DIVERSITY AND DISTRIBUTION OF MOLLUSCS IN THE HIGH SHORE MANGROVES OF PENINSULAR MALAYSIA WITH EMPHASIS ON THE FAMILY ELLOBIIDAE

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DIVERSITY AND DISTRIBUTION OF MOLLUSCS IN THE HIGH SHORE MANGROVES OF PENINSULAR MALAYSIA WITH EMPHASIS ON THE FAMILY ELLOBIIDAE

ABSTRACT

The high shore mangrove or the dry land forest with its fauna is first and most vulnerable part of the mangrove ecosystem to be subjected to anthropogenic disturbance such as land conversion for aquaculture, agriculture, housing schemes, infrastructure and harbour facilities. This study aimed to document the diversity, occurrence and distribution of high shore molluscs in Peninsular Malaysia, the Ellobiidae, in order to assess their vulnerability to human disturbance. One major objective of the study was to construct a taxonomic key to the Ellobiidae of the high shore mangroves. Field surveys and samplings of high shore molluscs were carried out at ten locations of mangroves in Peninsular Malaysia from September 2013 to April 2015, where the mangroves ranged from disturbed, mixed to pristine. At Matang Mangrove Forest Reserve, field visits were made monthly from February 2014 until May 2015 (16 months); here, high-shore molluscs were sampled on a permanent sampling plot, as well as sampling molluscs at the lower shore. Fifty-four species and 17 families of molluscs were recorded from the ten sampling locations throughout the peninsula’s coastline. A total of 19 molluscs species from eight genera and five families, were recorded for the first time in Peninsular Malaysia. One species, *Ellobium scheepmakeri*, once thought to be locally extinct, is rediscovered in Bukit Belimbing (Kuala Selangor) in Selangor. Most of the high-shore species were from the family Ellobiidae (15 species, 6 genera), and Cyrenidae (2 species, 1 genus). Taxonomic keys to the species of *Auriculastra*, *Cassidula*, *Cylindrotis*, *Ellobium*, *Melampus*, *Laemodonta* and *Pythia* are constructed for the Ellobiidae. Correspondence analysis of mollusc distribution in the Matang mangrove indicates that while the intertidal molluscs display the typical zonation

pattern that can be ascribed to tidal immersion or emersion, various species also display microhabitat preference (e.g. living on foliage, tree trunks, fallen logs). In general, the high-shore ellobiids tend to live on higher places and/or cluster together (especially *E. aurismidae*) and are present throughout the year. Since ellobiids are adapted to live on the high shore margins of mangrove forests, they can be useful bioindicators of anthropogenic impacts on the mangrove and other coastal ecosystems.

Keywords: molluscs, high shore mangroves, ellobiidae, taxonomic keys, microhabitat.

KEPELBAGAIAN DAN TABURAN MOLUSKA DI HUTAN PAYA BAKAU TINGGI DI SEMENANJUNG MALAYSIA DENGAN PENEKANAN KEPADA KELUARGA ELLOBIIDAE

ABSTRAK

Paya bakau tinggi atau hutan darat dengan faunanya adalah bahagian awal dan paling lemah dalam ekosistem bakau yang diancam oleh gangguan antropogenik seperti penukaran tanah untuk pembangunan akuakultur, pertanian, kemudahan infrastruktur dan pelabuhan. Kajian ini bertujuan untuk mendokumenkan kepelbagaian, keterdapatan dan taburan moluska paya bakau tinggi di Semenanjung Malaysia, khususnya Ellobiidae, untuk menilai kerentanan mereka terhadap gangguan manusia. Satu matlamat utama kajian ini adalah untuk membina kunci taksonomi kepada Ellobiidae daripada hutan bakau tinggi. Tinjauan lapangan dan penyampelan moluska paya bakau tinggi telah dijalankan di sepuluh lokasi hutan bakau di Semenanjung Malaysia dari September 2013 hingga April 2015, di mana bakau terdiri daripada terganggu, bercampur dengan bebas gangguan. Di Hutan Simpan Paya Laut Matang, lawatan lapangan dibuat setiap bulan daripada Februari 2014 sehingga Mei 2015 (16 bulan); di sini, moluska pantai tinggi telah disample dalam plot persampelan kekal, serta penyampelan moluska di paya bakau rendah. Lima puluh empat spesies dan 17 keluarga moluska direkodkan dari sepuluh lokasi persampelan di seluruh pantai Semenanjung. Sejumlah 19 spesies moluska dari lapan genera dan lima keluarga direkodkan buat kali pertama di Semenanjung Malaysia. Satu spesies, *Ellobium scheepmakeri*, yang pernah dikatakan telah pupus, ditemui semula di Bukit Belimbing (Kuala Selangor) di Selangor. Kebanyakan spesies pantai tinggi berasal dari keluarga Ellobiidae (15 spesies, 6 genera), dan Cyrenidae (2 spesies, 1 genus). Kunci taksonomi kepada spesies *Auriculastra*, *Cassidula*, *Cylindrotis*, *Ellobium*, *Melampus*, *Laemodonta* dan *Pythia* dihasilkan untuk Ellobiidae paya bakau tinggi. Analisis koresponden penyebaran moluska di paya bakau Matang menunjukkan bahawa sementara moluska intertidal memaparkan corak zonasi biasa yang dipengaruhi oleh rendaman atau penyusupan pasang surut, pelbagai spesies juga memaparkan keutamaan microhabitat (contohnya. hidup di dedaunan, batang pokok, kayu reput). Secara umum, ellobiid paya bakau tinggi cenderung untuk hidup di tempat yang lebih tinggi dan / atau berkumpul bersama (terutamanya *E. aurismidae*), dan terdapat sepanjang tahun. Oleh kerana ellobiid terdapat di hutan paya bakau tinggi, mereka boleh dijadikan sebagai penunjuk aras biologi berguna untuk kesan antropogenik pada hutan bakau dan ekosistem pantai yang lain.

Kata kunci: moluska, paya bakau tinggi, ellobiidae, kekunci taksonomi, mikrohabitat.

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CHAPTER 1: INTRODUCTION

1.1 Scope of study

Mollusca is one of the most diverse groups of animals on Earth with more than 50, 000 living species (Appeltans *et al.*, 2012; Bouchet, 2006; Chapman, 2006) including the classes of Bivalvia, Caudofoveata, Cephalopoda, Gastropoda, Monoplacophora, Polyplacophora, Rostroconchia, Scaphopoda, and Solenogastres. As the largest marine phylum comprising about 23% of the named marine organisms, these highly diverse molluscs also occupy various freshwater and terrestrial habitats. Molluscs, which are one of the dominant groups of invertebrates found in mangroves, play a significant role in the structure and function of mangrove ecosystems (Ashton *et al*., 2003; Macintosh *et al*., 2002; Ng & Sivasothi, 1999; Tan & Chou, 2000). Several studies have been conducted on molluscs in Malaysian mangroves (Alfian *et al*., 2005; Ashton *et al*., 2003; Berry, 1972; Faezah & Farah, 2011; Morris & Purchon, 1981; Purchon & Purchon, 1981; Sasekumar, 1974; Sasekumar & Chong, 1998; Sasekumar & Moh, 2010; Sasekumar & Ooi, 2005; Tan *et al*., 2008; Way & Purchon, 1981; Wong *et al*., 2008; Wong & Arshad, 2011; Zaidi *et al*., 2008; Singh & Norashekin, 2016).

Though marine science has received much attention in Malaysia in recent years, molluscs studies are still neglected by many researchers, leading to shortage of basic information such as the diversity data and species check list. In Malaysia, mollusc taxonomic studies started from the study of the land snails by the British in the pre-independence era. The earliest records and findings were published in the Raffles Bulletin of Zoology (then The Bulletin of the Raffles Museum) between 1930s to the 1960s (van Benthem Jutting, 1949; Berry, 1965; van Benthem Jutting, 1950, 1952; Laidlaw, 1932, 1937, 1940; Pathansali, 1963; Purchon & Enoch, 1954; Robson, 1932; Tweedie, 1961), but there is a lack of studies solely focusing on the high shore mangrove habitats which are only inundated by extreme spring tides a few times a month. There are about 105, 537 ha of mangrove forest reserves in Peninsular Malaysia which consisted of 77.8% productive forest across the sheltered west coast and the more exposed east coast (Latiff, 2012). Nevertheless, given their enormous importance, research on the microbenthic faunas in the Malaysian's mangroves has received only limited scientific consideration. This study was carried out to help fill the gaps in knowledge on the molluscan community living in the threatened high shore mangroves.

1.2 Significance of Study

The species richness of marine molluscs offers great research opportunities to Malaysian scientists who have interest in this remarkable group. As the molluscan fauna in this country are poorly known, more attention should be given to examine them. The study of molluscs will not only provide useful baseline information but could also assist in other applied aspects of malacology such as of mollusc culture and pest control. This study focuses on the mangrove high shore molluscs and the air-breathing family Ellobiidae that are typically abundant among boulders and inside crevices at the upper littoral zone of the mangroves and salt marshes. The upper littoral or high shore mangroves are the first forest to be encroached by humans due to rapid development in the coastal zone, including brackish water aquaculture. Since these ellobiids have an obligatory existence in mangrove forests, the removal of mangrove forests can lead to local species extinctions (Singh & Norashekin, 2016).

Molluscs is the major predominant invertebrate group in the mangroves beside crabs (Ellison, 2008; Nagelkerken *et al.*, 2008) that represent the link between primary detritus at the bottom of the food chain (Bosire *et al*., 2005), consumers in higher trophic levels (Macintosh, 1984; Dahdouh-Guebas *et al*., 2002), and the predators at the highest levels (Cannicci *et al*., 1996). Molluscs helps to aerate the soil through the digging activity, which affecting the productivity and development of mangroves (Stieglitz *et al*., 2000; Smith *et al*., 2009). Molluscs also altering forest structure in both natural and replanted by the predation of propagules (Steele *et al*., 1999; Bosire *et al*., 2005; Dahdouh-Guebas *et al*., 2010).

This study will contribute new knowledge on the molluscan species found across Peninsular Malaysia that depend on the high shore mangrove areas as their habitat. As our knowledge concerning the relationship between molluscan and high shore mangrove is still limited, this study will elucidate the role of microhabitat to molluscs. This is important in view of the increasing trend of coastal area reclamation in high shore mangroves which are often considered as wastelands.

1.3 Research questions

1. What are the species of molluscs found on the high shore mangroves?
2. How are the molluscs distributed on the high shore mangrove?
3. What are the effects of tidal height and other environmental factors (soil pH, temperature, salinity) on the distribution of high shore molluscs?

1.4 Aims and Objectives

The overall aim of this study was to document the diversity, occurrence and distribution of molluscs in the high shore mangroves of Peninsular Malaysia, and ultimately, to enable assessment of the vulnerability of these molluscs to human disturbance. To achieve this aim, the objectives of this study were to:

1. Survey, identify and record the species of molluscs found in selected high shore mangroves in Peninsular Malaysia.
2. Describe the ellobiid species and construct relevant taxonomic keys to the family Ellobiidae of the high shore mangroves.

3. Determine the spatial and temporal distribution of the mangrove molluscs, and in particular the family Ellobiidae, in a selected mangrove forest.

CHAPTER 2: LITERATURE REVIEW

2.1 Mangroves

Mangroves are basically salt-tolerant forest ecosystems found mainly in tropical and subtropical intertidal regions (Davis, 1940; Mendelssohn & McKee, 2000; Smith, 1992). The major or true mangroves that forming pure stands include 34 species in nine genera and five families (Tomlinson, 1986). The minor species contribute another 23 species in 11 genera and 11 families. Globally, a total of 53 mangrove species in 20 genera and 16 families are present. Duke (2013) identified 69 Australian mangrove species belonging to 26 genera in 20 families. One family fall in the fern division (Polypodiophyta) and the remaining are the angiosperms (Magnoliophyta). The families containing purely mangrove species are Aegialitidaceae, Avicenniaceae, Nypaceae and Pellicieraceae. The orders Myrtales and Rhizophorales contain 25% of all mangrove families while harbouring 50% of all major and minor mangroves species. To date, 65 mangrove species in 22 genera and 16 families were recognized based on previous works by (Duke, 2013; Kathiresan & Bingham, 2001; Tomlinson, 1986).

In Southeast Asia, the naturally occurring mangrove forests usually have the single species zonation that is parallel to the coastline and the river banks as the result of colonization and successional growth (Ong *et al*., 1991). The seaward boundary is usually occupied by *Avicennia alba* Blume and *Sonneratia alba* Sm. followed by *Rhizophora apiculata* Blume and *R. mucronata* Lam. Other species such as *Bruguiera* Lam., *Xylocarpus* J. Koenig, *Ceriops tagal* (Perr.) C. B. Rob., and *Heritiera* Aiton were found to dominate the back mangroves. Ferns *Acrostichum* L. can be found on the slightly higher ground than the normal elevation and on the mounds of mud lobster, *Thallasina* (Latreille, 1806). *Nypa fructicans* Wurmb may develop along the river banks or exists as the lagoon-fringing plants.

A survey of the tidal regime and plant distribution by Watson (1928) in the Port Klang area in Malaysia proposed that the mangrove zonation is based on the number of tides flooding the area per month (Figure 2.1). Mudflats are placed under Class 1 which covers all the high tides of 56 to 62 per month and usually occupied by the seedlings of *A. alba*. Pioneer species like *A. alba* and *Sonneratia* L.f. sp. grow under Class 2 inundation of medium-high tides of 45 to 59 times per month. For Class 3 with normal high tides of 20 to 45 tides monthly, the shore level is dominated *by Rhizophora* L. and others like *Ceriops tagal* (Perr.) C. B. Rob., and *Xylocarpus* J. Koenig. *Bruguiera cylindrica* (L.) Blume and *B. gymnorhiza* (L.) Savigny may be dominant at Class 4 area with spring high tides of 2 to 20 high tides per month. The dry substrate also supports few *Rhizophora* L. and *Xylocarpus* J. Koenig. *B. gymnorhiza* may survive on the landward side which is flooded by occasional tides of less than 2 tides per month for Class 5 areas.

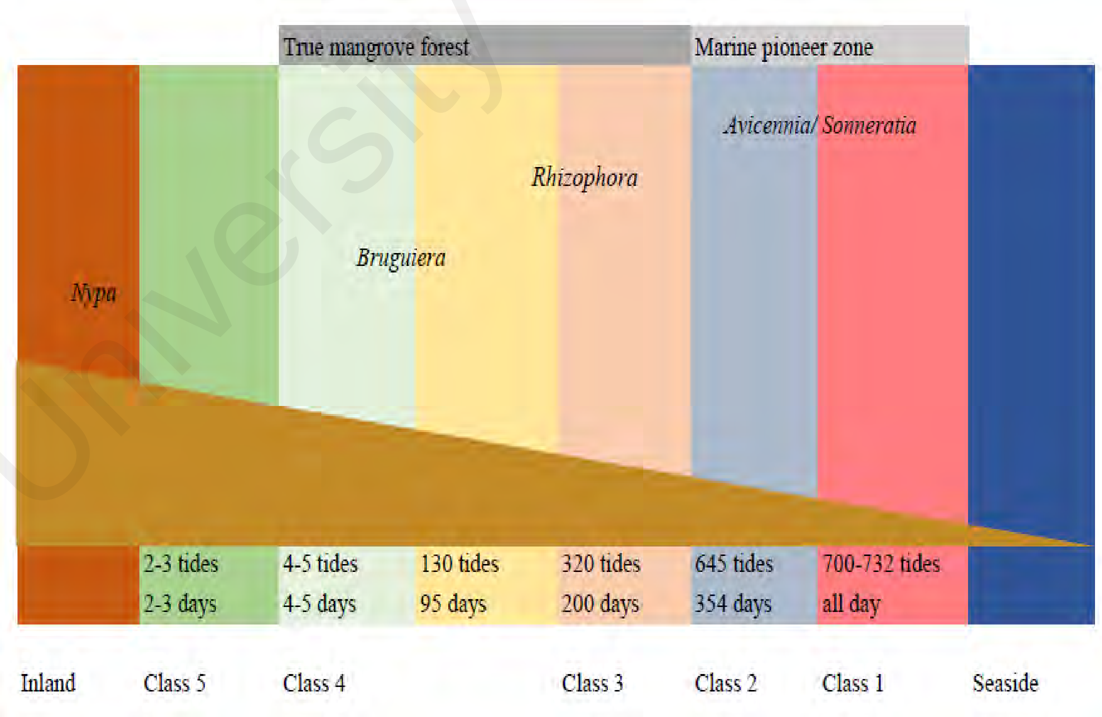

Figure 2.1: Zonation of mangrove based on the number of flooding monthly, adapted from Watson (1928) and Berry (1972).

There are 9 major forest types can be observed in the Malaysian mangroves and these forest types can be sorted in a successional way. The first type is the accumulating *Avicennia* forest which normally occurs towards the seafront bordering the Straits of Malacca. Representing the newly formed forest areas, these forests are characterized by young stands of *Avicennia* species invading the mud flats of the estuaries and foreshores (Ong *et al*., 1991). Common species include *Avicennia alba* and *A. marina* that are sometimes interspersed with *Sonneratia*, *Rhizophora* and *Bruguiera* species. The transitional new forest typically straddles between the accreting *Avicennia* forest and the *Rhizophora-Bruguiera* forest (Latiff, 2012). Normally, it comprises the older accreting *Avicennia* forest, which carries in its intermittent stands of both *Rhizophora* and *Bruguiera* species in varying proportions.

After the *Rhizophora* forest, the *Bruguiera* forest usually consists of pure stands of *Bruguiera cylindrica* with small populations of *Rhizophora* and other *Bruguiera* species. Its occurrence is almost totally along the seafront which renders the area an environmentally sensitive site that warrants conservation and prudent management. The *Bruguiera parviflora* forest is an occasional forest, which usually comprises a mixture of *B. parviflora* with *Rhizophora* species towards the mainland and *B. cylindrica* towards the seafront, as observed by Soepadmo and Pandi Mat Zain (1989). *B. parviflora* forest is more prevalent towards the mainland and is more abundant in the southern part of the Matang mangroves.

Rhizophora forest is the major forest type in Matang Mangroves. It comprises about 85% of the total forested area. This forest type consists predominantly of *Rhizophora apiculata* and *R. mucronata*, the two main commercial species (Goessens *et al.*, 2014). This forest is characterized by trees with straight boles and even canopy heights. The transitional forest is found to straddle in between the luxuriant stand of pure *Rhizophora* forest and the true dryland forest. The forest contains a mixture of sparse stands of *Rhizophora* species and a large population of relic *Bruguiera* species with a dense crop of *Acrostichum* ferns on the forest floor. It is most vulnerable to be transformed to the true dryland forest once the forest cover is removed in one single cutting.

The dryland forest in Matang Mangroves is primarily pristine. It occurs as isolated patches in the more elevated interior of the island and mainland reserves (Chan, 1989). It denotes the final stage of mangrove succession and the transition into inland forest type (Watson, 1928). Structurally, it consists of three canopy layers, namely emergent, main and understorey. The emergent trees can reach diameters and heights of more than 50 cm and 30 m, respectively. In terms of species diversity, the dryland forest is evidently the richest in Matang Mangroves (Chan, 1989). *Nypa* Forest is confined to the upper stretches of river banks of tidal rivers where there is a greater freshwater influence. The palms grow gregariously, interspersed with *Avicennia* and *Sonneratia* species near estuaries, with *Rhizophora* and *Bruguiera* species further inland, and *Heritiera* and *Excoecaria* species in the hinterland with little tidal influence. The undergrowth comprises mainly *Acrostichum* ferns growing on the mud lobster mounds.

The intrusive forest is special and observed in the Matang Mangroves. Here, it comprises of two patches of *Rhizophora* and *Bruguiera* stands within two of the largest dryland forests in Matang Mangroves which have expanded considerably from 1989 to 1998 species (Goessens *et al.,* 2014). This phenomenon is unique as in the normal course of succession in a mangrove forest, the *Rhizophora* or *Bruguiera* forest precedes the dryland forest (Roslan and Nik Mohd Shah, 2014). In this situation, however, the once sparsely populated dryland forest now carries an emerging stand of almost pure *Rhizophora* forest. This forest type is especially highlighted or categorized not for its economic importance, but for the conduct of scientific investigations and research in understanding the development of such forest.

The zonation based on the one-vegetation types may be common along the west coast of Peninsular Malaysia and the distribution of vegetation along the shore gradient generally follows Watson's scheme (Sasekumar *et al.*, 2012). Even so, the local topography and the freshwater runoff may alter the vegetation (Tomlinson, 1986), and certain species may colonize the area as the results of geomorphological processes (Thom, 1967). Besides that, the zonation of mangrove species also reflected the eco-physiological responses of the plants to one or various environmental gradients (i.e. the combination of a variety of elements such as frequency and duration of the inundation, water-logging property of the substrate, the pore water salinity and the pore water potential, that normally determines which plants grows at specific area) (Woodroffe, 1992).

2.2 High Shore Mangrove

According to Watson (1928), the high shore mangroves or dryland forest denotes the last state of mangrove forest succession and the transition state of the inland forest. This kind of forest is usually found at the landward side of the mangrove forest or in the interior portion of the mangrove island where mangroves are only occasionally inundated by exceptional or equinoctial tides. The high shore forest that lies between the mean high-water mark (MHWM) of neap tides and above the mean high-water mark of spring tides is exposed to air for almost 90% of the times as weak tides may fail to cover it for days (Berry, 1972). With less sea water covering the sediment during high tides and longer exposure to the air, the salinity might drop to 9 or 10 ppt (part per thousand) from the normal mean salinity of 25 ppt. During the extreme drought where the only source of water comes from the rain fall, the salinity drops to zero. The pH value usually lies between 6.0 and 7.1 as the result of decomposition of organic materials as well as respiration of the infauna (Gong and Ong, 1990; Forja *et al*., 2004).

The forest floor is normally well shaded by vegetation and is rich with fallen leaves and organic materials. For the true dryland forest, the light fringe of *Rhizophora apiculata* can be found growing along its margin. The forests are normally characterized by the presence of the mud lobster mounds and the *Acrostichum* where a mixture of sparse stands of *Rhizophora* or *Bruguiera* occurs with a dense *Acrostichum* on the forest floor. In terms of species diversity, the dryland forest is the richest in the Matang Mangroves. Species such as *Rhizophora apiculata*, *Heritiera littoralis*, *Ficus microcarpa*, *Flacourtia jangomas*, *Oncosperma tigillarium* and *Bruguiera gymnorhiza* have been reported (Chan, 1989).

2.3 Distribution of High Shore Mangroves in Peninsular Malaysia

In Peninsular Malaysia, mangroves are found primarily along the sheltered west coast of Kedah, Perak, Selangor and Johor (Jusoff & Taha, 2008). The near-shore inlands are also predominantly covered by mangroves such as Klang Islands of Selangor and Pulau Kukup in Johor. Along the rocky shore, small mangrove patches occur in Langkawi (Kedah), Pulau Pangkor (Perak) and Port Dickson, Negeri Sembilan. Moving south, the mangroves colonize the estuaries of Sungai Pulai and Sungai Johor as well as along the Straits of Johor. On the east coast, mangrove forests can be found in the sheltered estuaries of Tok Bali and the delta of Tumpat in Kelantan, Setiu Wetland and Kemaman in Terengganu, and Sungai Bebar of Pahang.

In the Matang Mangrove Forest Reserve of Perak, the extent of the high shore mangroves was reported to be about 2, 305 ha or 5.3% of the total area (Haron, 1981). As stated by Haron (1981), the high shore mangrove has been classified as unproductive forest under the Matang Mangrove Forest Working Plant (1980-1989). The very common and widespread species in the high shore mangrove are *Rhizophora apiculata*, *Heretiera littoralis* and *Ficus microcarpa*. The common species are *Flacourta jangomas*, *Oncosperma tigillarium*, *Bruguiera gymnorrhiza* and *Teijsmanniodendron hollrungii*. *R. apiculata* and *B. gymnorrhiza* are the commercial firewood species. A noteworthy feature of this natural mangrove forest type is the presence of very large trees of *B. gymnorrhiza* which forms the emergent stratum of the forest canopy with 27-30 m in height. High quality timber species such as *O. tigillarium* and *Intsia bijuga* are unique only to the high shore mangroves. *Xylocarpus moluccensis* is another high shore mangrove species which produce high-quality timber for furniture (Watson, 1928) and wood carvings (Chan & Salleh, 1987).

2.4 Marine and Intertidal Molluscs

The tropical malacofauna of Southeast Asia is well known for its species richness as this region is situated between the Indian and Pacific Oceans (Benzie, 1998). A total of 581 species of marine molluscs comprising 384 from the class Gastropoda and 206 species from the class Bivalvia has been compiled by Wong and Arshad (2011) for Malaysia based on the scientific writings and compilation of marine molluscs. In Malaysia, the early studies on molluscan taxonomy started from the study of land snails by the British in the pre-independence era. Their findings were recorded and published in The Raffles Bulletin of Zoology (then The Bulletin of the Raffles Museum) between 1930s to 1960s (Robson, 1932; Laidlaw, 1932, 1937, 1940; Van Jutting, 1949, 1950, 1952; Purchon and Enoch, 1954; Tweedie, 1961, Pathansali, 1963; Berry, 1965).

The early surveys on marine mollusc diversity in Malaysia were conducted in Peninsular Malaysia and Singapore (Purchon & Purchon, 1981; Way & Purchon, 1981; Morris & Purchon, 1981). Most of the recent studies were done in shorter periods and focused on specific areas and ecosystems which were thus less intensive and extensive as compared to the work of Purchon and Purchon (1981). Unlike Purchon and Purchon (1981), the recent studies lack proper documentation thus making it impossible for specimens to be re-examined for species confirmation. In addition, various marine ecosystems such as mangrove and mudflat have not been surveyed intensively for their mollusc fauna.

A total of 82 marine mollusc species from Peninsular Malaysia from 39 families and 58 genera has been compiled from the available literature (Table 2.1). The families Ellobiidae (11 species from five genera), Littorinidae (11 species from three genera) and Neritidae (six species from three genera) have the greatest number of recorded species. These are followed by the family Potamididae (five species from three genera), Onchidiidae (four species from three genera), Assimineidae (three species from one genera), Muricidae (three species from three genera), Veneridae (three species from three genera), Haminoeidae (two species from one genera), Ostreidae (two species from two genera), Glauconomidae (two species from one genera), Mytilidae (two species from two genera), Nassariidae (two species from one genera) and Naticidae (two species from two genera).

The other families of Anomiidae, Aplustridae, Arcidae, Cypraeidae, Cyrenidae, Columbellidae, Conidae, Iravadiidae, Lucinidae, Marginellidae, Myidae, Nereididae, Noetiidae, Pachychilidae, Pharidae, Pholadidae, Pteriidae, Siphonariidae, Solenidae, Stenothyridae, Strombidae, Teredinidae, Thiaridae, Trochidae, and Turbinidae are so far represented by a single recorded species only (Table 2.1).

Table 2.1: List of intertidal and marine molluscs in Malaysia compiled from published literature.

Family	Species	Reference
Anomiidae	*Enigmonia aenigmatica* (Holten, 1802)	Ashton *et al.* (1999)
Aplustridae	*Hydatina* sp. (Schumacher, 1817)	Sasekumar and Ooi (2005)
Arcidae	*Tegillarca granosa* (Linnaeus, 1758)	Sasekumar and Ooi (2005)
Assimineidae	*Assiminea beddomiana* (Nevill, 1881)	Ashton *et al.* (1999)
	Assiminea brevicula (Pfeiffer, 1855)	Sasekumar (1974)
	Assiminea microsculpta (Nevill, 1880)	Ashton *et al.* (1999)
Cypraeidae	*Erosaria erosa* (Linnaeus, 1758)	Singh and Then (2005)
Cyrenidae	*Geloina erosa* (Lightfoot, 1786)	Ashton *et al.* (1999)
Columbellidae	*Pseudanachis basedowi* (Hedley, 1918)	Sasekumar (1974)
Conidae	*Conus radiatus* (Gmelin, 1791)	Singh and Then (2005)
Ellobiidae	*Cassidula aurisfelis* (Bruguiere, 1789)	Sasekumar (1974)
	Cassidula doliolum (Petit de la Saussaye, 1842)	Sasekumar (1974)
	Cassidula mustelina (Deshayes, 1830)	Ashton *et al.* (1999)
	Cassidula plecotrematoides (Möllendorf, 1885)	Ashton *et al.* (1999)
	Ellobium aurisjudae (Linnaeus, 1758)	Sasekumar (1974)
	Ellobium aurismidae (Linnaeus, 1758)	Sasekumar (1974)
	Laemodonta punctatostriata (H. Adams & A. Adams, 1853)	Sasekumar (1974)
	Laemodonta punctigera (H. Adams & A. Adams, 1853)	Sasekumar (1974)
	Melampus sincaporensis (Pfeiffer, 1855)	Sasekumar (1974)
	Pythia plicata (Ferussac, 1821)	Faezah and Farah (2011)
	Pythia scarabaeus (Linnaeus, 1758)	Sasekumar and Moh (2010)
Haminoeidae	*Haminoea* sp. (A) (Turton & Kingston [in Carrington], 1830)	Sasekumar (1974)
	Haminoea sp. (B) (Turton & Kingston [in Carrington], 1830)	Sasekumar (1974)
Iravadiidae	*Iravadia quadrasi* (O. Boettger, 1893)	Ashton *et al.* (1999)
Glauconomidae	*Glauconome* sp. (Gray, 1828)	Singh and Then (2005)

Table 2.1, continued.

Family	Species	Reference
	Glauconome chinensis (Gray, 1828)	Ashton *et al.* (1999)
Littorinidae	*Echinolittorina melanacme* (E. A. Smith, 1876)	Sasekumar and Moh (2010)
	Littoraria carinifera (Gray, 1830)	Singh and Then (2005)
	Littoraria conica (Philippi, 1846)	Ashton *et al.* (1999)
	Littoraria intermedia (Philippi, 1846)	Ashton *et al.* (1999)
	Littoraria melanostoma (Gray, 1839)	Sasekumar (1974)
	Littoraria pallescens (Philippi, 1846)	Ashton *et al.* (1999)
	Littoraria scabra (Linnaeus, 1758)	Sasekumar (1974)
	Littoraria strigata (Philippi, 1846)	Ashton *et al.* (1999)
	Littoraria undulata (Gray, 1839)	Sasekumar (1974)
	Littoraria vespacea (Reid, 1986)	Singh and Then (2005)
	Mainwaringia leithii (E. A. Smith, 1876)	Ashton *et al.* (1999)
Lucinidae	*Austriella corrugata* (Deshayes, 1843)	Ashton *et al.* (1999)
Marginellidae	Marginellidae (Fleming, 1828)	Singh and Then (2005)
Muricidae	*Chicoreus capucinus* (Lamarck, 1822)	Sasekumar (1974)
	Semiricinula tissoti (Petit de la Saussaye, 1852)	Sasekumar (1974)
	Thais sp. (Röding, 1798)	Singh and Then (2005)
Myidae	*Sphenia* sp. (W. Turton, 1822)	Ashton *et al.* (1999)
Mytilidae	*Perna viridis* (Linnaeus, 1758)	Ashton *et al.* (1999)
	Xenostrobus mangle (Ockelmann, 1983)	Sasekumar (1974)
Nassariidae	*Nassarius olivaceus* (Bruguière, 1789)	Ashton *et al.* (1999)
	Nassarius reeveanus (Dunker, 1847)	Sasekumar (1974)
Naticidae	Naticidae sp. (Guilding, 1834)	Singh and Then (2005)
	Polinices sp. (Montfort, 1810)	Singh and Then (2005)
Nereididae	Nereididae (Blainville, 1818)	Singh and Then (2005)
Neritidae	*Clithon oualaniense* (Lesson, 1831)	Sasekumar and Moh (2010)
	Nerita albicilla (Linnaeus, 1758)	Singh and Then (2005)

Table 2.1, continued.

Family	Species	Reference
	Nerita balteata (Reeve, 1855)	Sasekumar and Ooi (2005)
	Nerita planospira (Anton, 1838)	Ashton *et al*. (1999)
	Neripteron cornucopia (Benson, 1836)	Ashton *et al*. (1999)
	*Neripteron violaceum (*Gmelin, 1791)	Ashton *et al*. (1999)
Onchidiidae	*Onchidina* sp. (Semper, 1882)	Hookham *et al*. (2014)
	Onchidium sp. (Buchannan, 1800)	Sasekumar (1974)
	Platyvindex sp. (H. B. Baker, 1938)	Sasekumar (1974)
	Platevindex coriaceum (Semper, 1885)	Ashton *et al*. (1999)
Ostreidae	*Crassostrea* sp. (Sacco, 1897)	Ashton *et al*. (1999)
	Saccostrea cucullata (Born, 1778)	Sasekumar (1974)
Pachychilidae	*Faunus ater* (Linnaeus, 1758)	Sasekumar and Moh (2010)
Pharidae	*Sinonovacula constricta* (Lamarck, 1818)	Ashton *et al*. (1999)
Pholadidae	*Martesia striata* (Linnaeus, 1758)	Ashton *et al*. (1999)
Potamididae	*Cerithidea cingulata* (Gmelin, 1791)	Sasekumar (1974)
	Cerithidea obtusa (Lamarck, 1822)	Sasekumar (1974)
	Cerithidea quoyii (Hombron & Jacquinot, 1848)	Sasekumar and Ooi (2005)
	Telescopium telescopium (Linnaeus, 1758)	Sasekumar (1974)
	Terebralia sulcata (Born, 1778)	Hookham *et al*. (2014)
Pteriidae	*Isognomon ephippium* (Linnaeus, 1758)	Sasekumar and Ooi (2005)
Siphonariidae	*Siphonaria* sp. (G. B. Sowerby I, 1823)	Singh and Then (2005)
Solenidae	Solenidae (Lamarck, 1809)	Singh and Then (2005)
Stenothyridae	*Stenothyra polita* (Adams, 1861)	Sasekumar (1974)
Strombidae	Strombidae sp. (Rafinesque, 1815)	Singh and Then (2005)
Teredinidae	*Teredo* sp. (Linnaeus, 1758)	Ashton *et al*. (1999)
Thiaridae	*Melanoides tuberculata* (Müller, 1774)	Ashton *et al*. (1999)
Trochidae	*Trochus* sp. (Linnaeus, 1758)	Singh and Then (2005)
Turbinidae	Turbinidae (Rafinesque, 1815)	Singh and Then (2005)
Veneridae	*Gafrarium* sp. (Röding, 1798)	Singh and Then (2005)
	Meretrix sp. (Lamarck, 1799)	Singh and Then (2005)
	Veneridae (Rafinesque, 1815)	Singh and Then (2005)

2.5 Distribution of Molluscs in Mangrove Forests

The distribution of mollusc species within the mangrove forest is influenced by variety of factors such as tidal exposure, salinity, substrate type and light intensity which are known as major factors determining the algal growth and influencing the humidity (Berry, 1972; Sasekumar, 1974; Ashton, 1999). The trophic position of the gastropods is equally varied, e. g. the sediment dweller feed selectively or not on the sediment's organic materials and/ or the microphytobenthos (Macintosh, 1980). Species like *Littoraria* feed on the epibenthic crusts on roots and stems, and some other species have been reported to feed on the mangrove litter and/ or the propagules (*Melampus coffeus* and the adult *Terebralia palustris*) (Cannicci *et al.,* 2008). Some scavenging and predatory species like *Nassarius* spp. and *Thais* spp. are much less abundant. Gastropods can attain a very high species diversity in some mangrove ecosystems; 39 species of gastropods in Australia (Camilleri, 1992), 28 species in mangrove forest of China (Jiang & Li, 1995), and 23 molluscs species were reported by Wells (1990) in the Hong Kong mangrove. Sasekumar (1974) identified 25 species of gastropods at one location in the Port Klang mangroves in Selangor while Ashton *et al.* (2003) found 44 molluscs species in Sarawak mangroves. Ashton *et al.* (1999) also found 54 species of molluscs at Merbok, Kedah.

Species diversity differs strongly in the different parts of the world – *Melampus coffeus* is the only gastropod present in the mangrove of Guadalupe (Plaziat, 1984). Sasekumar (1974) found that the numerical abundance and biomass of molluscs can be equally impressive, and in some cases, they can even reach higher densities and biomass than brachyuran crabs (Wells, 1984), although such comparative studies are limited. Some of the gastropods species (*Littoraria scabra*, *Terebralia palustris*) and genera (*Ellobium* and *Enigmonia*) appear to occur exclusively in the mangrove ecosystems

(Plaziat, 1984). Ellison *et al*. (1999) mentioned that the global patterns in species richness of the mangrove gastropods closely follows that of the mangrove trees.

The class Bivalvia is often considered to be confined to a narrow seaward zone due to their larval settlement and feeding restrictions (Plaziat, 1984). However, in Southeast Asia, the mud clam *Polymesoda erosa* is adapted for a semi-terrestrial area by living on the high shore where only occasional high tides inundate the habitat (Morton, 1976). Lebata and Primavera (2001) reported several bivalves from mangroves with chemo-symbiotic association. The wood-boring bivalves are also very common in the mangroves where Singh and Sasekumar (1994) observed 10 species of teredinids and one pholadid in several mangroves along the west coast of Peninsular Malaysia. Waterbury *et al.* (1983) noted that the wood-boring bivalves are ecologically significant where they stimulate the decomposition of the wood while living in symbiosis with the nitrogen-fixing bacteria. Even though the mangrove associated bivalves are only rarely studied, their diversity is quite remarkable high. 29 species of bivalves were reported by Alvarez-Leon (1983) from the mangrove root of Colombia, and Jiang and Li (1995) found 24 species from a mangrove system in Hong Kong.

2.6 Role of Molluscs in Mangrove Ecosystem Functioning

Mangroves are among the most productive ecosystems on earth as it is situated between the land and sea (Alongi, 2009). The Indo-West Pacific region was reported to have occupied the largest combination of mangrove area throughout the world that supports the highest biodiversity in Southeast Asia (Sandilyan & Kathiresan, 2012). The vascular plants with their own different physical adaptive features (e.g. the tree trunks, buttresses and pneumatophores) play important roles in maintaining the habitat complexity within the mangrove ecosystems (MacKenzie & Cormier, 2012). The complex network of the mangroves provides valuable habitat for various organisms such as the transient and resident fish, molluscs, crabs and shrimps (Bosire *et al.*, 2004; Chong, 2007; Hogarth, 2007; Hoque *et al*., 2015; Odum & Heald, 1972; Shahraki & Fry, 2016), and also hosts distinct assemblages of macroalgae (Cribb, 1996).

The macrobenthos such as molluscs and crabs are part of the important components of the mangroves (Dahdouh-Guebas *et al*., 1997; Lee, 1998) that regulate the structure and functioning of this unique ecosystem (Cannicci *et al*., 2008). They established the critical links between the lower trophic detritus and the consumer of the higher trophic level (Macintosh, 1980). For example, the molluscs, crabs and several crustaceans ingest the mangrove litters and the macroalgal mats and help to retain the nutrients and the acceleration of decomposition process. Cannicci *et al*. (2008) stated that crabs enhance the nutrient retention capacity of the habitat by giving the significant contribution in the turnover of mangrove litter and organic material recycling mainly through their feeding activities. Molluscs can be found to occupy various ecological niches throughout the mangrove ecosystem as they live on and in the muds, firmly attached on the roots and stems of the trees, or foraging within the canopy (Cantera *et al*., 1983; Plaziat, 1984; Bosire *et al*., 2004). The physical conditions normally influence the nature of molluscan communities. Jiang and Li (1995) found that the density and biomass of 52 species of molluscs were consistently higher in the high tide zones and decreased with the water depth. The species abundance of China's molluscs also increased with salinity. Such a distribution pattern is also found in other mangals and this sensitivity of the intertidal molluscs to their physical and chemical environment makes them good bioindicators (Lee, 2008). The composition of the molluscan assemblage has been used to assess the health of urban mangroves (Skilleter, 1996).

As the molluscan fauna in the mangroves are primarily comprised of bivalves and snails, most studies have focused on these groups (Balasubrahmanyan, 1994). Much of the work on bivalves and gastropods usually were focused on the individual species and their specific adaptations to the mangrove ecosystem. As an example, Dious and Kasinathan (1994) studied the desiccation salinity and temperature tolerances of two pulmonates, *Cassidula nucleus* and *Melampus ceylonicus* from a South Indian mangrove forest. The movement of the intertidal snail *Bembicium auratum* on the rocky shore and mangrove was compared by Crowe (1996); the pattern of movement on the mangrove was very different despite of having similar distribution and this suggests that models developed in the rocky intertidal community may not be directly applicable to the mangrove community.

2.7 The Ellobiid Molluscs

The family Ellobiidae or hollow-shelled snails are primitive pulmonate gastropods that colonize the intertidal and supratidal zones of mangroves and muddy shores in tropical regions beside salt marshes and upper littoral rocky areas of temperate areas (Martins, 1996). The ellobiids also occupy the terrestrial domain that is independent from any aquatic habitats, for examples, *Pythia colmani* (Martins, 1995) lives in the Papua New Guinea's rainforest, *Carychium* (Muller, 1773) lives in the litterfall of forest and Holarctic riparian zones, and *Zospeum* (Bourguignat, 1856) lives inside the European karst caves (Barker, 2001). Though more than 800 species of Ellobiidae are available in the literature, only 100 (Peter & Christopher, 2008) to 250 (Weigand *et al*., 2013) of them are likely to be valid due to the frequent low variability and high degree of homoplasy in terms of morphological characteristics. Martin (2007) has classified ellobiids based on their morphological and anatomical characters into five taxonomic subfamilies: Ellobiinae, Carychiinae, Melampodinae, Pedipedinae and Pythiinae.

The earliest records of ellobiids from Malaysia was derived from Berry (1968) which include *Ellobium aurisjudae* (Linnaeus, 1758), *Cassidula aurisfelis* (Bruguiere, 1789) and *Pythia scarabaeus* (Linnaeus, 1758). Sasekumar (1974) added *Cassidula doliolum* (Petit de la Saussaye, 1842), *Laemodonta punctigera* (Adams & Adams, 1853), *L. punctastostriata* (Adams & Adams, 1853) and *Melampus* (Montfort, 1810) to the list. Ashton *et al*. (1999) listed *Cassidula nucleus* (Gmelin, 1791), *Cassidula plectotrematoides* (Möllendorf, 1885) and *Auriculastra* (Von Martens, 1880) from the Merbok Mangroves in Kedah.

Currently, in Peninsular Malaysia, there are seven ellobiid species from three genera in the state of Selangor (Sasekumar, 2012), 29 species from five genera in the Malaysian peninsula (Berry, 1968; Sasekumar, 1974; Ashton *et al*., 1999; Raven &

Vermeulen, 2007; Faezah & Farah, 2011). In comparison with the number of species recorded in the South East Asian countries such as Philippines (Poppe, 2010), Singapore (Tan & Chou, 2000; Tan *et al*., 2009), and Brunei (Raven & Vermeulen, 2007), there are still many ellobiid species that had not been recorded in Malaysia (Table 2.2). Moreover, most countries in South East Asia including Malaysia have only provided lists of species names without taxonomic descriptions, keys to species and relevant illustrations.

Table 2.2: Overview of the previous records (Berry, 1968; Sasekumar, 1974; Ashton *et al.*, 1999; Tan and Chou, 2000; Raven and Vermeulen, 2007; Tan *et al.*, 2009; Poppe, 2010; Faezah and Farah, 2011; Sasekumar, 2012) of ellobiid species known from Peninsular Malaysia, East Malaysia and elsewhere in Southeast Asia such as Singapore, Brunei, Thailand and Indonesia. (+) indicates present, (-) absent.

Species	Peninsular Malaysia	East Malaysia	Southeast Asia
Auriculastra brachyspira	-	+	+
A. duplicata	-	+	+
A. oparica	-	+	+
A. semiplicata	+	+	+
A. siamensis	-	+	+
A. subula	-	+	+
Blauneria quadrasi	-	+	+
Ellobium aurisjudae	+	+	+
E. aurismidae	+	+	+
E. scheepmakeri	+	+	+
E. tornatelliforme	-	+	+
Melampus adamsius	-	+	+
M. fasciatus	-	+	+
M. granifer	-	+	+
M. nucleolus	-	-	+
M. pulchellus	-	+	+
M. sincaporensis	+	+	-
Microtralia sp.	-	+	+
Cassidula aurisfelis	+	+	+
C. nucleus	+	+	+
C. sowerbyana	-	+	+
C. vespertilionis	-	+	+
Laemodonta minuta	-	+	+
L. monilifera		+	+
L. punctatostriata	+	+	+
La. punctigera	+	+	+
L. siamensis	+	+	+
L. typica	+	+	+
Pythia pantherina	+	+	+
P. plicata	+	+	+
P. scarabaeus	+	+	+
P. trigonus	-	+	+

CHAPTER 3: METHODOLOGY

3.1 Study Sites

Field surveys and samplings were carried at various ten locations (L1 to L10) throughout the coastline of the Peninsular Malaysia (Figure 3.1). These are as follows:

1) L1: Langkawi Island (6˚26’ 59.8’’ N, 99˚48’ 59.2’’ E), which is in the state of Kedah, in northern western Peninsular Malaysia. The samplings were conducted at Kilim (6°24'19.6"N 99°51'26.6"E), Tanjung Rhu (6°27'03.9"N 99°49'10.5"E) and Pulau Dayang Bunting (6°12'44.6"N 99°46'46.6"E).

2) L2: The Merbok Forest Reserve (5˚41’ 8.6 N, 100˚28’ 6.5 E) which is in the district of Sungai Petani in the state of Kedah, with an area of 4,037 hectares covering a total of 18 forest management compartments. The mangrove forests are gazetted as permanent forest reserve since 1951 and is the most extensive and best managed mangroves in Kedah. The samplings were conducted at the Merbok River.

3) L3: The Matang Mangrove Forest Reserve centred at Kuala Sepetang (4˚50’ 27.1 N, 100˚38’13.8 E) which is a thriving fishing village located in the state of Perak. The 40,000-hectare Matang Mangrove Forest Reserve was gazetted as a Permanent Forest Reserve since 1906 and is now recognized as the best managed sustainable mangrove ecosystem in the world.

4) L4 and L5: Selangor mangrove forests. In the state of Selangor, there are three main areas with protected mangrove forests totalling 18,000 hectares. The largest tract is located in the Klang Island with about 5,611.81 hectares. The others are located at Kuala Selangor (L4), Port Klang, Carey Island (L5) and Banting. Sampling were conducted at various locations - Jugra (2˚49’ 56.3 N, 101˚24’ 47.4 E), Carey Island (2˚49’ 25.8 N, 101˚21’ 19.1 E) and Sepang (2˚41’ 26.7 N, 100˚45’ 16.0 E).

5) L6: Lukut mangrove in the state of Negeri Sembilan. Sampling location for this study was at the vicinity of Lukut (2˚33’ 39.8 N, 101˚47’ 59.9 E).

6) L7: Sungai Pulai mangrove, in the state of Johor. Johor has a total of 20,533 ha of mangrove forests which are mostly found in the Sungai Pulai Forest Reserve, Sungai Johor Forest Reserve, and Sungai Santi Forest Reserve. The sampling location was at the Sungai Pulai Forest Reserve (1°25’ 24.7 N, 103°28’ 33.7 E).

7) L8: Sungai Bebar mangrove, in the state of Pahang. The majority of 2,416 ha mangroves in Pahang are found in the sheltered estuaries along the Sungai Kuantan and Sungai Rompin. Among the visited locations sampled in this study was Sungai Bebar (3˚07’16.5 N, 103˚26’25.2 E).

8) L9: Setiu mangrove, state of Terengganu. One sampling site was carried out at Setiu (5˚37’56.5 N, 102˚47’09.5 E) which consisted of mixed forests.

9) L10: Tumpat mangrove and Tok Bali lagoon, state of Kelantan. The mangroves of Tumpat are located in the River Kelantan Delta of 1200 ha. Locations visited were at Tumpat (6˚12’ 46.9 N, 102˚10’ 03.8 E) and the nearby Tok Bali lagoon (5˚51’29.2 N, 102˚30’51.9 E).

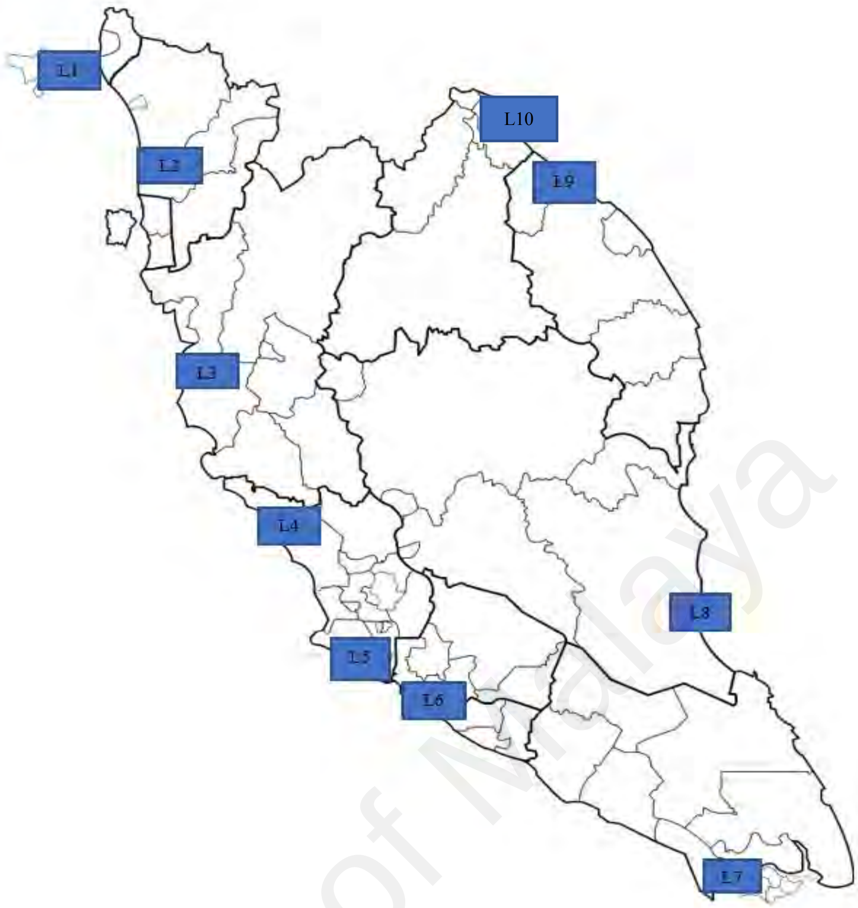

Figure 3.1: The location of high shore mangrove in Peninsular Malaysia that were sampled in this study. L1: Langkawi; L2: Merbok; L3: Matang Mangroves; L4: Kuala Selangor; L5: Carey Island; L6: Lukut; L7: Sungai Pulai; L8: Sungai Bebar; L9: Setiu; and L10: Tumpat.

3.1.1 Study Sites and Samplings

For ellobiids, samplings in the high shore mangrove were conducted in the eight states throughout Peninsular Malaysia. These selected localities were chosen based on accessibility and the suitability of the high shore mangroves (Table 3.1). At the ten sampling sites located along the coastline of Peninsular Malaysia, haphazard samplings of molluscs were carried out during low tide (spring tide or neap tide) by walking through the mangrove forest, starting either from the lower shore or from the upper shore. The molluscs sampling took between four to six hours to complete depending on the distance of the mangrove shore. With an exception of the Matang mangrove, all other sites were visited once from September 2013 to April 2015. For Matang mangrove, field visits were made between February 2014 to May 2015 (16 monthly trips).

Mollusc specimens were collected by hand from the sediment surface and subsurface (up to a depth of 10 cm), among roots of trees and ferns, on the tree trunks and foliage under dead leaves and inside the decomposing wood. Specimens collected were stored in 10% formaldehyde, and later transferred into 90% ethanol for identification. As ellobiids are known to occur at various microhabitats, specimens were collected from different places or environments such as (1) under rotten logs, (2) crevices between ferns, (3) sediment surface, and (4) tree trunks. At the Matang Mangrove Forest Reserve, ellobiids were sampled at a permanent sampling plot established at the Eco-Education Center, at Reba River (Figure 3.2) during the low tide (neap tide cycle) every month for 16 months (February 2014 to May 2015) (see details in section 3.2 below).

Table 3.1: Sampling locations in Peninsular Malaysia where ellobiids were collected.

Code	Localities	Habitat types
L1	Langkawi Island	Rocky shores
L2	Merbok Mangroves	Pristine mangroves
L3	Matang Mangroves	Pristine mangroves
L4	Kuala Selangor Nature Park	Mangroves
L5	Carey Island	Disturbed mangroves
L6	Lukut	Disturbed mangroves
L7	Sungai Pulai	Disturbed mangroves
L8	Sungai Bebar	Disturbed mangroves
L9	Setiu Wetlands	Mixed mangroves
L10	Tok Bali Lagoon	Disturbed mangroves

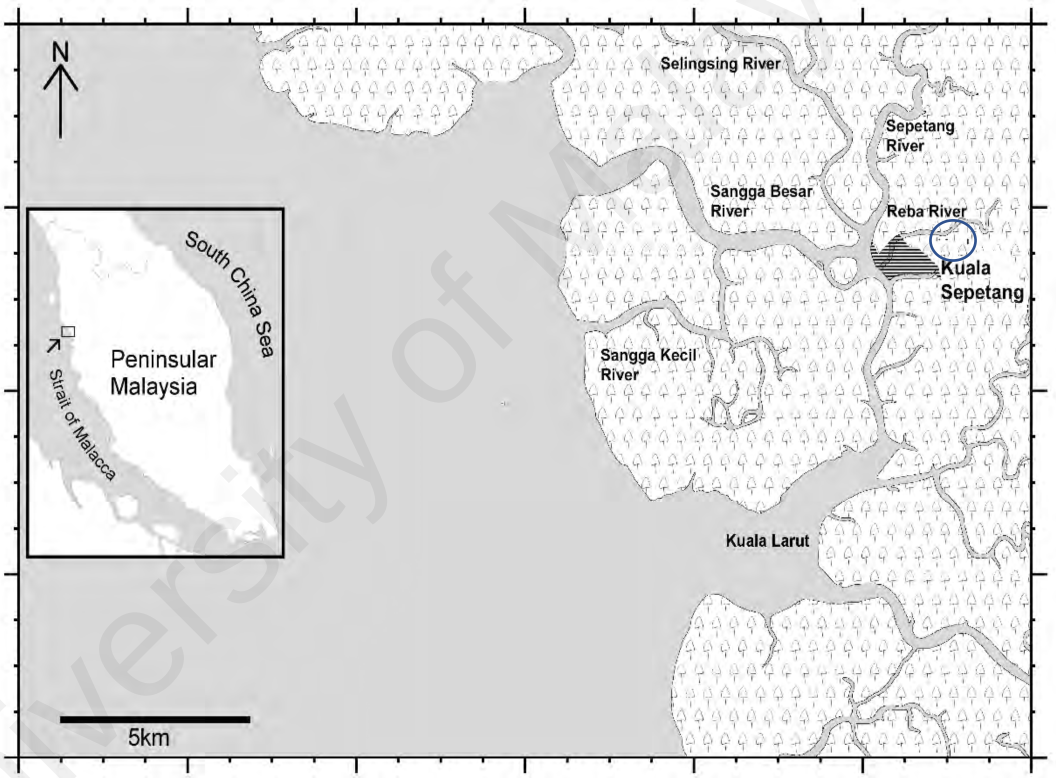

Figure 3.2: The sampling location of Kuala Sepetang (blue circle) within the Matang Mangrove Forest Reserve (MMFR), Perak.

3.2 High Shore Mangrove of Matang Mangrove Forest Reserve (MMFR)

The MMFR was chosen as a longer-term sampling site for molluscs due to its reservation status and the presence of relatively pristine of undisturbed forest patches (i.e. those not under forestry production). The chosen mangrove reserve is located at the Pejabat Hutan Kecil Paya Laut Kuala Sepetang (4˚50.422" N 100˚38.166" E), the site or local office of the MMFR. This forest patch, known as Eco-Education Center Matang Mangrove Forest, is a protected forest of 43 ha reserved for educational purposes. The mangrove trees are at least 40 years old, roughly 20 to 25 meters in height and dominated by *R. apiculata*, *R. mucronata*, *Bruguiera* and fern, *Acrostichum aureum*. There are also some *Derris* species.

Stratified sampling of molluscs, parallel to the Reba River, were carried out during the low tide. Molluscs were sampled along three parallel transect lines (namely T1, T2 and T3) established at a distance of about 50 m from each other (Figure 3.3). Along each transect, 15 quadrats (0.5 x 0.5 m) were set up with distance of 10 m each. Thus, the sampling layout effectively resembled a 3 x 15 sampling grid that covered an approximately total area of 15000 m^2 (150 m x 100 m). Within each quadrat, all soil surface molluscs found were collected. All samples were preserved in 10% formaldehyde and later in 90% ethanol. In addition, gastropods that were not sampled by quadrat sampling were also collected opportunistically through a walk-and-search approach from the mangrove area for general collection. Physical parameters such as salinity, pH, dissolved oxygen water and air temperature were measured in situ (Multiparameter Meter HI 9829 Portable). Spade was used to make a 10 cm deep hole in the soil during the low tide to measure the salinity and dissolved oxygen water. Measurements were taken after allowing the interstitial water to seep in the hole about 15 minutes. pH of the soil was taken at depth of 3 cm using the probe. The air temperature was recorded in the shaded area of the high shore mangrove for the period of 12 months. The same sampling grid for molluscs in the same area was utilized every month from February 2014 until May 2015.

The mangrove zonation (zone 1 to zone 5 inundation class) was determined by using tidal regime scheme by Watson (1981). At each proposed zonation; e.g. Zone 5, three tide poles were used to determine the tidal flooding at the given month (this was conducted once only during the spring tide). Each pole with test tube (covered with plastic slight above the tip of the tube to avoid rainwater) at 10 cm interval was erected. From the seawater collected in the test tube (vertical movement of seawater), the zonation was established based on the tide table. In addition, the plant zonation by Berry (1972) was also used to calculate the tide zonation, e.g. the Class 1 to Class 5 zonation (refer Figure 2.1).

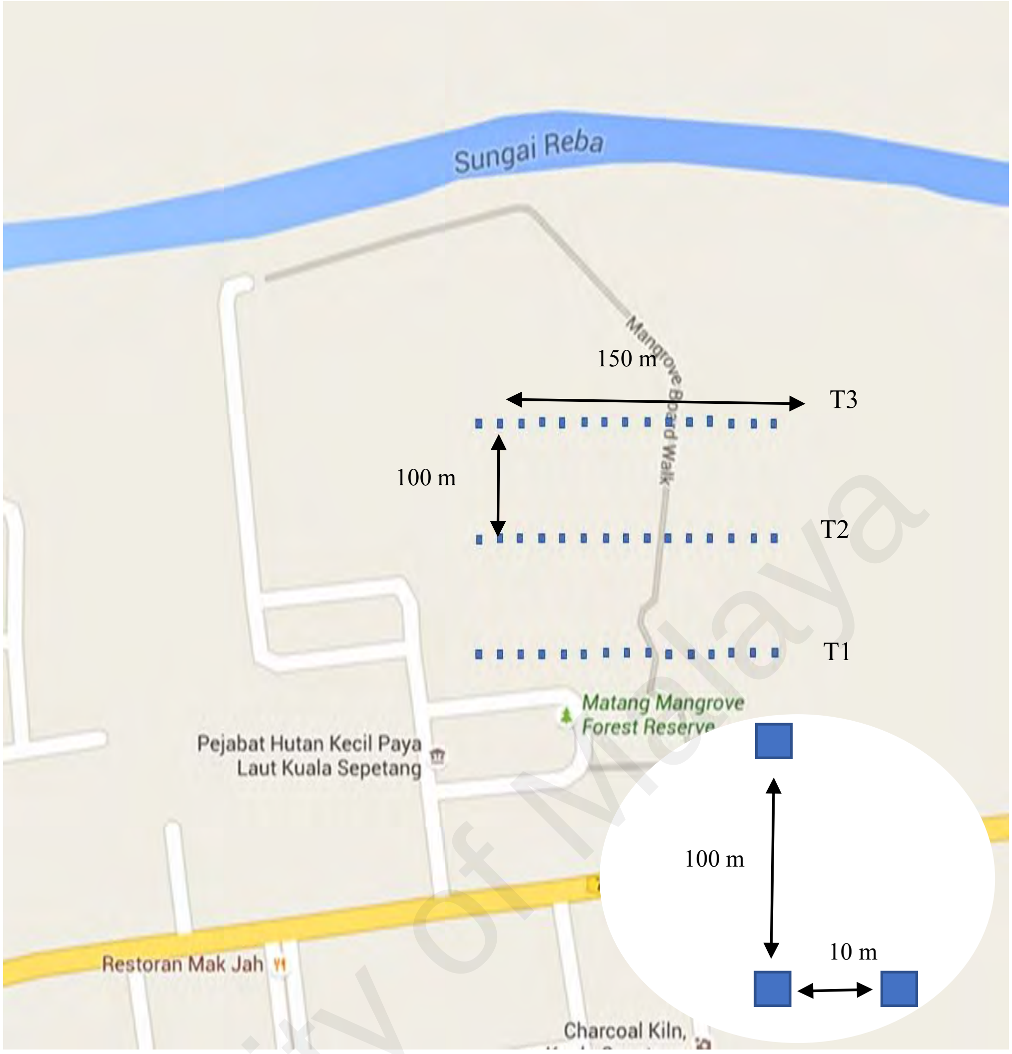

Figure 3.3: Map of sampling location with three transects (sampling layout) established at Kuala Sepetang, Matang Mangrove Forest Reserve. Circle: the position of blue quadrat (0.5 m x 0.5 m). Map adapted from Google Maps (Google, n.d.).

3.3 Species Identification

In the laboratory, the preserved molluscs collected was carefully sorted. Taxonomic identification was done under a Leica MZ 8 binocular microscope. Each collected molluscs species was described and diagnosed using the anatomy features based on the closest species (Figure 3.4). The utilized and described morphological characters included the four main features: (1) shell, (2) whorl, (3) sculpture, and (4) aperture design. Species identification was performed according to the morphology description by van Benthem Jutting (1939) and were supported by additional references (Berry, 1972; Sasekumar, 1974; Sasekumar, & Chong, 1998; Dharma, 2005; Raven & Vermeulen, 2007; Tan *et al.,* 2009; Sasekumar, 2012) and other relevant literature.

The valid or accepted species names are referenced to their previous names or synonyms, and their descriptions are compared to the closest related species within the same genus as previously described in the literature. Original illustrations or/ and photographs are given where available; if not, they are taken from the literature in order to support the taxonomic descriptions. Selected morphological characters were used to diagnose the ellobiid species collected in the present study, and to construct the relevant taxonomic keys to the genera and species of Ellobiidae in Peninsular Malaysia.

In case of ambiguities, confirmations were sought from various authorities from Singapore, Thailand and Netherlands. Ellobiids samples were identified and/ or confirmed by Dr. J.G.M. (Han) Raven, Naturalis Biodiversity Center, Netherlands. Ellobiid specimens were compared to collections in Thailand (Phuket Marine Biological Centre) and Netherlands (specimens were sent to Naturalis Biodiversity Center).

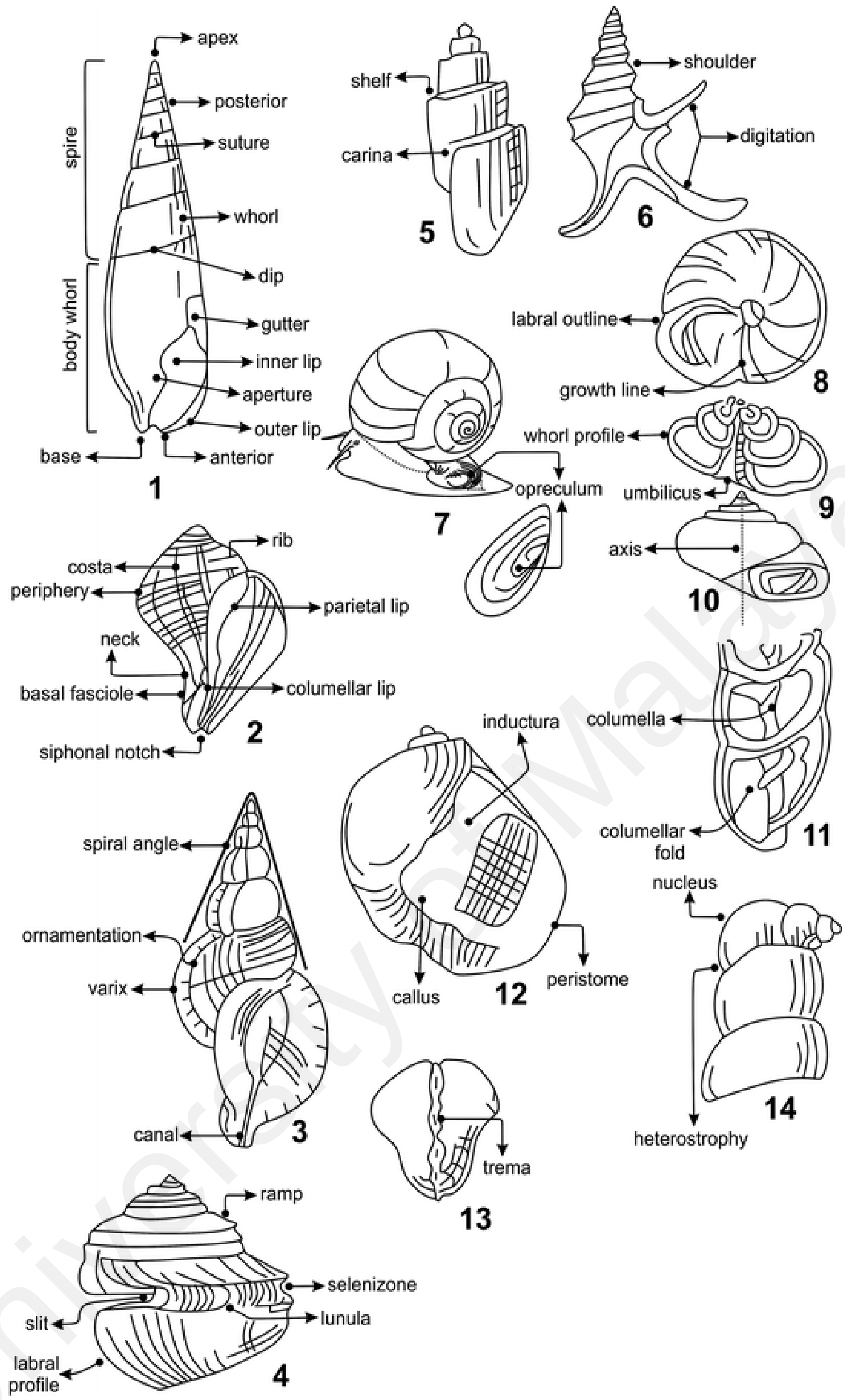

Figure 3.4: Examples of morphological characters and features used for identification: (1) shell shape, (2) whorl, (3) sculpture, and (4) aperture design. Other distinct features from drawing number 1 to 14 were used on certain species only. Figure adapted from Jain (2017).

3.4 Data Analysis

Ordination techniques such as principal component analysis and correspondence analysis are commonly used to reduce the variation in community composition to the scatter of samples and species in an ordination diagram. The latter facilitates interpretation when environmental variables are correlated with the ordination axes. Correspondence analysis (CA) is a multivariate technique commonly applied to incidence or abundance matrices. First applied in ecology under the name of "reciprocal averaging" (Hill, 1973), CA uses matrices that record the presence-absence or abundance of species sampled in quadrats or defined areas (Ter Braak, 1985). CA is based on the rationale that species are observed to typically show unimodal (bell-shaped) response curves with respect to the environmental gradients. For example, a mollusc species may prefer a certain soil moisture content, and not grow at all places where the soil is either too dry or too wet. Each species is therefore restricted to a suitable envelope (or optimum) of the said environmental variable. CA thus differs from principal components analysis (PCA) which assumes a linear response model (see ter Braak and Smilauer, 2002). In the ordination diagram of CA, the distance rule is more appropriated (with Hill's scaling). The distance rule is an extension of the centroid principle, that a sample that is close to the species point is more likely to contain the species than a sample that is far from the species point.

Correspondence analysis was used to analyse the incidence (presence, absence) data of molluscs sampled along the three transects from the middle to the upper shore, i.e. from Zone 3 through Zone 4 to Zone 5. The data included 38 species of molluscs and their microhabitats including creek, sediment, mangrove tree trunk, mangrove tree root, on fallen wood, inside fallen wood, leaf on tree and fern *Acrosticum*. The data matrix is as given in Appendix A. For the CA analysis, the software CANOCO 4.5 was used (Ter

Braak & Smilauer 2002). The analysis focused on the inter-sample distance using Hill's scaling which measures the dissimilarity based on the generalized Mahalanobis distance.

The differences in abundance between two monsoon seasons; dry and wet season of Southwest Monsoon (SWM), and dry and wet season of Northeast Monsoon (NEM) were determined with Kruskal-Wallis test. Post hoc analysis were conducted for comparing the different transects.

CHAPTER 4: RESULTS

4.1 The High Shore Mangroves of Peninsular Malaysia

L1. Langkawi mangrove

Langkawi Island (6˚26’ 59.8’’ N, 99˚48’ 59.2’’ E) is located at the northern part of Peninsular Malaysia with an atypical natural settings and beautiful landscapes. The mangroves can be found on the shallow limestone substratum such as in the Kilim-Kisap Langkawi Geopark. Based on the field survey, the present threat to the Langkawi mangroves are largely from infrastructure development, tourism and aquaculture (Table 4.1). The present sampling sites were at Kilim (6°24'19.6"N 99°51'26.6"E), Tanjung Rhu (6°27'03.9"N 99°49'10.5"E) and Pulau Dayang Bunting (6°12'44.6"N 99°46'46.6"E).

L2. Merbok mangrove

The Merbok Forest Reserve (5˚41’ 8.6 N, 100˚28’ 6.5 E) is in the district of Sungai Petani, Kedah with an area of 4, 037 hectares covering a total of 18 management compartments. Mangrove species that dominate this area were *Rhizophora*, *Bruguiera*, *Avicennia* and *Sonneratia*. The mangrove forests are gazetted as permanent forest reserve since 1951 and is the most extensive and best managed mangroves in Kedah. The mangroves are dominated by *Rhizophora apiculata* and *Bruguiera parviflora*, with the water margins fringed by rows *of Rhizophora mucronata*. Most of the trees were estimated to be more than 15 m tall and 20 years old (based on Hookham *et al.,* 2014). The main threats to the mangroves are infrastructure, development, agriculture and aquaculture (Table 4.1). The mollusc samplings were conducted at the Merbok River (5˚41’ 8.6 N, 100˚28’ 6.5 E).

L3. Matang mangrove

Kuala Sepetang (4˚50’ 27.1 N, 100˚38’13.8 E) is a thriving fishing village located in Perak. The 40,000-hectare Matang Mangrove Forest Reserve (MMFR) was gazetted as a Permanent Forest Reserve since 1906 and is now recognized as the best managed sustainable mangrove ecosystem in the world. Within the reserve, there are silviculture programmes of the *Rhizophora* and *Bruguiera* forests carried out by the Perak State Forestry Department for the production of charcoal, firewood and poles for both local and international markets. The silviculture practice here is based on a 3-year rotation cycle, at the end of which all mangrove trees are clear felled and then replanted. Since the forest is a gazetted production reserve, there is low human impact in most parts of the reserve except those forests that are felled for charcoal production (<2.5%). Nevertheless, the surrounding areas have been developed for agriculture, aquaculture and human settlements. Sampling sites occurred at the vicinity of the Reba river (4˚50’ 27.1 N, 100˚38’13.8 E) that drains into the upper Sepetang river close to the town of Kuala Sepetang.

This was the mangrove site where more intensive samplings of molluscs were made on a monthly basis to examine spatial and temporal distribution of the animals. Measurements of the physical environment which included air temperature, soil-water salinity and pH were as follows:

(i) Salinity – the salinity of pore water ranged from 9 ppt (Jan 2014) to 14 ppt from January 2014 to December 2014. The lowest reading (9 ppt) was recorded during January and November, while the highest reading (14 ppt) was recorded during May (Figure 4.1).

(ii) pH - the pH of the sediment (3 cm depth) showed acidic nature with readings that ranged from the lowest of 6.46 in February 2014 to the highest of 6.80 in October (Figure 4.2)

(iii) Air temperature - the air temperature in the shaded area of the high shore mangrove was recorded for the 12 month - period with the lowest reading at 26.0 °C in September and the highest temperature at 27.7 °C observed in October 2014 (Figure 4.3). For most of the time of the year, the average temperature was about 26.5 °C (Figure 4.3).

Figure 4.1: The monthly (mean) pore water salinity recorded at Matang Mangrove Forest Reserve from January 2014 to December 2014.

Figure 4.2: The monthly (mean) sediment pH recorded at depth of 3 cm at Matang Mangrove Forest Reserve from January 2014 to December 2014.

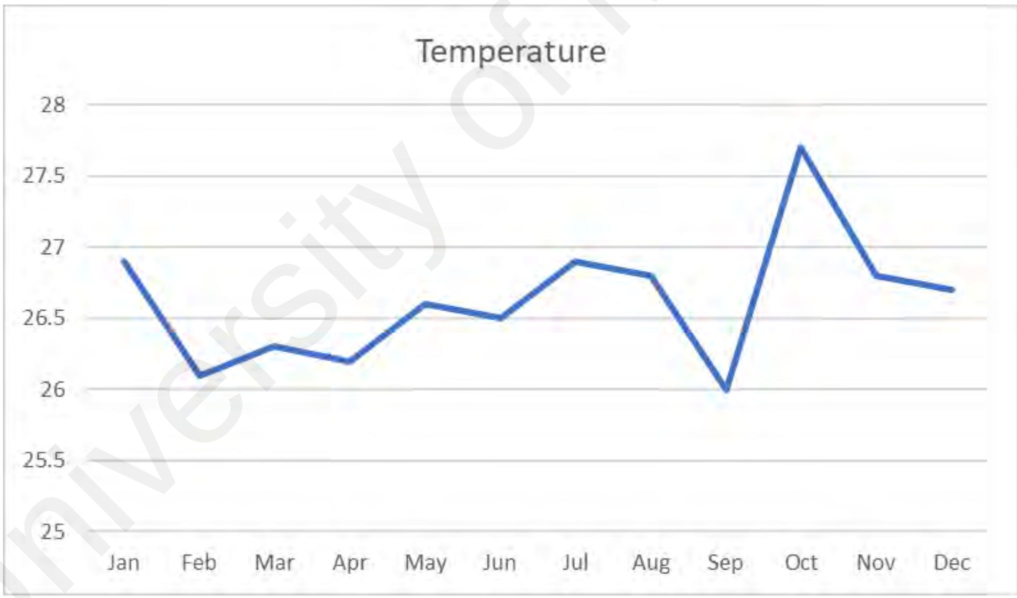

Figure 4.3: The monthly (mean) air temperature recorded at Matang Mangrove Forest Reserve from January 2014 to December 2014.

L4. Kuala Selangor Nature Park mangrove

In Selangor, there are three main areas with protected mangrove forest totalling 18,000 hectares, with the largest in Port Klang about 5,611.81 hectares. The others are in Kuala Selangor, Port Klang and Banting. The Kuala Selangor mangrove forest is mainly occupied by *Rhizophora apiculata*, *R. mucronata*, *Sonneratia* sp. and *Bruguiera*. Potential threats are from surrounding infrastructure development and agriculture. Sampling locations were in the Kuala Selangor Nature Park (KSNP) (3°20'13.3"N 101°14'11.8"E), Jugra (2˚49’ 56.3 N, 101˚24’ 47.4 E), and Sepang (2˚41’ 26.7 N, 100˚45’ 16.0 E).

L5. Carey Island mangrove

Carey Island (2˚49’ 25.8 N, 101˚21’ 19.1 E) separated from the Selangor coast by the Langat river and Klang River is located within the group of Klang Islands that comprised eight small islets. The 161.87 km^2 area of Carey Island originally contained large mangrove forests that were reclaimed for agricultural activities such as palm oil plantations. Since the island elevation is lower than the mean high tide level, coastal dikes have been constructed to protect the oil palm plantations inside from sea water intrusion. Coastal bunding have further depleted the fringing mangroves due to decreasing silty-clay layer on the beachfront. Presently, mangrove species such as *Avicennia* and *Rhizophora* can be found dominating the island fringes and in particular the south-eastern corner of the island where the Jugra mangrove forest remains. The main threats to the mangroves come from infrastructure development and agriculture. Sampling site was located at (2˚49’ 25.8 N, 101˚21’ 19.1 E).

L6. Lukut mangrove

In 1994, it was reported that only 879 ha of mangroves were left, but those in Sungai Linggi and Port Dickson of Negeri Sembilan areas were very disturbed. The

Sepang-Lukut mangrove forest appears as a strip of few meters in width at the upstream of the Sepang Besar River. *Rhizophora mucronata* is the dominant species accompanied by *R. apiculata*, *Avicennia alba*, *Sonneratia alba* and *Bruguiera gymnorrhiza*. Aquaculture remains as the main threat for the mangrove as most areas were reclaimed for fish and prawn farming. Sampling location for this study was in Lukut (2˚33’ 39.8 N, 101˚47’ 59.9 E).

L7. Sungai Pulai mangrove

Johor has a total of 20,533 ha of mangrove forests which are mostly found in Sungai Pulai Mangrove Forest Reserve (1°25’ 24.7 N, 103°28’ 33.7 E), Sungai Johor Forest Reserve, and Sungai Santi Forest Reserve. The Sungai Pulai mangrove is one of the largest riverine mangrove systems in Peninsular Malaysia and has been managed for wood production of *Rhizophora mucronata* and *Bruguiera parviflora* by using a silviculture practice based on 20-year rotation cycle. The main threats to the mangroves come from infrastructure development which included the port facilities (Port of Tanjung Pelepas) and a power plant (Tanjung Bin). The present location of sampling was at Sungai Pulai Forest Reserve (1°25’ 24.7 N, 103°28’ 33.7 E).

L8. Sungai Bebar mangrove

In Pahang, the majority of 2, 416 ha mangroves are found in the sheltered estuaries along the Sungai Kuantan and Sungai Rompin. Among the visited locations sampled in this study was Sungai Bebar (3˚07’16.5 N, 103˚26’25.2 E), which is a protected area of forest reserve with minimal human disturbance.

L9. Setiu Wetlands mangrove

Another sampling site was the Setiu Wetlands mangrove (5˚37’56.5 N, 102˚47’09.5 E) in Terengganu which consists of mixed mangrove species and a species of *Melaleuca*. Most of the mangroves are affected by reclamation for agriculture and aquaculture such as fish farming and shrimp ponds.

L10. Tok Bali Lagoon and Tumpat mangrove

The mangroves of Tumpat are in the River Kelantan Delta which has undergone alterations induced by human activities such as aquaculture and settlements. Mangrove species in the 1200 ha delta are represented by *Avicennia*, *Bruguiera*, *Nypa fruticans*, *Rhizophora* and *Sonneratia*. Locations visited were Tumpat (6˚12’ 46.9 N, 102˚10’ 03.8 E) and Tok Bali lagoon (TBLK) (5˚51’29.2 N, 102˚30’51.9 E), where there are three mixed mangrove areas (15.8 ha) on both sides side of the river.

Table 4.1: Mangrove forests of Peninsular Malaysia surveyed for high shore molluscs including assessment of anthropogenic impacts.

Mangrove forest	Area/ha	Status	Vegetation	Assessed Anthropogenic Impacts
Setiu, Terengganu	1350	State Park	Mixed mangrove (*Rhizophora*, *Nypa* and *Melaleuca*)	Aquaculture
Semerak, Pasir Putih, delta of Sungai Kelantan and Tumpat, Kelantan	744	Forest Reserve	*Rhizophora*, *Nypa*	Aquaculture and development
Rompin, Sungai Bebar, Kuantan, Pahang	4,200	Forest Reserve	*Rhizophora*, *Xylocarpus*	Agriculture (Oil palm plantations)
Matang, Perak	42, 351	Forest Reserve	Mainly *Rhizophora* (charcoal production)	Low impact in most forest to good management
Klang islands, Banjar, Jugra, Carey Island, Kuala Selangor, Selangor	14, 897	Forest Reserve	Mainly *Rhizophora*	Agriculture, development and pollution
Lukut, Negeri Sembilan	204	Forest Reserve	*Rhizophora*, *Avicennia*	Aquaculture, development
Sungai Pulai, Johor	17, 185	Forest Reserve	*Rhizophora*, *Avicennia*	Development, harbour facility, aquaculture
Merbok and Langkawi, Kedah	7201	Forest Reserve	Mainly *Rhizophora*, *Bruguiera*	Development, agriculture and aquaculture

4.2 Taxonomy of Species of Ellobiidae in Peninsular Malaysia

The following taxonomic descriptions are based on filed specimens collected from the present study.

Ellobiidae H. & A. Adams, 1858

This family is a very diverse group with shells ranging from barely even 1 mm (Leuconopsis) to more than 100 mm (Ellobium) in total shell length. Shell shape varies from globose (Cassidula) to tall (Auriculastra), and in intermediate forms such as reverse-conical, ovate, cylindrical and fusiform (Melampus, Microtralia and Pythia respectively) to sinistral (Blauneria). Shell surface varies from hairy (Laemodonta) to shiny and smooth (Creedonia) and even rugose (Pedipes). The aperture characteristic such as the width of the columellar plate, number of columellar teeth, parietal tooth and folds were used for identification. The adult animal dissolves the inner walls of the spire. The tentacle normally round and tapering to the end.

Distribution: worldwide.

Habitat: most of the species live amphibiously in *Nypa* palm and mangrove swamps; some are littoral and terrestrial species.

Key to the main genera of Ellobiidae in Peninsular Malaysia

1. Outer wall of aperture with folds or teeth within …………….…………...… 2
   - Outer wall of aperture of smooth within …………….……………………….. 3
2. Shell greatly compressed dorso-ventrally, with lateral varix ……….....… *Pythia*
   - Shell not compressed, without varix.……………………….……….…….... 4
3. Shell longer than 30 mm ……………………………………………...…... 5
   - Shell longer than 35 mm ……………………………………….… *Ellobium*

4. Shell solid, broad with dark periderm ……………………………………....… 6

   - Shell thin, slender, cylindrical, corneus, without periderm ......…. *Cylindrotis*

5. Shell broad, conical, diameter 10 mm and larger ……...……….………. *Cassidula*

   - Shell slender, fusiform, diameter 6 mm and smaller.…...……… *Auriculastra*

6. Surface smooth or with weak spiral sculpture, aperture with folds.… *Melampus*

   - Surface with strong spiral sculpture, aperture with teeth within.. *Laemodonta*

Auriculastra Von Martens, 1880

The genus *Auriculastra* is characterized by the dextral shell, with size rather small to very small, thin to solid, slightly translucent to opaque, pale greenish, yellowish or brownish without colour pattern (except, sometimes, *A. brachyspira*), not dorsoventrally flattened, without varices, ovoid, inverted ovoid or spindle-shaped. The sculpture is fine, comparatively inconspicuous. Aperture with one to two columellaris, one parietalis, without palatales (except *A. semiplicata*), palatal peristome not or hardly thickened. Shell normally ranges from 5.9 to 15.5 mm in high.

Key to the *Auriculastra* species

1. Shell spindle-shaped …………………….……………………………………... 2
   - Shell shape oval …………………………………………...………….. 3
2. Shell with more regularly rounded sides ……………….………..... *A. oparica*
   - Shell sides often conspicuously rounded around the periphery …... *A. subula*
3. Shape about ellipsoid oval with well-rounded sides ……………….. *A. duplicata*
   - Shell shape inverted ovoid……………………………….………………… 4
4. Shell subcylindrical except for a slight tapering towards the base. *A. brachyspira*
   - shape narrowly ovoid with slightly convex or flat sides …...... *A. semiplicata*
5. Deep and narrow umbilicus ……………………………………….. *A. saccata*

Auriculastra brachyspira (Möllendorff, 1894)

Melampus brachyspirus Möllendorff, 1894: 115 (Cebu Island, Philippines)

Cylindrotis siamensis — Harbeck, 1996: 53, figs 142-147 [non-Brandt, 1974]

Status in current study: new record for Peninsular Malaysia.

Closest species for comparison: *Auriculastra subula* (Quoy & Gaimard, 1832).

Diagnosis: the general shell shape of *A. subula* is more varies compared to *A. brachyspira* which is subcylindrical and with tapering slightly towards the base.

Illustrations/ photographs: Figure 1-2; p 34, Raven and Vermeulen (2007).

Distribution: Malaysia (Matang Mangrove Forest Reserve, Perak; Sarawak), Brunei (Tutong), Singapore (Changi, Pulau Tekong) and Vietnam (Haiphong province) (Raven and Vermeulen 2007).

Habitat: In MMFR, this species could be found on the high shore mangroves usually in the area with decomposing wood materials. This species also can be found in the estuaries, normally on the muddy tidal flats and on the low salt marshes with short grass. In some cases, they can be alive under the dead wood or debris on the rocks near the coast.

Materials examined. 2 specimens (8 and 9 mm in shell length) from MMFR.

Description: Shell appearance: shell is small, thin, slightly translucent and rather dull. The coloration usually yellowish to off-white, underneath a pale greenish-corneus periostracum. Sometimes with two pale brownish spirals bands appears on the upper half of the last whorl. Shell shape: the shape is slightly inverted ovoid (inverted egg shaped) with only slightly convex sides, and more conspicuously rounded towards both ends. The last whorl around 5/6 of the total shell height in adults with very low spire.

Radial sculpture with inconspicuous growth lines. Spiral sculpture fine with regular but wavy spiral striation, which sometimes partly absent. Aperture: the aperture with one to two weak to distinct columellar folds, and a rather distinct parietal fold at about 1/3 of the height of the aperture. Shell height normally up to 10 mm high.

***Auriculastra duplicata* (Pfeiffer, 1854)**

Melampus duplicatus Pfeiffer, 1854: 151 (China)

Status in current study: new record in Peninsular Malaysia.

Closest species for comparison: *Auriculastra brachyspira* (Möllendorff, 1894).

Diagnosis: the general shell shape of *A. duplicata* is ellipsoid with well-rounded sides compared to *A. brachyspira* which is more to subcylindrical and with tapering slightly towards the base. The unique characteristics of *A. duplicata* is this species is usually small with a globose ovoid shell and their convex upper whorls forming the low spire.

Illustrations/ photographs: Figure 1.A, Jun-Sang and Yong-Seok (2015).

Distributions: Malaysia (Matang Mangrove Forest Reserve, Perak; Sarawak), Singapore (East Changi, Johor Straits), South Korea and China (Raven and Vermeulen, 2007).

Habitat: In MMFR, this species has been found alive under the dead wood. In other areas based on literature, it is usually found on the low salt marshes with short grass vegetation.

Materials examined. 1 specimen (7 mm in shell length) from MMFR.

Description: Shell appearance: shell is small, thin, slightly translucent and somewhat shiny. The coloration is off-white underneath a pale yellowish-corneus periostracum. The periostracum also has yellowish colour with a glossy surface. Shell shape: the shape is about ellipsoid with well-rounded sides. The last whorl around ¾ of the shell height in adults with rounded and rather low spire. Radial sculpture commonly rather with inconspicuous growth lines. Spiral sculpture a very fine with regular but wavy spiral striation that's sometimes partly absent. Aperture: the aperture is typically with two distinct columellar folds and 1 rather distinct parietal fold at about 1/3 of the height of the aperture. The aperture usually narrows towards the top. Shell up to 10 mm high.

Auriculastra oparica (H. & A. Adams, 1854)

Ellobium oparicum H. & A. Adams, 1854: 9 (Opara Island in the Society Islands, French Polynesia)

Auricula nevillei Morelet, 1882100, pl. 4 fig. 5 (Mauritius)

Auriculastra subula — Van Benthem Jutting, 1927: 14. (Buru Island, Indonesia) [non Quoy & Gaimard, 1832]

Status in current study: new record in Peninsular Malaysia.

Closest species for comparison: *Auriculastra subula* (Quoy & Gaimard, 1832).

Diagnosis: *A. oparica* is distinct from *A. subula* based on its regularly rounded shell and the sharp columellar folds in the adult shells. In *A. subula*, the similar folds might appear in juveniles. Besides that, the periostracum's colour and the radial sculpture also are the distinctive features.

Illustrations/ photographs: Figure 4-5; p 34, Raven and Vermeulen (2007).

Distributions: Malaysia (Matang Mangrove Forest Reserve, Perak; Sabah, Sarawak), Indonesia (East Kalimantan), Singapore (Changi Beach), Vietnam (Quang Ninh province), Mauritius and French Polynesia (Raven and Vermeulen, 2007).

Habitat: In MMFR, this species has been found alive under the dead wood in the high shore mangroves. This species also can be found in the estuaries of nipa and mangroves, the salt marshes with long grass above the normal high tide range.

Materials examined: 1 specimen (10 mm in shell height) from MMFR.

Description: Shell appearance: shell is rather small, rather solid, opaque and rather shiny. The coloration generally yellowish underneath a pale greenish or pale orange brown periostracum. Sometimes darker orange brown streaks occur following the growth lines. Shell shape: the shape typically about spindle-shaped with well-rounded sides. The width of the shell is greatest slightly below the middle. The last whorl around 3/5 of the shell height in adults, spire rather high and pointed. The radial sculpture with sinuous growth, particularly below the suture often developing into low, rounded slightly irregularly spaced riblets. The spiral sculpture absent. Aperture: the aperture with a rather weak columellar folds and a rather weak parietal fold at about 2/5 of the height of the aperture or slightly more. The columellar edge normally is folded sharply. The shell height mostly up to 13 mm high.

Auriculastra saccata (L. Pfeiffer, 1856)

Ellobium elongatum, H. & A. Adams (in Mus. Cuming)

Auricula saccata, Pfeiffer in Proceedings of Zoological Society 1854, p. 121

Ellobium saccatum, H. & A. Adams, Gen, rec. MoU, ii p. 237. Hah. Manilla (H. Cuming)

Status in current study: new record in Peninsular Malaysia.

Closest species for comparison: *Auriculastra subula* (Quoy & Gaimard, 1832).

Diagnosis: this species is identified by the presence of a deep and narrow umbilicus with an extra one to two whorls (usually four to five whorls for each *Auriculastra*). The bag-shaped last whorl where the widest point lies near the base also serves as the unique characteristic of this species.

Illustrations/ photographs: Plate 914/3, Poppe (2010).

Distributions: Malaysia (Matang Mangrove Forest Reserve, Perak), Philippines (Manila) and Japan (Kagoshima) (Raven and Vermeulen, 2007).

Habitat: In MMFR, this species can be found near the rotting woods on the landward side of the mangroves.

Materials examined: 2 specimens (10 mm and 11 mm in shell height) from MMFR.

Description: Shell appearance: shell is short and deeply fissured. The coloration is slightly shining of fuscous-yellow. Shell shape: the club-shaped shell is usually solid, faintly striated and eroded irregularly. The spire is elogately conic and pointed, with an irregular flat suture. The whorls normally eight to nine and flat, with the last one almost long as the spire. Sometimes the whorls dilated towards the swollen base. Aperture: the aperture is perpendicular and narrowly ovate. The parietal fold is single and small, usually placed on the middle. The columellaris is indistinctly bidenticulate. The peristome is blunt with the right margin sinuate above and thickened within at the middle part. The columellar margin is dilated and callously spreading. The shell size up to 14 mm high.

Auriculastra semiplicata (H. & A. Adams, 1854)

Ellobium oparicum H. & A. Adams, 1854: 8 (Singapore)

Cylindrotis quadrasi Möllendorff In Quadras & Möllendorff, 1895: 76-77 (Philippines)

Status in current study: new record in Peninsular Malaysia.

Closest species for comparison: *Auriculastra brachyspira* (Möllendorff, 1894).

Diagnosis: *A. semiplicata* is characterized uniquely by the presence on one to three palatal folds. Usually, the shell shape of the juvenile is ellipsoid with a low and rounded spire. Though this may also occur in *A. brachyspira*, the palatal folds are always can be distinguished between those two species.

Illustrations/ photographs: Figure 6-7; p 34, Raven and Vermeulen (2007).

Distributions: Malaysia (Matang Mangrove Forest Reserve, Perak; Selangor, Sarawak), Indonesia (Java), Singapore (Kranji river) and Philippines (Raven and Vermeulen, 2007).

Habitat: In MMFR, this species can be found near the rotting woods on the landward side of the mangroves. This species also can be found on the salt marshes, under the dead wood in short grass in the tidal area and in long grass above the normal high tide line.

Materials examined: 1 specimen (8 mm in shell height) from MMFR.

Description: Shell appearance: shell is usually small, rather thin to rather solid. The coloration is opaque and shiny, with yellowish underneath a greenish brown periostracum. Shell shape: the shell shape is narrowly ovoid with slightly convex or flat sides. The last whorl about 2/3 of shell height in juveniles. In adults, the last whorls might be slightly less than 1/2 of the shell height. The spire normally is high with a rounded top. The radial sculpture usually with sinuous growth lines. Occasionally, the below part of the suture sometimes developing into low and rounded, with slightly irregularly spaced riblets. The spiral sculpture is absent. If the spiral sculpture is locally present, inconspicuously. Aperture: the aperture part with a rather distinct columellar fold and a rather distinct parietal fold at about 1/3 to 2/5 of the height of the aperture. Normally, one to three palatal ridges about parallel to the suture with the lowermost of these is always present and situated at or slightly below 1/2 of the height of the aperture. The shell size is up to 10 mm in length.

***Auriculastra subula* (Quoy & Gaimard, 1832)**

Auricula subula Quoy & Gaymard, 1832: 171, pl. 13 figs 39- 40 (New Ireland)

Auricula dunkeri Pfeiffer, 1853: 125-126 (Madras, India)

Auricula dunkeri Pfeiffer — Issel, 1853: 59 (Borneo)

Auriculastra subula (Quoy & Gaimard, 1832) — Von Martens, 1897: 58 (Singapore)

Auriculastra subula Van Benthem Jutting, 1927: 14 [non Quoy & Gaimard = *A. oparica*]

Status in current study: new record in Peninsular Malaysia.

Closest species for comparison: *Auriculastra oparica* (H. & A. Adams, 1854)

Diagnosis: this species has a very variable shape and the most similar species that causes confusion is *A. oparica* as the juvenile of *A. subula* may be observed with same sharp columellar fold on adult *A. oparica*. *A. subula* normally having less rounded shell compared to *A. oparica*.

Illustrations/ photographs: Figure 9, page 34, Raven and Vermeulen (2007).

Distributions: Malaysia (Matang Mangrove Forest Reserve, Perak; Selangor, Sarawak), Singapore (Changi beach), Thailand, Papua New Guinea and India (Raven and Vermeulen, 2007).

Habitat: In MMFR, this species can be found within the rotting woods and on the debris or driftwood on the landward side of the mangroves. Besides that, this species also resides in the estuary and in the low salt marshes with short grass.

Materials examined: 3 specimens (10 mm, 11 mm and 11.5 mm in shell length) from MMFR.

Description: Shell appearance: shell is rather small and solid. The coloration usually opaque and rather shiny, with whitish underneath a yellowish brown to greenish periostracum. Shell shape: the shell shape is about spindle-shaped, with both sides often conspicuously rounded around the periphery. In some specimens, it appears to be much less or even flat and concave slightly toward the shell's apex. The greatest width sometimes occurs slightly below the middle. The last whorl about 1/2 to 3/5 of the shell height in adults, with the spire is high and pointed. The radial sculpture with straight growth lines, that usually rather inconspicuous. The spiral sculpture is almost absent. Aperture: the aperture normally with one to two rather weak columellar folds and one rather weak parietal fold at about 2/5 of the height of the aperture or slightly more. The columellar edge obtusely folded (rather more sharply in most juveniles). Shell size is normally up to 15.5 mm high.

Cassidula Férussac, 1821

Generally, shell is usually medium sized, solid and opaque. The coloration is usually yellowish, brownish or purplish brown, with or without colour bands. The shell is with a thick, medium to dark brown periostracum. The shell is not dorsoventrally flattened, without varices. The outline is inverted ovoid (obovoid) with a short conical spire. The sculpture composed of fine spiral grooves or ridgelets. The aperture with a columellaris that may be bifurcate. The two parietales and the palatal peristome with a distinct lip can be identified, and a deep notch near the angular corner.

Key to the *Cassidula* species

1. Shell inverted ovoid ……………………………..…………………………….. 2
    - Shell oval ……………………..……………………………………....…….. 3
2. Short spire of convex whorls ……………..………...……………... *C. aurisfelis*
    - Short spire of flat whorls ……………………….....……………….... *C. nucleus*
3. Shell thick and short ……………………………………………….... *C. doliolum*
    - Shell elongated ovate ……………….……………......… *C. plecotrematoides*

Cassidula aurisfelis (Bruguière, 1789)

Bulimus aurisfelis Bruguière, 1789: 343, pl. 460 fig. 5 (India)

Auricula felis — Metcalfe, 1852: 72 (Sarawak, Malaysia)

Cassidula aurisfelis (Bruguière, 1789) — Boettger, 1890: 165 (Singapore)

Status in current study: present record (previously recorded in Peninsular Malaysia).

Closest species for comparison: *Cassidula nucleus* (Gmelin, 1791).

Diagnosis: The unique characteristic of this species is the presence of a bifurcate columellar fold. This species can be distinguished from *C. nucleus* by its larger shell with overall more rounded outline. The shoulder part of the shell normally more convex and the aperture is not straight with a thicker palatal ridge. The juvenile maybe covered with a cuticular periderm which will lost with age. In some specimens, the shell is whitish.

Illustrations/ photographs: Figure 34, page 43, Raven and Vermeulen (2007).

Distributions: Malaysia (Perak, Selangor, Negeri Sembilan, Terengganu, Kelantan, Pahang, Sabah, Sarawak), Indonesia (Kalimantan), Singapore (Pasir Ris, Johor Straits), Australia, Hong Kong and Thailand (Raven and Vermeulen, 2007).

Habitat: in MMFR and most locations in Peninsular Malaysia, this species is common in the mangroves, usually on the mud in the shaded areas and on the tree trunks or driftwood materials. *C. aurisfelis* also inhabits the estuaries and nipa swamps.

Materials examined: 20 specimens (size ranges from 15 mm to 20 mm in shell high) from MMFR and KSNP.

Description: Shell appearance: shell is medium sized, solid and opaque. The coloration is uniformly dark brown colour and a single paler band at the periphery of the shell. The periostracum is absent in adult specimens. Shell shape: the typical outline is inverted ovoid, with a short spire of convex whorls. The body whorl is large with series of fine spiral grooves. Aperture: the aperture with a bifurcate columellar fold and two parietales. The palatal side with a thick lip that has a marked notch at about a quarter from the top. Several shallow incisions can be seen below it. The aperture is cream coloured, and in some specimen is occasionally pink. The shell size usually up to 22 mm high.

***Cassidula doliolum* (Petit de la Saussaye, 1842)**

Auricula doliolum (Petit de la Saussaye, 1842) in Proceeding of Zoological Society, p. 201

Cassidula (*Cassidulta*) *doliolum* (Petit de la Saussaye, 1843)

Cassidula doliolum, H. and A. Adams, in Proceeding of Zoological Society, 1854, p. 31

Status in current study: present record (previously recorded in Peninsular Malaysia).

Closest species for comparison: *Cassidula nucleus* (Gmelin, 1791).

Diagnosis: the coloration of *C. doliolum* and *C. nucleus* is quite similar, but the alternating brown and blue strips on *C. nucleus* is more repetitive and obvious compared to *C. doliolum*. *C. nucleus* also has twice size larger than *C. doliolum*. Another distinct feature of *C. doliolum* is the barrel shape shell that is oval or oblong-ovate.

Illustrations/ photographs: Figure 3, page 189, Hoang (2015).

Distributions: Malaysia (Selangor) and Vietnam (Raven and Vermeulen, 2007).

Habitat: this species can be found on the decaying mangrove woods with seawater influence such as estuaries and tidal areas.

Materials examined: 1 specimen (9 mm in shell length) from KSNP.

Description: Shell appearance: shell is subrimate and solid. The coloration is brown (in some specimen, brownish or whitish grey) with alternate twisted blue strands. Shell shape: the shell shape is commonly oval or oblong-ovate sometimes with regular spiral grooves. The spire is convexly conoidal and slight mucronate with the impressed suture. The whorls seven, scarcely convex, and the last body whorl forming 2/3 of the total shell length. The whorl indistinctly angled above and gradually attenuated towards the rounded base. Aperture: the aperture is almost perpendicular and narrowly semi ovate. The peristome is simple with the right margin reflexed little, three teeth inside where the middle one stronger and the lowest one indistinct. The parietalis is single, compressed horizontally, and sometimes with an indistinct small tubercle above it. The columellaris is similar to *C. nucleus* but smaller. The shell size is 10 mm with 6 mm width.

Cassidula nucleus (Gmelin, 1791)

Helix nucleus Martyn, 17841784: II: pl 67 fig. Ex. Ed. Chenu; pl 24 fig. 2 (Otaheite - Cooktown, Queensland, Australia) [invalid name, ICZN]

Helix nucleus Gmelin, 1791: 3651 (Queensland, Australia)

Auricula mustelina Deshayes, 1830, vol. 2: 92 (New Zealand)

Auricula mustelina — Metcalfe, 1852: 72 (Sarawak, Malaysia)

Auricula mustelina —Von Martens, 1897: 144, pl. 8 fig. 15 (Borneo)

Cassidula mustelina (Deshayes, 1830) — Von Martens, 1908: 281 (East Kalimantan, Indonesia)

Status in current study: present record (previously recorded in Peninsular Malaysia).

Closest species for comparison: *Cassidula aurisfelis* (Bruguière, 1789).

Diagnosis: the unique characteristic of *C. nucleus* compared to other *Cassidula* is the simple and not bifurcate columellar fold, beside its smaller size and relatively shorter spire.

Illustrations/ photographs: Figure 35-35, page 43, Raven and Vermeulen (2007).

Distributions: Malaysia (Perak, Selangor, Pahang, Sabah, Sarawak), Brunei (Belait), Singapore (Changi), Indonesia, Vietnam (Quan Ninh province), China, India, Australia and New Zealand (Raven and Vermeulen, 2007).

Habitat: this species is present in estuaries area especially on the salt marshes with short grass, occasionally occur directly on the muddy tidal flats and on the mangrove roots or trunks in the mangrove forest.

Materials examined: 9 specimens (size ranges from 14 mm to 20 mm) from MMFR and KSNP.

Description: Shell appearance: shell is medium sized, solid and opaque. The coloration is dark brown with a single paler band just above the periphery. In some specimens, an alternating dark brown and cream coloured band can observe above the periphery. The adult specimens lack periostracum. Shell shape: the shell outline inverted ovoid with the short spire made up of rather flat whorls. Fine spiral grooves usually covering the large body whorls. Aperture: the aperture with a columellar fold and two parietales. The palatal side with a thick lip that has a marked notch at about a quarter from the top. In some specimens, several shallow incisions occur in the part below this and a tooth just above it. The aperture is usually cream coloured, but in some specimens, it appears as bright pink. Shell size is up to 22 mm high.

Cassidula plecotrematoides (Möllendorf, 1885)

Cassidula plecotrematoides japonica Möllendorf, 1901

Cassidula plecotrematoides plecotrematoides (Möllendorf, 1895)

Status in current study: present record (previously recorded in Peninsular Malaysia).

Closest species for comparison: *Cassidula aurisfelis* (Bruguière, 1789).

Diagnosis: this species can be identified by its distinctive chestnut shell.

Illustrations/ photographs: Figure 7F, page 39, Martins (1998).

Distributions: Malaysia (Selangor), Japan, and Hong Kong (Raven and Vermeulen, 2007).

Habitat: this species usually found in the mangrove ecosystems occurring near the population of *C. aurisfelis.*

Materials examined: 2 specimens (9 mm and 11 mm) from KSNP.

Description: Shell appearance: shell is subrimate and solid. The coloration is chestnut. Shell shape: the shell shape is elongated ovate-conical, with longitudinal striate and spirally groove. The sub suture is distinct. The spire is acute. The whorls usually consisted of eight to nine whorls and almost flat on the side of the shell. The body whorl is about 2/3 of the total shell length, with the last whorl forming basic carina that elevated around. Aperture: the aperture is oblique, oval and rounded at the base. The peristome is pale fuscous with the right direction and the inside is flat. The edges (lip) is thin. The upper right part inside is strong with minute bidentate teeth. The columellar is broadened. The parietalis normally forming two folds, with the upper is short nodiform, and the below one spiralling to forming a strong horizontal fold. The shell size is up to 13 mm.

Ellobium Röding, 1798

The general shell shape is dextral, medium size to large, generally thick and opaque, whitish with a thick pale to dark brown periostracum. The shell is not dorsoventrally flattened and without varices. Shape is ellipsoid to obovoid. The sculpture is fine, but gradually coarsening to a slightly irregular pattern of granules towards the suture. The aperture with a columellaris, a parietalis (sometimes smaller parietal teeth above this), with or without a palatal swelling.

Key to the *Ellobium* species

1. Shell thin ………………………….…………………….…………………………….. 2
   - Shell thick ………………………………………………………………….. 3
2. Off-white underneath a thin pale yellow periostracum ...……. *E. tornatelliforme*
3. Shell medium large, with a corneous brown periostracum ..…...... *E. aurisjudae*
   - Shell medium large to large ……………………………….………………… 4
4. Shell with thick medium to dark brown periostracum …...……… *E. aurismidae*
   - Shell with thick medium to dark brown periostracum, with a well-developed subsutural sulcus ………………………………….…… *E. scheepmakeri*

***Ellobium aurisjudae* (Linnaeus, 1758)**

Bulla aurisjudae Linnaeus, 1758: 728 (type locality: not mentioned)

Auricula polita Metcalfe, 1852: 72 (Sarawak, Malaysia)

Auricula judae (Linnaeus, 1758) — Von Martens, 1897: 154, pl. 8 figs 6-11 (Singapore; West Kalimantan, Indonesia)

Auricula aurisjudae (Linnaeus, 1758) – Von Martens, 1908: 282 (Kalimantan, Indonesia)

Auricula percha Prashad, 1921: 467 (Sumatra, Indonesia)

Status in current study: present record (previously recorded in Peninsular Malaysia).

Closest species for comparison: *Ellobium aurismidae* (Linnaeus, 1758).

Diagnosis: this medium sized species has varied shell shape from ellipsoid in the juveniles to elongated ovoid in the adult specimens.

Illustrations/ photographs: Figure 10-13, page 38, Raven and Vermeulen (2007).

Distributions: Malaysia (Kedah, Perak, Selangor, Pahang, Sabah and Sarawak), Indonesia (Kalimantan), Brunei (Muara, Tutong), Singapore (Sungei Buluh Nature Park), Thailand, Philippines, Australia, Papua New Guinea and Vietnam (Kien Giang province) (Raven and Vermeulen, 2007).

Habitat: this species is commonly found in the estuaries (KSNP, MMFR), on the salt marshes above the normal high tide line or under the rotting wood between the long grass, and in the mangroves. In Sarawak and Langkawi Island, this species was recorded in the coastal forest on the sandy soil bordering a low, sandy beach.

Materials examined: 15 specimens (34.2 mm to 50.0 mm in total shell length) from MMFR and KSNP.

Description: Shell appearance: shell is normally medium large, rather thick (mostly in older or adult specimens), with a corneous brown periostracum. Shell shape: the shell outline is quite variable, from ellipsoid in most young specimens to the elongate ovoid in the adult. Normally, the sculpture of spiral rows of fine granules can be observed in the shoulder part of the shell. A weaker sculpture of such rows of granules and irregular axial lines also can be identified elsewhere on the shell. Aperture: the aperture with a thick lip that has a swelling above the middle. Most adult specimens have a well-developed parietalis. Shell size: the shell size is about five to six cm in high.

Ellobium aurismidae (Linnaeus, 1758)

Bulla auris-midae Linnaeus, 1758: 728 (type locality: not mentioned)

Auricula midae (Linnaeus, 1758) — Von Martens, 1897: 150 (Singapore; NW Borneo)

Auricula aurismidae (Linnaeus, 1758) — Von Martens, 1908: 282 (Kalimantan, Indonesia)

Status in current study: present record (previously recorded in Peninsular Malaysia).

Closest species for comparison: *Ellobium aurisjudae* (Linnaeus, 1758).

Diagnosis: this is the largest species within the family with shell larger than 11 cm in height. The very large shell accompanied by the thick periostracum usually in medium to dark brown coloration. The strong shoulder with well-developed sculpture of irregular granules in rows of spiral can be observed.

Illustrations/ photographs: Figure 14-15, page 38, Raven and Vermeulen (2007).

Distributions: Malaysia (Kedah, Perak, Selangor, Negeri Sembilan, Johor, Pahang, Terengganu, Kelantan Sabah and Sarawak), Indonesia, Brunei, Thailand, Singapore, Australia, China and Papua New Guinea (Raven and Vermeulen, 2007).

Habitat: this species is very common on mangroves and estuaries; they can normally be seen with the smaller *E. aurisjudae* in the same locality. Besides that, *E. aurismidae* is also resides on the salt marshes just above the normal high tide line and in the nipa swamps.

Materials examined: 15 specimens (shell length of 79.66 mm to100.00 mm) from MMFR, KSNP, Merbok, Kedah.

Description: Shell appearance: shell is very large and thick. The periostracum is thick with medium to dark brown coloration. The dark brown might appear pale white in some adult specimens as the results of chemical reactions of the mangrove substrate. In most of the juveniles, the pale corneous brown coloration can be observed. Shell shape: the shell outline is ellipsoid to ovoid with a high spire. The unique feature is the strong shoulder. In some specimens, several peristomes usually developed before this species is being fully grown. The well-developed sculpture of the spiral rows of irregular granules appears on the shoulder while weak granules and irregular axial lines can be recognized on the rest of the shell. Aperture: the aperture is large with a thick lip that has swelling in the middle. Shell size: this species might grow larger than 11 cm in shell length.

Ellobium scheepmakeri (Petit de la Saussaye, 1850)

Helix auris-malchi O.F. Müller, 1774: 112 (type locality: not mentioned)

Auricula scheepmakeri Petit de la Saussaye, 1850: 405-406 (Sumatra, Indonesia)

Auricula subnodosa Metcalfe, 1852: 72 (Sarawak, Malaysia)

Auricula subnodosa — Von Martens, 1897: 152 (Singapore)

Status in current study: rediscovery record (previously thought locally extinct in Peninsular Malaysia).

Closest species for comparison: *Ellobium aurismidae* (Linnaeus, 1758) and *Ellobium aurisjudae* (Linnaeus, 1758).

Diagnostic: The sculptured shoulder with the regularly spaced wrinkles (can be noted when viewing the shell from the apex) and the spirals rows of fine granules are the unique characteristics of this species.

Illustrations/ photographs: Figure 3, page 3, Ismail *et al*. (2017).

Distributions: Malaysia (Selangor, Johor, Sarawak), Singapore (Sungei Mandai) and Indonesia (Sumatra and Java) (Raven and Vermeulen, 2007).

Habitat: this species was discovered at the high shore mangrove in the upper estuary of the Selangor River. In addition, this rarely recorded species can be found in the estuaries and on the salt marshes above the high tide line.

Materials examined: 25 specimens (43.81 mm to 67.22 mm in shell length) from KSNP.

Description: Shell appearance: shell is rather large and thick. The periostracum normally thick medium to dark brown in coloration. Shell shape: the typical outline is ellipsoid with a conical spire. The rounded shoulder is well-developed with a well-developed subsutural sulcus. The shoulder also is sculptured with regularly spaced wrinkles and covered with fine granules of spiral rows. In some specimens, a weak sculpture of spiral rows of granules and irregular lines can be observed. Aperture: the aperture is large with a relatively weak lip which has no swelling. Shell size: the shell length can be up to 85.00 mm.

***Ellobium tornatelliforme* (Petit de la Saussaye, 1843)**

Auricula tornatelliformis Petit de la Saussaye, 1843: 201 (Negros Island, Philippines)

Status in current study: new record in Peninsular Malaysia.

Closest species for comparison: *Ellobium aurismidae* (Linnaeus, 1758) and *Ellobium aurisjudae* (Linnaeus, 1758).

Diagnosis: The adult *E. tornatelliforme* is about the same size as juvenile *E. aurismidae,* both species can be distinguished by the more rounded shell that is slightly tapering towards the base of the shell in *E. aurismidae*. Though some of the juveniles of *E. aurisjudae* normally resemble *E. tornatelliforme* in the general outline of the shell, the higher spire and the upper parietal tooth of *E. aurisjudae* positioned higher up above the parietal peristome can be used for identification.

Illustrations/ photographs: Figure 20, page 38, Raven and Vermeulen (2007).

Distributions: Malaysia (Matang Mangrove Forest Reserve, Perak; Sabah), Indonesia (Kalimantan), Singapore (Changi Beach) and Philippines (Raven and Vermeulen, 2007).

Habitat: In high shore mangrove of MMFR, this species can be found residing inside the dead logs. Besides that, this species also colonizes the estuaries and salt marshes with long grass above the normal high tide line.

Materials examined: 2 specimens (15 mm and 17 mm in total shell length) from MMFR.

Description: Shell appearance: shell is small and rather thin with an off-white underneath a thin pale corneous yellow periostracum. Shell shape: the shell generally has an ellipsoid outline and rather globose in shape. The sculpture of light radial wrinkles following the slightly s-shaped apertural outline. On the shoulder and in the umbilical region, the spirals of fine granules can be observed. Aperture: the aperture has a relatively weak lip. Shell size: this is the smallest species of the genus with shell length up to 20 mm high.

Laemodonta Philippi, 1846

The shell is generally small, solid, and opaque. The usual coloration is yellow to dark brown, and occasionally with spiral colour bands. The shell is sculptured with spiral ridges and covered with radial ribs. In some specimens, a reticulate sculpture that may be modified into a pattern of pits can be observed. The normal shell shape is elliptical to ovoid or obovoid, with a conical spire. The aperture often with a columellaris and one to two parietales. The palatal peristome has a lip and almost without palatales, or with one to four palatales, some of which may be conspicuous.

Key to the *Laemodonta* species

1. Shell small, solid and yellow …….……...…………….………….…………..…… 2
   - Shell small, solid and dark brown ……………………………………….... 3
2. Shell yellow with spiral sculpture of broad and flat ridges ….…..... *L. monilifera*
   - Shell with yellowish brown ………………………………...……...……. 4
3. Shell with decussate sculpture of broad and flat spiral ridges ……... *L. siamensis*
4. Spiral rows of fine pits …………………………...………. *L. punctatostriata*
   - Spiral rows of rather large pits ……………………..……...…. *L. punctigera*

Laemodonta monilifera (H. & A. Adams, 1854)

Plecotrema monilifera H. & A. Adams, 1854: 120 (type locality: not mentioned)

Status in current study: new record in Peninsular Malaysia.

Closest species for comparison: *Laemodonta siamensis* (Morelet, 1875) and *Laemodonta punctatostriata* (H. & A. Adams, 1854).

Diagnosis: this species can be distinguished from *L. siamensis* as *L. monilifera* has a pointed spire and lighter coloured shell. The sculpture consisted only of spiral ridges, without the radial riblets that cause the decussated sculpture in *L. siamensis*. Though absent in this study, almost similar species of *L. typica* can be differentiated from *L. monilifera* by *L. typica* having an open umbilicus with a carina and the angular shell shape compared to lack of umbilicus and wide body whorl in *L. monilifera*.

Illustrations/ photographs: Figure 44, page 46, Raven and Vermeulen (2007).

Distributions: Malaysia (Matang Mangrove Forest Reserve, Perak; Sabah) and Philippines (Raven and Vermeulen, 2007).

Habitat: In MMFR, this species can be found in the high shore, landward side of the mangroves. In addition, this species also found on rocks in a tidal area just above the normal high tide mark.

Materials examined: 2 specimens (shell length of 5.0 mm and 6.0 mm) from MMFR.

Description: Shell appearance: shell is small, solid and yellow in coloration. The spiral sculpture consisted of broad and flat ridges separated by narrow furrows. Shell shape: the typical outline is ellipsoid, with a high pointed spire. The umbilicus is closed. Aperture: the aperture with a columellar fold, two parietales of which the lower one may be bifurcate, and two palatales. Shell size: the shell is up to 6 mm in high.

Laemodonta punctatostriata (H. & A. Adams, 1854)

Plecotrema punctatostriata H. & A. Adams, 1854: 121 (Kalimantan, Indonesia)

Plecotrema punctatostriata — Pfeiffer, 1856: 106 (Singapore & Borneo)

Status in current study: present record (previously recorded in Peninsular Malaysia).

Closest species for comparison: *Laemodonta punctigera* (H. & A. Adams, 1854).

Diagnosis: the unique feature of this species is the numerous spiral rows and the smaller pits compared to *L. punctigera*.

Illustrations/ photographs: Figure 45, page 46, Raven and Vermeulen (2007).

Distributions: Malaysia (Kuala Selangor Nature Park, Selangor; Sabah) and Singapore (Changi Beach) (Raven and Vermeulen, 2007).

Habitat: this species can be found in the mangrove of KSNP in the landward side. Besides that, this species also occurs on the rocks in a tidal flat and salt marshes just above the high tide mark.

Materials examined: 5 specimens (shell length of 5.0 mm to 6.5 mm) from KSNP.

Description: Shell appearance: shell is generally small and solid. The coloration is uniformly yellowish-brown. The spiral rows consisted of fine pits, with two to three subsutural grooves. Shell shape: the outline is ovoid with a high and rounded spire. Aperture: the aperture with a columellar fold, two parietales the lower one of which may be bifurcate. The palatales usually two to four. Shell size: the shell is up to 7 mm high.

***Laemodonta punctigera* (H. & A. Adams, 1854)**

Plecotrema punctigera H. & A. Adams, 1854: 120 (Kalimantan, Indonesia)

Plecotrema punctigera — Pfeiffer, 1856: 105 (Borneo & Singapore)

Status in current study: present record (previously recorded in Peninsular Malaysia).

Closest species for comparison: *Laemodonta punctatostriata* (H. & A. Adams, 1854).

Diagnosis: this species can be differentiated *L. punctatostriata* by the larger pits on the spiral rows of *L. punctigera*. The dark brown spiral that resembles tiger's stripe giving this species its name.

Illustrations/ photographs: Figure 46-47, page 46, Raven and Vermeulen (2007).

Distributions: Malaysia (Kuala Selangor Nature Park, Selangor; Sarawak), Indonesia, Singapore (Changi Beach), Thailand, Australia and Papua New Guinea (Raven and Vermeulen, 2007).

Habitat: this species can be found in the mangroves of KSNP. In addition, this species also found on the salt marshes above the normal high tide line and in the estuaries.

Materials examined: 3 specimens (shell length of 5.5 mm to 6.5 mm) from KSNP.

Description: Shell appearance: shell is generally small and solid. The coloration normally with yellowish brown background and three dark brown spiral bands. The sculptured of spiral rows of rather large pits. Shell shape: the usual outline is ovoid and globose. The spire is relatively low and rounded. Aperture: the aperture with a columellar fold, two parietals and two to four palatales. Shell size: the shell is up to 7 mm high.

Laemodonta siamensis (Morelet, 1875)

Plecotrema siamensis Morelet, 1875: 273, pl. 13 fig. 6 (Thailand)

Status in current study: new record in Peninsular Malaysia.

Closest species for comparison: *Laemodonta monilifera* (H. & A. Adams, 1854).

Diagnosis: This species is the largest of the genera. *L. monilifera* differs from this species based on the pointed spire and the sculpture consisted of only ridges.

Illustrations/ photographs: Figure 48, page 46, Raven and Vermeulen (2007).

Distributions: Distribution: Malaysia (Matang Mangrove Forest Reserve, Perak; Sarawak), Indonesia (Sumbawa), Thailand, Singapore (Changi Beach), Japan and South Korea (Raven and Vermeulen, 2007).

Habitat: this species can be found in estuaries of MMFR and in the mangrove areas. Besides that, this species residing under the rotting wood on salt marshes in tidal zone above the normal high tide mark.

Materials examined: 4 specimens from MMFR (shell length of 6.5 mm to 8.0 mm).

Description: Shell appearance: shell is small and solid, with dark brown coloration. The decussate sculpture of rather broad and flat spiral ridges crossed by the radial riblets. Shell shape: the outline is ovoid, with a medium high and obtuse spire. Aperture: the aperture with a columellar fold, two parietales, and one to two palatales. Shell size: the shell is up to 9 mm in high.

Melampus Montfort, 1810

The shell is generally dextral, usually small, but sometimes medium sized for the genera (12 mm). The shell is rather solid, opaque. The shell is often whitish, yellowish to dark brown, with a colour pattern (line). The shell is not dorsoventrally flattened and without varices. The normal outline is either ellipsoid or obovoid. The shell sculpture is fine and usually relatively inconspicuous with most distinctly present on the top whorls. The aperture with a columellaris, two to numerous parietales, and two to numerous palatales. The palatal peristome not thickened, but aperture usually with a thickened ridge deeper inside on the palatal wall. Shell size usually up to 15 mm in high.

Key to the *Melampus* species

1. Shell small sized, solid …….………...………..…….……….………………… 2
   - Shell medium sized, solid ……………………………......…….…….………... 3
2. Shell reddish brown with inverted ovoid outline ……...……..……. *M. nucleolus*
   - Shell opaque and somewhat shiny with obovoid outline …..…. *M. pulchellus*
3. Shell opaque, shiny with creamy white to yellowish brown ...... *M. sincaporensis*

Melampus nucleolus Von Martens, 1865

Melampus nucleolus Von Martens, 1865: 55 (Bohol, Philippines)

Status in current study: new record in Peninsular Malaysia.

Closest species for comparison: *Melampus sincaporensis* (Pfeiffer, 1855).

Diagnosis: this species can be identified from other *Melampus* species at given area by its very large body whorl, the low obtuse spire and the numerous and regular palatales.

Illustrations/ photographs: Figure 29, page 42, Raven and Vermeulen (2007).

Distributions: Malaysia (Matang Mangrove Forest Reserve, Perak), Indonesia (Ambon), Philippines, Thailand and Singapore (Changi Beach) (Raven and Vermeulen, 2007).

Habitat: this species is normally found in the mangroves.

Materials examined: 5 specimens (shell length 9 mm to 9.5 mm) from MMFR.

Description: Shell appearance: shell is small and solid. The coloration is reddish brown. The normal outline is inverted ovoid, usually pointed towards the base. The spire is rounded and low. The fine spiral lines can be observed over the entire surface. The aperture with a strong columellar fold. Two strong parietales and up to six smaller parietal teeth above can be identified. The palatal ridge with ten to 15 small palatales. Shell size: the shell is up to 10 mm high.

Melampus pulchellus (Petit de la Saussaye, 1843)

Auricula pulchella Petit de la Saussaye, 1843: 202 (Cebu, Philippines)

Melampus pulchellus — Pfeiffer, 1856: 35 (Singapore)

Status in current study: new record in Peninsular Malaysia.

Closest species for comparison: *Melampus sincaporensis* (Pfeiffer, 1855).

Diagnosis: the unique characteristic of this species is the smaller size, with the partly or entirely pitted surface and the sharp columellar fold.

Illustrations/ photographs: Figure 30-31, page 42, Raven and Vermeulen (2007).

Distributions: Malaysia (Matang Mangrove Forest Reserve, Perak; Sarawak, Sabah), Indonesia (Kalimantan), Philippines, Vietnam (Haiphong province, Quang Ninh province) and Singapore (Raven and Vermeulen, 2007).

Habitat: in MMFR, this species can be found in the estuaries, on the muddy substrate and under the woods. Besides that, this species also occurs on the grass in salt marshes with short grass.

Materials examined: 3 specimens from MMFR (shell size from 7.5 to 8.5 mm).

Description: Shell appearance: shell is small, solid and opaque. The usual coloration is shiny with creamy white to yellowish brown. The vivid pattern of dark brown spiral or radial banding can be observed. Shell shape: the normal outline is obovoid with well-rounded sides. The radial sculpture consisted of the growth lines only. The spiral sculpture can be seen below the suture and in the umbilical region, and in most specimens, always extending over the entire shell. On the second whorl, a spiral striation started and later dissolving into a pattern of well-spaced, distinct pits. In the umbilical region, it appears as a continuous, wavy striation for a few more whorls.

Aperture: the aperture consisted of a very distinct and sharp columellaris. Two parietalis can be seen in the lower third of the parietal wall, and the lowermost of which often a distinct knob and partly fused to the upper one. A smaller tooth exists above these parietales; the palatal side with a white callus deep in the aperture. Seven to 13 teeth can be observed on its crest, with the second, third and fourth reaching deepest in the shell. Shell size: the shell is usually up to 9 mm in high.

Melampus sincaporensis (Pfeiffer, 1855)

Melampus sincaporensis Pfeiffer, 1855: 8 (Singapore)

Melampus siamensis Von Martens, 1865: 54 (Petchabury, Thailand)

Melampus siamensis — Issel, 1874: 57 (Borneo)

Melampus siamensis — Von Martens, 1897: 165, pl. 8 fig. 24 (Singapore; Kalimantan, Indonesia)

Melampus siamensis — Vermeulen & Whitten, 1998: 75-76, fig. 57 (Bali)

Status in current study: present record (previously recorded in Peninsular Malaysia).

Closest species for comparison: *Melampus nucleolus* (Von Martens, 1865).

Diagnosis: the unique characteristics of this species are the dull colouring in adult shells. The shell is normally with vague spiral banding which is indicative but only the sculpture on the shell (including the top whorls) differs from other species. In terms of shell shape, the juveniles are more distinctly obovoid, and usually almost inverted conical with rounded edges. The coloration of juvenile is more brightly coloured with narrow, bands of reddish brown on a yellow or honey-coloured background.

Illustrations/ photographs: Figure 32-33, page 42, Raven and Vermeulen (2007).

Distributions: Malaysia (Matang Mangrove Forest Reserve, Perak; Pahang, Sabah, Sarawak), Thailand, Vietnam (Quang Ninh province) and Singapore (Sungei Buloh Nature Park) (Raven and Vermeulen, 2007).

Habitat: Habitat: this species can be seen in estuaries of MMFR, on the nipa palm trunk near mangroves, and under the driftwood materials on salt marshes with short grass.

Materials examined: 4 specimens from MMFR (shell size from 10.5 mm to 12.0 mm).

Description: Shell appearance: shell is medium sized, solid, opaque, and somewhat shiny. The coloration of shell is creamy white to yellowish brown. Two to nine vaguely outlined and slightly darker brown bands can be observed on the shell. Shell shape: the shell outline is obovoid, often with slightly shouldered whorls. The radial sculpture normally predominant and fine, with well-spaced ribs from the first whorl onwards and disappearing after four to five whorls. From that then only some growth lines. The spiral sculpture can be observed below the suture and in the umbilical region, and often (in juveniles) or sometimes in adult's specimens, extending over the entire shell. A striation can be diagnosed starting in the first whorl and soon partly dissolving into rows of closely set or touching pits. Aperture: the aperture with a rather distinct columellar fold and a parietalis in the lower third of the parietal wall. Above these, one to five smaller teeth which may partly fuse into a callus can be seen. The palatal side normally without or with a white callus deep in the aperture, with four to seven teeth. The upper part usually high but rather short, while the lower ones inconspicuous but reaching deep inside the aperture, often (partly) disappearing in adult shells. Shell size: the shell is up to 14 mm in total high.

Pythia Röding, 1798

Shell is generally medium sized and relatively thick, and opaque. The coloration is usually yellowish, brownish or purplish brown, with colour bands or a pattern of spots. The periostracum is thick with medium to dark brown on colour. The outline is distinctly dorsoventrally flattened, with varices at intervals of ½ whorl, and ovoid to almost triangular with a short conical spire. The shell is with or without spiral grooves and with or without radial riblets. The riblets if appear are usually located below the suture. The aperture is with a columellaris and two parietales, where the lower one may be cleft, while the upper one usually takes the shape of a transverse callus. The palatal peristome with a distinct lip often occurred deep in the aperture, and can be observed with several palatales. This genus is uniquely characterized by its dorsoventrally compressed shells. This flattening process results in an edge at opposite sides of the spire, where the edge is further accentuated by the varices on its crest.

Key to the *Pythia* species

1. Shell medium sized, solid …….………………………………...………………… 2
   - Shell medium sized, solid with triangular outline …...…………... *P. trigona*
2. Shell with ovate outline and large body whorl……………………..……. *P. plicata*
   - Shell with tear-drop shaped ……………………………………..………. 3
3. Shell with widest point below the middle………….……….…..… *P. scarabaeus*
   - Shell with slightly concave upper whorls ……...…………..…. *P. pantherina*

Pythia pantherina (A. Adams, 1851)

Scarabus pantherinus Adams & Reeve, 1850: pl. 14 fig. 13 (Philippines)

Scarabus pantherinus A. Adams, 1851: 152 (Philippines)

Scarabus pantherinus — Issel, 1874: 61 (Sarawak, Malaysia)

Pythia reeveana Pfeiffer, 1853: 190 (Philippines)

Pythia reeveana — Von Martens, 1908: 280 (East Kalimantan, Indonesia)

Status in current study: new record in Peninsular Malaysia.

Closest species for comparison: *Pythia scarabaeus* (Linnaeus, 1758).

Diagnosis: The unique characteristics of this species are the strong radial lines which extend from the suture over a large part of the whorl. In some larger specimens, the penultimate outer lip protrudes like a radial ridge. The upper whorls of *P. pantherina* usually with a concave outline and the shell with greyish background colour. The periostracum is smooth and thin.

Illustrations/ photographs: Figure 50-56, page 47, Raven and Vermeulen (2007).

Distributions: Malaysia (Matang Mangrove Forest Reserve, Perak; Selangor, Sabah, Sarawak), Brunei (Muara), Indonesia (Aru Island, Biak, Java) and Philippines (Raven and Vermeulen, 2007).

Habitat: this species can be found along the shore, usually just above the normal high tide line, between leaves in rocks and sediments.

Materials examined: 15 specimens from MMFR, KSNP (shell length of 20 mm to 29 mm).

Description: Shell appearance: shell is normally medium sized and solid. The coloration is generally greyish with irregular dark brown spots that are often so numerous sometimes that they merge together resulting in shell to appearing brown with greyish spots. Shell shape: the typical outline is tear-shaped with slightly concave upper whorls and almost straight sides. The periostracum is pale corneus brown, very thin and smooth. The surface is rather smooth with slight wrinkles that are most pronounced in a 2 – 7 mm wide zone below the suture which sometimes extend over the entire surface. Aperture: the palatal ridge is curved, and close to the shell edge with the same colours as the shell. Behind the aperture, there is a paler zone, bordered by a pair of irregular colours bands of white and dark brown. The colour of paler zone is white in juveniles. Shell size: the shell is up to 30 mm in high.

Pythia plicata (Férussac, 1821)

Scarabus plicatus Férussac, 1821: 105 (Bengal, India)

Scarabus imperforatus A. Adams, 1851: 151 (Borneo)

Scarabus plicatus Férussac, 1821 var. *major* Metcalfe, 1852: 72 (Sarawak, Malaysia)

Pythia inflata Pfeiffer, 1853: 192 (Borneo)

Pythia imperforata — Vermeulen & Whitten, 1998: 63, fig 45 [not A. Adams; = *P. scarabaeus*]

Status in current study: present record (previously recorded in Peninsular Malaysia).

Closest species for comparison: *Pythia scarabaeus* (Linnaeus, 1758).

Diagnosis: the ovate shape of the shell can be used to differentiate this species from another *Pythia*. Due to its similarity, there are errors in identification of *Scarabus imperforatus* in various literature causing both specimens of *P. plicata* and *P. scarabaeus* to be misidentified as *S. imperforatus.*

Illustrations/ photographs: Figure 57, page 47, Raven and Vermeulen (2007).

Distributions: Malaysia (Matang Mangrove Forest Reserve, Perak; Kedah, Penang, Sarawak), Indonesia (Kalimantan, Sumatra), Singapore (Mandar), Vietnam (Kien Giang province), Philippines and India (Raven and Vermeulen, 2007).

Habitat: this species can be observed in the estuaries, on the salt marshes with long grass and on the rotting wood in the mangroves (MMFR) above the normal high tide mark. They also reside near the coastal forests on the East Coast of Peninsular Malaysia.

Materials examined: 10 specimens from MMFR (Shell length of 15 mm to 23 mm).

Description: Shell appearance: shell is medium sized and solid. The normal coloration is pale brown with irregular pattern of large darker brown spots and irregular bands, always purplish at the apex and callus. Shell shape: the usual outline is ovate with a large and inflated body whorl. Aperture: the aperture is wide with a broad lip. Normally, the callus covers almost half the ventral side of the penultimate whorl. Shell size: the shell usually up to 25 mm in high.

Pythia scarabaeus (Linnaeus, 1758)

Helix scarabaeus Linnaeus, 1758: 768 (type locality: In Asiae montibus)

Pythia imperforata — Vermeulen & Whitten, 1998: 63, fig. 45 [not A. Adams]

Status in current study: present record (previously recorded in Peninsular Malaysia).

Closest species for comparison: *Pythia pantherina* (A. Adams, 1851).

Diagnosis: The juvenile specimens have a very different outline from the adults and often are widest above the middle. Generally, *P. scarabaeus* has a larger shell compared to *P. pantherina*, with convex upper whorls, a darker colour and a periostracum with fine lines. The upper whorls of *P. pantherina* have a concave outline and its shell is usually with a greyish background colour, and a smooth, thin periostracum.

Illustrations/ photographs: Figure 58-60, page 47, Raven and Vermeulen (2007).

Distributions: Malaysia (Matang Mangrove Forest Reserve, Perak; Kuala Selangor Nature Park, Selangor; Sungai Bebar, Pahang; Johor, Sabah, Sarawak), Brunei (Belait), Indonesia (Java, Kalimantan), Philippines and Australia (Raven and Vermeulen, 2007).

Habitat: this species is common and can be seen along the shore, usually on leaves and on the rotting wood in the shaded areas and the forests above the high tide line.

Materials examined: 10 specimens from MMFR (Shell length of 25 mm to 33 mm).

Description: Shell appearance: shell is medium sized and solid. The usual coloration is medium brown with irregular darker brown spots which can be present over the entire surface. The periostracum is corneous brown, with fine radial sculpture following the growth lines. The surface is rather smooth with slight wrinkles which are most pronounced in a 2-4 mm wide zone below the suture. Shell shape: the usual outline for adults is tear-drop shaped, with the widest point below the middle. The upper whorls have a slightly convex outline. Aperture: the palatal ridge is straight and positioned away from the lip, thus creating a smooth lip and a narrow opening between the parietals and palatales. The peristome, callus and teeth are white. A paler zone can be observed behind the aperture, bordered by a pair of irregular colour bands of pale and dark brown. Shell size: the shell is up to 35 mm in high.

Pythia trigona (Troschel, 1838)

Polyodonta carinata Beck, 1837: 101 [nomen nudum] (from Singapore)

Scarabus trigonus Troschel, 1838: 207 (Sumatra, Indonesia)

Scarabus trigonus — Adams 1851: 148 (Borneo)

Scarabus trigonus — Issel 1874: 61 (Sarawak, Sabah, Malaysia)

Scarabus trigonus — Von Martens 1897: 130, pl. 8 fig. 1 (West Kalimantan, Indonesia)

Pythia trigona (Troschel, 1838) — Dharma, 1988: 78, pl. 17 fig. 11 (West Kalimantan, Indonesia)

Status in current study: new record in Peninsular Malaysia.

Closest species for comparison: *Pythia scarabaeus* (Linnaeus, 1758).

Diagnosis: the unique characteristics of the genus is the almost triangular shell and the distinct elongated groove at the umbilicus. The shell also is even more compressed than in other *Pythia* species.

Illustrations/ photographs: Figure 61, page 47, Raven and Vermeulen (2007).

Distributions: Malaysia (Matang Mangrove Forest Reserve, Perak; Tok Bali Lagoon, Kelantan; Sabah, Sarawak), Indonesia (Kalimantan), Brunei (Muara) and Singapore (Johor Straits, Sungei Buloh Nature Park) (Raven and Vermeulen, 2007).

Habitat: This species usually resides in estuaries (MMFR), on the salt marshes with long grass, and on the rotting wood and leaves at areas above the normal high tide line in the mangroves (TBLK).

Materials examined: 5 specimens from MMFR (Shell size 15 mm to 20 mm).

Description: Shell appearance: shell is medium sized and solid. The usual coloration is medium brown with small darker browns spots. Shell shape: the normal outline is triangular. The periostracum is thin, medium brown, with smooth surface. Aperture: the outer edge of the aperture normally protrudes thus giving the shell a wavy carina. Shell size: the shell is up to 20 mm in total high.

4.3 High Shore Molluscs in The Mangroves of Peninsular Malaysia

From the survey conducted in Peninsular Malaysia, a total of 54 species of molluscs from 17 families were recorded at the high shore mangroves (Table 4.2). The total included 26 species of ellobiids (Ellobiidae), five species of potamidids (Potamididae), four species of nerites (Neritidae), three species of littorinids (Littorinidae), two species of assimineids (Assimineidae), two species of corbiculids (Cyrenidae), and two species of onch slugs (Onchidiidae). Anomiids (Anomiidae), iravadiids (Iravadiidae), lucinids (Lucinidae), muricids (Muricidae), mytilids (Mytilidae), nassarids (Nassariidae), pachychilids (Pachychilidae), stenothyrids (Stenothyridae), thiarids (Thiaridae) and the sea slugs (Plakobranchidae) occurred with one species each. Overall, the high shore mangroves were dominated by gastropods with 48 species and five species of bivalves were found.

Table 4.2: List of mollusc species collected from high shore mangroves in Peninsular Malaysia.

Family	Genus	Species
Anomiidae	*Enigmonia*	*Enigmonia aenigmatica* (Holten, 1802)
Assimineidae	*Assiminea*	*Assiminea brevicula* (Pfeiffer, 1855)
		Assiminea spp.
Cyrenidae	*Geloina*	*Geloina erosa* (Lightfoot, 1786)
		Geloina expansa (Mousson, 1849)
Ellobiidae	*Auriculastra*	*Auriculastra brachyspira* (Möllendorff, 1894) *
		Auriculastra duplicata (Pfeiffer, 1854)
		Auriculastra oparica (H. & A. Adams, 1854) *
		Auriculastra saccata (Pfeiffer, 1856) *
		Auriculastra semiplicata (Pfeiffer, 1856) *
		Auriculastra subula (Quoy & Gaimard, 1832)
	Cassidula	*Cassidula aurisfelis* (Bruguiere, 1789)
		Cassidula doliolum (Petit de la Saussaye, 1842)
		Cassidula nucleus (Gmelin, 1791) *
		Cassidula plecotrematoides (Möllendorf, 1885)
	Ellobium	*Ellobium aurisjudae* (Linnaeus, 1758)
		Ellobium aurismidae (Linnaeus, 1758)
		Ellobium pallidum (Sowerby, 1839) *
		Ellobium scheepmakeri (Petit de la Saussaye, 1850) *
		Ellobium tornatelliforme (Petit de la Saussaye, 1842) *
	Laemodonta	*Laemodonta monilifera* (H. & A. Adams, 1854) *
		Laemodonta punctatostriata (H. & A. Adams, 1854)
		Laemodonta punctigera (H. & A. Adams, 1854)

Table 4.2, continued.

Family	Genus	Species
		Laemodonta siamensis (Morelete, 1875) *
	Melampus	*Melampus nucleolus* (Von Martens, 1865)
		Melampus pulchellus (Petit, 1842) *
		Melampus sincaporensis (Pfeiffer, 1855)
	Pythia	*Pythia pantherina* (A. Adams, 1851)
		Pythia plicata (Ferussac, 1821) *
		Pythia scarabaeus (Linnaeus, 1758)
		Pythia trigona (Troschel, 1838)
Iravadiidae	*Iravadia*	*Iravadia* spp. (*Fairbankia*)
Littorinidae	*Littoraria*	*Littoraria carinifera* (Menke, 1830)
		Littoraria melanostoma (Gray, 1839)
		Littoraria vespacea (Reid, 1986)
Lucinidae	*Austriella*	*Austriella corrugata* (Deshayes, 1843)
Muricidae	*Chicoreus*	*Chicoreus capucinus* (Lamarck, 1822)
Mytilidae	*Brachidontes*	*Xenostrobus* sp.
Nassariidae	*Nassarius*	*Nassarius reeveanus* (Dunker, 1847)
Neritidae	*Clithon*	*Clithon oualaniense* (Lesson, 1831)
	Nerita	*Nerita balteata* (Reeve, 1855)
	Neripteron	*Neripteron cornucopia* (Benson, 1836)
		Neripteron violaceum (Gmelin, 1791)
Onchidiidae	*Onchidium*	*Onchidium* spp.
		Platyvindex spp.
Pachychilidae	*Faunus*	*Faunus ater* (Linnaeus, 1758)
Plakobranchidae	*Elysia*	*Elysia* spp.
Potamididae	*Cerithidea*	*Cerithidea cingulata* (Gremlin, 1791)
		Cerithidea obtusa (Lamarck, 1822)
		Cerithidea quoyii (Hombron & Jacquinot, 1848)
	Telescopium	*Telescopium mauritsi* (Linnaeus, 1758)
		Telescopium telescopium (Linnaeus, 1758)
Stenothyridae	*Stenothyra*	*Stenothyra glabra* (Adams, 1861)
Thiaridae	*Melanoides*	*Melanoides tuberculata* (O. F. Müller, 1774)

* New record

A total of 26 ellobiid species from six genera were collected in Peninsular Malaysia (Table 4.3). This included four newly recorded species from Matang Mangrove Forest Reserve, Perak. Only 83.9 % of ellobiid species richness were sampled at various location in Peninsular Malaysia compared to 31 recorded species in Malaysia and Southeast Asia based on previous studies. In term of number of individuals, the most abundant species collected are *Cassidula aurisfelis*, *C. nucleus*, *Ellobium aurisjudae*, *E. aurismidae*, *Laemodonta punctatostriata*, *L. punctigera*, *L. siamensis*, *Melampus nucleolus*, *M. sincaporensis*, *Pythia pantherina*, *P. scarabaeus* and *P. trigona*. In addition, *Auriculastra* was the least collected genera.

From the nine selected localities, Matang Mangrove Forest Reserve and Kuala Selangor Nature Park recorded relatively more mollusc species and number of individuals compared to other localities. Twenty-one species were recorded from Matang Mangrove Forest Reserve while 13 species were from Kuala Selangor Nature Park. The least number of species were recorded from Lukut (i.e. two species only).

In term of species occurrence, *Cassidula aurisfelis*, *C. nucleus*, *Ellobium aurisjudae*, *E. aurismidae*, and *Pythia scarabaeus* were found within at least six selected localities (66.7 %), while *Auriculastra brachyspira*, *A. oparica*, *A. saccata*, *A. semiplicata*, *E. pallidum*, *E. scheepmakeri*, *E. tornatelliforme*, *Laemodonta monilifera*, *Melampus nucleolus*, *M. pulchellus*, and *P. plicata* were recorded in only one locality (Table 4.3).

Table 4.3: Occurrence of ellobiids in selected study sites in Peninsular Malaysia.

Species	L1	L2	L3	L4	L5	L6	L7	L8	L9
Auriculastra brachyspira	-	-	+	-	-	-	-	-	-
A. duplicata	-	-	+	-	-	-	-	-	-
A. oparica	-	-	+	-	-	-	-	-	-
A. saccata	-	-	+	-	-	-	-	-	-
A. semiplicata	-	-	+	-	-	-	-	-	-
A. subula	-	-	+	+	-	-	-	-	-
Cassidula aurisfelis	+	+	+	-	+	+	+	+	+
C. doliolum	-	-	-	+	-	-	-	-	-
C. nucleus	+	-	+	+	+	+	+	-	+
C. plecotrematoides	-	-	+	-	-	-	-	-	-
Ellobium aurisjudae	+	+	+	+	-	+	+	+	+
E. aurismidae	+	+	+	+	-	+	+	+	+
E. pallidum	-	-	+	-	-	-	-	-	-
E. scheepmakeri	-	-	-	+	-	-	-	-	-
E. tornatelliforme	-	-	+	-	-	-	-	-	-
Laemodonta monilifera	-	-	+	-	-	-	-	-	-
L. punctatostriata	-	-	+	+	-	-	-	-	-
L. punctigera	+	-	-	+	-	-	-	-	+
L. siamensis	-	-	+	+	-	-	-	-	-
Melampus nucleolus	-	-	-	+	-	-	-	-	-
M. pulchellus	-	-	+	-	-	-	-	-	-
M. sincaporensis	+	-	-	+	-	-	-	+	+
Pythia pantherina	-	-	+	+	-	-	+	-	+
P. plicata	-	-	+	-	-	-	-	-	-
P. scarabaeus	+	-	+	+	-	-	+	+	+
P. trigona	-	-	+	-	-	-	-	+	+

L1: Langkawi Island, L2: Merbok Mangrove, L3: Matang Mangroves, L4: Kuala Selangor Nature Park, L5: Lukut, L6: Sungai Pulai, L7: Sungai Bebar, L8: Setiu Wetlands, L9: Tok Bali Lagoon; +: present; -: absent.

4.4 Habitats and Distribution of Molluscs in High Shore Mangroves

The habitats of molluscs in the high shore mangroves of Peninsular Malaysia encompassed several ecological niches with some species found buried and living under the dead and rotten logs (e.g. *Ellobium*, *Auriculastra*, and *Melampus*) and among the cleft between the ferns (e.g. *Ellobium*, *Laemodonta*, *Melampus*, and *Pythia*) (Table 4.4). There were also some species that were almost fully buried in the soft muddy sediment like the bivalve *Geloina* and *Austriella*. Other species such as *Assiminea*, *Cassidula*, *Telescopium*, *Terebralia*, *Faunus*, and *Stenothyra* could be found on the surface of mangrove sediment, and hard substrates such as the driftwood materials (*Enigmonia*, *Littoraria*, and *Onchidium*). Some species inhabit the surface of the tree barks and trunks (*Cerithidea* and *Onchidium*), roots (*Cerithidea* and *Cassidula*), high branches (*Pythia*) and leaves (*Enigmonia* and *Pythia*). *Pythi*a was usually found on the leaves of various trees such as *Rhizophora*. *Clithon* was found to occur in the shallow creeks within the mangroves.

Table 4.4: A checklist of molluscs found in various ecological niches in the high shore (i.e. Zonation class 3 to 5) in Peninsular Malaysia (*) indicates present. Zonation classes 1 and 2 were determined based on available literature of the mollusc occurrence.

Genus	Zonation Class					Living Tree			Dead Logs		Ferns		Sediment		Creek	
	1	2	3	4	5	Leaf	Trunk	Roots	In	On	Leaf	Roots	In	On	Middle	Edge
Assiminea	*	*	*	*						*				*		*
Auriculastra				*	*				*	*						
Austriella			*	*	*								*			*
Brachidontes		*	*	*									*			
Cassidula		*	*	*	*											*
Cerithidea	*	*	*	*				*		*				*		*
Clithon		*	*	*										*		*
Chicoreus	*	*	*	*				*						*		*
Enigmonia	*	*	*	*		*										
Ellobium			*	*	*			*	*	*		*		*		*
Elysia	*	*	*	*												*
Faunus	*	*	*	*										*	*	*
Geloina		*	*	*	*								*			
Iravadia			*	*	*									*		
Laemodonta			*	*	*			*	*	*				*		
Littoraria	*	*	*	*		*	*	*		*						
Melampus			*	*	*			*	*	*				*		
Melanoides		*	*	*										*		*
Nassarius	*	*	*	*										*	*	*
Nerita		*	*	*	*		*	*		*						
Neritina	*	*	*	*										*		*
Onchidium		*	*	*	*		*	*		*						
Pythia			*	*	*	*	*	*	*	*	*	*				
Stenothyra	*	*	*	*										*		*
Telescopium	*	*	*	*									*	*	*	*

4.5 Spatial and Temporal Distribution of High Shore Molluscs in Matang Mangrove Forest Reserve (MMFR)

4.5.1 High shore mangrove mollusc diversity

The molluscs collected from the high shore mangrove of MMFR mostly belonged to three main families; namely Ellobiidae, Neritidae and Cyrenidae (Figure 4.4). Most of the molluscs collected were from the family Ellobiidae with 2729 individuals, followed by Neritidae (210 individuals) and Cyrenidae with six individuals. It was found that quadrat sampling missed other species that occurred in the sampling area. These other species not sampled in the quadrats but opportunistically by walking and searching in a fixed area of 15000 m^2 (150 m x 100 m) yielded an additional eight species (*Auriculastra brachyspira, A. duplicata, A. oparica, A. saccata, A. semiplicata, A. subula, Ellobium pallidum, E. tornatelliforme*), thus giving a total of 32 species (Table 4.5).

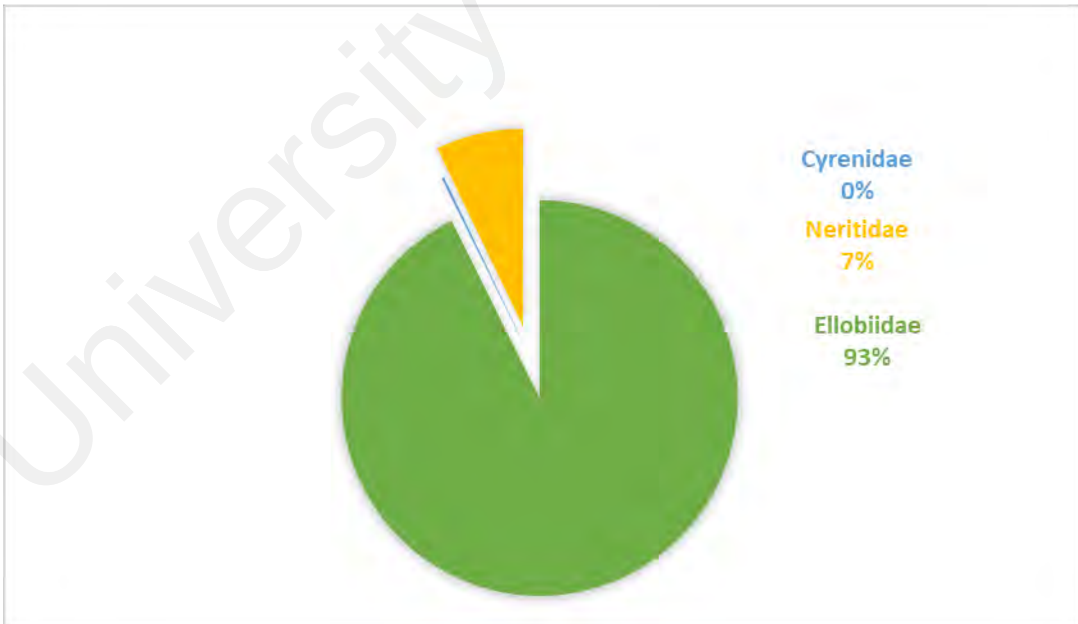

Figure 4.4: The percentage of main molluscan families collected within the designated quadrat at Matang Mangrove Forest Reserve.

Table 4.5: Lists of molluscs collected from Matang Mangrove Forest Reserve.

Family	Genus	Species
Anomiidae	*Enigmonia*	*Enigmonia aenigmatica* (Holten, 1802)
Assimineidae	*Assiminea*	*Assiminea brevicula* (Pfeiffer, 1855)
		Assiminea spp.
Cyrenidae	*Geloina*	*Geloina erosa* (Lightfoot, 1786)
Ellobiidae	*Auriculastra*	*Auriculastra brachyspira* (Möllendorff, 1894)
		Auriculastra duplicata (Pfeiffer, 1854)
		Auriculastra oparica (H. & A. Adams, 1854)
		Auriculastra saccata (Pfeiffer, 1856)
		Auriculastra semiplicata (Pfeiffer, 1856)
		Auriculastra subula (Quoy & Gaimard, 1832)
	Cassidula	*Cassidula aurisfelis* (Bruguiere, 1789)
		Cassidula nucleus (Gmelin, 1791)
	Ellobium	*Ellobium aurisjudae* (Linnaeus, 1758)
		Ellobium aurismidae (Linnaeus, 1758)
		Ellobium pallidum (Sowerby, 1839)
		Ellobium tornatelliforme (Petit de la Saussaye, 1842)
	Laemodonta	*Laemodonta punctatostriata* (H. & A. Adams, 1854)
		Laemodonta siamensis (Morelete, 1875)
	Pythia	*Pythia pantherina* (A. Adams, 1851)
		Pythia plicata (Ferussac, 1821)
		Pythia scarabaeus (Linnaeus, 1758)
		Pythia trigona (Troschel, 1838)
Iravadiidae	*Iravadia*	*Iravadia* spp. (*Fairbankia*)
Muricidae	*Chicoreus*	*Chicoreus capucinus* (Lamarck, 1822)
Mytilidae	*Brachidontes*	*Xenostrobus* sp.
Neritidae	*Neripteron*	*Neripteron cornucopia* (Benson, 1836)
		Neripteron violaceum (Gmelin, 1791)
Onchidiidae	*Onchidium*	*Onchidium* spp.
		Platyvindex spp.
Potamididae	*Cerithidea*	*Cerithidea quoyii* (Hombron & Jacquinot, 1848)
Stenothyridae	*Stenothyra*	*Stenothyra glabra* (Adams, 1861)

4.5.2 Spatial distribution of species

(i) Along the gradient of inundation frequency

The corresponding analysis (CA) was used to visualize the distribution of molluscs sampled through five inundation classes of mangroves and from different microhabitats in the Matang mangrove. On the mangrove forest floor (sediment), the mollusc species were found from the lower shore at or near the bank of the river (Sg.) Reba up to the upper dry shore of the mangrove forest. The CA ordination diagram in Fig. 4.5 shows this distribution of mollusc species with respect to the constructed line drawn from zones 1 to zone 5, that is, the gradient of high to lower tidal inundation or frequency of tidal wetting. Axes 1 and 2 of the CA diagrams accounted for 61% of the cumulative percentage variance of species data, with eigenvalues of 0.321 and 0.209, respectively. The total inertia or sum of all eigen-values was 0.868.

Genera such as *Elysia*, *Telescopium*, *Nassarius*, *Stenothyra* found on the lower shore were not found on the upper shore which was inhabited by genera such as *Ellobium*, *Melampus*, *Laemodonta*, *Auriculastra* and *Cylindrotis quadrasi* which were not found at the lower shore. The latter two species were encountered on the highest ground. On the forest floor, genera found on the middle zone included *Nerita*, *Cassidula*, *Neritina* and *Geloina*. Certain molluscs were more often encountered in the particular habitats. *Assiminea*, *Xenostrobus*, *Melanoides*, *Neritina* and *Cassidula* were found at or near creeks or very wet areas or sediments. Genera that were found on mangrove roots or /and fallen wood included *Nerita*, *Onchidium* and *Ellobium*. *Ellobium aurisjudae* and two other ellobiid species *Ellobium aurismidae* and *Ellobium* spp., *Auriculastra* and all three *Laemodonta* species were also found inside or underneath the peeling bark of fallen wood. Species that were encountered higher on the tree trunks included *Cerithidea*, *Littoraria*, *Enigmonia*, and *Ellobium* aurisjudae. Four species, *Enigmonia aenigmatica*, *Littoraria melanostoma*, and *Pythia scarabaeus* and *Pythia trigona* were found higher on the mangrove leaves. Both *Pythia* species were also found on fern leaves.

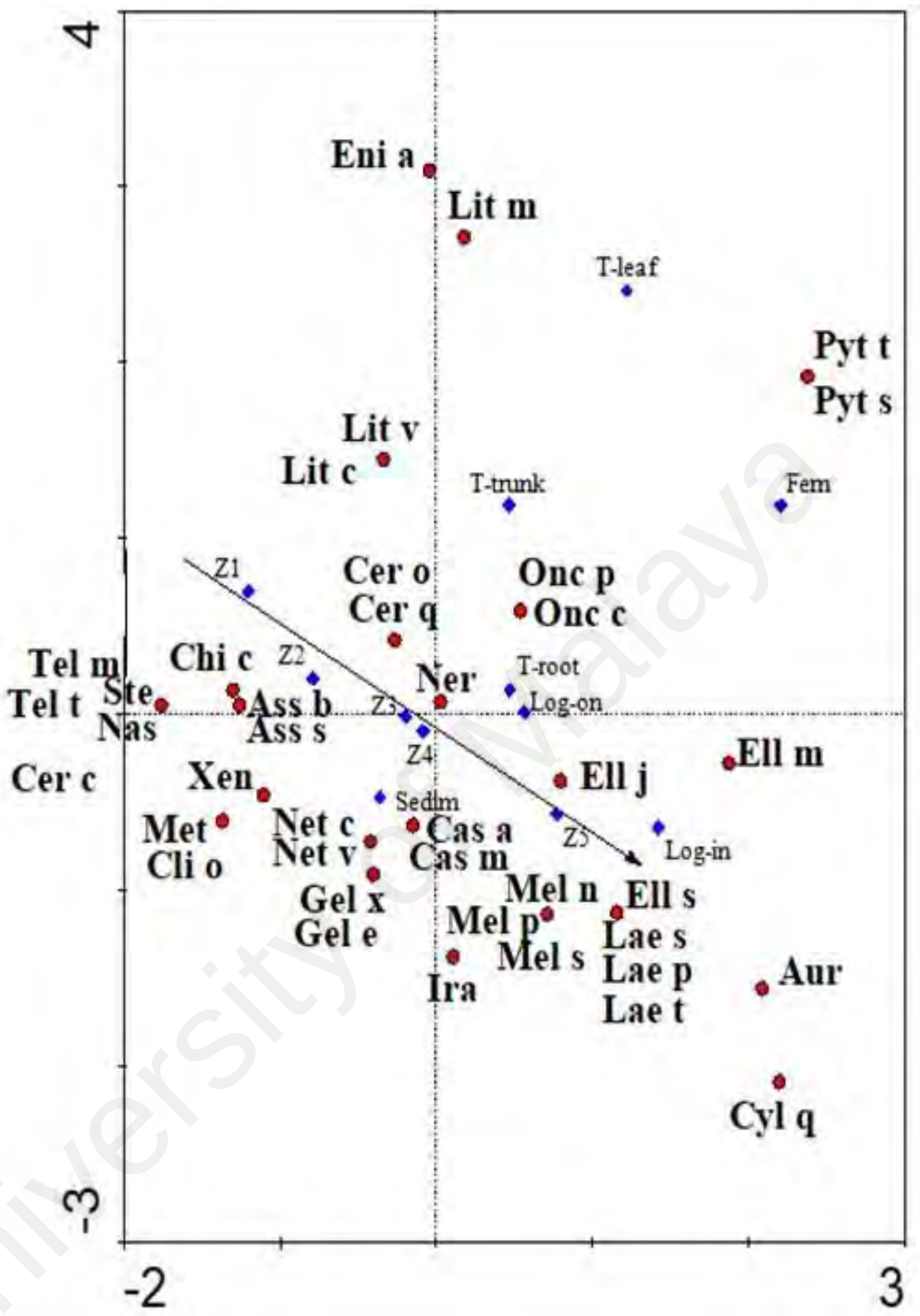

Figure 4.5: Correspondence Analysis ordination diagram of the mollusc distribution data of Matang *M*angrove *Forest Reserve*, based on Hill's scaling. The first axis is the horizontal and the second axis is the vertical. The red circles indicate the species (detailed names of acronyms as given in Appendix A and the blue diamonds indicate the Zones 1, 2, 3, 4, 5 and the sampled microhabitats. Direction of increasing frequency of tidal inundation (from Z1 to Z5) is indicated by arrow. Microhabitat acronyms: Creek= creek to Sg. Reba, Sediment = sediment, T-root = root of tree, T- trunk = tree trunk, T-leaf = leaf on tree, Fern = ferns, Log-in = in the dead logs, Log-on = on the dead logs.

(ii) Across transects (high shore)

Ellobiids, in particular on the high shore, showed variable distribution in terms of elevation, i.e. from lowest (T3) to uppermost transect (T1). Kruskal – Wallis test results revealed the highest abundance at middle transect, T2 followed by T1 and T3, with no significant difference between T2 and T1 ($p=0.088$); however, both T2 and T1 were significantly much higher than T3 ($p <0.01$).

Figure 4.6 shows the mean density gradients of ellobiids (numbers/m^2) plotted as contours in the sampled plot at Reba river site (Eco-Education Center Matang Mangrove, Matang MMFR). As observed, the highest numbers of ellobiids could be found at the middle and upper zones of the upper shore, but the snails appeared to show patchy distribution, i.e. they were not evenly distributed within both zones. The contour plot of the distribution of *Ellobium aurismidae* at the same sampling plot shows a similar pattern as total ellobiids, thus reflecting the dominance of this species (Figure 4.7).

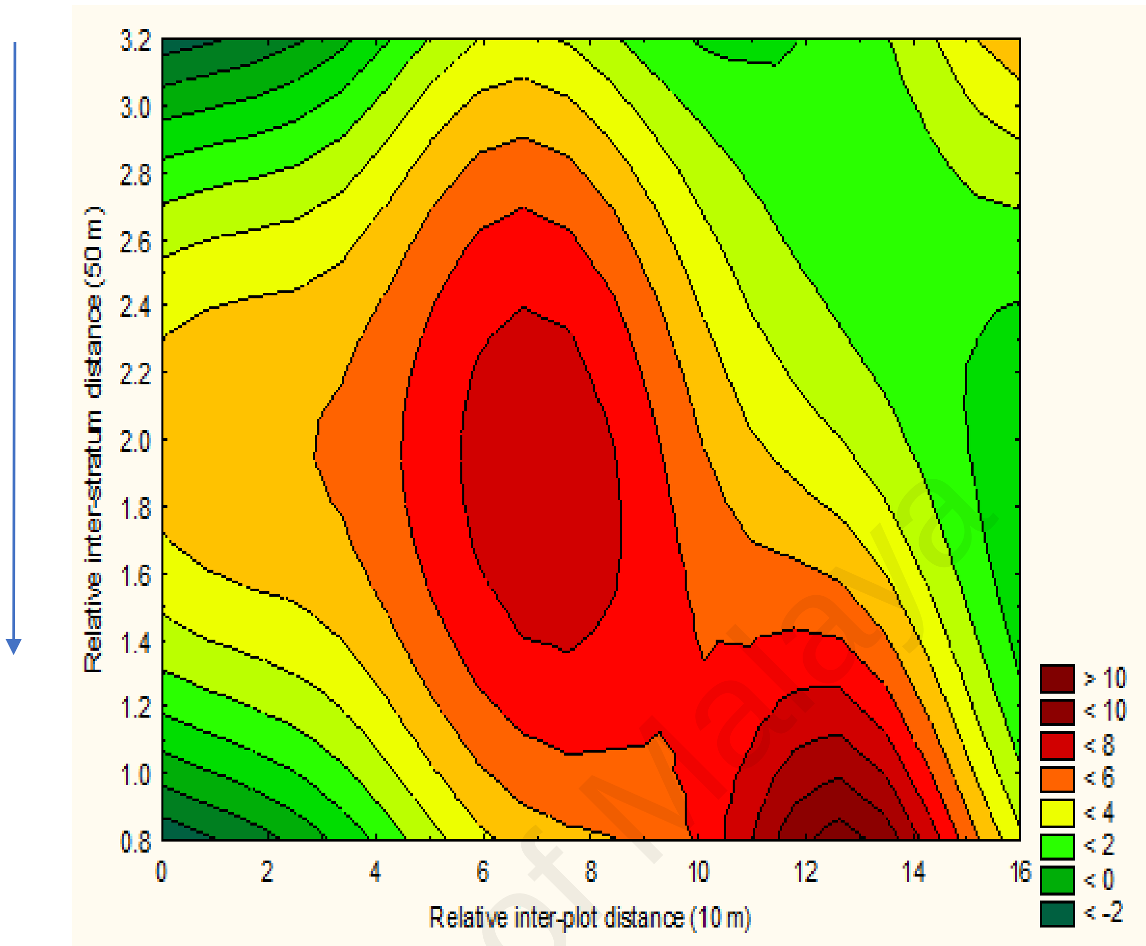

Figure 4.6: Mean density (no./m^2) distribution of ellobiids at Eco-Education Center Matang Mangrove Forest Reserve. Grid samplings conducted in a permanent sampling plot of 150 m x 150 m, according to three strata and 15 plots (=45 grid plots). Each grid plot sampled using 0.5 x 0.5 quadrat over a period of 16 months from month February 2014 to May 2015. Density contours interpolated and drawn using the distance weighted least squares method in Statistica v. 7.0. Arrow indicates gradient of decreasing tidal inundation.

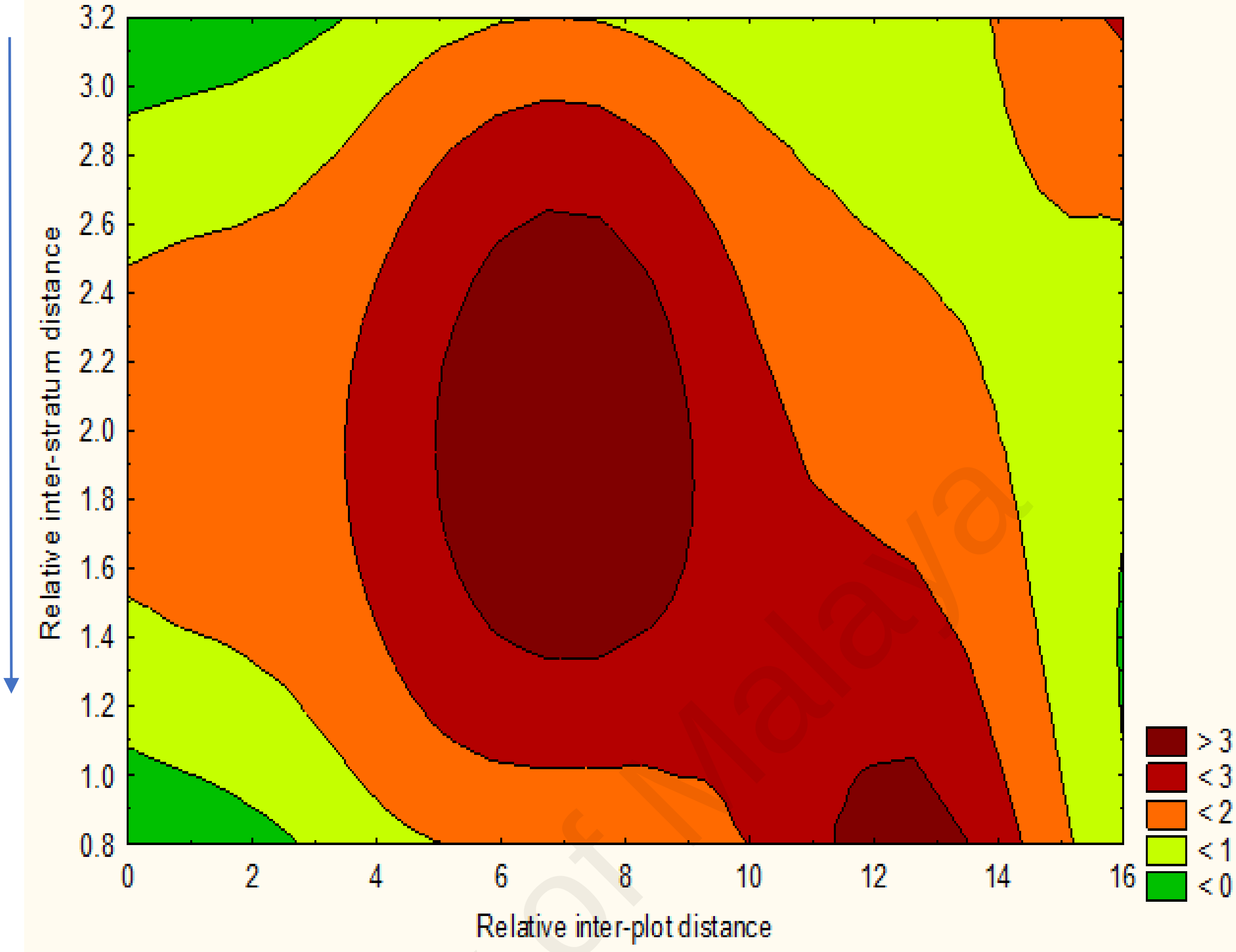

Figure 4.7: Mean density (no./m^2) distribution of *Ellobium aurismidae* at Eco-Education Center Matang Mangrove Forest Reserve. Grid samplings conducted in a permanent sampling plot of 150 m x 150 m, according to three strata and 15 plots (=45 grid plots). Each grid plot sampled using 0.5 x 0.5 quadrat over a period of 16 months from month February 2014 to May 2015. Density contours interpolated and drawn using the distance weighted least squares method in Statistica v. 7.0. Arrow indicates gradient of decreasing tidal inundation.

Analysis of species by transect revealed that *E. aurismidae* was most abundant at T2, then in T1 (no significant difference between T2 and T1, p=0.054), followed by T2. However, only T2 was significantly higher in abundance compared to T3 (p=0.005). For *E. aurisjudae*, both abundance in T2 (highest) and T1 were significantly higher than at T3 (p<0.01), but abundance at T2 and T1 were not significant (p=0.86). For *Cassidula aurisfelis*, its abundance in the three strata was significantly different from each other (P<0.05); the highest abundance was at T2, followed by T3 and T1. For *Melampus* sp., abundance at the three strata (no animals sampled in T2) was not significantly different among each other ($p>0.10$). The two *Pythia* species, *Pythia trigona* and *P. scarabaeus*, each constituted less than 10% of the total mollusc abundance. Both species show identical distribution in that abundance was highest at T1.

4.5.3 Temporal abundance of molluscs

A total of 2957 molluscan individuals were collected from the high shore mangrove of the MMFR during the 16 months (February 2014 until May 2015) of sampling which covered both monsoon seasons. This total was based on quadrat samplings. The lowest number of individuals collected was in March 2014 with 83 individuals and the highest number of individuals collected was in July 2014 with 250 individuals (Figure 4.8).

The total sampling effort using fifteen 0.5 m x 0.5 m quadrats, with each on three line transects covered an area of 11.25 m^2 every month for 16 months of sampling. The mean monthly molluscs density (number/ m^2) based on quadrat sampling in the high shore mangrove thus varied between 7.4 to 22.2 with a mean of 16.35 ± SD 3.73.

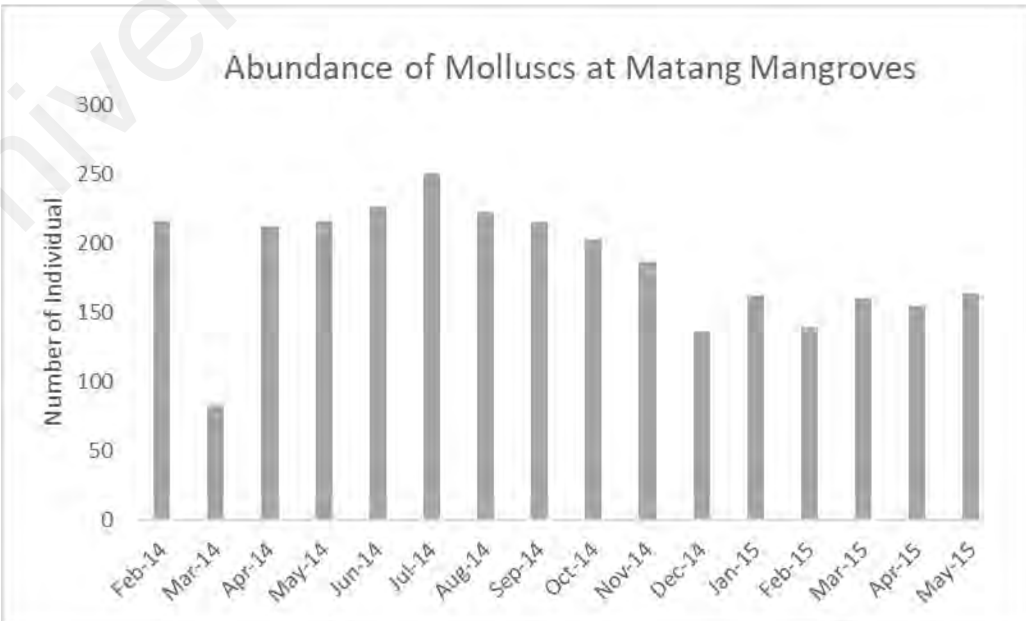

Figure 4.8: The abundance of molluscs collected at Matang Mangrove Forest Reserve from February 2014 to May 2015. Total area sampled per month = 11.25 m^2.

A Kruskal-Wallis test indicated that there was no significant difference in total mollusc abundance between the two monsoons ($p = 0.06$). In term of Ellobiidae abundance between the Southwest Monsoon (SWM) and Northeast Monsoon (NEM), no significant difference could be observed. There was also no significant difference among months for ellobiid abundance. However, there was a significant difference in ellobiid abundance between monsoonal periods, i.e. between dry SWM and dry NEM as shown by the Kruskal-Wallis test ($p = 0.05$). The Ellobiidae abundance for both periods were equal during the wet season, but lower during the dry NEM compared to dry SWM period.

CHAPTER 5: DISCUSSION

5.1 High Shore Molluscs in The Mangroves of Peninsular Malaysia

Most of the molluscs collected from this study such as Ellobiidae, Littorinidae, Neritidae and Potamididae are common molluscs inhabiting the mangroves especially in the tropics (MacNae, 1968). By comparison to the previous study on molluscs in Malaysia, this study managed to find in total 53 species of molluscs compared to Berry (1972) in Kuala Selangor with 48 species, 26 species by Sasekumar (1974) in Port Klang, Selangor, 14 species at Matang, Perak (Sasekumar & Chong, 1998), 13 species at Tanjung Dawai and Pulau Sayak, Kedah by (Faezah & Farah, 2011); 12 species at Pulau Langkawi (Sasekumar & Ooi, 2005). The large number of gastropod species recorded in this study comes from collections from several locations on the east and west coasts of Peninsular Malaysia.

In the present study, a total of 19 mollusc species from 4 families; eight genera, were recorded for the first time in Peninsular Malaysia. Additionally, 82 mollusc species from 39 families and 58 genera were compiled from various available literature. The increase in mollusc diversity as recorded in this study is anticipated to spur further interests amongst malacologists to uncover new species or records of molluscs that still remain under-studied until today. It is likely that the current records (including the newly recorded species from the present study) do not come close to the actual number of mollusc species in Malaysia since most of them are found in other Southeast Asian countries. Thus, it is expected that many more species found in the neighbouring countries will eventually be discovered in Malaysia given the same habitat types, topographies and climatic conditions. It is also expected that more gastropod and bivalve species will be discovered in countries that have larger mangrove coverage, greater habitat variability and larger coastal land mass.

Almost 90% of the entire number of mollusc species recorded in this present study in the high shores of Peninsular Malaysia are gastropods and the rest are bivalves. The number of bivalves are lower because bivalves prefer to live at the lower and middle shores since many species are filter feeders that require a regular supply of sea water containing phytoplankton food and cannot tolerate long periods of exposure to air. According to Plaziat (1984), bivalves are often limited to the narrow seaward zone probably due to their feeding preferences and larval settlement at the lower intertidal mangrove sediments found where benthic microalgae, and macroalgae dominate (Tanaka & Chihara, 1988; Aikanathan & Sasekumar, 1994; Sarpedonti & Sasekumar, 1996). However, there are bivalves such as *Geloina erosa* which live in the high shore mangrove and are adapted to a semi-terrestrial life (Morton, 1976).

The pachychilid, *Faunus ater* was absent on the west coast, but very abundant on the east coast (Kelantan and Terengganu), especially in the estuaries where there was a mixture of sand and mud substrate (Kasawani *et al.*, 2007). This species was similarly found in a bar-built estuary (lagoon) at Bachok, Kelantan (Sasekumar & Moh, 2010). Hence, the occurrence of this monotypic species indicates it preference for shallow brackish water estuaries, whereas the other members of the family Pachychilidae are freshwater inhabitants (Köhler, 2002).

During the field survey to document the molluscs on the west coast of Peninsular Malaysia, we encountered many common species that were easily found and collected but may have been overlooked, and therefore not recorded in the latest checklist by Wong and Arshad (2011). This study thus provides more recent mollusc species records focusing mainly on the west coast of Peninsular Malaysia. The current compilation of recorded molluscs thus includes our recent observations added to the checklist.

The high shore mangroves are normally occupied by the air breathing ellobiids such as *Ellobium aurismidae*, *E. aurisjudae*, *Cassidula aurisfelis*, *Pythia scarabaeus* and *P. trigona* which prefer the rich organic debris and microalgae present on the sediment surface. Surprisingly, the rare *E. scheepmakeri* was found to colonize the high shore *Nypa* forest in the estuary of the Selangor River. This shade tolerant species usually hides under rotting wooden logs, mangrove roots and clumps of ferns that provides moisture as the gastropod intolerant to desiccation. Due to their habitat preferences for back mangroves or high shore areas, the occurrence of family Ellobiidae are useful as an indicator for pristine and older mangroves (Singh & Norashekin, 2016). Sadly, they are now primarily threatened by landward anthropogenic disturbances that eventually imping on the mangrove ecosystems.

As a developing country, Malaysia has undergone rapid development especially in the coastal areas where mangrove forests occur. Extensive areas of mangroves have been converted for aquaculture, agriculture, port development, infrastructural development, commercial and tourism related industries. In the early years, mangroves were once considered as "useless swamps", and thousands of hectares of mangroves had been cleared for rice fields and shrimp pond farming (Ong, 1982). Due to social-economic pressures, conservation efforts seem not to succeed as extensive mangroves on the coastal mainland and islands of Pulau Indah and Carey Island in Selangor were used for agriculture, aquaculture and port infrastructure facilities (Latiff, 2012). Although there is some success in mangrove restoration and conservation, mangroves are still threatened by the discharge of aquaculture wastewater, oil pollution and water transportation that are eroding the riverbanks (Latiff, 2012). In Peninsular Malaysia, Selangor has the largest mangrove area after Matang Mangroves, estimated at 28, 954.6 ha back in 1989 but declined to 22, 213.16 ha in 2001 and further reduced to 19, 456.12 ha in 2007 (Khali *et al*, 2009, Sasekumar *et al*., 2012). The contributing factors were rapid urban and settlement development, aquaculture farms, expansion of agricultural land as well as coastal erosion.

5.2 Ellobiids of Peninsular Malaysia

5.2.1 Taxa diversity

The ellobiid molluscs of the East Coast and West Coast of Peninsular Malaysia are successfully compiled in this study. Currently, there are five genera that have been recorded in Peninsular Malaysia which include *Cassidula*, *Ellobium*, *Laemodonta*, *Melampus* and *Pythia* (Sasekumar, 1974; Ashton *et al*., 1999; Sasekumar & Moh, 2010; Faezah & Farah, 2011). Six genera of Ellobiidae were recorded in this study; *Auriculastra*, *Cassidula*, *Ellobium*, *Laemodonta*, *Melampus* and *Pythia* (Table 5.2). Nevertheless, some species from these genera were not observed in the present study though they had been recorded elsewhere in Malaysia. For example, *M. adamsius* and *M. fasciatus* were recorded in Sabah (Raven & Vermeulen, 2007). The current study managed to record 26 species of ellobiids compared to 31 species previously known in Malaysia as well as in Southeast Asia, and 166 species worldwide (Table 5.1).

Table 5.1: The number of ellobiid species in eight genera from specific regions compared to the present study in Peninsular Malaysia.

Genus	[1]Worldwide	[2]Southeast Asia	[3]Malaysia	Present study
Auriculastra	12	6	6	6
Blauneria	2	1	1	0
Cassidula	17	4	4	4
Ellobium	13	4	4	5
Laemodonta	14	6	6	4
Microtralia	9	1	1	0
Melampus	38	5	5	3
Pythia	11	4	4	4
Total	116	31	31	26

[1,2,3] The number of ellobiid species are compiled from the following references, 1: MolluscaBase, 2018, 2: Tan & Chou, 2000; Raven & Vermeulen, 2007; Tan *et al*., 2009; Poppe, 2010, 3: Berry, 1967; Sasekumar, 1974; Ashton *et al*., 1999; Raven & Vermeulen, 2007; Faezah & Farah, 2011.

5.2.2 Habitat preference

Species such as *Cassidula aurisfelis*, *Ellobium aurisjudae*, *E. aurismidae*, *Pythia scarabaeus* and *P. trigona* are some of the common ellobiids that inhabit the high shore mangrove. These species prefer the rich organic debris on the sediment surface where microalgae are abundant (Salmo & Duke, 2010). These shade tolerant species, traditionally known to hide under rotting wooden logs, mangroves roots or crevice under clumps of ferns, lack an operculum to reduce desiccation when exposed to air. Ellobiids have however developed a remarkable way to store some water within the shell so as to overcome or help reduce desiccation stress when immersion in tidal seawater is reduced during long neap tidal periods (personal observation). However, their occurrence can also be affected by submersion as well as exposure between tides; they normally avoid submersion by staying on the high ground near the mound of the mud lobster *Thallasina*, under the fern *Acrostichum* or decaying fallen logs.

According to Martins (1992), the Indo-Pacific region can be regarded as the geographical headquarters of the Ellobiidae, the air-breathing molluscs that can be classified into several groups based on their habitat preferences, namely, supratidal and estuarine, intertidal and crevice-dwelling, coastal terrestrial and inland terrestrial. Most of the ellobiids normally live at the high shore which is usually inundated by the highest spring tides and have a wide range of salinity tolerance. *Cassidula* and *Ellobium* can be found on the mangrove floor after the tides recede while *Pythia* normally stays on the higher parts of the tree or fern, and never ventures down onto the wet and damp mud (Martin, 1992). Some members of the ellobiids live in estuarine waters that have lower calcium concentration while others thrive as calciphile (Morton & Graham, 1955). *E. aurismidae* develops a very strong and thick epidermis on the shell (periostracum) that might aid them to cope with shell erosion due to the low pH condition. The abundance of ellobiids on the high shore mangroves may be attributed to the occurrence of dead wood on the forest floor (Teoh *et al.,* 2018). Ellobiids were found feeding on the surface and within clumps of the decomposing woods. *E. aurisjudae* was found to assimilate the refractory mangrove carbon from wood and leaf litter, and thus utilize the carbon resources on the forest floor (Teoh *et al.,* 2018).

In the coastal zone, especially on rocks in the spray zone, some species of ellobiids just live on the bare rocks, just above the normal high tide line, in the zone where there is a spray of saltwater and which is occasionally inundated during high tide. In some of the areas in Peninsular Malaysia, this coastal zone consists of disturbed mangroves such as in the mainland of Selangor and Lukut on the coast of Negeri Sembilan. Examples of the ellobiids found in these areas are *Laemodonta monilifera*, *L. punctatostriata* and *L. typica*. In some rocky shores, such as in Langkawi Island, species such as *Auriculastra* and *Melampus* can be found on tide-breaker blocks, whereas the same species in Merbok and Matang mangroves are found on coastal vegetation and accumulated dead leaves. In other coastal zones with sand or with loose rocks, some species of *Pythia* may occur such as in the East Coast of Peninsular Malaysia. *P. pantherina* can be found under strewn driftwoods and on three branches. Moving higher into the coastal fringe forest and well above the high tide line, *P. scarabaeus* and *P. plicata* are widely distributed under dead wood, between fallen leaves and on living vegetation.

Typically, the estuarine habitats such as mangroves, tidal flats and salt marshes which are inundated daily or occasionally are shelters for the Ellobiidae. Though impacted by human activities, the mangrove forests still can be found most of the estuaries in Malaysia Traditionally, vegetation like *Bruguiera*, *Rhizophora*, *Sonneratia* and *Avicennia* are the dominant species that occur in the mangroves beside the nipa palm trees that border the river banks upstream. These mangroves provide sanctuary for ellobiids where species such as *Cassidula nucleus*, *C. aurisfelis*, *Ellobium aurisjudae*, *E. aurismidae*, *Laemodonta punctigera* and *Melampus sincaporensis* can be easily found (Raven & Vermeulen, 2007). In and under the rotting wood or debris, species like *Auriculastra*, juvenile *E. aurisjudae*, *Laemodonta siamensis* and *Pythia plicata* exists. *Cassidula* also lives on the mud under the shade of the vegetation. In some areas such as in the Kelantan River and Tok Bali Lagoon, *Pythia* species live on the nipa palm trunks just above the water level. In particular, *P. scarabaeus* is generally present in sandy coastal areas vegetated by the Sea Hibiscus (*Talipariti tiliaceum*). *Melampus* and *Cassidula* also inhabit the higher parts of the tidal flats especially at the mouth of the riverbanks that passed into the low salt marshes of the mangrove forests.

In the high shore mangroves or the dryland forest which are typically flooded for a few hours during the highest tide, species of *Ellobium* and *Pythia* can occur directly on the sandy or muddy soil where they mostly live in holes within tree trunks or under driftwoods. The driftwood and trunk holes protect them from direct sunlight as well providing them food sources including the algae and sedimented organic materials (Raven & Vermeulen, 2007). *Ellobium aurisjudae* especially the juveniles are abundant in decomposing tree trunks, while the adults roam outside. Interestingly, the upper shore in MMFR & KSNP for example are replete with tree trunks since fallen tree trunks are buoyant and normally floats into the estuarine area during the high tides. Hence, the highest tides of the month will bring them into the dryland area where most of the wood may be found above the normal high tide range. Some ellobiid species are usually confined to this area, which includes *Auriculastra*, *E. aurisjudae*, *E. aurismidae*, *E. scheepmakeri*, *E. tornatelliforme*, *Laemodonta punctatostriata*, *L. punctigera*, *P. plicata* and *P. trigonus*. A large species of *Ellobium*, *E. scheepmakeri* is found only in the upper reaches of Kuala Selangor mangrove estuary in predominantly *Nypa* forest where the sediment salinity measured 6 to 7 ppt. Its favourite habitat is the beneath the logs of decomposing mangrove wood (Hanif *et al*., 2017).

5.2.3 Vulnerability of ellobiids to human disturbance

The vulnerability of the Ellobiidae to human impacts is was emphasized here since some species that were once dominant on the high shore mangroves are rarely reported in the present study. The human impacts on mangrove forests cannot be more emphasized here given that approximately 62% of the Selangor's original mangroves were lost to development from 1975 to 1999 (Haliza, 2004). Various Permanent Forest Reserves such as Kapar, Pulau Lumut, Banjar Utara, Banjar Selatan and Jugra have lost more than 80% of their original area due to various conversions (Sasekumar *et al*., 2012). It is reported that the degazettement of mangrove and forest reserves for agriculture land for example has been another leading factor in the extirpation of mangrove and peat swamps in the country (Norhayati *et al*., 2009).

In spite of the threats to the high shore molluscs that live closest to human settlements and activities, community participation in mangrove conservation efforts appeared to have benefited these molluscs. A case in point is the preservation of a rare species of ellobiid, *Ellobium scheepmakeri*, that has persisted in the conserved mangrove forest at Bukit Belimbing, a rural town in Selangor. The site here is part of a mangrove forest area that is home to the Selangor's iconic fireflies (*Pteroptyx tener*) that support an important ecotourism industry at Kampung Kuantan. The discovery of *Ellobium scheepmakeri* highlighted its resilience in a small protected mangrove area surrounded by bludgeoning infrastructural development as well as the importance of local community management. In this case this case, community-based management of the fireflies ecotourism industry at Kampung Kuantan, by protecting the fireflies and mangrove trees, likely protects *E. scheepmakeri* probably from local extinction. It is foreseen that the cooperation between the local community, researchers and non-governmental organizations can go a long way to protect even the most threatened species by conserving an adequate area of mangrove forest.

5.3 Distribution of molluscs in Matang Mangrove Forest Reserve (MMFR)

In the present study, a total of 31 mollusc species from 15 genera and 11 families were recorded from the lower to higher shore mangrove at the Reba River in the Eco-Education Center Matang Mangrove Forest Reserve (ECM). The total number of species collected is higher than reported by Sasekumar and Chong (1998), also from Matang Mangrove Forest Reserve with 14 species, Sasekumar (1974) in Kuala Selangor, Selangor with 26 species, Faezah and Farah (2011) in Pulau Sayak, Kedah with 13 species, and Sasekumar and Ooi (2005) with 12 species from Langkawi Island. The high shore mangrove molluscs at ECM however belonged to 21 species mostly from three main families; the Ellobiidae, Neritidae and Cyrenidae. A similar trend was observed for the mollusc's species in tropical mangroves where Littorinidae, Neritidae, Potamididae, and Ellobiidae were reported as the common families (MacNae,1968).

The species richness and diversity of mangrove molluscs are closely related to the diversity of mangrove trees (Ellison *et al*., 1999). Camilleri (1992) found more than 39 species of molluscs in the mangroves of Australia compared to 28 species reported by Jiang and Li (1995) in China. Certain taxa of molluscs such as *Ellobium*, *Enigmonia*, *Terebralia palustris* and *Littoraria scabra* appear to exclusively occur in the mangrove ecosystems (Plaziat, 1984). Nevertheless, the distribution of molluscs within mangroves is principally influenced by various factors such as tidal exposure, salinity, light intensity and types of substrate (Nagelkerken *et al*., 2008). On top of that, diet preferences and predation also contribute to the species distribution (Nagelkerken *et al.,* 2008).

The present study through sampling of molluscs from the river bank to the upper shore has revealed a clear change in mollusc species and distribution (see Section 4.5.2) reflecting species zonation, probably as a result of their adaptation to tidal immersion or emersion. Thus, it is expected that species that cannot adapt to longer periods of air exposure or desiccation are those that are found at lower elevations. In the present study, species such as *Assiminea*, *Telescopium*, *Nassarius* and *Stenothyra* can be found to colonize the lower part of the mangroves (tidal class zonation 1 and 2), and are not generally found on the upper shore of the mangroves (tidal class zonation 4 and 5) which is inhabited by ellobiids such as *Ellobium*, *Melampus*, *Laemodonta*, *Auriculastra* and *Cylindrotis*. According to Morton and Graham (1955), the ellobiids are pulmonates that usually characterize the fauna of the upper and supralittoral zones of mangroves and salt marshes. Berry *et al*. (1967) also reported that *Ellobium* is common on the muddy surface just below the high tide mark, living around the mangrove's roots and decomposing woods.

On the middle shore (tidal class zonation 3), more species of molluscs can be observed such as *Assiminea*, *Nerita*, *Cassidula*, *Neritina* and *Geloina*. Additionally, species like *Xenostrobus* and *Melanoides* are found at the wet sediment areas or near creeks. Areas that receive daily seawater wash are usually rich in organic materials and nutrients that are needed by the molluscs, thus affecting their distribution (Cintron & Schaefer-Novelli, 1984). Species such as *Littoraria*, *Cerithidea*, *Ellobium aurisjudae* and *Enigmonia aenigmatica* are found in the same zone but inhabit the tree trunks and mangrove leaves. The mangrove stands in zone 3 are normally dominated by *Littoraria melanostoma* as the younger mangrove plant are shorter with denser canopy, serving as perfect refuge for arboreal molluscs as this species feed on the epibenthic crusts on the stems as well as grazing on the leaves (Lee *et al*., 2001). On the middle shore, the potamids such as *Cerithidea* are usually observed on the tree trunks during high tide, or crawling on the sediments below trees after the tide recedes before returning to the trunks to avoid submersion by the next high tide.

Unlike the clear spatial distribution of molluscs or ellobiids in the mangrove, the molluscs in Matang did not exhibit any obvious temporal variability whether on the monthly or seasonal basis (section 4.5.3). However, according to Chew *et al*., (2011), there is no well-defined dry and wet seasons at Matang; the mean total rainfall (221 mm) and mean number of rainy days (17 days) during the SWM period, however, tend to be lower than that (416 mm, 25 days) during the NEM. Fig. 4.5.3 in the Result section showed relatively more molluscs being sampled during the SWM (April-October) as compared to the NEM (November-March), but there was no significant difference. Generally, abundance of ellobiids at the high shore also showed no marked variation or significant difference among the wet and dry periods of the two monsoon periods, except higher abundance during the dry SWM as compared to the dry NEM. Thus, with the exception of high-shore ellobiids which might be affected by higher rainfall (March, December), other intertidal molluscs appeared not to be affected. Thus, it is possible that the observed temporal variability in mollusc abundance at Matang reflects more of their reproductive activity. More studies, however, should be carried out to confirm this.

The present study however, failed to observe any relationship between the physical parameters (salinity, pH and air temperature) measured and mollusc abundance at Matang mangrove. Thus, it is very unlikely that the soil parameters measured during ebb tide when the mangrove forest floor was exposed to air are suitable parameters to relate with mollusc abundance. Nevertheless, the soil-water salinity did reflect the rainfall amount at the locality, that is, the soil-water salinity gradually increased from January to May during the dry period of the NEM, and subsequently dropped with the onset of the wet SWM period. Both the measured pH and air temperature values fluctuated haphazardly (Figures. 4.2 and 4.3), indicating that continuous monitoring of these parameters, rather than instantaneous or snap-shot measurements, is needed in future studies to give good interpretable information.

5.4 Limitations and Future Studies

The present study has achieved the set objectives, but during the study, some questions arose which require further study to achieve a better species identification technique and understanding of the Ellobiidae life history. Documenting the molluscan fauna and providing the sampling localities is very important especially when the species are specialized to certain microhabitat and very cryptic. The current challenge to uncover more unrecorded molluscs for Malaysia is due to the very limited references and studies conducted in this country. Moreover, studies in most countries in South East Asia including Malaysia have only provided lists of species names without taxonomic descriptions, keys to species and illustrations.

There are so many other unidentified molluscs specimens in our collections that demonstrate a crucial need for extensive collaboration with local and foreign malacologists in order to determine and describe many other undescribed species. In addition to the taxonomic problem, the taxonomic revision has moved many species into different groups and introduced new genera. This had led to many synonymous names erected for some genera and species when in fact, they refer to the same mollusc (see World Register of Marine Species). On the other hand, some type material species with descriptions were destroyed or lost, or not formally stored for future references making it difficult to clarify the presence of the mentioned species within the region.

As difficulties arises particularly during identification of molluscs at species level, it is suggested that future work must provide good live specimen photographs coupled with illustration of the shell for every species to avoid confusion. Additionally, taxonomic problems should be resolved and supported by phylogenetic work added using DNA barcodes and/or other gene markers. In this way, the inaccuracy of species identification and grouping could be tackled in the near future.

CHAPTER 6: CONCLUSION

This study has managed to document a total of 54 species of molluscs from the high shore mangroves of Peninsular Malaysia. Of these, a total of 26 species and six genera are from the Ellobiidae, a group known to have on record 32 species and eight genera in the Malesian region. Nineteen species from eight genera and four families of molluscs are recorded for the first time. Four of these species are new records from the Matang Mangrove Forest Reserve, and one species, *Ellobium scheepmakeri*, once thought to be locally extinct, is rediscovered in Bukit Belimbing, Kuala Selangor. Taxonomic keys for the identification of ellobiids in high shore mangroves of Peninsular Malaysia have been constructed. The intertidal molluscs in Matang mangrove show the typical zonation (as also observed in other fauna) that can be ascribed to tidal immersion or emersion. Since ellobiids are adapted to live on the high shore margins of mangrove forests, they can be used as useful bioindicators of anthropogenic impacts on the mangrove and other coastal ecosystems. More studies should be done to assess the relationship between ellobiid diversity or abundance with human impacts, such as deforestation and pollution. It is anticipated that the significant increase in mollusc diversity as revealed in this study will encourage more ecological and environmental studies concerning intertidal molluscs.

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