	-	1	-	2	-
Loxoglypta subpallida	-	-	-	1	-
Circe scripta	-	-	-	1	-
Tivela mactroides	2	-	-	-	1
Total	13	9	6	12	3

APPENDIX C

Table C1: The strength of the Pearson correlation coefficient value (Salleh *et al.*, 2013).

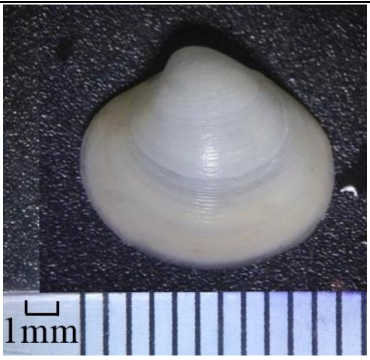
Pearson correlation coefficient value	Strength
0.91 to 1.00 or -0.91 to -1.00	Very strong
0.68 to 0.90 or -.68 to -0.90	Strong
0.50 to 0.70 or -0.51 to -0.70	Medium
0.31 to 0.50 or -0.31 to -0.50	Weak
0.01 to 0.30 or -0.01 to -0.30	Very weak
0.00	No correlation

Table C2: The relationship between the Shannon Diversity index and ecological level (Ghosh & Biswas, 2015).

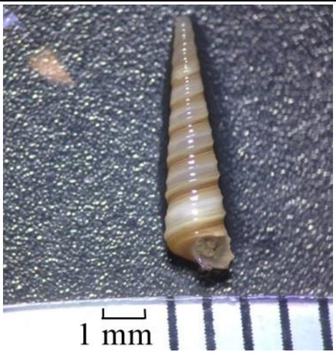
Diversity value	Ecosystem health
Higher than 4	High status
3 to 4	Good status
2 to 3	Moderate status
1 to 2	Poor status
0 to 1	Bad status

APPENDIX D

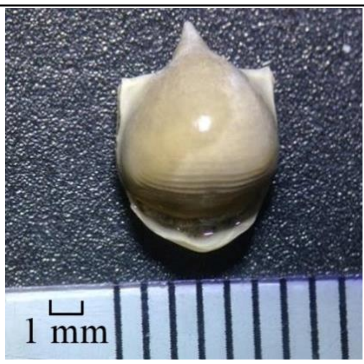
Most abundant species of gastropod and bivalve from EEZ of Sarawak waters and Sarawak Intertidal



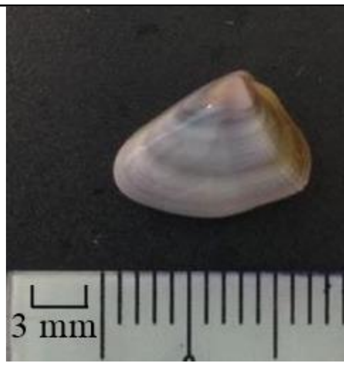
Pitar citrinus



Turritella cingulifera

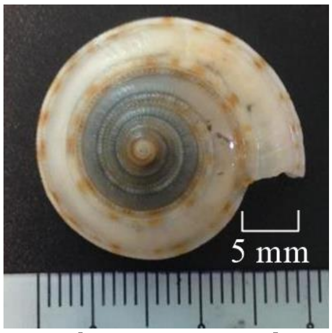


Cavolinia globulosa



Donax variabilis

Megacardita turgida



Architectonica perdix

Donax sp.

Anadara granosa