UNIVERSITI PUTRA MALAYSIA

THE COMMUNITY STRUCTURE OF MACROBENTHOS IN SIBUTI MANGROVE, SARAWAK

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THE COMMUNITY STRUCTURE OF MACROBENTHOS IN SIBUTI MANGROVE, SARAWAK

By

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ABSTRACT

The community structure of macrobenthos in this study depends on the species diversity, richness, and evenness, which are the reflection of the biotic factors. The objectives of this study are to identify macrobenthos species, besides, to assess the community structure of macrobenthic communities. This study was carried out in Kuala Sibuti, Miri, Sarawak. The quadrat transect method was used to obtain the samples (pore water, macrobenthos, and sediment samples). Pore water quality parameters (pH, total dissolved solids, salinity, temperature, turbidity, conductivity, and dissolved oxygen) were measured using Portable Water Quality Meter, and water analysis (ammonia, nitrite, phosphate, and nitrate) were analyzed in the laboratory. In this study, 17 macrobenthos species were identified. Gastropoda is the most dominant Class among the species identified, followed by Polychaetes, Bivalvia, and Clitellata. The most abundant species of Gastropoda are *Cerithidea charbonnieri*; Polychaetes, *Nephtys polybranchia*; Bivalvia, *Crassostrea rhizophorae*; and Clitellata, *Glossiphonia* sp. respectively. The macrobenthos species is more diverse in Plot 1 (2.006) compared to Plot 2 (0.756) and 3 (1.345). The high diversity of macrobenthos has indicated that the sediment characteristics (sand 95.32%; silt 4.86%) and great pore water quality, turbidity, influenced the species diversity. Hence, the collected data may assist as a baseline for further studies and can also be an approach to illustrating the diversity of macrobenthos.

ABSTRAK

Struktur komuniti makrobentos dalam kajian ini bergantung kepada kepelbagaian spesies, kekayaan, dan kesamarataan, yang merupakan pantulan faktor biotik. Objektif kajian ini adalah untuk mengenal pasti spesies makrobentos, selain itu, untuk menilai struktur komuniti makrobentik. Kajian ini telah dijalankan di Kuala Sibuti, Miri, Sarawak. Kaedah transek kuadrat telah digunakan untuk mendapatkan sampel (sampel air liang, makrobentos, dan sedimen). Parameter kualiti air di liang (pH, jumlah pepejal terlarut, kemasinan, suhu, kekeruhan, kekonduksian, dan oksigen terlarut) diukur menggunakan Meter kualiti air mudah alih, dan analisis air (ammonia, nitrit, fosfat, dan nitrat) dianalisis di makmal. Dalam kajian ini, 17 spesies makrobentos telah dikenal pasti. Gastropoda ialah Kelas yang paling dominan dalam kalangan spesies yang dikenal pasti, masing-masing diikuti oleh Polychaetes, Bivalvia, dan Clitellata. Spesies Gastropoda yang paling banyak ialah *Cerithidea charbonnieri*; Polychaetes, *Nephtys polybranchia*; Bivalvia, *Crassostrea rhizophorae*; dan Clitellata, *Glossiphonia* sp. Spesies makrobentos adalah lebih pelbagai dalam Plot 1 (2.006) berbanding Plot 2 (0.756) dan Plot 3 (1.345). Kepelbagaian makrobentos yang tinggi telah menunjukkan bahawa ciri sedimen (pasir 95.32%; kelodak 4.86%) dan kualiti air liang yang tinggi kekeruhan mempengaruhi kepelbagaian spesies. Oleh yang demikian, data terkumpul boleh digunakan untuk kajian lanjut di samping menjadi pendekatan untuk menggambarkan kepelbagaian makrobentos.

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APPROVAL SHEET

I certify that this research project report entitled "**The Community Structure Of Macrobenthos In Sibuti Mangrove, Sarawak**" has been examined and approved as a partial fulfilment of the requirement for the degree of Bachelor of Aquaculture Science with Honor in the Faculty of Agricultural and Forestry Sciences, Universiti Putra Malaysia Bintulu Sarawak Campus.

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CHAPTER 1

INTRODUCTION

1.1 Study Background

The term mangroves can be defined as the coastline wooded areas found in the tropics and subtropics along rivers (Biswas et al. 2012; Biswas & Biswas, 2019). Several terms also describe the mangrove forest, which are, “mangal vegetation”, “tidal forest”, “intertidal forest”, and “halophytic vegetation” (Biswas & Biswas, 2019). The mangroves are ecologically important in aiding coastal stabilization and lessening the devastation caused by calamities such as tropical cyclones and tsunamis. They can also act as nurseries and breeding sites for important commercial use of coastal finfish and shellfish species (Kumar et al., 2014). This means that the mangrove mainly ensures the survival of marine ecosystems and subsistence (Singh, 2020).

The mangrove ecosystems are found mostly in Malaysia along the western coastline of Peninsular Malaysia, along the harbors of the Sarawak (1st Division), Rejang (6th Division), and Trusan-Lawas (5th Division) rivers in Sarawak, as well as along the east coast of Sabah (Abd. Shukor, 2004). In total, 112 Mangrove Forest Reserves (441,092 ha) in Malaysia categorized as Permanent Forest Reserve (PFR), which were gazetted to maintain production and provide protection by the Forestry Department. However, the PFR, or state land forest areas, decreased by about 21,274 ha in 2017 as it was used for state development (Omar et al., 2020).

Most mangrove species in Malaysia are the red mangroves, *Rhizopora* sp., where the roots can evolve the ultrafiltration process via tissues around the xylem (Ahmad et al., 2018). The ultrafiltration system can be defined as the process of filtering sodium ions, Na^+, from surroundings via the roots (Kim et al., 2016). However, there are also other species, which is *Avicennia* sp., that are less efficient in excreting salt due to the process of excreting salt using special glands in their leaves (Ahmad et al., 2018).

Even though the environment in mangrove areas is harsh for some species to grow, terrestrial species, also known as macrobenthos, can adapt to this condition. Hence, macrobenthos can be defined as a creature that lives at the base of a water stream and is invisible to the naked eye. The sizes can vary from 0.5 mm to 1.0 mm (Sanapi, 2012a). Based on studies by Lardicci et al. (2004), the macrobenthos community includes polychaetes, bivalve, amphipod and decapod crustaceans, and echinoderms. However, bivalves were most diverse in the mangals, followed by gastropods (Hena et al., 2016). There are also larvae of fish and worms in the macrobenthos community.

1.2 Problem Statement

The macrobenthos is important to the mangrove system as they maintain the surrounding ecosystem. As the mangrove area went through a tidal fluctuation, several effects may threaten the mangrove ecosystem, such as the pollution of fertilizers and pesticide runoff, including undisposed wastes. However, the information regarding the community structure of macrobenthos in Sibuti, Sarawak, is currently limited. There are only a few researches that were done a few years back by Hena et al. (2016) and Kamal et al. (2016a), which makes the community structure of macrobenthos in Sibuti, Sarawak, still outdated. Last but not least, there needs to be more information regarding the pattern of the diversity index. Hence, by conducting this research on the community structure of macrobenthos, the data can be used for the young generation to provide a reference as regards the macrobenthos found in Sibuti, Sarawak.

1.3 Objectives

The objectives of this study are:

1. to identify macrobenthos species in the Sibuti mangrove, Sarawak
2. to assess the community structure of macrobenthos at different mangrove zonation in Sibuti mangrove, Sarawak

CHAPTER 2

LITERATURE REVIEW

2.1 Mangroves

Mangroves are tidal wetlands that are vital for maintaining the productivity of coastal environments (Duke, 2011). The ecosystems in mangroves are suitable for coastal main production as breeding and nursery sites for the marine aquatic life, besides as the shelter from storms, river flows, and tidal surges (Robertson et al., 1992; Duke, 2011). There are various mangrove plants where it ranges from trees (*Avicennia*, *Rhizophora*), to shrubs (species of *Aegiceras, Aegialitis, Pemphis,* and *Conocarpus*), to the trunkless palm (*Nypa fructicans*), and ground fern (*Acrostichum*) (Duke, 2011). The most emblematic adaptations of mangrove-specialized root systems are buttress roots (*Xylocarpus granatum*), flying buttresses (*Rhizophora* sp.), prop roots (*Rhizophora apiculata*), stilt roots (*R. stylosa*), spreading roots (*Rhizophora* sp.), cable roots with pneumatophores, cone roots (*Avicennia* sp.) (Srikanth et al., 2016a).

2.1.1 *Avicennia*

According to Duke (1991), *Avicennia* consists of a tiny percentage of tree species found mostly in the mangrove zone of tropical, protected coasts. *Avicennia* is usually in an exclusive tree or shrub form which is found in subtropical and humid environments. Throughout the world, there are five out of eight species of *Avicennia* Pacific (*A. alba, A. integra, A. marina, A. officinalis,* and *A. rumphiana*) found in East

Africa and Indo-Pacific whereas the other three species (*A. bicolor, A. germinans and A. schaueriana*) are found in New World and West Africa (Duke, 1991; Spalding et al., 2010; Chan et al., 2022).

Different leaf anatomical characteristics of the *Avicennia* species make the species easier to be identified. For example, *A. alba* has four hypodermal layers whereas *A. officinalis* only have three hypothermal layers that are underneath the adaxial epidermis (Syaheera et al., 2015). The hypodermal layers act as the supporting and protecting system for the plants. Basically, the layers help to prevent water loss during the transpiration process occurs. Figure 2.1.1 below shows the morphology of the *Avicennia marina*.

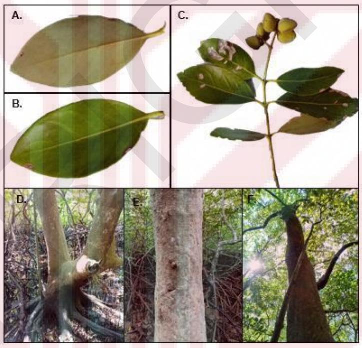


Figure 2.1.1 Morphology of *Avicennia marina (*A) Leaf abaxial surface (yellowish); (B) Leaf margin (adaxial surface); (C) Leaf arrangement (opposite); (D) Roots (pencil-like pneumatophores); (E) Tree trunk (smooth bark w/lenticels); (F) Tree crown. (Mariano et al., 2019)

2.1.2 *Rhizophora*

The genus, *Rhizophora* is a genus of tropical mangrove trees, which are also commonly known as true mangroves. True mangroves can be defined as species of plant that only can be found in mangrove forests, have a major role in forming the structure of mangrove, contains specialized morphology towards the mangrove environment, and have a specific system to excrete salt contained in the plants (Tomlinson, 2016; Quadros & Zimmer, 2017). According to FAO (2007), it is easier to recognize the mangroves due to the tidal environment, which is via their aerial rooting system. For the *Rhizopora* sp., the stilt roots can grow from the trunk and lower branches. Based on the research from Srikanth et al. (2016), there are various types of specialized roots for *Rhizophora* sp., such as flying buttresses, prop roots, stilt roots (*Rhizophora stylosa*), and spreading roots. Figure 2.1.2 shows the root of *Rhizophora mucronate* as one of the prop roots.

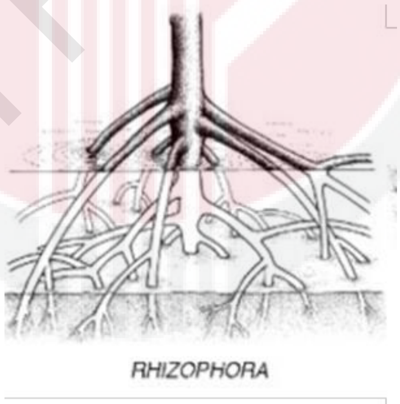


Figure 2.1.2 The root of *Rhizophora mucronate* (prop roots) (Takarina, 2020)

Moreover, the seed of the Rhizophoraceae family are germinated on the parents' tree, and the seedling acts as the propagule, which also means vivipary (Juncosa, 1982; FAO, 2007). Both the seeds and propagules have different morphological adaptations which can make them float on the water (Baskin & Baskin, 2001; Hogarth, 1999; Tomlinson, 1986; Srikanth et al., 2016). The seeds may float on water for over a year and settle down anywhere where the tidal bring.

2.1.3 *Nypa fructicans*

Nypa palm or also known as *Nypa fructicans*, is also commonly found along river edges in mangrove areas (Widodo et al., 2020). According to Tsuji et al. (2011), the Nypa also grows in large colonies with underground stems that can reach half a meter long. The leaves, or fronds, are feather-like and can reach more than 7 meters, and the leaflets are shorter towards the top of the frond. The stalk ends have a cluster of female flowers enclosed with bracts and sides with unstalked spikes of male flowers.

The seeds commonly germinate naturally (Tsuji et al., 2011) and allows it to disperse along with ocean currents (Widodo et al., 2020). By doing that, the seedlings of Nypa can survive in harsh environments even though there is insufficient source such as nutrients for the growth. The Nypa have a high tolerance towards freshwater and brackish environments, where they can survive in high turbidity and low salinity (Widodo et al., 2020).

Based on the previous research from Shah et al. (2016), the estuary of the bank in Sibuti, Sarawak, is dominated by *Nypa fructicans*. It is due to the high soil nutrients in the study area compared to other mangrove areas (Rambok et al., 2010; Shah et al., 2016). The nutrients needed for the growth of *Nypa fructicans* are carbon (C), hydrogen (H), oxygen (O), nitrogen (N), and others (Bautista & Espino, 1994;

Mantiquilla et al., 2019). However, the soil characteristics which include pH, texture, and the amount of organic nutrients also can influence the growth of crops (Mantiquilla et al., 2019)

2.2 Macrobenthos

According to Sajeeb (2021), a benthos can be defined as the organism that populates at the bottom of the water body. There are three types of benthic organisms, which are macrobenthos, meiobenthos, and microbenthos, where this benthos play crucial roles in the food chains of the aquatic ecosystem. Based on the research conducted by Kamal et al. (2016), the macrobenthos found in Kuala Sibuti Mangrove is from various classes, such as polychaete, gastropod, bivalve, and crustacean.

2.2.1 Polychaeta

Polychaetes, from phylum Annelida, consists of a segmented body, which is commonly found all around the marine environment, such as in mangrove areas and in the pelagic water column (Díaz-Castañeda & Reish, 2009). Based on research from Martin and Britayev (1998), there are 292 species of commensal polychaetes are reported involved in 713 different commensal relationships with various organisms such as bivalves, gastropods, decapods, cnidarians, and other polychaetes. Most of the polychaetes have a crucial role where they involve in composing the organic matter. Therefore, they have extensive morphology and symbiotic relationships that show greater lifestyles.

Some of the polychaetes that live in the intertidal environment have the greatest thermal resistance, where they can survive in high heat (Díaz-Castañeda & Reish, 2009). Even though the conditions to survive are extreme, some of the polychaetes have high growth rates and be numerically dominant to the environment. According to Glasby et al. (2021), several polychaete species, including *Amphisamytha galapagensis*, can reach densities of 2200 to 3000 individuals approximately.

2.2.2 Gastropod

Gastropod are belonging to the class Gastropoda, which are also the largest group in the phylum Mollusca. In Peninsular Malaysia, gastropod is locally known as "*Siput*", meanwhile in Sarawak, it is known as "*Tekoyong*" (Hamli, 2013). Figure 2.2.2 shows the edible gastropods that are commonly found in Sarawak. Gastropods can be considered successful due to they can survive in three major habitats, which are ocean, freshwater, and land. Besides that, gastropods also can adapt and survive in harsh conditions, such as mangroves (Rusnaningsih, 2012; Manullang et al., 2018).

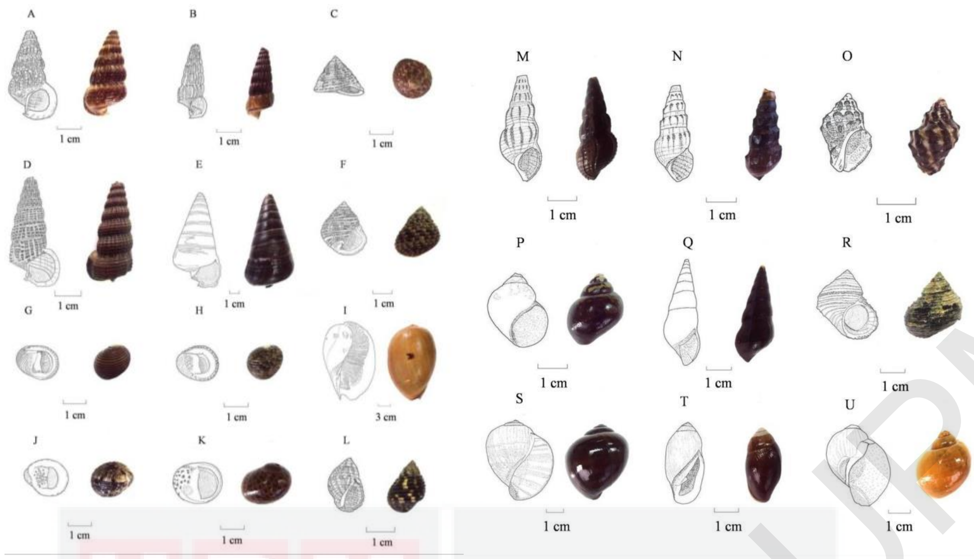


Figure 2.2.2 Edible gastropods from Sarawak; (A) *Cerithidea obtusa*, (B) *Cerithidea rizophorarum*, (C) *Trochus radiatus*, (D) *Cerithidea quoyii*, (E) *Telescopium telescopium*, (F) *Monodonta labio*, (G) *Nerita articulata*, (H) *Nerita chamaeleon*, (I) *Melo melo*, (J) *Nerita albicilla*, (K) *Clithon ritropictus*, (L) *Planaxis sulcatus*, (M) *Brotia costula*, (N) *Melanoides costellaris*, (O) *Tylothais virgata*, (P) *Blanocochlis glandiformis*, (Q) *Tylomelania helmuti*, (R) *Turbo crasus*, (S) *Pilla ampullacea*, (T), *Ellobium aurisjudae* and (U) *Pomacea bridgesii* **(**Idris et al., 2021)

The major role of molluscs is to help aerate the soil by digging the soil, which can affect the productivity and development of mangrove areas (Stieglitz et al., 2000; Smith et al., 2009; Ismail, 2019). Besides that, the molluscs such as gastropods also ingest the mangrove litter and assist in speed up the decomposition process.

2.2.3 Bivalve

Mud clams, locally known as *lokan*, from the genus *Polymesoda*, are widely distributed in the mangrove habitat (Mohd Hamdan et al., 2018). Sarawak's native names for bivalve include "*lokan*, *kepah*, *ambal*, *kerang*, and *kunang*," depending on the species (Hamli, 2013). Figure 2.2.3 below shows the edible bivalve species that are commonly found in Sarawak.

Figure 2.2.3 Edible bivalve species in Sarawak; (A) *Geloina expansa*, (B) *Geloina erosa*, (C) *Geloina bengalensis* (D) *Meretrix meretrix* (E) *Meretrix lyrata* (F) *Paratapes undulatus* (G) *Circe scripta* (H) *Solen regularies* (I) *Solen lamacrkii* (J) *Pharella acutidens* (Idris et al., 2021)

Sabah also has been blessed with the wide distribution of these mud clams, *Polymesoda* sp. (Harsono et al., 2017; Mohd Hamdan et al., 2018), which have become a popular grilled delicacy around Kota Kinabalu, Sabah (Mohd Hamdan et al., 2016; (Mohd Hamdan et al., 2018). Another research from Ka Han (2011) stated that one of the *Lokan* species, *Polymesoda expansa* is adapting well to the mangrove ecosystem since it can endure extended low tide by burrowing just into the muck and quickly begins filter-feeding when flooded.

2.2.4 Larvae

The seagrass beds and mangrove ecosystem also have become the habitat for fish larvae to grow (Ara et al., 2014). They stay in these places during their juvenile stage as these habitats have provided a huge amount of food sources and low predation from predators (Huijibers et al., 2008; Ara et al., 2014) Therefore, immediately following the planktonic phase, the majority of fish larvae born by coastal fish species actively move or drift to these nursery zones from nearby habitats, such as open seas, while some finish the planktonic period in mangrove and seagrass ecosystems (Leis et al., 1996; Patrick & Strydom, 2008; Teodosio & Garel, 2015; Tarimo, 2022).

2.3 Community Structure

According to Serosero et al. (2020), the condition of mangrove ecosystems can be determined by their community structure. The community structure of mangrove differs between deep and shallow water, and their community composition are related to the type of sediment, water temperature, and dissolved oxygen (DO). Hence, the number of species and diversity index are mostly correlated with the sand percentage (Kim et al., 2023). Besides that, the ecosystems are essentially filled with various resources such as habitats for aquatic organisms in the water and for birds in the terrestrial (Serosero et al., 2020). Moreover, the community of mangroves is also used by humans for numerous functions. For instance, it can be used as timber for house pillars, agricultural land, tourism destinations, and transportation.

2.3.1 Distribution of Macrobenthos in Mangrove

Mangrove ecosystems have become the habitat of various organisms. This is due to mangrove leaves that fall undergoing the decomposition process and basically producing nutrients and organic materials for the macrobenthos to consume (Muskananfola et al., 2020). Even though the environment in the mangroves is harsh for several organisms, some organisms such as gastropods, polychaetes, and, others, can adapt to the conditions. As for that, the macrobenthos have become the indicators for the pollution level in the aquatic environment (Tweedley et al., 2012; Muskananfola & Sulardion, 2020).

The macrobenthos that are commonly found in mangrove areas are Gastropoda, Mollusca, Bivalvia, Annelida, and Echinodermata (Gray, 1981; McLusky & Elliot, 2004; Lu et al., 2008; Muskananfola & Sulardiono, 2020). Mostly, the macrobenthos are living creatures that are sessile, movable, and dig holes on the seafloor. They usually decompose and mineralize the organic matter to provide nutrients for other organisms (Parsons et al., 1984; Muskananfola & Sulardiono, 2020).

However, the distribution of macrobenthos also depends on different zones in the mangrove areas. Based on the articles from Waycott et al. (2006a), three zones are commonly found in the mangrove habitats, which are seaward zone, mid-zone, and landward zone. The area most often subjected to tidal changes is the seaward zone. The mangrove trees were only exposed in the mid-zone due to variations in spring high tide. The landward zone, which is subject to groundwater or land runoff, is often only submerged at the highest spring tides. The examples of mangrove trees that are commonly distributed according to different is illustrated in Figure 2.3.1 below.

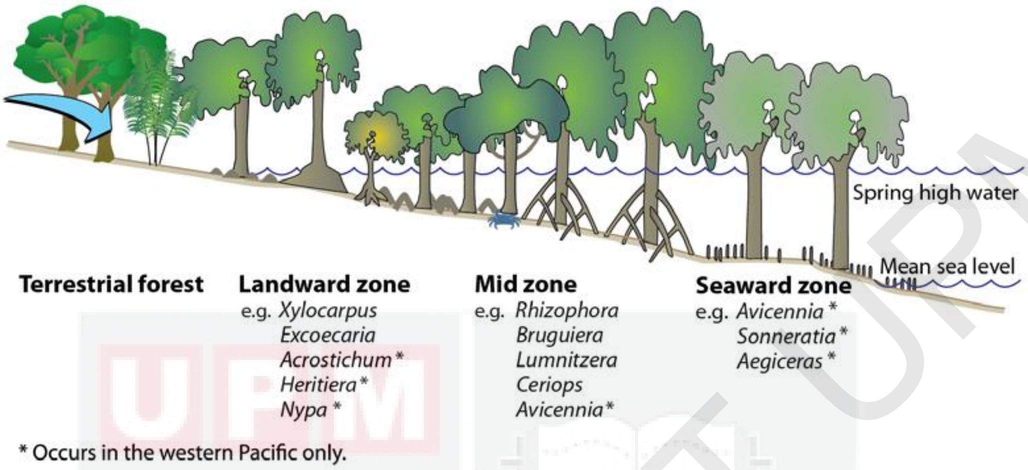


Figure 2.3.1 Mangrove trees based on the zones (Waycott et al., 2006a)

2.4 Abiotic Factor

According to Balasubramanian (2008), abiotic factors are the components of non-living things in the ecosystem. The factors can be divided into three categories, which are climatic and physical factors (water, sunlight, temperature, soil texture), inorganic substances (carbon, sulphur, phosphorus, nitrogen), and organic compounds (proteins, carbohydrates, lipids). Hence, for mangrove ecosystems, the factors that influence the growth of mangroves are water quality, sediments, and also climate change.

2.4.1 Water Quality

Mangrove ecosystems are one of the productive tropical ecosystems, as it become the habitats for various organisms. It is the most ideal breeding place for marine and brackish water fish (Saravakumar et al., 2008; Satheeshkumar & Khan, 2012).

However, environmental conditions such as pH, oxygen, temperature, salinity, and nutrients have affected the distribution and growth of the organisms (Ajithkumar et al., 2006; Satheeshkumar & Khan, 2012). For example, Bagheri Tavani & Tavani (2016) results have shown that changes in environmental parameters such as salinity and pH can cause a decrease in the diversity and density of macrobenthos respectively.

Temperature is the most important factor as it can influence the chemical and biochemical reactions in the water bodies (Othman & Wan Daud, 2018). According to Noor et al. (2015), mangrove plants are intolerant to low temperatures, which means the water and air temperatures should never be below 0˚C. However, high temperatures also can inhibit the growth of mangroves as they prevent the trees from settling. Hence, when the water hits 35, most mangrove species will decrease extremely in the photosynthesis process.

Besides that, the salinity also can influence the mangrove ecosystems, for example, the mangrove plants. Mangrove plants are halophytes, which causes them to grow in a salinity of 90 ppt, however, better growth in salinity ranges from 5 to 75 ppt (Krauss et al., 2008; Noor et al., 2015). Hence, the adaptations of mangrove plants will avoid salt uptake to make sure the water uptake from marine life has osmotic water potential (Hogarth, 2007; Noor et al., 2015). According to past research from Cabañas-Mendoza et al. (2020), the pH increased in the substrate at higher salinity, however, the relationship between these two factors is still low. Some environmental variables also can affect the changes in pH, for instance, temperature, can cause pH decreases if temperature increases (Dotro et al., 1994; Cabañas-Mendoza et al., 2020). The soils in the ecosystems also have the potential to influence the changes in pH and other physiochemical variables (oxide reduction process) (Lugo & Medina, 2014; Naidoo, 2016; Cabañas-Mendoza et al., 2020).

2.4.2 Sediment

Sediments are thrived in the mangroves, especially during the tides. Mostly, the sediments will be trapped and decomposed with organic matter to form stable soils (Kathiresan, 2003). However, a huge number of sediments can cause the trees to die off as the flow of water is blocked. Moreover, the burial of root systems by excess sediment also can cause destruction to the mangrove environment. For instance, *Sonneratia* spp. has vertical pneumatophores that allow the aeration process via root submergence. But, due to the deposition or increase in sediments, the root system was exposed to danger (Ellison, 1999; Nardin et al., 2021).

High content of organic sediments can increase the abundance and richness of macrobenthos (Levin et al., 1998; Kawaida et al., 2019; Pan et al., 2021). The oxic layer around the mangrove roots also can increase plenty of microbes, which are the food source of polychaetes (Gleason et al., 2003; Pan et al., 2021). Moreover, as stated by Muskananfola and Sulardiono (2020), the abundance of macrobenthos in October, which is also the dry season, is increased as the organic contents are also abundant.

2.4.3 Season

Climate change also has an impact on the mangrove environment, such as macrobenthos. As stated in this research (Zhao et al., 2019; Wang et al., 2019; Shih, 2020; Pan et al., 2021), sea level rise may have effects on the growth and distribution of mangroves. It is due to the changes in the coastal biogeochemical cycles as it is affected by the tidal. However, the inconsistent microbenthic abundance and community composition responses to mangrove vegetation (Pan et al., 2021).

According to Muskananfola and Sulardiono (2020), the distribution and abundance of macrobenthos are higher in March (end of the rainy season) than in October (dry season). The content of organic elements, the amount of silt and clay, and the salinity of the sediments are the main variables influencing these findings; consequently, the benthos density rises from land to sea.

CHAPTER 3

METHODOLOGY

3.1 Study Area

The Sibuti mangrove area is around 45 kilometers from Miri town, Sarawak. It is surrounded by Bungai farmlands on the North, the South China Sea in the West, and Kuala Sibuti, Kelulit, and Rachah Ranchah on the South and East along with the Sibuti River (Kaleem et al., 2015; Shah et al., 2016). During low tides, the mudflats will extend for about one kilometer toward the sea. Hence, the sediments and benthos sampling were carried out at three different locations as shown in Figure 3.1.1. The coordinate of these three locations is shown in Table 3.1.1.

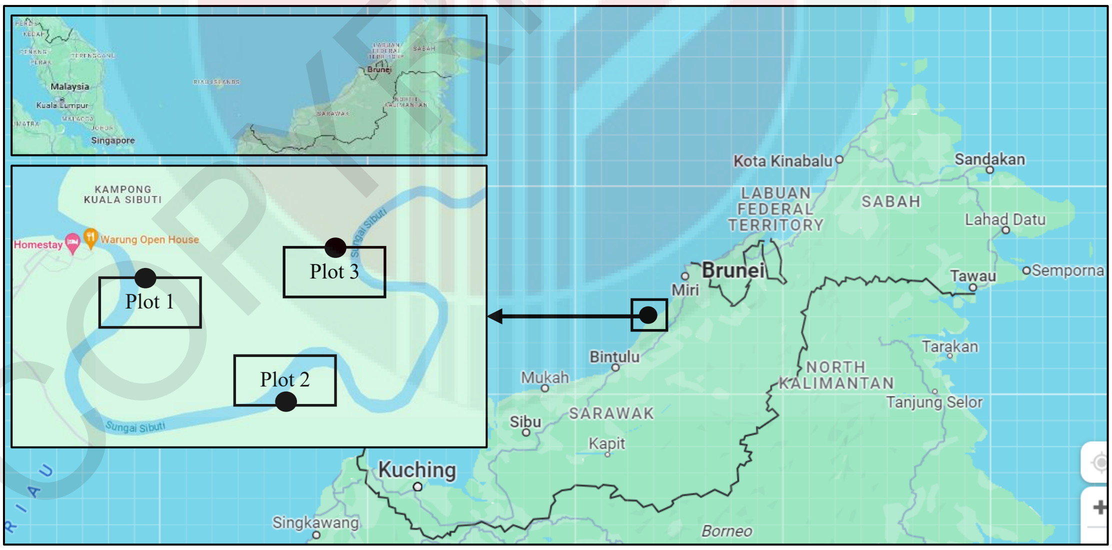


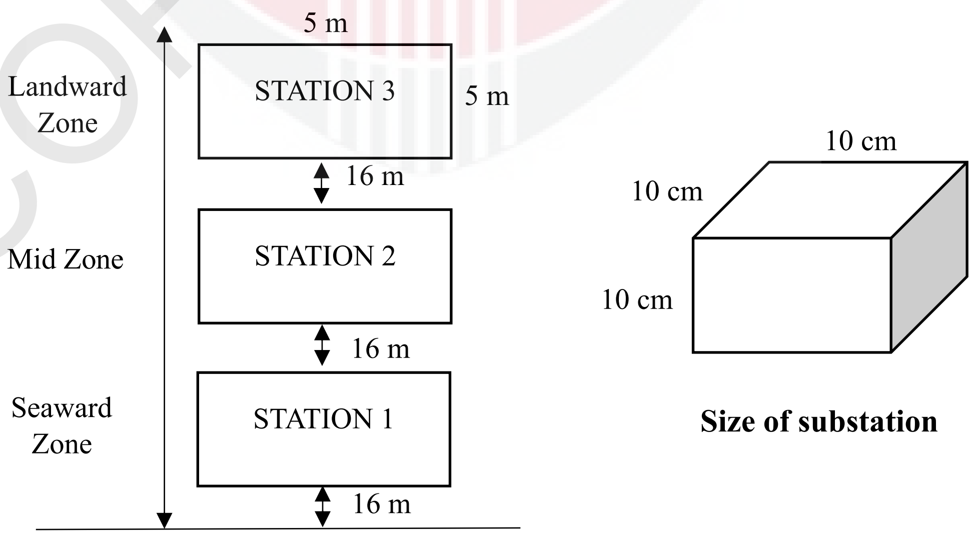
Figure 3.1.1 Locations of the sampling station in Kuala Sibuti. Miri, Sarawak.

Table 3.1.1 The coordinates of sampling locations

Plot	Coordinate
1	N 3˚59’26.6”
	E 113˚43’52.0”
2	N 3˚5’55.4”
	E 113˚44’18.0”
3	N 3˚59’28.7”
	E 113˚44’34.9”

3.2 Sampling Procedure

Several procedures were being used for the collection of samples, such as macrobenthos, sediment, and pore water. One of the methods that were used is the quadrat transect method. Three transects were placed from the shoreline towards the land, and each transect contains 3 stations. The size of each station was 5 m × 5 m, and the distance between each station was 16 m. In each station, there was one substation that was randomly picked in the station to collect the sample, where the size of the substation is 10 cm × 10 cm × 10 cm. The illustration is shown below (Figure 3.2.1).



Size of each station

Figure 3.2.1 The illustration of the quadrat transect method

3.3 Sample Collection

Several samples were collected in each plot, such as the collection of sediments, macrobenthos, and pore water. The procedures of sample collection are described below.

3.3.1 Sediment Collection

The sediment samples were collected from the sampling sites during low tide. Quadrat transect was used to make sure the distance between each substation was the same. It was placed from the shoreline towards the land. Then, the shovel was used to collect the sediment samples, where the sediments were collected $10 \times 10 \times 10\ cm$ in size for three substations in each location. On the boat, the sample is described, and a note is recorded regarding the surface characteristics, the density of the individual, and the presence of organic debris (Tagliapietra & Sigovini, 2010). Then, the sediments were stored in labelled plastics and put into ice boxes for further analysis in the laboratory (Md Isa et al., 2017)

3.3.2 Macrobenthos Collection

For the macrobenthos collection, the collected sediment samples were sieved using 1 mm, 500 μm, and 300 μm mesh screens to obtain the macrobenthos. According to Tagliapietra and Sigovini (2010), during the sieving process, the water needed to be sprinkled onto the sample but with minimal force to avoid any damage to the macrobenthos. After the sieving process, the benthos collected can be put in labelled containers. However, the samples also can be held in waterproof plastic bags in a thermally separated container for further analysis in the laboratory. The macroinvertebrates that are larger than $500\mu m$ are separated from the substrate and hand-picked and stored in plastic jars filled with 7% formalin solution for the identification process in the laboratory. The benthos were identified at the species level. (Bendary et al., 2021).

3.3.3 Pore Water Quality

The pore water quality also being recorded during the sampling. Water quality parameters such as pH, total dissolved solid (TDS), salinity, temperature, turbidity, conductivity, and dissolved oxygen (DO), are taken from the water column within one meter of the sediment. In excessively deep rivers, the depth outlines (at least surface, mid-depth, and bottom) should be taken for these parameters (Taft & Jones, 2001). The water quality is measured using the WQC-24 Portable Water Quality Meter, and Portable Turbidity Meter LTM A16. Pore water from each substation was filled in plastic sample bottles and was further analysed in the laboratory.

3.4 Preservation of Macrobenthos

The macrobenthos that were obtained after the sieving process were preserved immediately using 10% formalin solution in the plastic containers, along with other residues (Tagliapietra & Sigovini, 2010). The containers are labelled for each location. Besides that, the samples can also be stained with Rose Bengal to increase the visibility of the macrobenthos, where the benthos are stained bright pink (Laboratory, 2004). The samples were further analysed in the laboratory.

3.5 Laboratory Analysis

Various analyses were done in the laboratory, such as the macrobenthos identification, sediment, and water analysis. The procedures of analysis are as stated below.

3.5.1 Macrobenthos Identification

The samples from each container are transferred into specimen bottles according to each location. Then, the formalin solution is changed with 70% ethanol for long-term preservation. For further analysis of the macrobenthos in the laboratory, the number of individuals was recorded (Kim et al., 2023). The benthos were observed under the microscope to determine their identification up to the species level (Sanapi, 2012b). The microscopes that were used are Leica Compound Light Microscopes and Leica Zoom 2000 Stereo Microscope.

3.5.2 Sediment Analysis

For the sediments, the wet sediments were spread on the stainless-steel tray according to each plot. Then, the sediment samples were left in the oven overnight at 105˚C for the drying process, where excess water was removed (Salleh-Mukri & Shuhaida, 2021). After 24 hours, the dried sediment samples were crushed using a pestle and mortar. The crushed dried soil was sieved using a laboratory test sieve that has different sizes of mesh, which are 1 mm, 500 μm, 250 μm, 150 μm, and 63 μm. However, the particles that are stuck in the sieve opening can be brushed using a brush, which allows the particle to pass through the sieves (Raad Al-Adhadh et al., 2020). Then, the weight of each sample was obtained from each level of the sieves. The weight of the sediment samples was used to calculate the percentage of soil content following the method by Blair and McPherson (1999) on coarse sedimentary particle identification.

3.5.3 Water Analysis

Four types of water analysis were conducted for this study, which are the analysis of ammonia, nitrite, phosphate, and nitrate. The procedures for each analysis are different and are described below (American Public Health Association (APHA), 1999).

Ammonia Analysis

Ammonium Sulphate, $(NH_4)_2SO_4$, was diluted with 1 L Deionized Water to form the Standard Ammonium Solution (SS1) that has a concentration of 1000 ppm. Next, to form the concentration of 10 ppm, 10 mL of SS1 was added to 990 mL of deionized water to form Standard Ammonium Solution (SS2). Different volumes of SS2, which are 1 mL, 5 mL, and 10 mL, were filled with deionized water up to 100 mL in the volumetric flask to form a solution with different concentrations, 0.1 ppm, 0.5 ppm, and 1.0 ppm. Then, one of the test tubes with 5.0 mL distilled water, which acts as the blank solution, 3 test tubes with a solution that has different concentrations, 0.1 ppm, 0.5 ppm, and 1.0 ppm, 9 test tubes with 5.0 mL filtered water samples from each station of the plots. After that, fill the test tubes with 0.2 mL Phenol Solution and shake the test tube, followed with 0.2 mL Sodium Nitroprusside Solution. Then, fill the test tubes with 0.5 mL Oxidation Reagent, Sodium Hypochlorite, and Alkaline Reagent, and shake it. The test tubes were left for 60 minutes before reading and recorded the readings using the 2800 P UV/VIS Spectrophotometer with a wavelength of 640 nm.

Nitrite Analysis

Sodium Nitrite, $NaNO_2$, was diluted with 1 L Distilled Water to form the Standard Nitrite Solution (SS1) with a concentration of 1000 ppm. To obtain the solution with a concentration of 10 ppm, 10 mL of SS1 was mixed with 990 mL of Distilled Water to form Standard Nitrite Solution (SS2). Deionized water was added to various amounts of SS2 (1 mL, 5 mL, and 10 mL) in a volumetric flask up to 100 mL to create a solution with varying concentrations of 0.1 ppm, 0.5 ppm, and 1.0 ppm. Next, put 5.0 mL of distilled water—which serves as the blank solution—into one test tube. Add solutions with varying concentrations—0.1, 0.5, and 1.0 ppm—into three more test tubes. Finally, put 5.0 mL of filtered water specimens from each plot station into nine test tubes. Next, 0.2 mL of Sulphanilamide solution was added to each test tube then shaken well, and waited for 8 minutes. After that, 0.2 mL of N-(1-naphthyl)-ethylenediamine dihydrochloride also being added. After 60 minutes, the readings were taken and recorded using a 2800 P UV/VIS Spectrophotometer with a wavelength of 543 nm.

Phosphate Analysis

Monopotassium Phosphate, KH_2PO_4, was diluted with 1 L of Distilled Water to form Standard Phosphate Solution (SS1). To obtain a concentration of 10 ppm, mix 10 mL of SS1 with 990 mL of Distilled Water to form the Standard Phosphate Solution (SS2). Next, to create a solution with varying concentrations of 0.1 ppm, 0.5 ppm, and 1.0 ppm, volumetric flasks containing 1 mL, 5 mL, and 10 mL of SS2 were filled with deionized water up to 100 mL. Then, fill one test tube with 5.0 mL of distilled water (which serves as the blank solution), three test tubes with solutions at 0.1 ppm, 0.5 ppm, and 1.0 ppm, and nine test tubes with 5.0 mL of filtered water samples from each plot station. Next, add 0.5 mL of Mixed Reagent Solution to the test tubes, where it was a mixture of Ammonium Molybdate, Sulphuric Acid, Ascorbic Acid, and Antimony Potassium Tartrate. After 1 hour, the readings were obtained and recorded using a 2800 P UV/VIS Spectrophotometer with a wavelength of 880 nm.

Nitrite Analysis

Potassium Nitrate, KNO3, was diluted in 1 L of Distilled Water to form SS1, Standard Nitrate Solution. Next, combine 10 mL of SS1 with 990 mL of distilled water to get a concentration of 10 ppm for Standard Nitrate Solution, or SS2. To create a solution with varying concentrations of 0.1 ppm, 0.5 ppm, and 1.0 ppm, volumetric flasks containing 1 mL, 5 mL, and 10 mL of SS2 were filled with deionized water up to 100 mL. Afterward, put 5.0 mL of distilled water in one test tube to serve as the blank solution; three test tubes were then filled with solutions of varying concentrations (0.1, 0.5, and 1.0 ppm); nine test tubes were then filled with 5.0 mL of filtered water samples from each plot station. Then, 0.25 mL of Mixed Reagent Solution was added into each test tube, followed by 0.5 mL of Sodium Hydroxide Solution, and 1 mL of Hydrazine Sulphate Solution. Next, the test tubes were put in the water bath for 30 minutes at a temperature of 33˚C. 1mL of Sulphanilamide Solution was added to the test tubes and leaves it for 20 minutes. Lastly, add 1 mL of N-(1-naphthyl)-ethylenediamine dihydrochloride (NED) to each test tube, and obtain the readings using 2800 P UV/VIS Spectrophotometer with a wavelength of 540 nm.

3.6 Data and Statistical Analysis

The number of macrobenthos species collected was calculated using Paleontological Statistics software, Past 3.15. There are 3 diversity indexes were used in this study and it is as described below.

Shannon-Wiener Diversity Index (*H'*) is used to measure the diversity of species where H' is the diversity index of species, s is the number of species and p_i is the proportion of individuals of each species that belong to the ith species of the total number of individuals (Nolan & Callahan, 2005).

$$H' = -\sum_{i=1}^{s} p_i \, ln \, p_i$$

Pielou's Evenness Index (*J'*) is used to determine the evenness and dominance of species at the sampling locations. The I is the diversity index, I_{min} and I_{max} are the values of the lowest and highest values for the given number of species and sample size (Herman & Soetaert, 1998).

$$E = \frac{I - I_{min}}{I_{max} - I_{min}} \text{ and } E = \frac{I}{I_{max}}$$

Margalef Species Richness Index (*d*) is used to indicate the richness of species in the community (Ain et al., 2022). The S is the number of species, while N is the total number of individuals (Iglesias-Rios & Mazzoni, 2014).

$$d = \frac{S - 1}{\ln N}$$

All the data collected were computed and tabulated in Microsoft Excel. The abiotic variables were analyzed with one-way analysis of variance (ANOVA) and the significant difference and mean were compared using the Tukey Test for Pairwise Mean Comparisons using Paleontological Statistics software, Past 3.15. The number of individuals and taxa of each plot were evaluated for the Shannon-Weiner Diveristy Index (*H'*), Pielou's Evenness Index (*J'*), and Margalef's Richness Index (*d*) using Paleontological Statistics software, Past 3.15. The correlation between abiotic variables and diversity indices was also analyzed with Pearson correlation coefficient (*r*) using the Past 3.15 software.

CHAPTER 4

RESULTS

4.1 Macrobenthos Species

In this study, there are a total of 18 species of macrobenthos that have been identified and recorded (Table 4.1.1). In general, the macrobenthos species in the phylum Annelida was mostly discovered in Plot 1, and only one species, *Mediomastus californiensis*, was discovered in Plot 2. However, none of the phylum Annelida was detected in Plot 3. As for the phylum Mollusca, three plots showed the presence of various species of Mollusca. Among three plots, Plot 2 shows the dominance of Mollusca as there were 8 species discovered, followed by Plot 1 that have 7 species that dominated the plot. Meanwhile, Plot 3 showed the lowest dominance as 6 species of Mollusca were identified.

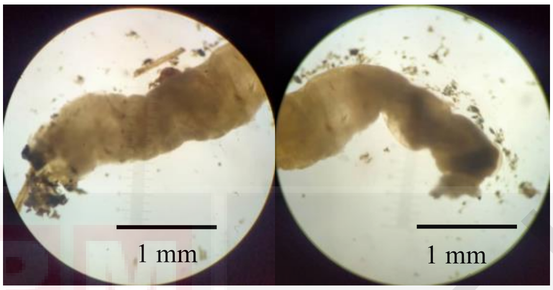
Table 4.1.1 Presence of macrobenthos species in Sibuti Mangrove, Sarawak.

Plots / Taxonomy	Plot 1	Plot 2	Plot 3
Annelida			
Mediomastus californiensis	+	+	–
Mediomastus sp.	+	–	–
Notomastus latericeus	+	–	–
Nephtys polybranchia	+	–	–
Namalycastis sp.	+	–	–
Glossiphonia sp.	+	–	–
Mollusca			
Geloina erosa	+	–	–
Crassostrea rhizophorae	+	–	–
Meretrix sp.	–	+	–
Littoraria scabra	+	+	–
Littoraria carinifera	+	+	+
Cerithidea charbonnieri	–	+	+
Cerithidea quoyii	+	+	–
Vittina coromandeliana	+	+	+
Neripteron violaceum	+	+	+
Neripteron cornucopia	–	+	–
Ellobium aurismidae	–	–	+

Notes: +: present, –: absent

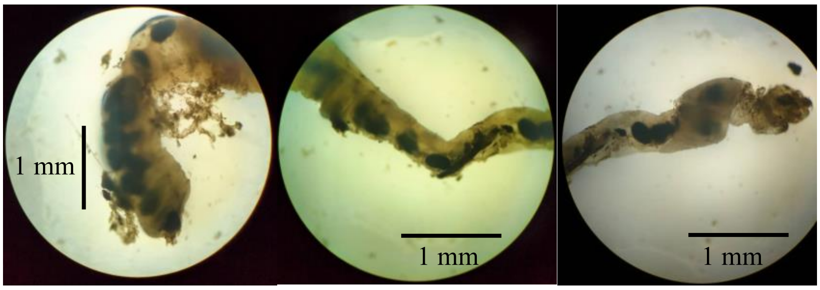
4.1.1 Phylum Annelida

There are six species were identified in the phylum of Annelida. The figures below show the classification of the species, along with their habitats and characteristics.



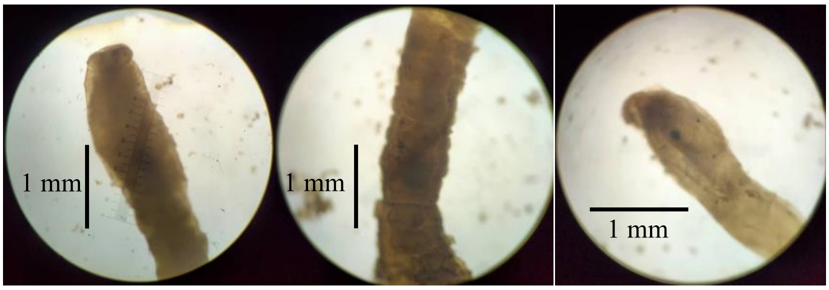
Figures 4.1.1 *Mediomastus californiensis* Hartman, 1944

Scientific name	*Mediomastus californiensis* Hartman, 1944
Classification	Phylum: Annelida Class: Polychaeta Family: Capitellidae Genus: *Mediomastus* Species: *Mediomastus californiensis*
Habitat	Can be found in fine muddy sand, or mangrove environments. Mostly found buried in the sediments.
Characteristics	It has a long and thread-like body, where the body is divided into anterior thoracic and posterior abdominal regions. It also has a small prostomium with a depressed ring. The thoracic parapodia are more developed and have simple unjointed capillary setae.



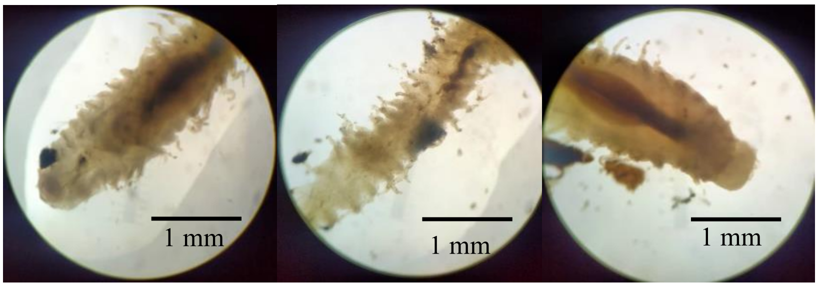
Figures 4.1.2 *Mediomastus* sp.

Scientific name	*Mediomastus* sp.
Classification	Phylum: Annelida Class: Polychaeta Family: Capitellidae Genus: *Mediomastus* Species: *Mediomastus* sp.
Habitats	Commonly found in the muddy bottom of mangrove areas. Can inhabit intertidal regions due to tolerance of harsh environments.
Characteristics	Have a long and segmented body with capillary setae. It also resembles an earthworm with a pointed anterior. Besides, it has a small prostomium and a depressed ring.



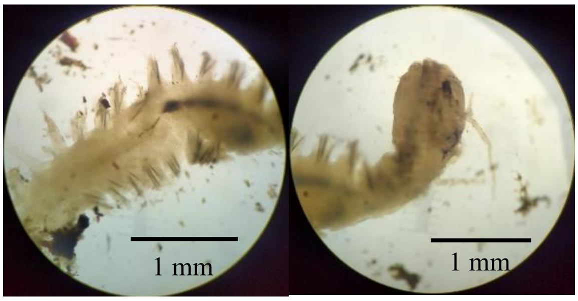
Figures 4.1.3 *Notomastus latericeus* Sars, 1851

Scientific name	*Notomastus latericeus* Sars, 1851
Classification	Phylum: Annelida Class: Polychaeta Family: Capitellidae Genus: *Notomastus* Species: *Notomastus latericeus*
Habitats	Discover in marine or estuarine environments. Usually inhabits the muddy bottom and can be found during lower shore.
Characteristics	Have brighter and yellowish posterior. The body is segmented with chitinous bristles (capillary chaetae). Conical prostomium with the presence of eyes. It also has enlarged abdominal hooks.



Figures 4.1.4 *Nephtys polybranchia* Southern, 1921

Scientific name	*Nephtys polybranchia* Southern, 1921
Classification	Phylum: Annelida Class: Polychaeta Family: Nephtyidae Genus: *Nephtys* Species: *Nephtys polybranchia*
Habitats	It can be found in muddy environments such as mangrove areas. Mostly found buried in the mudflats.
Characteristics	Generally small in size, and the body can become slender. Have a pair of antennae and paired pulp. The parapodia are mostly directed forward and have branchia on it.



Figures 4.1.5 *Namalycastis* sp.

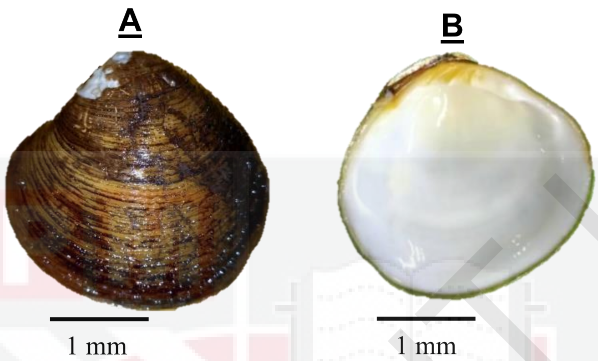
Scientific name	*Namalycastis* sp.
Classification	Phylum: Annelida Class: Polychaeta Family: Nereididae Genus: *Namalycastis* Species: *Namalycastis* sp.
Habitats	Can be found in marine and muddy mangrove environments. Usually found buried in the mudflats.
Characteristics	Have a pair of jaws and antennae, whereas the anterior and posterior eyes are the same size. Uniform width anteriorly to midbody, besides having peristomium and pharynx.

Figures 4.1.6 *Glossiphonia* sp.

Scientific name	*Glossiphonia* sp.
Classification	Phylum: Annelida Class: Clitellata Family: Glossiphoniidae Genus: *Glossiphonia* Species: *Glossiphonia* sp.
Habitats	Found in marine and mangrove environments. Commonly attach itself on hard substrate such as rocks, or trunks of mangrove roots.
Characteristics	Have elastic proboscis that can pierce the victim for blood-sucking, and have dark pigmentation on the body.

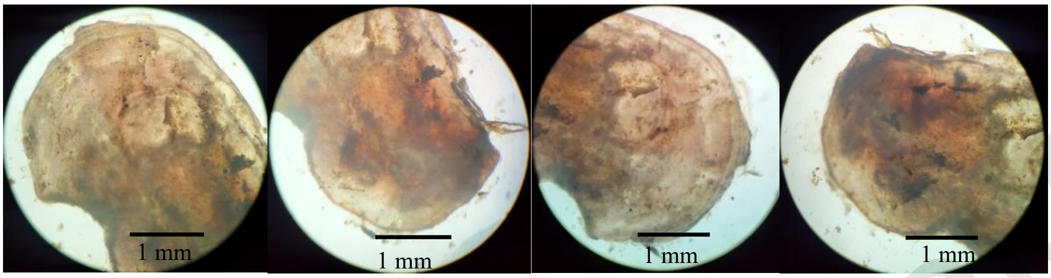
4.1.2 Phylum Mollusca

In phylum Mollusca, there are 11 species that have been identified. Hence, the figures below show the classification of the species, along with their habitats and characteristics.



Figures 4.1.7 *Geloina erosa* auct. Non [Lightfoot], 1786, A: Outer, B: Inner

Scientific name	*Geloina erosa* auct. Non [Lightfoot], 1786
Classification	Phylum: Mollusca Class: Bivalvia Family: Cyrenoididae Genus: *Geloina* Species: *Geloina erosa*
Habitats	Frequently found buried in mangrove mud, and able to inhabit low tide areas for long periods while filter-feeding.
Characteristics	Have two valves or shells, and are joined by a hinge. It also has bilateral symmetry with brown colour shell. Besides has a muscular foot to allow the clam to burrow itself in sand or mud.



Anterior view Posterior view

Figures 4.1.8 *Crassostrea rhizophorae* (Guilding, 1828)

Scientific name	*Crassostrea rhizophorae* (Guilding, 1828)
Classification	Phylum: Mollusca Class: Bivalvia Family: Ostreidae Genus: *Crassostrea* Species: *Crassostrea rhizophorae*
Habitats	Commonly found in benthic environments such as mangrove or estuarine regions. Attach themselves to hard substrates, rocks, and also mangrove roots (*Rhizophora* and others).
Characteristics	It has a cupped-like shell shape, besides having a promyal chamber and small ostia. The muscle scar is near the dorsal margin of the shell, which is often unpigmented.

Figure 4.1.9 *Meretrix* sp.

Scientific name	*Meretrix* sp.
Classification	Phylum: Mollusca Class: Bivalvia Family: Veneridae Genus: *Meretrix* Species: *Meretrix* sp.
Habitats	Frequently found in intertidal areas such as mangrove areas or brackish water. Commonly found buried in mudflats.
Characteristics	The shell is thin and smooth, and has fine concentric growth lines on the shell. Shell colour varies, some are black or white. Have a strong round ventral margin.

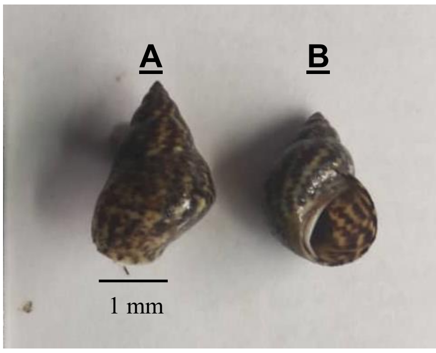


Figure 4.1.10 *Littoraria scabra* (Linnaeus, 1758), A: Dorsal, B: Ventral

Scientific name	*Littoraria scabra* (Linnaeus, 1758)
Classification	Phylum: Mollusca Class: Gastropod Family: Littorinidae Genus: *Littoraria* Species: *Littoraria scabra*
Habitats	Usually found on the trunks or roots of mangrove trees, and occasionally on driftwood on sandy beaches. Moreover, it also can occupy high intertidal habitats.
Characteristics	Have shell lengths ranging from 8 mm to 15 mm, besides having an irregular dark stripe pattern on the shell. With a high, conical spire and low sculpting, the shell is thin yet sturdy. Convex spire whorls with narrow and flattened spiral cords. A raised, rounded cord defines a well-marked angle at the perimeter.

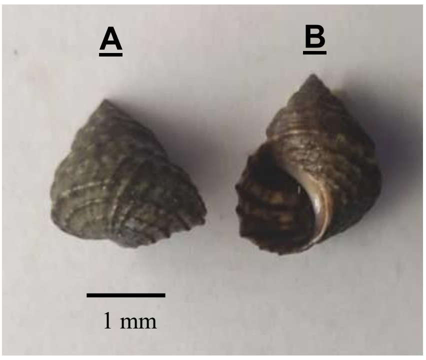


Figure 4.1.11 *Littoraria carinifera* (Menke, 1830), A: Dorsal, B: Ventral

Scientific name	*Littoraria carinifera* (Menke, 1830)
Classification	Phylum: Mollusca Class: Gastropod Family: Littorinidae Genus: *Littoraria* Species: *Littoraria carinifera*
Habitats	Most of the time were found scattered around the Rhizophore trunks. *L. carinifera* also prefers living on mangrove trees that have protruding roots and branches to allow the gastropod to move to other trees to search for their food source.
Characteristics	Have prominent ribs along the side of the shell, besides having a consistent shape and dark brown colour. The length of this species ranges from 0.74 mm to 18 mm.

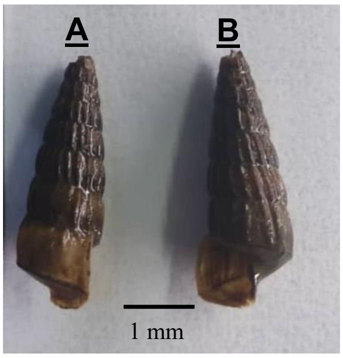


Figure 4.1.12 *Cerithidea charbonnieri* (Petit de la Saussaye, 1851), A: Dorsal, B: Ventral

Scientific name	*Cerithidea charbonnieri* (Petit de la Saussaye, 1851)
Classification	Phylum: Mollusca Class: Gastropod Family: Potamididae Genus: *Cerithidea* Species: *Cerithidea charbonnieri*
Habitats	Usually found in muddy mangrove areas and also on the trunks of mangrove trees (*Rhizophora, Nypa,* and others). Besides, this species also can be found in tropical zones or tidal swamps.
Characteristics	The shells are tall and thin spiral-shaped which formed the 'horned' look. Have darker and brown spiral cords, with flattened whorls and a convex spire. The lip of the adult flared, and slightly thickened.

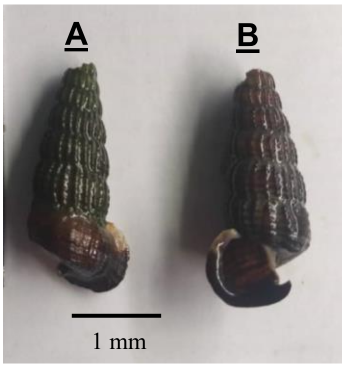


Figure 4.1.13 *Cerithidea quoyii* (Hombron & Jacquinot, 1848),
A: Dorsal, B: Ventral

Scientific name	*Cerithidea quoyii* (Hombron & Jacquinot, 1848)
Classification	Phylum: Mollusca Class: Gastropod Family: Potamididae Genus: *Cerithidea* Species: *Cerithidea quoyii*
Habitats	Mostly found in intertidal zones besides in muddy mangrove areas. Easily found on the trunks or roots of mangrove trees, because they usually attach themselves to it, especially during the high tides.
Characteristics	Has a low spire with an oval body-shaped, and flared-shaped aperture. The operculum has multiple concentric rings. The tip of the spire has eroded apex. The shell is brown, and its length ranges from 34 mm to 44 mm. The depth of the shell ranges from 26 mm to 32 mm.

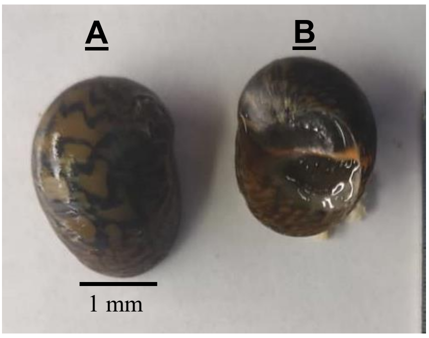


Figure 4.1.14 *Vittina coromandeliana* (G.B. Sowerby I, 1836), A: Dorsal, B: Ventral

Scientific name	*Vittina coromandeliana* (G.B. Sowerby I, 1836)
Classification	Phylum: Mollusca Class: Gastropod Family: Neritidae Genus: *Vittina* Species: *Vittina coromandeliana*
Habitats	Commonly found in intertidal mangrove areas, which have continuous tidal variation. Besides, it is also can be found in muddy sediments and on rocks or trunks of mangrove trees.
Characteristics	It has a length between 8 mm to 22 mm, and shell width ranges from 5 mm to 16 mm. The shell is brown with black stripes on it.

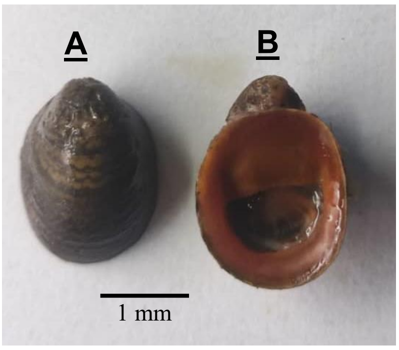


Figure 4.1.15 *Neripteron violaceum* (Gmelin, 1791), A: Dorsal, B: Ventral

Scientific name	*Neripterona violaceum* (Gmelin, 1791)
Classification	Phylum: Mollusca Class: Gastropod Family: Neritidae Genus: *Neripteron* Species: *Neripterona violaceum*
Habitats	Usually found in mangrove areas, attached to the rocks, and buried in the muddy sediments. Commonly found in tropical zones or tidal swamps.
Characteristics	Have yellow and dark brown colour shells, with small spiral cords on the surface of the shells. Depressed shell with expanding body whorl. It has a sunken spire and brownish round aperture, reddish outer and inner lip.

Figure 4.1.16 *Neripteron cornucopia* (W. H. Benson, 1836), A: Dorsal, B: Ventral

Scientific name	*Neripteron cornucopia* (W. H. Benson, 1836)
Classification	Phylum: Mollusca Class: Gastropod Family: Neritidae Genus: *Neripteron* Species: *Neripteron cornucopia*
Habitats	Frequently found on mudflats, tidal zones, and on the mangrove roots. This species usually attaches itself to the mangrove root as the roots can provide protection and a food source for them.
Characteristics	Have body length ranges from 19 mm to 25 mm, and the body width of 12 mm to 16 mm. Besides, also have columella teeth between 9 to 18. The greyish colour of the shell with straight lines across its body.

Figure 4.1.17 *Ellobium aurismidae* (Linnaeus, 1758), A: Dorsal, B: Ventral

Scientific name	*Ellobium aurismidae* (Linnaeus, 1758)
Classification	Phylum: Mollusca Class:Gastropod Family: Elobidae Genus: *Ellobium* Species: *Ellobium aurismidae*
Habitats	Found in muddy areas and mangrove swamps. Besides, also can be found in the environment of brackish water and salt marshes.
Characteristics	Have large size shell ranging from 81 mm to 82 mm, with flat spire whorls. The brown or dark brown shell surface has a fine spiral cord, with a white interior shell. The outer and inner lips are brown in colour.

4.2 Macrobenthic Population Parameters

The macrobenthic population parameters for the plots are presented in Table 4.2.1. Based on the data in the table, the highest number of taxa and individuals are from Plot 1, followed by Plots 2 and 3. Besides that, the macrobenthos in Plot 1 also showed higher diversity than the other two plots. However, Plot 3 has the evenness and richness of macrobenthos communities compared to Plots 1 and 2. Hence, the bar charts below (Figure 4.2.1, 4.2.2, and 4.2.3) show the comparison of macrobenthic population parameters between the plots.

Table 4.2.1 The macrobenthic population parameters in Sibuti Mangrove, Sarawak.

Plots / Index	Plot 1	Plot 2	Plot 3
Number of Taxa (*S*)	13	9	5
Number of Individuals (*N*)	81	102	116
Shannon-Weiner Diversity (*H'*)	2.006	0.756	1.345
Pielou's Evenness (*J'*)	0.572	0.237	0.767
Margalef's Richness (*d*)	1.487	1.4	1.737

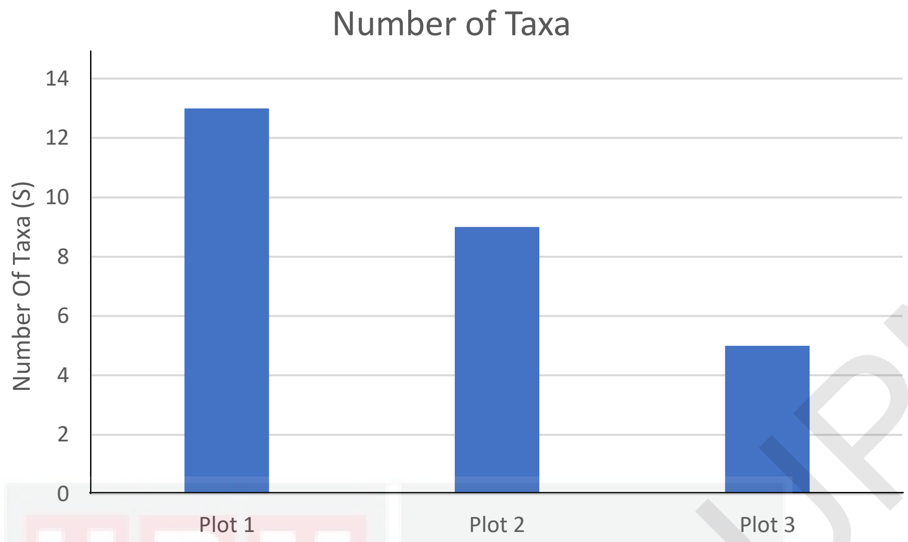


Figure 4.2.1 The number of taxa in macrobenthic communities between the plots in Sibuti Mangrove, Sarawak.

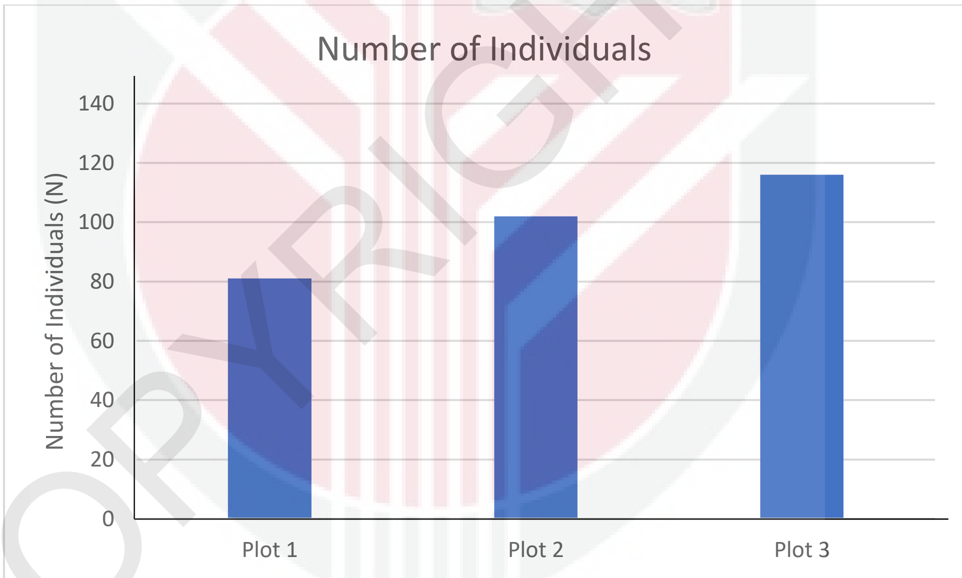


Figure 4.2.2 The number of individuals in microbenthic communities between the plots in Sibuti Mangrove, Sarawak.

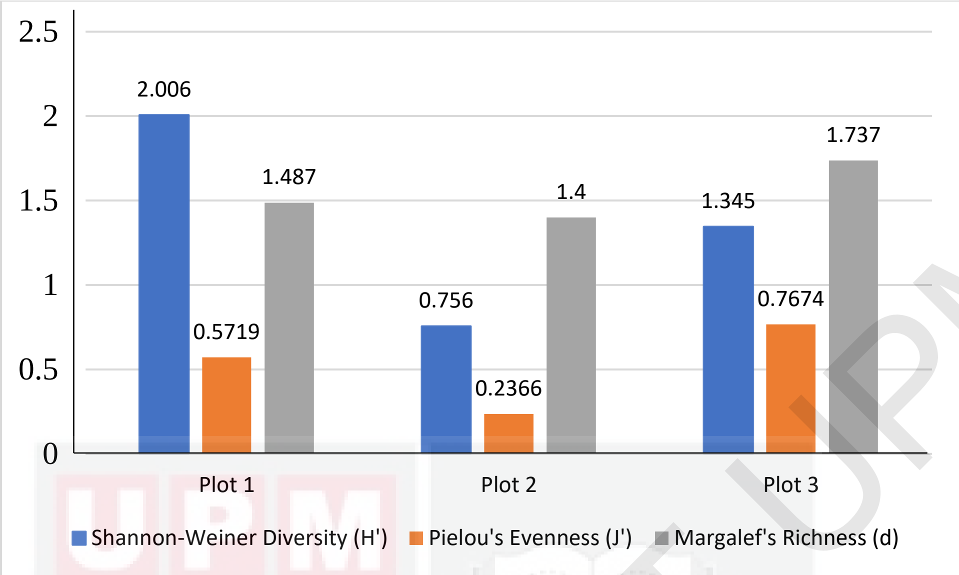


Figure 4.2.3 Comparison of microbenthic communities in Sibuti Mangrove, Sarawak, based on Shannon-Weiner Diversity Index (*H'*), Pielou's Evenness Index (*J'*) and Margalef's Richness Index (*d*).

4.3 Granule Structure Classification

Based on the table below (Table 4.3.1), there were two types of grain texture classified, which are the texture of sand and silt. However, there were also several categories in the texture of sand, which included very coarse sand, coarse sand, medium sand, fine sand, and very fine sand. In the category of very coarse sand, Plot 2 showed the highest percentage (24.31 %), followed by Plot 3 (21.09 %) and Plot 1 (17.15 %). Moreover, Plot 2 also has the highest percentage of coarse sand (19.54 %). As for the medium sand, Plot 1 showed the greatest percentage (24.72 %) among the other two plots, Plot 2 (20.49 %) and Plot 3 (21.66 %). For the fine sand category, Plot 2 has the lowest percentage (25.87 %) between Plot 1 and Plot 3. In addition, in the category of very fine sand, Plot 2 also has the lowest percentage (6.33 %), followed by Plot 3 (7.81 %), and Plot 1 (8.49 %). Last but not least, the silt grain category, in which Plot 3 showed the greatest percentage (5.46 %) among Plot 1 (5.11 %) and Plot 2 (3.46 %).

Table 4.3.1 Grain structure classification between the plots in Sibuti Mangrove, Sarawak.

Plots / Grain Category	Plot 1	Plot 2	Plot 3
1000μm : Very coarse sand (%)	17.15	24.31	21.09
500μm : Coarse sand (%)	15.05	19.54	15.15
250μm : Medium sand (%)	24.72	20.49	21.66
150μm : Fine sand (%)	29.48	25.87	28.83
63μm : Very fine sand (%)	8.49	6.33	7.81
<63μm : Silt (%)	5.11	3.46	5.46
TOTAL (%)	100	100	100

4.4 Pore Water Quality

The pore water quality parameters between the plots in the Sibuti mangrove are shown below in Table 4.4.1. There was a significant difference (P<0.05) between the plots and the turbidity, dissolved oxygen, ammonia, nitrite, and phosphate. Based on the data in the table below (Table 4.4.1), the dissolved oxygen in Plot 1 (4.02±0.32 mg/L) was the highest among the other two plots. Meanwhile, the turbidity, Plot 2 has the highest turbidity (816.67±174.75 NTU) compared to Plots 1 and 3. However, it is different for ammonia, nitrite, and phosphate, all these parameters have the highest values in Plot 3 (T= 2.364±0.504 mg/L, 0.745±0.359 mg/L, 0.851±0.061 mg/L) respectively.

Table 4.4.1 The pore water quality parameters between the plots at Sibuti Mangrove, Sarawak.

Plots / Parameters	Plot 1 (Mean±SD)	Plot 2 (Mean±SD)	Plot 3 (Mean±SD)	*P*-value
pH	6.5±0.1^{a}	6.4±0.1^{a}	6.3±0.1^{a}	0.163
TDS (ppm)	10.612±2.054^{a}	10.479±1.763^{a}	9.044±2.890^{a}	0.490
Salinity (ppt)	6.8±1.2^{a}	6.7±1.2^{a}	5.8±0.2^{a}	0.457
Temperature (˚C)	26.10±0.10^{a}	25.80±0.46^{a}	25.27±0.25^{a}	0.094
Turbidity (NTU)	179.00± 65.82^{ab}	816.61± 174.75^{a}	463.33± 121.82^{b}	0.008*
Conductivity (S/m)	1.175±0.183^{a}	1.167±0.18^{a}	1.033±0.029^{a}	0.521
DO (mg/L)	4.02±0.32^{a}	3.06±0.25^{b}	2.47±0.40^{b}	0.014*
Ammonia (mg/L)	0.873±0.153^{a}	1.268±0.250^{a}	2.364±0.504^{b}	0.014*
Nitrite (mg/L)	0.480±0.260^{a}	0.661±0.161^{a}	0.745±0.359^{b}	0.049*
Phosphate(mg/L)	0.214±0.083^{a}	0.573±0.081^{b}	0.851±0.061^{c}	0.003*
Nitrate (mg/L)	0.376±0.230^{a}	0.439±0.227^{a}	1.094±0.547^{a}	0.171

Notes: SD: standard deviation, TDS: total dissolved solids, DO: dissolved oxygen, *: different letters between columns indicate a significant difference (P<0.05)

There was no significant difference (*P*>0.05) between the plots and the pore water quality parameters (pH, total dissolved solids, salinity, temperature, conductivity, and nitrate). The value of pH in Plot 1 has the highest value (6.5±0.1), followed by Plot 2 (6.4±0.1), and lastly Plot 3 (6.3±0.1). The total dissolved solid, salinity, and temperature of Plot 1 also showed the highest (T = 10.612±2.054 ppm, 6.8±1.2 ppt, 26.10±0.10 ˚C) compared to Plots 2 and 3. However, it is different for the conductivity, as Plot 2 has the highest conductivity (1.167±0.18 S/m) compared to the other two plots. Moreover, the highest value of nitrate is in Plot 3 (1.094±0.547 mg/L), followed by Plot 2 (0.439±0.227 mg/L), and Plot 1 (0.376±0.230 mg/L).

4.5 Pearson Correlation Between Diversity Index and Pore Water Quality Parameters

Three diversity indexes were used to determine the correlation relationship between the diversity indexes and the pore water quality parameters. The diversity indexes are the Shannon-Weiner Diversity Index (*H′*), Pielou's Evenness Index (*J′*), and Margalef's Richness Index (*d*). The relationship between the diversity indexes and the parameters is described below.

4.5.1 Shannon-Weiner Diversity Index (*H′*)

A Pearson correlation coefficient was computed to determine the linear relationship between the Shannon-Weiner Diversity Index (*H′*) and pore water quality parameters in Sibuti mangrove, Sarawak. Based on the table below (Table 4.5.1), the parameters included are pH, total dissolved solids, salinity, temperature, turbidity, conductivity, dissolved oxygen, ammonia, nitrite, phosphate, and nitrate.

Table 4.5.1 Pearson correlation coefficient between Shannon-Weiner Diversity Index (*H'*) and pore water quality parameters in Sibuti mangrove, Sarawak.

Water Quality Parameters	Correlation coefficient (*r*) value	*P*-value (2-tailed)
pH	0.4693	0.689
TDS (ppm)	0.0396	0.975
Salinity (ppt)	0.0558	0.964
Temperature (˚C)	0.3239	0.790
Turbidity (NTU)	-0.9996	0.017*
Conductivity (S/m)	0.0151	0.990
DO (mg/L)	0.5855	0.602
Ammonia (mg/L)	-0.2216	0.858
Nitrite (mg/L)	-0.1533	0.902
Phosphate(mg/L)	-0.5327	0.642
Nitrate (mg/L)	-0.0442	0.972

Notes: *: significant correlate ($P<0.05$)

There was a moderately positive linear correlation but statistically non-significant ($P>0.05$) between the Shannon-Weiner Diversity Index and the parameters dissolved oxygen (r= 0.5855). The parameters of pH (r= 0.4693), and temperature (r= 0.3239) have shown a weakly positive linear correlation between the Shannon-Weiner Diversity Index. However, the parameters such as salinity (r= 0.0558), total dissolved solids (r= 0.0396), and conductivity (r=0.0151) have shown no correlation between the Shannon-Weiner Diversity Index.

There was a perfectly linear negative correlation with statistically significant (*P*<0.05) between the Shannon-Weiner Diversity Index and the parameters of turbidity (*r*= -0.996). Besides, there was also a moderately negative linear correlation with statistically non-significant (*P*<0.05) between the Shannon-Weiner Diversity Index and the parameters of phosphate (*r*= -0.5327). Moreover, the Shannon-Weiner Diversity Index and the parameters of ammonia have shown a weakly negative correlation (*r*= -0.2216). Meanwhile, the parameters of nitrite (*r*= -0.1533) and nitrate (*r*= -0.0442) have shown no correlation with statistically non-significant (*P*<0.05) between the Shannon-Wiener Diversity Index.

4.5.2 Pielou's Evenness Index (*J′*)

A Pearson correlation coefficient was computed to determine the linear relationship between the Pielou's Evenness Index (*J′*) and pore water quality parameters in Sibuti mangrove, Sarawak. The parameters included pH, total dissolved solids, salinity, temperature, turbidity, conductivity, dissolved oxygen, ammonia, nitrite, phosphate, and nitrate.

Table 4.5.2 Pearson correlation coefficient between Pielou's Evenness Index (*J'*) and pore water quality parameters in Sibuti mangrove, Sarawak.

Water Quality Parameters	Correlation coefficient (*r*) value	*P*-value (2-tailed)
pH	-0.2492	0.840
TDS (ppm)	-0.6448	0.554
Salinity (ppt)	-0.6323	0.564
Temperature (˚C)	-0.3991	0.739
Turbidity (NTU)	-0.7564	0.454
Conductivity (S/m)	-0.6633	0.538
DO (mg/L)	-0.1146	0.927
Ammonia (mg/L)	0.4942	0.671
Nitrite (mg/L)	0.5534	0.627
Phosphate(mg/L)	0.1776	0.886
Nitrate (mg/L)	0.6413	0.557

Based on the table above (Table 4.5.2), there was a moderately positive correlation with statistically non-significance between the Pielou's Evenness Index (*J'*) and the parameters of nitrate (r= 0.6413, P= 0.557), and nitrite (r= 0.5534, P= 0.627). Besides, there was also a weakly positive correlation with statistically non-significance (P>0.05) between the Pielou's Evenness Index (*J'*) and the parameters of ammonia (r= 0.4942). There was also no correlation between the Pielou's Evenness Index (*J'*) and the parameters of phosphate (r= 0.1776, P= 0.886), and dissolved oxygen (r= -0.1146, P= 0.927).

There was a strongly negative correlation between Pielou's Evenness Index and the parameters of turbidity (*r*= -0.7564, *P*= 0.454). Besides, there was also a moderate negative correlation with statistically non-significant (*P*<0.05) between Pielou's Evenness Index and the parameters of conductivity (*r*= -0.6633, *P*= 0.538), followed by total dissolved solids (*r*= -0.6448, *P*= 0.554), salinity (*r*= -0.6323, *P*= 0.564). Moreover, there was a weak correlation between Pielou's Evenness Index and the parameters of temperature (*r*= -0.3991, *P*= 0.739), and pH (*r*= -0.2492, *P*= 0.840).

4.5.3 Margalef's Richness Index (*d*)

A Pearson correlation coefficient was computed to determine the linear relationship between Margalef's Richness Index (*d*) and pore water quality parameters in Sibuti mangrove, Sarawak. Based on the table below (Table 4.5.3), there was a strongly positive correlation with statistically non-significance between the Margalef's Richness Index (*d*) and pore water quality parameters of nitrate (*r*= 0.9857), followed by nitrite (*r*= 0.9613), and ammonia (*r*= 0.9398). There was also a moderately positive correlation with statistically non-significant between Margalef's Richness Index (*d*) and pore water quality parameters of phosphate (*r*= 0.7731).

There was a strongly negative linear correlation (*r*>-0.80) with statistically non-significance (*P*>0.05) between Margalef's Richness Index and the parameters which included total dissolved solids, conductivity, salinity, temperature, and Ph. There was also a moderately negative linear correlation between Margalef's Richness Index and the parameters of dissolved oxygen (*r*= -0.7311, *P*= 0.478). Moreover, there was also no linear correlation with statistically non-significance between Margalef's Richness Index and the parameters of turbidity (*r*= -0.1521) and ammonia (*r*= 0.9398).

Table 4.5.3 Pearson correlation coefficient between Margalef's Richness Index (*d*) and pore water quality parameters in Sibuti mangrove, Sarawak.

Water Quality Parameters	Correlation coefficient (*r*) value	*P*-value (2-tailed)
pH	-0.8174	0.391
TDS (ppm)	-0.9864	0.105
Salinity (ppt)	-0.9836	0.115
Temperature (˚C)	-0.8982	0.290
Turbidity (NTU)	-0.1521	0.903
Conductivity (S/m)	-0.9902	0.089
DO (mg/L)	-0.7311	0.478
Ammonia (mg/L)	0.9398	0.222
Nitrite (mg/L)	0.9613	0.178
Phosphate(mg/L)	0.7731	0.437
Nitrate (mg/L)	0.9857	0.108

CHAPTER 5

DISCUSSION

5.1 Distribution of Macrobenthic Community

Mangroves are one of the ecosystems that allow only certain organisms to survive. This is due to harsh conditions or environments that restrict organisms from growing and adapting to these conditions. However, terrestrial species which also known as macrobenthos, is one of the creatures that live in this harsh environment (Iglesias-Rios & Mazzoni, 2014). Therefore, macrobenthic communities that are commonly found in mangrove areas are Polychaetes, Bivalvia, Gastropod, and Crustaceans (Lardicci et al., 2004).

In this study, the recorded macrobenthic communities are Polychaetes, Clitellata, Bivalvia, and Gastropod. The highest amount of benthos among the Classes is Gastropod, followed by Polychaetes, Bivalvia, and Clitellata. According to Galgani et al. (2023), predation, competition, food availability, and environmental factors all affect the spread of gastropods. Furthermore, because gastropods are plentiful in environments ideal for their habitat, their presence can therefore be interpreted as a sign of greater water quality. The distribution of macrobenthos in mangrove areas also can classified into several zones, which are seaward, mid, and landward zones, depending on where the tidal position occurs (Waycott et al., 2006b). The seaward zone is the zone where it is fully exposed to all tides, whereas the mid-zone is usually less influenced by tides. The landward zone is only inundated by the highest spring tides, which are exposed to land runoff or groundwater.

Based on the sampling locations, Plot 3 has the greatest abundance of gastropods, as this site area was located at the upper stream, where there is no pollution occurring around the sampling location. Moreover, Plot 3 is the farthest from the village which means less human activities around the sampling area. The Gastropoda families Plot 3 site area are Littorinidae, Potamididae, Neritidae, and Elobidae. However, among the gastropod species that have been identified, *Cerithidea charbonnieri* from the family of Potamididae has the highest distribution around Plot 3. The family of Potamididae is one of the Gastropoda family that commonly dominates the mangrove site (Maturbongs et al., 2017; Baderan et al., 2019). Besides, Baderan et al. (2019) also stated that this family can adapt well to their habitat environments, which makes them able to live longer than other classes. *C. charbonnieri* also dominated the seaward zone, in which they are mostly found on the roots, trunks, and leaves of the mangrove trees, *Rhizophora*.

However, it differs from Plot 1, as this location was near the village. Therefore, the abundance of gastropods in Plot 1 was the lowest among the other two plots. The Gastropod families found in this site are Littorinidae, Potamididae, and Neritidae. Two species of the Littorinidae family dominated Plot 1, which are *Littoraria scabra* and *Littoraria carinifera*. According to Budiman (1991); and (Baderan et al., 2019), species of Littorinidae are commonly found living on the stem, trunks, leaves, and branches of mangrove trees. Besides, the distribution is based on the habitat characteristics and availability of various vegetation types. They are also able to crawl to higher places using their slime in most vegetation. Hence, most of these species were found in the mid-zone due to greater vegetation than the seaward zone and landward zone.

For the class of Polychaetes, 3 families were identified in this study, which are Capitellidae (3 species), Nepthtyidae (1 species), and Nereididae (1 species). Most of the polychaetes species were found in Plot 1, which is from the seaward zone. This is due to Plot 1 being situated near the coastal area. According to Mustapha Mohamad Pazi et al. (2016), the seaward zone is more likely affected by seawater than the freshwater. Hence, the pH of the soil becomes the factor that affects the distribution of macrobenthos. Other than that, the sediment characteristics also affect the distribution of the polychaete species. This is because the grain structure in Plot 1 was mostly sand, which makes the macrobenthos able to bury themselves in it (Chowdhury et al., 2022). However, it differed for Plot 3, there were no polychaetes found during the identification process. This might be due to the roots of the mangrove tree, *Rhizophora*, which makes the polychaetes hard to survive in those environments. Even though the grain structure in Plot 3 was mostly sand, however, there is no domination of polychaetes.

There were also several species of class Bivalvia identified in this study, which are *Geloina erosa*, *Crassostrea rhizophorae*, and *Meretrix* sp. Most of these species were also identified in Plot 1 however no domination in Plot 3. One of the reasons is the sediment characteristics that allow the Bivalves to live in it. The grain structure of Plot 1 is mostly sand and silt, which makes the Bivalves burry themselves easily. According to Hermi et al. (2021), the clam species' existence was influenced by the environment. Bivalves' range is also further restricted by several variables, including genetics and the way they select their environment. Hence, the density of bivalves in the natural world might serve as a sign of habitat suitability (Doddy, 1998; Hermi et al., 2021).

5.2 Macrobenthic Communities Population Parameters

Diversity indices can reveal details about the habitat that organisms inhabit rather than just consider the taxa of individuals (Gaufin 1973; Hawkes, 1979; Teles, 1994; Yap et al., 2003). The Number and Taxa (*S*) was the highest in Plot 1 (13), followed by Plot 2 (9), and Plot 3 (5) (Table 4.2.1). Meanwhile, the Number of Individuals (*N*) ranged from 81 to 116 individuals, increasing gradually towards upstream, Plot 3. Even though Plot 1 has the lowest Number of Individuals (*N*) but has the greatest Number of Taxa (S), this means that Plot 1 exhibits more equally distributed abundance with more diversified macrobenthos.

The diversity index for the three plots ranged between 0.756 to 2.006; the evenness index ranged between 0.237 to 0.767; and the richness index ranged from 1.4 to 1.737. Based on a past study in the year 2016 in Kuala Sibuti, the diversity index ranged from 1.23 to 1.57; the evenness index ranged from 0.71 to 0.92; and the richness index ranged from 1.10 to 1.88 (Kamal et al., 2016b). The diversity of benthos communities has increased distribution as the years passed by. This might be due to the changes in natural environments, sediment, and soil texture, which make the organisms inhabit the areas. Besides, in the study from Semenyih River, Selangor also stated that the diversity index is 0.98; the evenness index is 0.84 and the richness index is 1.91 (Yap et al., 2003). Moreover, according to another study from Sungai Pulai Estuary, Johor, the diversity index ranged between 1.15 to 1.64; the evenness index ranged between 0.55 to 0.70; and the richness index ranged between 1.70 to 2.24 (Wan Shi et al., 2014). Basically, all of the values from past studies are relevant to this study. Nevertheless, some research has shown that the sensitivity to tiny fractions (Hennink & Zeven, 1991) meant that the Shannon-Wiener Diversity Index (H') could not quantify this study with accuracy (Hennink & Zeven, 1991; Kalimuthu et al., 2022).

5.3 Pore Water Quality Parameters

The water quality parameters that were observed in this study are pH, total dissolved solids, salinity, temperature, turbidity, conductivity, dissolved oxygen, ammonia, nitrite, phosphate, and nitrate. There was a significant difference ($P<0.05$) between the plots and the turbidity ($P=0.003$). Turbidity values in this study ranged between 178 to 816.67 NTU. This value is considered higher than the optimum turbidity values in mangrove areas. According to Soeprobowati et al. (2022), climate change also can influence the increase of tidal levels. The silt suspended in water columns can cause the water to be more turbid. Besides, the values of turbidity also might be affected by the measurement time, which means the weather for example rainy season during the site visit.

Dissolved oxygen also showed a significant difference between the plots ($P=0.003$), where it ranged between 2.47 to 4.02 mg/L. These results occurred due to the organic matter decomposition performed by the microbenthic communities, which also enhanced the microbial activities in the sediments (Constable, 1999; Bremmer, 2005; Hajializadeh et al., 2020). The microbial activities mostly consume oxygen, which affects the depletion of dissolved oxygen in the sediment. Hence, the dissolved oxygen levels in the studying areas are affected by several factors that might influence its fluctuation.

Moreover, the parameters of ammonia (*P*= 0.014), nitrite (*P*= 0.049), and phosphate (*P*=0.003), also have shown a significant difference between the plots (*P*<0.05). These three components are important in contributing to the nutrient cycle, which can provide nutrients for the mangrove trees, as well as the macrobenthos in the mangrove areas. Mostly, some factors might have influenced the nutrient cycle around the mangrove area, which are the decomposition of organic matter and tides. For the decomposition of organic matter, macrobenthos play important roles in decomposing organic matter into sediments (Heip et al., 1995; Herman et al., 1999; (Wan Hussin & Ab Lah, 2020). Therefore, as the tidal fluctuations in the mangrove area, the nutrients were distributed around the area, which caused the macrobenthic communities to have enough nutrients and increases their abundance composition.

Plots and the pore water quality metrics (pH, total dissolved solids, salinity, conductivity, and nitrate) did not significantly vary (*P*>0.05). This means that most of the pore water quality parameters might be consistent in all of the plots. Besides, the sediment characteristics also might affect the pore water quality. For example, all of the selected study areas have almost the same percentage of sand and silt. The substrate features also play a major role in defining the distinctions between species (Coblentz et al., 2015; Zakirah et al., 2019; Norouzi & Tavani, 2016; Almaniar et al., 2021). Therefore, the sediment in study areas might be the same, where it affects the pore water quality values.

Besides, the temperature in this study area ranged between 25.27 to 26.10 ˚C, which is an optimal temperature for the macrobenthic communities to grow (Basyuni et al., 2018; Wang et al., 2020; Almaniar et al., 2021). However, the non-significant relationship between the plots and temperature might be affected by the climate change that influences the temperature and hydrological cycles, thus affecting the water quality. In addition, the temperature of the water also can be impacted by the shade provided by the vegetation and the delayed measurement time (Leatemia et al., 2017; Almaniar et al., 2021).

5.4 Correlation Between Diversity and Pore Water Quality Parameters

Correlation analysis was conducted to determine the relationship between the diversity indexes and the pore water quality parameters. The relationship between the diversity of macrobenthos and turbidity has shown a strongly negative correlation (r= -0.9996) with statistical significance (P= 0.017). The turbidity of the plots ranged between 179.00 NTU to 816.67 NTU. Plot 1 has shown the lowest turbidity (179.00 NTU), followed by Plot 3 (463.33 NTU), and Plot 2 has the highest turbidity (816.67 NTU). According to Azis et al. (2015), both organic and inorganic matter that is largely retained and dispersed throughout the water columns have an impact on turbidity. Based on the data obtained, the turbidity in Plot 1 was the lowest among the other two plots. This means that the lower the turbidity, the greater the diversity of macrobenthos.

The relationship between the diversity of macrobenthos and the dissolved oxygen has shown a moderate positive non-significant correlation (r= 0.5855, P>0.05). As a result, this relationship indicates that the higher dissolved oxygen levels are associated with greater diversity of macrobenthos. According to Hajializadeh et al., (2020), the ecological features of the region, including tides and water chemistry, have an impact on the benthos. Hence, there are weakly positive non-significant relationships between the diversity of microbenthic communities and parameters of pH (r= 0.4693, P>0.05) and temperature (r= 0.3239, P>0.05). Hajializadeh et al. (2020) also mentioned that the abundance and diversity of macrobenthic communities are influenced by the roots of mangrove trees which also influence the sediment characteristics. Due to that, diverse macrobenthos were identified in Plot 1 than in the other two plots. Therefore, the parameters such as pH and temperature in the pore water may affect the diversity of macrobenthos.

In addition, there is also a negative non-significant correlation between the evenness and richness of microbenthic communities against the pore water quality parameters. In terms of evenness, the species distribution is poor, implying that some of the species in this research region may be dominating. This species may demonstrate the potential of biological processes to maintain and enhance water quality. Based on the study by Rahman et al. (2021), macrobenthic communities are commonly known as bio-indicators to monitor the environment, such as pollution, and ecological patterns. Therefore, they can maintain the water quality around the mangrove area.

CHAPTER 6

CONCLUSION

The community structure of macrobenthos is influenced by diversity indices, environmental conditions, sediment properties, and species diversity. After doing some research, there is a significant difference between the plots and turbidity, dissolved oxygen, ammonia, nitrite, and phosphate. There is also a strongly negative significant correlation between diversity and turbidity. Therefore, it can be concluded that the diversity of macrobenthos in different zones is affected by pore water quality, mainly turbidity, followed by phosphate, dissolved oxygen, ammonia, and nitrite. However, further studies needed to be done to observe and identify the diversity of macrobenthos in Kuala Sibuti, Miri, besides to determine the environmental factors that affect the diversity.

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APPENDIX A

The Macrobenthos Species Identified

Phylum	Class	Species	Plot 1	Plot 2	Plot 3
Annelida	Polychaeta	*Mediomastus californiensis*	3	1	0
		Mediomastus sp.	4	0	0
		Notomastus latericeus	5	0	0
		Nephtys polybranchia	8	0	0
		Namalycastis sp.	3	0	0
	Clitellata	*Glossiphonia* sp.	2	0	0
Mollusca	Bivalvia	*Geloina erosa*	3	0	0
		Crassostrea rhizophorae	4	0	0
		Meretrix sp.	0	2	0
	Gastropod	*Littoraria scabra*	10	1	0
		Littoraria carinifera	16	7	23
		Cerithidea charbonnieri	0	16	59
		Cerithidea quoyii	7	5	0
		Vittina coromandeliana	14	26	13
		Neripteron violaceum	2	40	11
		Neripteron cornucopia	0	4	0
		Ellobium aurismidae	0	0	10
		TOTAL	**81**	**102**	**116**

APPENDIX B

Results of ANOVA and Tukey analysis of Pore Water Quality Parameters

pH

Test for equal means (ANOVA)					
	Sum of sqrs	df	Mean square	F	p (same)
Rows:	0.004822	2	0.002411	0.2889	0.7635
Columns:	0.049422	2	0.024711	2.961	0.1625
Error:	0.033378	4	0.008344		
Total:	0.087622	8			

Tukey			
	P1	P2	P3
P1		0.8182	0.08337
P2	0.8683		0.182
P3	3.763	2.894	

Salinity

Test for equal means (ANOVA)					
	Sum of sqrs	df	Mean square	F	p (same)
Rows:	1.60889	2	0.804444	0.8213	0.5025
Columns:	1.87556	2	0.937778	0.9575	0.4573
Error:	3.91778	4	0.979444		
Total:	7.40222	8			

Tukey			
	P1	P2	P3
P1		0.9961	0.4572
P2	0.1203		0.5002
P3	1.805	1.684	

Total Dissolved Solids

Test for equal means (ANOVA)					
	Sum of sqrs	df	Mean square	F	p (same)
Rows:	4.23E+06	2	2.11E+06	0.7982	0.5108
Columns:	4.54E+06	2	2.27E+06	0.8562	0.4903
Error:	1.06E+07	4	2.65E+06		
Total:	1.94E+07	8			

Tukey			
	P1	P2	P3
P1		0.9941	0.4843
P2	0.1471		0.5387
P3	1.728	1.581	

Temperature

Test for equal means (ANOVA)					
	Sum of sqrs	df	Mean square	F	p (same)
Rows:	0.095556	2	0.047778	0.4057	0.6912
Columns:	1.06889	2	0.534444	4.538	0.0936
Error:	0.471111	4	0.117778		
Total:	1.63556	8			

Tukey			
	P1	P2	P3
P1		0.4978	0.0369
P2	1.691		0.1647
P3	4.697	3.006	

Turbidity

Test for equal means (ANOVA)					
	Sum of sqrs	df	Mean square	F	p (same)
Rows:	37760.7	2	18880.3	1.225	0.3846
Columns:	612309	2	306154	19.86	0.00837
Error:	61658.7	4	15414.7		
Total:	711728	8			

Tukey			
	P1	P2	P3
P1		0.00238	0.0788
P2	8.58		0.0351
P3	3.826	4.754	

Conductivity

Test for equal means (ANOVA)					
	Sum of sqrs	df	Mean square	F	p (same)
Rows:	0.03885	2	0.019425	0.791	0.5135
Columns:	0.037917	2	0.018958	0.772	0.5206
Error:	0.098233	4	0.024558		
Total:	0.175	8			

Tukey			
	P1	P2	P3
P1		0.9976	0.5228
P2	0.09549		0.5591
P3	1.623	1.528	

Dissolved Oxygen

Test for equal means (ANOVA)					
	Sum of sqrs	df	Mean square	F	p (same)
Rows:	0.149622	2	0.074811	0.6098	0.5873
Columns:	3.65796	2	1.82898	14.91	0.01399
Error:	0.490711	4	0.122678		
Total:	4.29829	8			

Tukey			
	P1	P2	P3
P1		0.02656	0.00295
P2	5.09		0.1499
P3	8.2	3.11	

Ammonia

Test for equal means (ANOVA)					
	Sum of sqrs	df	Mean square	F	p (same)
Rows:	0.193549	2	0.096775	0.7957	0.5118
Columns:	3.58027	2	1.79014	14.72	0.01431
Error:	0.486508	4	0.121627		
Total:	4.26033	8			

Tukey			
	P1	P2	P3
P1		0.3816	0.00407
P2	2.034		0.01713
P3	7.671	5.637	

Nitrite

Test for equal means (ANOVA)					
	Sum of sqrs	df	Mean square	F	p (same)
Rows:	0.065659	2	0.03283	0.332	0.7355
Columns:	1.39254	2	0.696272	7.042	0.04893
Error:	0.395507	4	0.098877		
Total:	1.85371	8			

Tukey			
	P1	P2	P3
P1		0.7159	0.01647
P2	1.134		0.04169
P3	5.687	4.553	

Phosphate

Test for equal means (ANOVA)					
	Sum of sqrs	df	Mean square	F	p (same)
Rows:	0.002018	2	0.001009	0.1236	0.887
Columns:	0.612933	2	0.306467	37.54	0.002558
Error:	0.032653	4	0.008163		
Total:	0.647605	8			

Tukey			
	P1	P2	P3
P1		0.00299	0.00032
P2	8.177		0.01001
P3	14.53	6.349	

Nitrate

Test for equal means (ANOVA)					
	Sum of sqrs	df	Mean square	F	p (same)
Rows:	0.136443	2	0.068222	0.4067	0.6906
Columns:	0.949781	2	0.47489	2.831	0.1714
Error:	0.671018	4	0.167755		
Total:	1.75724	8			

Tukey			
	P1	P2	P3
P1		0.9759	0.1163
P2	0.2985		0.1522
P3	3.393	3.094	

APPENDIX C

Pearson Correlation of Diversity Index and Pore Water Quality Parameters

	pH	TDS (ppm)	Salinity (ppt)	Temp. (˚C)	Turbidity (NTU)
pH		0.2858	0.27546	0.101	0.70639
TDS (ppm)	0.90091		0.01034	0.1848	0.99219
Salinity (ppt)	0.90784	0.99987		0.17446	0.98185
Temperature (˚C)	0.98744	0.95816	0.96268		0.80739
Turbidity (NTU)	-0.44502	-0.012266	-0.028504	-0.29796	
Conductivity (S/m)	0.89001	0.9997	0.99917	0.95086	0.012238
DO (mg/L)	0.99064	0.83322	0.84209	0.95663	-0.56312
Ammonia (mg/L)	-0.96508	-0.98314	-0.98598	-0.99434	0.19489
Nitrite (mg/L)	-0.94454	-0.99347	-0.99519	-0.98456	0.12625
Phosphate(mg/L)	-0.99732	-0.86672	-0.8747	-0.97323	0.50939
Nitrate (mg/L)	-0.90292	-0.99999	-0.99993	-0.95948	0.016907
Shannon-Weiner Diversity Index (*H'*)	0.46931	0.039568	0.055792	0.32392	-0.99963
Pielou's Evenness (*J'*)	-0.24918	-0.64481	-0.63231	-0.39905	-0.75638
Margalef's Richness Index (*d*)	-0.81743	-0.98643	-0.98363	-0.89817	-0.15207

*Continued

	Cond. (S/m)	DO (mg/L)	Ammonia (mg/L)	Nitrite (mg/L)	Phosphate (mg/L)
pH	0.3014	0.087189	0.16874	0.21302	0.046654
TDS (ppm)	0.0156	0.37299	0.11706	0.072782	0.33245
Salinity (ppt)	0.02594	0.36265	0.10672	0.062442	0.32211
Temperature (˚C)	0.2004	0.18819	0.067744	0.11202	0.14765
Turbidity (NTU)	0.99221	0.6192	0.87513	0.91941	0.65974
Conductivity (S/m)		0.38859	0.13266	0.088382	0.34805
DO (mg/L)	0.81942		0.25593	0.30021	0.040535
Ammonia (mg/L)	-0.97837	-0.92028		0.044276	0.21539
Nitrite (mg/L)	-0.99038	-0.89086	0.99758		0.25967
Phosphate(mg/L)	-0.85423	-0.99797	0.94331	0.91796	
Nitrate (mg/L)	-0.99958	-0.83578	0.98398	0.99399	0.86902
Shannon-Weiner Diversity Index (*H'*)	0.015073	0.58548	-0.2216	-0.1533	-0.53271
Pielou's Evenness (*J'*)	-0.66334	-0.11463	0.49418	0.5534	0.17761
Margalef's Richness Index (*d*)	-0.99016	-0.73113	0.93978	0.96126	0.77306

*Continued

	Nitrate (mg/L)	Shannon-Weiner Diversity Index (*H'*)	Pielou's Evenness (*J'*)	Margalef's Richness Index (*d*)
pH	0.28284	0.689	0.83968	0.39079
TDS (ppm)	0.0029547	0.9748	0.55388	0.10499
Salinity (ppt)	0.0073854	0.96446	0.56422	0.11533
Temperature (˚C)	0.18185	0.79	0.73868	0.2898
Turbidity (NTU)	0.98924	0.017388	0.45393	0.90281
Conductivity (S/m)	0.018555	0.9904	0.53828	0.089394
DO (mg/L)	0.37003	0.60182	0.92686	0.47798
Ammonia (mg/L)	0.1141	0.85775	0.67093	0.22205
Nitrite (mg/L)	0.069827	0.90202	0.62666	0.17778
Phosphate(mg/L)	0.3295	0.64235	0.88633	0.43745
Nitrate (mg/L)		0.97185	0.55683	0.10795
Shannon-Weiner Diversity Index (*H'*)	-0.044205		0.47132	0.9202
Pielou's Evenness (*J'*)	0.64125	0.73823		0.44888
Margalef's Richness Index (*d*)	0.98566	0.12502	0.76155	