SPATIOTEMPORAL UTILIZATION AND FEEDING HABITS OF FISH COMMUNITY IN KLANG COASTAL MUDFLATS, MALAYSIA

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ABSTRACT

The intertidal mudflats are non-vegetated coastal biotope often deemed as wastelands that should be reclaimed for coastal development. This stems from the lack of knowledge and understanding of the mudflat‘s ecology and contribution to fisheries and human welfare. This study thus investigated the mudflat‘s fish community in Klang Strait (Straits of Malacca), in particular, its species diversity, standing stocks and trophodynamics in relation to various environmental and spatio-temporal factors. Monthly and diel sampling was done using barrier net and gill nets at two mudflat sites, two monsoon seasons, and under the effect of three factors: period (wet/dry), moon phase (full/new moon) and diel (day/night). Stomach content and stable isotope analysis was conducted to elucidate the fish trophodynamics. Overall, the measured water parameters (salinity, temperature, dissolved oxygen concentration and pH) in the Klang Strait mudflats were rather homogeneous and relatively marine, but varied spatially in terms of the sediment characteristics (particle sizes, organic matter and chlorophyll *a* content). A total of 116 species of mainly juvenile and small-sized fish species made high-tide ingressions into the mudflats. Fish diversity and abundance varied spatially and temporally. The Bagan Sungai Buloh mudflat had higher species diversity but lower fish abundance than the Bagan Pasir mudflat. However, both sites shared 64 % common fish species mainly from the families of Ariidae, Clupeidae, Engraulidae, Mugillidae and Sciaenidae. More fishes were recorded during the northeast monsoon than southwest monsoon. Fish species composition differed between the dry and wet period of the monsoon. More species of predatory fish were observed during day time but large numbers of small fishes occurred during night time. Moon light had no effect on species composition. The mudflat fishes can be categorized into eight trophic guilds that occupied five trophic levels. Shrimp feeders formed the dominant guild supported by high abundance of shrimps from the families of Penaeidae and Sergestidae which were also fed by four other guilds. This sharing of an abundant prey (shrimp) resource may explain the many species of fish cohabiting the mudflat. A variable degree of food resource partitioning however occurred among species especially in the mixed macrobenthos feeders. Iliophages, copepod feeders and polychaete feeders exhibited specialized feeding with little food overlaps. Stable isotope analysis revealed that the mudflat‘s food web is mainly fueled by high production of the mudflat‘s microphytobenthos and phytoplankton sustained by close coupling of pelagic-benthic processes due to strong tidal mixing in the shallow water. Despite the presence of adjacent mangrove forests, the contribution of allochthonous mangrove carbon to the nutrition of mudflat fishes appears very limited. The findings of this study affirm the importance of mudflat as a feeding ground and refugia for juveniles of a diverse fish community. Most of these fishes are of commercial value or support subsistence fishing. Rational development planning and conservation of mudflats should therefore be part of any coastal zone management initiative. Meanwhile, the fisheries department should take cognizance of the vast fisheries contribution of coastal mudflats and treat them as an essential fish habitat for fisheries management.

Keywords: Mudflat, fish community structure, fish standing stocks, fish feeding guild, stable isotope analysis.

PENGGUNAAN RUANG-MASA DAN TABIAT PEMAKANAN KOMUNITI IKAN DI DATARAN LUMPUR KLANG, MALAYSIA

ABSTRAK

Dataran lumpur merupakan biotope persisiran tanpa tumbuhan dan sering dianggap sebagai lapangan terbiar yang harus ditebus guna untuk pembangunan tepi pantai. Ini berpunca daripada kekurangan pengetahuan dan pemahaman dalam ekologi dataran lumpur serta sumbangannya kepada perikanan dan kebajikan manusia. Justeru, kajian ini menyiasat komuniti ikan dataran lumpur di Selat Klang (Selat Melaka), khususnya, kepelbagaian spesis, sumber dirian dan trofodinamik berhubung dengan pelbagai faktor alam sekitar dan ruang-masa. Penyampelan bulanan dan diel (siang/malam) dijalankan dengan menggunakan belat dan pukat hanyut di dua kawasan dataran lumpur, pada two musim monsun, dan di bawah pengaruh tiga faktor: tempoh (lembap/kering), fasa bulan (bulan purnama/baru) dan diel. Analisis kandungan perut dan isotop stabil telah dijalankan untuk mengkaji trofodinamik ikan. Secara keseruluhanya, parameter air yang diukur (kemasinan, suhu, oksigen terlarut dan pH) di dataran lumpur Selat Klang agak seragam dan marin, tetapi berbeza secara tempatan dari segi ciri-ciri mendapan (saiz zarah, kandungan organik dan klorofil-a). Sejumlah 116 spesis ikan yang kebanyakkannya juvana dan bersaiz kecil masuk ke dalam dataran lumpur semasa air pasang. Kepelbagaian dan kelimpahan ikan berbeza dari segi tempatan dan tempoh masa. Dataran lumpur Bagan Sungai Buloh mempunyai kepelbagaian spesis yang lebih tinggi tetapi kelimpahan yang lebih rendah berbanding dengan dataran lumpur Bagan Pasir. Walau bagaimanapun, kedua-dua kawasan tersebut mempunyai 64 % spesis ikan yang sama khususnya dari famili Ariidae, Clupeidae, Engraulidae, Mugillidae dan Sciaenidae. Monsun timur laut mempunyai lebih banyak ikan berbanding dengan monsun barat daya. Komposisi spesis ikan berbeza antara tempoh monsun kering dan lembap. Lebih banyak spesis ikan pemangsa yang dapat diperhatikan pada waktu siang manakala waktu malam mempunyai lebih banyak ikan yang bersaiz kecil. Cahaya bulan tidak ada pengaruh terhadap komposisi spesis. Ikan dataran lumpur boleh dikategorikan kepada lapan kumpulan pemakan dan lima tahap trofik. Pemakan udang adalah kumpulan pemakan yang dominan, dibekal oleh kelimpahan udang famili Penaeidae dan Sergestidae yang tinggi dan juga dimakan oleh empat pemakan yang lain. Perkongsian sumber mangsa (udang) yang banyak boleh menjelaskan bagaimana pelbagai jenis spesis ikan boleh bersekedudukan di dalam dataran lumpur. Walau bagaimanapun, pelbagai tahap pembahagian sumber dijumpai dalam spesis ikan terutamanya dari pemakan makrobenthos campur. Pemakan ilio (‗*Iliophage’*), pemakan kopepod dan pemakan polikaet menunjukkan pemakanan yang khusus dan tidak bertindih. Isotop stabil menunjukkan bahawa siratan makanan dataran lumpur dibekal oleh pengeluaran fitoplankton dan fitoplankton bentik yang tinggi, dan dikekal oleh gandingan rapat antara pelagik dan bentik hasil daripada campuran pasang surut dalam air cetek. Walaupun terdapat hutan paya bakau berhampiran, sumbangan karbon paya bakau kepada nutrisi ikan dataran lumpur agak terhad. Kajian ini telah mengesahkan kepentingan dataran lumpur sebagai tapak pemakanan dan refugia kepada komuniti ikan yang juvana dan pelbagai. Kebanyakan ikan tersebut mempunyai nilai komersil dan mampu tampung perikanan sara diri. Oleh itu, perancangan pembangunan yang rasional dan pemeriharaan dataran lumpur harus dimasukkan dalam inisiatif pengurusan zon pantai. Sementara itu, Jabatan Perikanan perlu mengambil kira sumbangan perikanan daripada dataran lumpur dan menganggap mereka sebagai habitat ikan yang penting bagi pengurusan perikanan.

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LIST OF SYMBOLS AND ABBREVIATIONS

℃	Degree Celsius
D	Margalef‘s species richness index
%	percentage
J‘	Pielou‘s evenness
H‘	Shannon-Wiener index
S	species richness
$\delta^{13}C$	stable carbon isotope ratios
$\delta^{15}N$	stable nitrogen isotope ratios
×	times
ANOVA	analysis of variance
BP	Bagan Pasir
SB	Bagan Sungai Buloh
MixSIAR	Bayesian isotopic mixing model
CAP	canonical analysis of principal coordinates
C	Carbon
CPUE	catch per unit effort
cm	centimeter
CO	copepod feeders
FO	Frequency of occurrence
GFC	glass fibre filter paper
GPS	Global Positioning System
g	gram
GF	gut fullness
ha	hectare

IL	iliophages
IM	insect/miscellaneous
IRI	index of relative importance
km	kilometer
MBL	Marine Biological Laboratory
MHWN	mean high water neaps
MHWS	mean high water springs
MLWN	mean low water neaps
MLWS	mean low water springs
m	meter
mm	milimeter
MX	mixed macrobenthos feeders
µm	micrometer
NTU	Nephelometric Turbidity Unit
N	Nitrogen
nMDS	non-metric multidimensional scaling
NEM	northeast monsoon
NW	northwest
n	number of observations
PERMANOVA	permutational multivariate analysis of variance
PO	polychaete feeders
sPOM	sediment particulate organic matter
SH	shrimp feeders
SD	shrimp/decapods feeders
ST	shrimp/teleost feeders
SZ	shrimp/zooplankton feeders

SIMPER	similarity percentage analysis
SIMPROF	similarity profile analysis
SWM	southwest monsoon
SIA	stable isotope analysis
SD	standard deviation
SE	standard error
SL	standard length
SPI	standardized precipitation index
PERMDISP	test of homogeneity of dispersions
TEF	trophic enrichment factor
TL	trophic level
TP	trophic position
USD	United States Dollar
V	volume
W	weigh

CHAPTER 1: INTRODUCTION

1. Introduction

The intertidal mudflat may be described as a type of coastal biotope often devoid of macrovegetation. It is characterized by soft-bottom, fine sediments or muddy substrate that is exposed to air during low tide. The intertidal mudflat can be found naturally at all latitudes in wide range of situations, such as in the coastal environment with high to low tidal range and exposed to considerable wave effects; and in sheltered estuaries and inlets where wave effects are considerably reduced (Dyer, 1998). Although the mudflat appears to be visually simple like a barren wasteland (Figure 1.1), intrinsically it is a complex and dynamic system due to its periodic inundation by seawater and then, exposure to air (Woodroffe, 2002). It is a transition zone between land and sea with open borders to the adjacent terrestrial and marine systems (Costanza et al., 1993; MacKinnon et al., 2012). The complex and dynamic nature of the intertidal mudflat may result from the close abiotic and biotic processes, and interactions with other commonly bound or adjacent biotopes such as the mangrove and seagrass (Alongi, 1997; Elliott et al., 1998; Bird, 2008). The influx of nutrient and energy sources into the mudflat coupled with in situ microphytobenthic production (Heip et al., 1995; Guarini et al., 2000) could explain the high productivity of the mudflat in supporting resident and transition fauna (Laegdsgaard & Johnson, 2001; Nagelkerken & van Der Velde, 2002).

Figure 1.1 Image showing the Bagan Pasir mudflat in Klang Strait mudflat during low tide. Note the barren, look-alike wasteland of soft mud.

Since juvenile fish and invertebrates of commercial value are known to make use of the mudflat as nursery or feeding habitat during high tide, a deeper understanding of its usage is important for fisheries and ecosystem management given its close linkage to fishery resources and local livelihoods (Hill et al., 1982; Nagelkerken & van der Velde, 2002; Melville and Connolly, 2005; Chong et al., 2012b). Furthermore, during low tide, shorebirds feed on the large biomass of macrobenthos available in the mudflat (Riak et al., 2003; McLusky & Elliott, 2004; Norma-Rashid & Teoh, 2012). Indeed, the mudflats of Southeast Asia serve as rich feeding grounds for large colonies of migratory birds from Siberia to Australia on their long winter migration (Norma-Rashid & Teoh, 2012; Norazlimi & Ramli, 2014a;b). Thus, coastal mudflats serve as a vital ecosystem for a variety of marine and terrestrial fauna.

The dynamic environment of the mudflat as a result of periodic flooding and ebbing of seawater challenges its inhabitants in terms of adapting to the heat, air exposure, tidal inundation, wave action and feeding (Elliott et al., 1998; Nagelkerken & van der Velde, 2002). While the lower shore of the mudflat is constantly submerged for short periods, the mid and upper shore areas are increasingly more exposed to air and solar irradiation. This dynamic feature of exposure and submergence creates habitat heterogeneity which also includes differences in sediment particle size thus affecting faunal adaptation and habitation (Dyer et al., 2000). Except some burrowing species, fish fauna only ingress into the mudflat during high tide to obtain their food or for refugial space, and retreat back to their respective habitat or simply occupying the coastal strip outside of the water line during low tide (Nagelkerken & van der Velde, 2002; Blaber, 2007). As such, fish species distribution and assemblage in the mudflat is attested to be shaped by a complex suite of physical factors that included water parameters (Thiel et al., 1995; Salgado et al., 2004; França et al., 2008), tidal action (Pritchard et al., 2002; Deloffre et al., 2006), spatiotemporal variations (Thiel et al., 1995; Terlizzi et al., 2005; Cardoso et al., 2011), sedimentology (Deloffre et al., 2007), wind events (Bassoullet et al., 2000), food availability and production (Laegdsgaard & Johnson, 2001; Nagelkerken & van der Velde, 2002), species competition (Kronfeld-Schor & Dayan, 2003), and predator-prey interactions (Gibson, 1994; Gibson et al., 2002). Various foraging adaptations such as niche partitioning to reduce inter- and intrapecific competition are among the most common observations made in studying fish species assemblages (Mérona et al., 2001; Potier et al., 2004; Varghese et al., 2014). On the other hand, it has been shown that fish species could coexist by sharing common food resources, and even exhibit diet specialization, if there is a surplus of prey organisms (Amundsen et al., 1996). Thus, it can be hypothesized that despite their diversity and abundance, mudflat fishes likely coexist by sharing similar food resources in abundance. This hypothesis is based on the premise of high diversity, productivity and abundant food resources in the mudflat as reported by various workers (Laedsgaard & Johnson, 2001; Nagelkerken & van der Velde, 2002; Kanou et al., 2005; Vinagre et al., 2006).

Although the intertidal mudflat is a recognizable global feature, the presence and extent of mudflats worldwide has yet to be documented thoroughly (Miththapala, 2013). Nevertheless, Deppe (1999) managed to compile a list of 350 different intertidal sand- or mudflat sites from all over the world, with only 79 of them being described in detail. Among them the Wadden Sea has the largest area of mudflat of over 1,000,000 ha, connecting the coasts of Denmark, Germany and Netherland over a length of 500 km (Deppe, 1999). Other prominent mudflats are found on the entire west coast of Korea stretching along the southeastern bank of the Yellow Sea (Deppe, 1999), in the Tagus estuary in Portugal (Salgado et al., 2004), and the Embley estuary in the eastern Gulf of Carpentaria, Australia (Blaber et al., 1989). These mudflats have been reported as highly productive ecosystems that function as important nursery areas to many marine organisms (Deppe, 1999; Miththapala, 2013). In Malaysia, about 32,000 ha of coastal mudflats cover much of the west coast of Peninsular Malaysia. The most extensive mudflat (12,000 ha) is located in the state of Selangor (MPP-EAS, 1999), where almost 10,000 ha are present in the Klang Strait. The ‗Klang Strait' mudflat is known for the culture of blood cockle (*Tegillarca granosa*) where up to 40,000 tonnes of blood cockles had been produced annually with a market value of USD 20 million (Department of Fisheries Malaysia, 2010). Previous studies have highlighted its importance as a nursery area for demersal fish and prawns (Chong et al., 1990; Marsitah & Chong, 2002). Moreover, more than 15,000 shorebirds had been reported to make use of the Klang mudflats for their food sources (Norhayati et al., 2009; Norma-Rashid & Teoh, 2012). The mean annual total economic value for the Malaysian mudflat which includes use and non-use values has been estimated at USD 861 per ha (MPP-EAS, 1999). Based on this estimate, the total economic value of Klang Strait mudflat is estimated at more than USD 8.6 million annually.

Mudflats are often associated with other adjacent biotopes such as mangrove and seagrass. Both biotopes are well known habitats that play nursery and refugia roles for juvenile fish (Laegdsgaard & Johnson, 2001; Lugendo et al., 2006; Tse et al., 2008). In particular, the mangrove forest can supply a rich source of detritus and potentially supports estuarine and coastal food webs via outwelling of nutrient and organic matter (Odum, 1972; Bouillon et al., 2003; Thimdee et al., 2008; Bouillon et al., 2008). Thus, the question asked is whether adjacent biotopes such as mangrove are sources of usable carbon for coastal mudflats. However, recent studies based on stable (C, N) isotope studies have generated much controversies over the role of mangrove carbon to coastal food chains (Fry & Ewel, 2003; Bouillon et al., 2008; Nagelkerken et al., 2008). Many workers argue that the mangrove carbon is rather refractory to fish species and make little contribution to pelagic food webs (Rodelli et al., 1984; Bouillon et al., 2008). On the other hand, others found significant contribution of mangrove carbon to mangrove crabs, prawns, and molluscs in the benthic food chain (Chong et al., 1996; Loneragan et al., 2005; Bui & Lee, 2014), and that this may be due to the animals‘ ability to digest even refractory lignocellulosic materials (Niiyama et al., 2012).

The North Banjar Forest Reserve, South Banjar Forest Reserve and Kapar Forest Reserve on the mainland and Klang Islands Mangrove Forest Reserves are the remaining mangroves that are found near to the coastal mudflats of Selangor. No other coastal biotopes such as seagrass beds are known here (Bujang et al., 2006). To understand the primary sources fueling the mudflats, the question asked is ―To what extent do the nearby mangroves support the Klang mudflat trophically, that is, via the allochthonous organic matter exported from it?" Therefore, given the present knowledge of mangrove carbon contribution to pelagic food webs, to answer the above question, one could test the hypothesis that the mudflat fish community is largely supported by autochthonous rather than allochthonous mangrove carbon inputs.

Mudflat studies in Malaysia have been sporadic and rather localized in the past, and the Klang Strait mudflat has been largely favoured (Leh, 1979; Broom, 1982; MacIntosh, 1984; Chong et al., 1990; Sasekumar & Chong, 1991; Riak et al., 2003). This may be due to various reasons, among which are the mudflat‘s poor aesthetic value, absence of vegetation, lack of economic interest, assumed lack of provision of ecological services, and the very challenging field conditions (e.g. soft mud, heat, insect bites) for fieldwork. Nevertheless, similar studies have recently gained traction (Chong et al., 2012b; Ramarn et al., 2012; Teoh & Chong, 2013; Norazlimi & Ramli, 2014a;b; Yurimoto et al., 2014; Teoh et al., 2016; Eeo et al., 2017). These are also reasons that mudflats, compared to other coastal biotopes, are prime candidates for coastal land reclamation (Kao et al., 1998; MacKinnon et al., 2012; Murray et al., 2014). Coastal reclamation projects for development in Malaysia have increased since 1988, where at least 31 coastal reclamation megaprojects have been approved between 1988 and 2016 (Table 1.1). It is also predicted that future sea level rise will remove extensive intertidal mudflat areas (Davidson et al., 1991; Burd, 1992).

Table 1.1 List of approved coastal reclamation projects in several states of Malaysia and estimated total reclaimed area by state (1988 - 2016). Source of information: Haliza et al. (2005), Ghazali (2006), Husin et al. (2009), Chee et al. (2017), Mohamed & Razman (2018), Department of Environment and Department of Irrigation and Drainage.

State	**Project and location**	**Estimated total reclaimed area (ha)**
Kedah	Entire coast	16,300
	Pulau Bunting, Daerah Yan	
Penang	Tanjung Tokong	950
	Bayan Lepas	
Perak	Lekir Coastal Development, Pulau Pangkor	12,400
	Teluk Muroh	
	Bagan Datoh	
Selangor	Jugra Block 1, 2, 3	14,600
	Kapar	
	Pulau Lumut	
	Telok Gadong	
	Westport, Pulau Indah Kelang	
Negeri Sembilan	Entire coast	960
Melaka	Pantai Kundur	2,300
	Malacca City	
	Pulau Panjang	
Johor	Southern International Gateway Project, Tanjung Puteri	1,400
	Lido Boulevard, Johor Bahru	
	Independent Deepwater Petroleum Terminal, Pengerang	
	Mersing Laguna	
	Phase III Dredging and reclamation work, Tanjung Pelepas Port	
	Marine Riverine Facilities, Sungai Batu Pahat	
	Integrated hub and Maritime Industrial Park, Tanjung Piai	
	Tanjung Puteri	
	Mukim Plentong	
	Jetty and industrial zone construction, Tumpat	
Sabah	Kudat	3,760

Due to the scarcity of scientific and quantitative information in this area, this study thus aims to characterize the fish community utilising mudflats spatiotemporally and the basal food web resources supporting these fish. The information obtained will be useful to provide valuation information of the mudflats as feeding and nursery areas and thus garner both goverment and public support for their protection. Therefore, the objectives of this study are:

1) to study the fish community structure in the Klang Strait mudflat in relation to the environmental factors;

2) to elucidate the trophic structure of Klang Strait mudflat fish community and construct its food web, and

3) to identify the primary energy sources fueling the Klang food web.

In this study, the following hypotheses will be tested:

1) Mudflat fishes are likely to coexist by sharing similar food resources in abundance.

2) Mudflat fish community is supported by autochthonous rather than allochthonous (mangrove) carbon inputs.

To achieve the above objectives, the following studies were conducted:

1) Identification of the environmental characteristic of Klang Strait mudflat (Chapter 4)

2) Elucidation of the spatiotemporal abundance and biomass of mudflat fish species in relation to different environment factors (Chapter 5)

3) Determination of fish diet and construction of the mudflat food web (Chapter 6)

4) Evaluation of the mudflat primary food sources that support coastal fish production (Chapter 7)

The research approach for the whole study is illustrated in Figure 1.2.

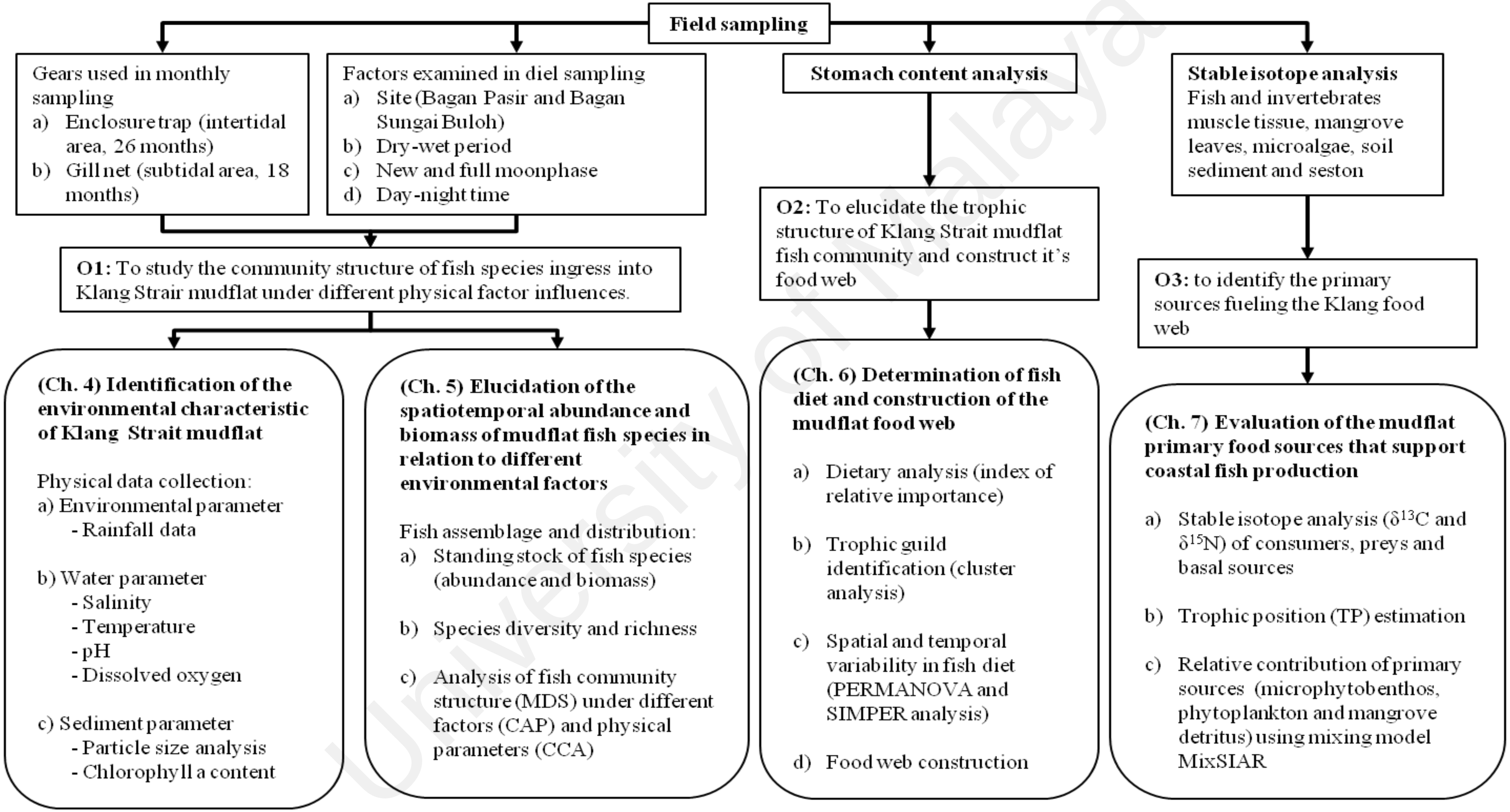

Figure 1.2 The research approach and studies conducted to achieve the stated objectives (O1, O2 and O3).

CHAPTER 2: LITERATURE REVIEW

2.1 Physical features of intertidal mudflats

Intertidal mudflats, also known as tidal flats, are coastal wetlands formed by consistent depositions of bare mud particles from sea and/or river in a periodically exposed shallow or intertidal coastal area (Dyer, 1998; Reise et al., 2010). The mudflat is formed from soft sediments deposited along a coastline that is protected from strong currents (Dyer, 1998). Mudflats are often found in sheltered coastal areas such as bays, lagoons, shallow inlets and estuaries, but can also be found on open coasts with considerable wave effects (Dyer, 1998; Bird, 2008). The soft sediments are composed of clay and silt and sometimes mixed with coarser sand. Mudflats appeared to undergo cycles of erosion and deposition. Rough sediment particle are more easily picked up by flowing current as opposed to smooth (round) particles (Gray & Elliott, 2009). While strong currents will keep these muddy sediments in suspension, deposition begins when the tide started to slacken, thus forming mudflats in the intertidal zones (Bird, 2008). Deposition is aided by the clustering and coagulation of clay particles into flocculated silt particles due to the electrolytic effect of sodium and chloride ions in brackish or marine water (Nichols & Biggs, 1985). Following the deposition, erosion happens when the overall elevational profile is concave upwards and the mean flat level is below the mean tide level, or during storms (Dyer, 1998). In estuaries, coastal mudflats can be seen to curve down to gentle slopes that are exposed during low tide on either side of a deep river mouth or channel (Bird, 2008).

Klein (1985) separated the intertidal mudflats into three distinct zones from sea to land: the subtidal, intertidal and supratidal zone. The subtidal zone lies below the low tide, or between the mean low water neap and mean low water spring tide levels. It is often subjected to strong tidal currents and consists of mostly sand particles of various sizes fashioned into variable bedforms such as ripples, dunes and sand waves (Klein, 1985). The intertidal zone, located between mean low water neaps and mean high water neaps, is exposed to the air twice a day in semidiurnal tides. Deposition of mud is more likely on the higher end of the intertidal zone due to more suspension transport of silts and clays. The middle part of the intertidal flat is covered by half of the tidal cycle, therefore it has nearly equal periods of suspension and bedload transport, creating a mixture of sand and mud but tend to coarsen in the seaward direction. The lower end of the intertidal flat is sandier as a result of the dominant bedload transport and deposition, and is only exposed at low tide. The supratidal zone lies between the mean high water neap and mean high water springs. It is the least inundated part of the mudflat and is only flooded at high water by spring tides. Vegetation growth such as mangrove or marsh grass is common in this area. In the temperate region, *Spartina* grass dominated marshes are commonly found in the intertidal area, as for examples in the Bay of Fundy (Ganong, 1903; Klein, 1970), San Francisco Bay (Josselyn, 1983; Palaima, 2012) and the Gulf of Mexico (Stout, 1984). In the tropical and sub-tropical areas, mangrove is more common in the supratidal zone of the intertidal mudflat. Examples of tidal flats that are associated with mangrove are Missionary Bay of North Queensland, Australia (Dittmann, 2001), Bay of Rest, West Australia (Wells, 1983) and the Klang-Langat Delta of Malaysia (Coleman et al., 1970).

The topography of the intertidal mudflat surface is subjected to frequent and rapid changes due to the strong waves and current action (Pethick, 1996). Strong tidal current particularly during spring tides will create mounds and banks separated by hollows and troughs, reshaping the mudflat as the tide rises and falls (Bird, 2008). The surface of mudflat is generally smooth, but often perturbed by marine organisms such as polychaetes and gastropods (Broom, 1982; Teoh, 2013; Eeo et al., 2017). Due to the periodic emersion and inundation during low tide and high tide respectively, the sediments at the lower mudflat can be exposed to atmospheric air for as long as 2.5 hours and the upper mudflat submerged in sea water for the same duration by semi-diurnal tides (Dyer, 1998). During exposure, the surface moisture content decreases due to heating and evaporation by sunlight and wind. However, rainfall will increase surface moisture which will cause erosion of the surface due to pitting and run-off (Amos et al., 1988). The overall sedimentary contexts of the mudflat are determined by the supply of muddy sediment, but a lower proportion of silt and clay will likely produce sandflats instead. A softer mud is generally homogeneous, indicating rapid sedimentation, with high suspended sediment concentrations and organic content. Meanwhile, mudflats with a slower rate of deposition will have a more consolidated structure and more oxygenated (Dyer, 1998). Compared to sandflats, mudflats have higher cohesiveness due to its high water content, electrolytic binding, organic stickiness, and are less likely to disintegrate and be mobilized by wave currents (Bird, 2008).

The Klang Strait, located in the Straits of Malacca, on the west coast of Peninsular Malaysia, is a narrow channel span between Klang Island and Che Mat Zin Island on the west, and Indah Island and Peninsular Malaysia mainland on the east (Figure 2.1). The strait extends to the northwest for about 45 km, while its southern end breaks up into several channels at the Klang-Langat Delta. The latter forms a complex network of inter-connecting tidal channels and extensive low tidal flats of sand-mud sediment. The Klang Strait mudflat continuously flanks the eastern seaboard of Klang Strait, spanning about 55 km in length and covering approximately 8,000 ha from Kapar to Sekinchan. The long coastal mudflat is interrupted only at the mouths of three major rivers: Buloh River, Kuala Selangor River and Tengi River. The mudflat extends seaward distances of 1 to 3 km from the shoreline.

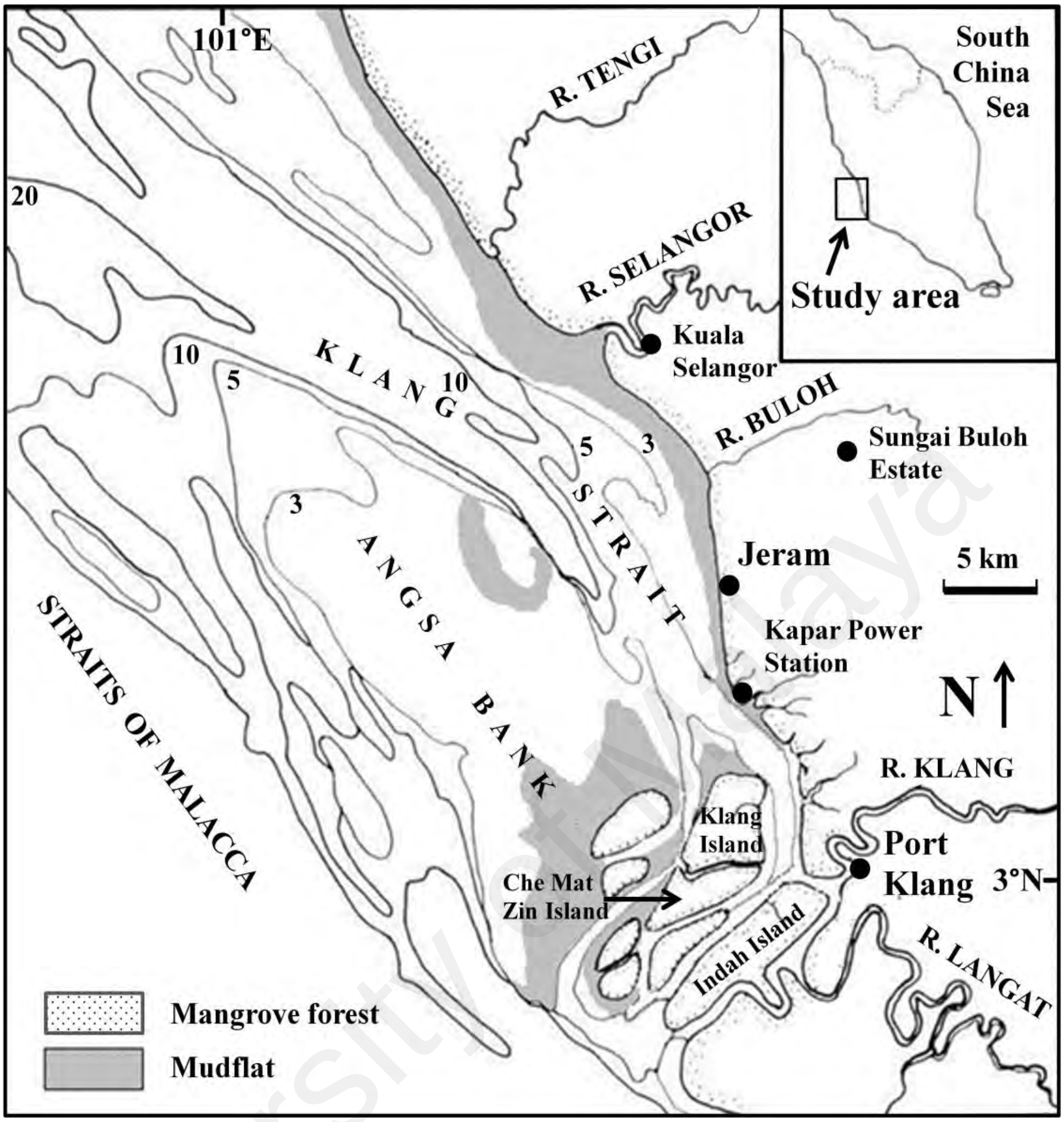

Figure 2.1 Map showing the coastal mudflat areas (shaded gray) at Klang Strait, Peninsular Malaysia. R denotes river. Isobaths in metres.

The tidal regime in Klang Straits is typically semidiurnal, with tidal heights at Mean High Water Springs (MHWS), Mean Low Water Springs (MLWS), Mean High Water Neaps (MHWN) and Mean Low Water Neaps (MLWN) that averaged 5.09 m, 0.98 m, 3.72 m and 2.35 m above chart datum, respectively (National Hydrographic Centre, 2018). Tides are macrotidal with large tidal amplitude of about 4.2 m during spring tide and 1.4 m during neap tide (National Hydrographic Centre, 2018). During high spring tide, the Klang mudflat is completely submerged under water, whereas during ebb tide, the mudflat is exposed as far as to 2 km away from the shoreline. During ebb tide, the tidal current streams toward the northwest direction while the flood tidal current streams southeasterly. Tidal velocities are strong reaching 1.5ms^{-1} during spring tide and 0.4 ms^{-1} during neap tide (Chong et al., 1996).

Previous works on the coastal mudflat sediments of Klang Strait generally show clay composition that varied from about 5 - 27 %, silt component of 45 - 75 % and sand component of 20 - 75 % (Zgozi, 2000; Chong et al., 2012a). The large variability in the clay and sand components illustrates sediment heterogeneity even in the mudflat depending on location (wave/tidal action) and the prevailing climatic (wind) condition. For example, the mudflat stretch from Jeram to Serdang becomes an eroding shore during the southwest monsoon but is overlain with a superficial fine mud layer during the northeast monsoon (Eeo, 2018). The Klang mudflat is exposed to two seasonal, alternating wind fields with their associated wave effects. During the southwest monsoon, the mainly southwesterly winds from the Indian Ocean veer southeasterly on approaching the southern end of the Malacca Strait due to Coriolis acceleration (Figure 2.2). During the northeast monsoon, the mainly northeasterly winds as they cross the South China Sea and approach the northern end of the straits, veer northwesterly. During the northeast monsoon period, the prevailing northwesterly wind due to the large wind fetch forms large waves that converge on the Selangor shore. The breaking waves result in cross-shore and longshore currents that erode and transport fine sediment along the Klang mudflat in the southerly direction (Fitri et al., 2015). These processes do not occur during the southwest monsoon period, and hence, the net erosive force (flood tide current) removes superficial mud from particularly, the mudflat stretch between Jeram to Serdang (Eeo, 2018).

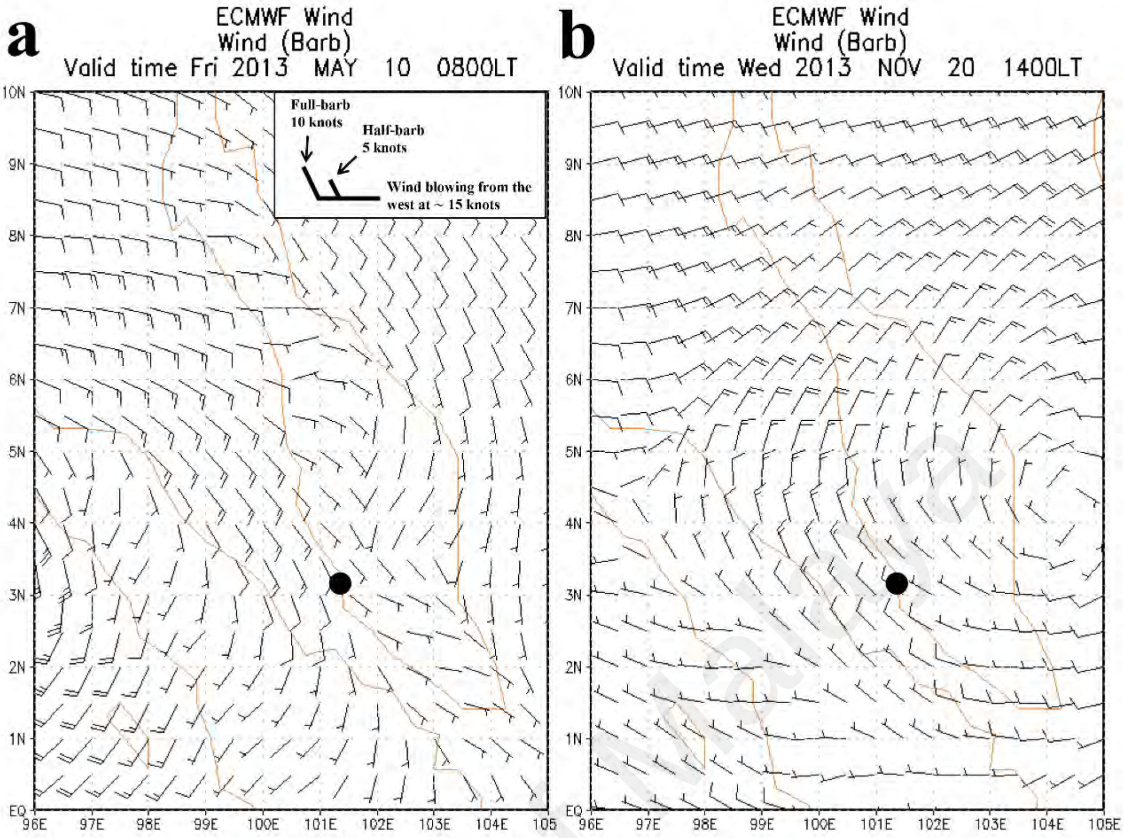

Figure 2.2 Map showing the surface wind direction and speed (wind barb figures) over Kuala Selangor study site (black circle) in Peninsular Malaysia (red contour line) and Sumatra (left red contour line), during (a) Southwest Monsoon (May) and (b) Northeast Monsoon (November). Note veering of southwest and northeast winds as they cross the equator due to the Coriolis effect. Wind barb figures are each plotted within a grid size of -.25° x 0.25°. Wind direction and approximate speed are explained in the inset. Map adapted from Eeo (2018).

The monsoons also have a profound effect on the rainfall pattern in Malaysia and the adjacent region which is subject to seasonal alternation of the northeast monsoon (November to March) and southwest monsoon (May to September). The early part of the monsoon is characterized by heavy rainfall which is followed by several cycles of dry spells (Cheang, 1988). As a result, two peak rainfall periods generally occur during a year, the larger one occurring in October/November. In the Klang Strait coastal area, the monthly rainfall ranged from about 15mm to 370mm (Chong et al., 2012a). The salinity pattern in Klang Strait weakly reflects the rainfall pattern; only the higher rainfall peak resulted in the lowest surface salinities (28-29) recorded a month later, usually in December/January (Chong, 1993). The highest mean salinity (32-33) occurred in July/August. The water in Klang Strait is vertically well-mixed, where the salinity and temperature differences between surface and bottom are small, not exceeding 2.5 ‰ salinity and 0.5 °C temperature for water depths of up to 20m (Chong, 1993). Mean water temperature ranged from 29.4 to 30.2 °C.

2.2 Resident flora and fauna in mudflat

In marine areas, salt-tolerant plants such as the seagrasses can grow in the tidal flat, while other halophytic plants can grow on the upper intertidal zone forming mangrove swamps or salt marshes. In temperate regions, the landward vegetation associated with mudflat are typically the salt marshes (Chapman, 1976). Salt-tolerant grasses, herbs and shrubs such as the *Salicornia* and *Spartina* grow between high spring tide and mid tide levels on shores sheltered from strong waves (Adam, 1990). Vegetation such as salt marshes are able to diminish wave action, reducing wave heights by 70 % and wave energy by over 90 % (Bird, 2008). Notable salt marshes include the Bay of Mont Saint Michel in northwest France and the Bay of Fundy in Canada (Davidson-Arnott et al., 2002). At the Bo Hai Bay, China, intertidal mudflat covered 38,534 ha of the bay, whereas reed marshes made up of 32,772 ha; together, they provide an excellent habitat for waterfowls (Eisma, 1998).

In the subtropical and tropical regions, mangrove covers the landward vegetation of the mudflat (Chapman, 1976). Mangroves occupy approximately 181,000 km^2 of tropical and subtropical coastlines worldwide, and have relatively low plant species diversity but high fauna diversity (Alongi, 2002). Mangrove plants are adapted to survive in a marine tidal environment, for example, *Avicennia marina* and *Sonneratia alba* have pneumatophores that surface above the mud to respire in a waterlogged environment. Other mangrove plants, such as the *Rhizophora* and *Bruguiera* have subaerial stilt roots that grow downward to the mud supporting the stem.

Seagrass beds can occur on the intertidal area, forming carpets of vegetation such as eel grasses (*Zostera*) that partially stabilize the surface and trap muddy sediment to form low depositional banks or terraces (Bird, 2008). During low tide, the seagrasses form a slumped carpet, but following the high tide the stems stand erect as a sediment-filtering meadow. Seagrasses occupy broad mudflat areas such as in the Northeast Westernport Bay in Australia (Bird, 2008) and Florida Bay in United States (Prager & Halley, 1999).

In Klang Strait, mangrove vegetation covers the coastline from the Tengi River south to the Klang-Langat Delta (Sasekumar et al., 2012) formed at the confluence of the Klang and Langat rivers (Figure 1.2). The mainland mangrove is however a broken, narrow coastal strip (100-300 m wide) of remaining forests that once covered 3,800 ha at their prime but about 90 % are lost due to unabated reclamation for development (Haliza et al., 2005). The most extensive mangrove forests are however found in the Kuala Selangor Nature Park (240 ha) at the mouth of the Selangor River, and the Klang deltaic islands comprising Klang Island (5,600 ha), Ketam Island (2,300 ha), Tengah Island (1,400 ha) and Che Mat Zin Island (1,400 ha). Mangrove zones of one-vegetation type are fairly common in Selangor, being dominated by *Avicennia alba* and *Sonneratia* species. (Sasekumar et al., 2012). Previously, Macnae (1968) described the vegetation zones at Kuala Selangor as consisting of mostly *Avicennia alba, Rhizophora* spp. and *Bruguiera cylindrica*. No visible seagrass beds or patches have been observed here. The closest seagrass meadows occur at the southern end of Peninsular Malaysia (Bujang et al., 2006).

Although structurally less complex than mangroves and other vegetated estuarine systems, the mudflat contains a high abundance and diversity of fauna, as well as fauna that periodically enter the mudflat during high tide (Laegdsgaard & Johnson, 2001; Chong et al., 2012b). The intertidal mudflat that has been characterized as sheltered, low energy areas with high organic matter, is a favorable habitat for macrobenthos such as gastropods, bivalves and sessile polychaetes (Jones & Keys, 1989; McLusky, 1989). Possibly among the earliest studies on the mudflat fauna in Klang Strait is that by Sasekumar (1974) and Broom (1982). Sasekumar's study mentioned the abundance of hermit crabs *Clibanarius* and *Diogenes*, and pistol prawn *Alpheus rapax* and *A. euphrosyne*. Broom's study detailed the dominant species of bivalves, particularly the blood cockle *Tegillarca (Anadara) granosa,* and *Pelecyora trigona*, and gastropods such as *Plicarcularia leptospira*, *Stenothyra glabrata* and *Cerithea cingulata* that thrived on the mudflat's high productivity. The culture of *T. granosa* on the Klang mudflat is the most intensive and extensive in Malaysia; at its peak, 41,000 tonnes of blood cockles were produced in 2010 (Department of Fisheries Malaysia, 2010).

Other prominent shellfish cultures in mudflat from other regions include oyster culture such as in Marennes-Oléron Bay, France (Leguerrier et al., 2004), clams and razor clams culture in the Yellow Sea and Bohai Sea, China (Mao et al., 2019) and several species of shellfish culture in Bandon Bay, Gulf of Thailand (Jarernpornnipat et al., 2004). These shellfish make use of the rich organic content from intertidal mudflat through deposit or suspension feeding. However, the mudflat's higher silt and clay content tend to favor the deposit feeders over suspension feeders which feed on the bacterial and microphytobenthos film surrounding the mud particles (Elliott et al., 1998). Deposit-feeding bivalves, such as the semelid bivalve *Theora lubrica,* feed dominantly on microphytobenthos in the mudflat, but shifts to coastal phytoplankton as their habitat shifts toward seaward (Yokoyama & Ishihi, 2003).

Macrocrustaceans such as brachyurans and anomurans are common resident organisms in the intertidal mudflat area. For example, the fiddler crabs or calling crabs which are semi-terrestrial construct burrows on the mudflat surface (Macintosh, 1979; Rosenberg, 2001). They are known as ecosystem engineers, and their burrowing activities promote nutrient cycling in their habitats (Mokhtari et al., 2008. Macintosh (1979) made a review of the species and distribution of nine fiddler crabs in west coast of Peninsular Malaysia. He observed that the species *Tubuca (Uca) dussumieri*, *T. forcipata*, *T. rosea* and *Paraleptuca (Uca) triangularis* were prominent on the muddy substrate. Fiddler crabs on the foreshore mudflat appeared to have higher nitrogen assimilation efficiency but lower carbon assimilation efficiency compared to the fiddler crabs in the mangrove forest (Macintosh, 1979). The mud crab *Scylla paramamosain* in the Mekong Delta, south of Vietnam, is also reported to feed at the boundary between mangrove and mudflat which serves as its nursery habitat (Walton et al., 2006). As the mud crab grows, it will move offshore away from the mangrove to forage. Hermit crabs are common inhabitants of the intertidal mudflat and are adapted to live in empty gastropod shells that protect them from predators. Hermit crabs do not predate on gastropods to acquire their shell (Scully, 1983), but rather depend on the natural mortality of gastropods (Scully, 1979). In the Matang mudflat, Teoh (2013) found a high abundance of the juvenile hermit crab C*libanarius infraspinatus* and *Diogenes moosai* that make use of the mudflat and adjacent areas, such as sandy shoals and river mouths, as their nursery grounds. Apparently, the percentage of ovigerous females was relatively higher during ebbing water of spring tides, suggesting larval dispersals by hermit crabs via the tidal stream.

Polychaete worms are also dominant resident organisms that thrive in the intertidal mudflat; many are opportunistic feeders or active predators (Meire et al., 1994). In the Klang Strait mudflat, the tube worms *Sabellaria jeramae* are especially dominant at

Jeram where they build large polychaete reef clumps that cycle or last for a year (Eeo et al., 2017). Suspended particles in the mudflat appear to facilitate the polychaete reef construction. The initial and primary reef construction by *S. jeramae* comes from fine sand particles but the reef subsequently deteriorates when depositional forces cover the reef with fine sediments, a situation when spionids (*Polydora cavitensis*) eventually take over the reef. This interesting cycle of the reef dynamics appear to be linked to the monsoon climate and local hydrological conditions (Eeo, 2018). Similar polychaete reef colonies found in the temperate region also feature numerous reef crevices and holes among constructed tubes that are reported to increase the topographical complexity of the mudflat, thereby increasing the number of sheltered microhabitats and facilitating the development of secondary diversity (Dubois et al., 2006). At Jeram, the presence of polychaete reefs has a positive effect on the macrobenthic diversity of the surrounding mudflat (Eeo, 2018). Similar polychaete reefs on the intertidal mudflat in other regions, such as the *Sabellaria alveolata* reefs in the Mont-Saint-Michel Bay, France (Noernberg et al., 2010), provide nursery habitats for other associated benthic communities (Almaca, 1990; Dubois et al., 2006; La Porta & Nicoletti, 2009).

The meiofauna in the sediment also form an important component of the mudflat‘s resident fauna. Meiofauna organisms commonly found in the mudflat are the nematodes and harpaticoid copepods. They represent an important food source for organisms of higher trophic levels (Danovaro et al., 2007). The main basal carbon sources fueling the nematodes and harpaticoid copepods on the intertidal mudflat come from the microphytobenthos and settling phytoplankton (Moens et al., 2002; Rzeznik-Orignac et al., 2008). Salinity of the benthic environment plays a crucial role in influencing the diversity of meiofauna, where their diversity increases proportionately with the salinity gradient (Soetaert et al., 1995). The tidal inundation cycle also causes significant changes on the sediment physical parameters such as the temperature, water content and oxygen content which create a horizontal distribution pattern of meiofauna (Armonies & Reise, 2000; Maria et al., 2013).

Resident fish fauna that are restricted to the coastal and estuarine habitat are the mudskippers, particularly the gobiid subfamily, Oxudercinae (Gordon et al., 1968; Clayton, 1993). They exhibited different degrees of adaptation to their amphibious lifestyle, and are able to colonise from the subtidal to supratidal zone (Murdy, 1989; King & Udo, 1997). Khaironizam and Norma-Rashid (2012) documented 13 species from 7 genera of mudskippers living on the Selangor coast. Among these, six species were found on the intertidal mudflats. The Goldspotted mudskipper *Periophthalmus chrysospilos*, Giant mudskipper *Periophthalmodon schlosseri* and Boddart's goggle-eyed goby *Boleophthalmus boddarti* occurred abundantly during low tide. The former two species will migrate into the forest following the rising tide whereas the Boddart's goggle-eyed goby would retreat into their burrows.

The rich and abundant resident macrofauna and meiofauna are exploited as food by periodic visitors to the tidal flats such as fishes and shrimps during flood tide (Melville & Connolly, 2005; França et al., 2008), as well as shore birds and animals (Riak et al., 2003; Chong, 2005; Norhayati et al., 2009; Norma-Rashid & Teoh, 2012), thus reinforcing the role of the mudflat as an important feeding ground.

2.3 Vagile and periodic visitors into the mudflat

The importance of the mudflat as a functional area providing habitat space, nursery, food and transit route to fish community was heralded by many studies before (Nagelkerken & van der Velde, 2002; Hindell & Jenkins, 2004; Blaber, 2007). Its importance even rivals the mangrove forest (Tse et al., 2008) which may be located adjacent to the mudflat area and regarded as one of the most important nursery ground for juvenile fishes (Alongi & Sasekumar 1992; Ruiz et al., 1993; Laegdsgaard & Johnson, 2001). The tidally-synchronized movements into the mudflat are attributed to both feeding and predator avoidance (Gibson, 2003; Ellis & Bell, 2004; Franco et al., 2006). For example, a study in a temperate mudflat has indicated fish species occurred at the full extent of the tidal flat in New Zealand during high tide (Morrison et al., 2002). This study also reported high abundance of small fish species including the juveniles of larger species and adults of smaller species occurred throughout the tidal flats. Other temperate mudflats such as the Tagus Estuary in Portugal (Cabral, 2000; Vinagre et al., 2006), Brouage mudflat in France (Le Pape et al., 2003) and many others (Potter et al., 1997; Pihl & Wennhage, 2002) are also known as important nursery habitats for fish species. In contrast, studies on the community structure of ingressing fish species into tropical mudflats are only represented by few examples: Embley estuary in Australia (Blaber et al., 1989); Chwaka Bay in Tanzania (Lugendo et al. 2007); Mamanguape River estuary in Brazil (Garcia & Pessanha, 2018); Matang coastal mudflat in Malaysia (Chong et al., 2012b). In most cases, the distribution of ingressing fish species in temperate mudflats appear to be seasonality driven (França et al., 2008; Chaudhuri et al., 2013). During spring and summer, the Tagus Estuary recorded a peak in fish density that corresponded to their recruitment period (França et al., 2008). On the other hand, changes in the fish assemblage in the tropical region appear to be attributed to the dry - wet seasons (Lowe-McConnell, 1987). Higher rainfall in tropical region is apparently associated with the increased inputs of allochthonous organic matter and primary productivity which apparently increase the food sources for juvenile fish (Livingston et al., 1997; Castillo-Rivera et al., 2010).

Fish diversity in the subtropical Indian Sundarban appears to be lowered during the dry pre-monsoon; apparently this is associated with the higher water pH value (Chaudhuri et al. 2013). On the other hand, heavy rainfall during the monsoon lowers the water salinity which favors the anadromous and estuarine fish species that enter the mudflat. Short term migration in term of diel movement has also been documented (Pessanha & Araújo, 2003; Vinagre et al., 2006). Partition in habitat use during the day/night cycle is one of the adaptative mechanisms to reduce competition among fish species in shallow waters for food and habitat space (Kronfeld-Schor & Dayan, 2003).

Macroinvertebrates are also prominent visitors of the mudflat, particularly the mobile predatory species such as crabs and shrimps that prey on the resident polychaetes and bivalves (Elliott et al., 1998). One particular example is the European Green Crab *Carcinus maenas* that prey heavily on various mudflat polychaetes in several European estuaries (Gee et al., 1985; Floyd & Williams, 2004; McLusky & Elliott, 2004). Several swimming crab species from Portunidae (*Portunus* and *Thalamita*) in Mtoni Estuary (Tanzania) were observed to make use of the mudflat detritus/leaves and will move out to the subtidal area when tide recedes (Kruitwagen et al., 2010). As for shrimps and prawns, the habitat requirements for juveniles are described as species dependent, varying from a specific nursery habitat to more than one habitat type (Coles et al., 1987; Dall et al., 1990). Macia (2004) did a comparative study on spatial distribution of several juvenile penaeid shrimp species between mangrove creek, sandflat, mudflat and seagrass meadow in a mangrove-fringed bay of Inhaca Island, Mozambique. He found that sandflats are more associated with the smaller shrimp‘s species as opposed to larger penaeid prawns species associated with the mudflat habitat. Commercially-important species of penaeid prawns particularly *Parapenaeopsis* and *Metapenaeus* species are found dependent on the mudflat as feeding area (Leh & Sasekumar, 1984; Marsitah & Chong, 2002; Chong et al., 2012a). In Klang Strait mudflat, juvenile penaeid prawns have higher abundance in the more extensive mudflats lying north of Buloh River (Chong et al., 2012b). *Fenneropenaeus merguensis, Parapenaeopsis sculptilis, P. maxillipedo, P. hardwickii* and *P.*

coromandelica are found distributed widely over the coastal mudflats (Zgozi, 2000). The juveniles of both *P. sculptilis* and *Solenocera subnuda* are relatively abundant on the Klang Strait mudflat (Marsitah & Chong, 2002). These species are found to consume mainly copepods, ostracods and brachyuran larvae (Leh & Sasekumar, 1984).

The intertidal mudflats worldwide are also known as important stopovers for both migratory and non-migratory birds to forage (Elliott et al., 1998; McLusky & Elliott, 2004). In particular, shorebirds in the temperate region utilize the intertidal mudflats and sandflats during long migrations over long distances between breeding and wintering grounds (Elliott et al., 1998). Most shorebirds feed on infaunal and epifaunal prey in the sediment (van de Kam et al., 2004; Spencer, 2010). These birds are highly mobile and exhibit tidal rhythm to effectively make use of the intertidal area (McLusky & Elliott, 2004). Examples are the redshank (*Tringa totanus*) and shelduck (*Tadorna tadorna*) which prey on the molluscs *Macoma* and *Hydrobia* in the intertidal area during low tide (Elliott et al., 1998). The Firth of Thames Ramsar Site offers an expansive wetland and mudflats that supported over 80 species of shorebirds, where 49 of them were migratory with several endangered species (Galbraith, 1992). In Klang Strait, a study on the shorebird population at Jeram and Remis Beach recorded a total of 32 species of shorebirds (Noralizmi & Ramli, 2014). Bivalves made up the most dominant prey items for these shore birds, followed by fish (Noralizmi & Ramli, 2015).

2.4 Mudflat fish community assemblages

In general, species diversity increases towards the trophic region in many marine habitats (Sanders, 1968; Ormond et al., 1997). However, the pattern of biodiversity changes across mudflat habitats is not clear. Table 2.1 compiles the records of species numbers from tropical, subtropical and temperate mudflats. In general, mudflats approaching the equator appear to have higher fish species diversity. However, differences among studies could be due to differences in the fishing gear used, sampling effort and the time of sampling.

Table 2.1 Total numbers of fish species reported from tropical, subtropical and temperate intertidal mudflats around the world. Sampling methods and cited studies are provided.

Location	Latitude	Species number	Fishing gear	Reference
Tropical region				
Chwaka Bay, Tanzania	6°10‘S	78	Seine net	Lugendo et al., 2007
Matang coastal mudflat, Malaysia	4°49‘N	77	Otter trawl/beam trawl/gill net	Chong et al., 2012b
Mamanguape River estuary, Brazil	6°46‘S	66	Beach seine	Garcia & Pessanha, 2018
Had Khanom Mu Ko Thale Tai National Park, Thailand	9°13‘N	55	Beach seine	Sichum et al., 2013
Embley Estuary, Australia	12°43‘S	39	Stake net	Blaber et al., 1989
Subtropical region				
Pueblo Viejo Lagoon, Mexico	22°10‘N	53	Seine net	Castillo-Rivera et al., 2010
Tolo Harbour, Hong Kong	22°26‘N	51	Beach seine	Tse et al., 2008
Sundarban Biosphere Reserve, India	21°50‘N	31	Gill net	Chaudhuri et al., 2013
Saco, Inhaca Island, Mozambique	26°04‘S	33	Beam trawl	de Boer & Prins, 2002a
Banco, Inhaca Island, Mozambique	26°03‘S	31	Beam trawl	de Boer & Prins, 2002b
Temperate region				
Victorian coastline, Australia	38°34‘S	39	Fyke net/ gill net/ beach seine	Hindell & Jenkins, 2004
Scheldt estuary, Belgium	51°24‘N	25	Fyke net	Stevens, 2006
Manukau Harbour, New Zealand	37°01‘S	22	Beach seine/ Outrigger trawl	Morrison et al., 2002
Tagus Estuary, Portugal	38°49‘N	22	Beam trawl	Salgado et al., 2004
Tama River estuary, Japan	35°32‘N	20	Beach seine	Kanou et al., 2005
Willapa Bay, United States	46°33‘N	17	Fyke net	Hosack et al., 2006
Tagus Estuary, Portugal	38°50‘N	13	Encircling net	França et al., 2008

Animal assemblages and distributions are influenced by a complex series of species responses to the physical and biological characteristics of the habitat (Odum & Heald, 1972). Fundamentally, organisms are driven to choose the best habitat(s) for growth and reproduction while adapting to any changes (Ponge, 2013; Wong & Candolin, 2015). For the mudflat, access is only available for ingress of nektons by following the tidal inundation cycle, indicating the important role of tidal migration of fish utilizing this habitat (Mumby et al., 2004; Castillo-Rivera et al., 2010). When the mudflat is exposed during low tide, macrobenthos such as brachyurans and molluscs will thrive on the surface (Dittmann, 1995; Dittmann, 2000) while nektons such as fish are forced to retreat to the mudflat‘s subtidal edge along the waterline or to their respective primary habitat. This in turn creates temporal variability in the fish assemblage resulting from the daily fish movements into and out of the mudflat (Gibson, 2003; Stevens et al., 2006), that may be related to the dynamics of feeding and predator avoidance.

Since the degree of tidal inundation is related to the tidal cycle, and the feeding-predation pattern is influenced by light intensity (Morrison et al., 2002; Shirantha & Wijeyaratne, 2002), the pattern of fish ingression into the mudflat may be affected by the diel (day-night) and lunar cycle, as evident in other associated biotopes (Stokesbury & Dadswell, 1989; Horký et al., 2006). By partitioning their temporal niche in the day-night cycle, fish species are able to reduce competition for food and space resources in shallow waters (Kronfeld-Schor & Dayan, 2003). Despite the diel nocturnal pattern exhibited by many fish species (Morrison et al., 2002; Pihl & Wennhage, 2002; Castillo-Rivera et al., 2010), stronger light intensity during full moon at night may also facilitate the hunt of prey fish by predators, while prey species may make use of the pitch black condition of the new moon to avoid predators (Stokesbury & Dadswell, 1989). On the other hand, by taking advantage of the tidal amplitude, juvenile and small fishes may migrate higher up the mudflat to avoid predation by larger fish (Burrows, 1994; Paterson & Whitfield, 1996). Coupled to the high turbidity of shallow water column (Blaber, 2000; McLusky & Elliott, 2004), shallow but variable water depth further reinforces the functional value of intertidal mudflat as nursery area for juvenile fish as evident in many studies (Kanou et al., 2005; Stevens et al., 2006; Tse et al., 2008).

Environmental factors such as variation in water parameters may modify the fish assemblage spatially and temporally (Terlizzi et al., 2005; França et al., 2008; Ooi & Chong, 2011; Jamizan & Chong, 2017). Often, species distribution and abundance reflects the seasonal and inter-annual variations of these environmental factors (Salgado et al., 2004; Cardoso et al., 2011). Such seasonal shifts in fish species assemblage appear to be common as shown in several studies (Thiel & Potter, 2001; Chaudhuri et al., 2013), and to some extent, certain species have been found to change their habitats due to seasonal rhythms and ontogeny (Morrison et al., 2002; Kanou et al., 2005). In tropical areas, long-term or seasonal variability in fish assemblage is usually related to both high rainfall and dry periods which may significantly influence environmental parameters such as salinity (Satpathy, 1996), temperature (Blaber, 2000) and pH (Chaudhuri et al., 2013). Lower salinity has been cited to act as cue for juvenile prawns and fishes to enter inshore nursery ground (Alongi, 2002), whereas temperature has been shown to influence fish growth (Gibson et al., 2002).

2.5 Mudflat fish trophodynamics

Trophodynamics is defined as the dynamics of nutrition or metabolism (Lindeman, 1942), and is fundamental to the understanding of energy flow through the food web. The study of trophodynamics and trophic relationship is important in ecological research (Nagelkerken et al., 2006; Layman et al., 2007; Hammerschlag et al., 2010; Whitehouse et al., 2016). Understanding the internal organization of the biotic assemblage and energy flow in the ecosystem allows better management of the fisheries resources (Bachok et al., 2004; Link & Browman, 2014; Travis et al., 2014). A fish trophodynamics study also provides vital information on the specific functional role played by individual species of fish within the ecosystem (Hajisamae et al., 2003), such as identifying the key primary consumers that transfer energy to higher trophic levels, or key predator(s) that regulate the ecosystem population dynamics. However, the study of trophodynamics of tropical mudflat nekton is relatively scarce as compared to temperate mudflats (e.g. Leguerrier et al., 2003; Dolbeth et al., 2008; França et al., 2008; Tse et al., 2008). To date, the only detailed trophodynamics study of fish in a Malaysian mudflat is by Chong et al. (2012b) in the Matang mudflat (Peninsular Malaysia) where 77 species of fishes were recorded. These authors recorded eight trophic guilds of fish. The fishes include the herbivore–detritivores, natantia (shrimp) feeders, mollusk feeders, polychaete feeders, crab/hermit crab feeders, copepod feeders, piscivores, and mixed feeders.

While the aforementioned environmental factors such as tidal action and water parameters can influence the assemblages of fish community, biological factors such as predation and food availability are also responsible for structuring fish assemblages (Edgar & Shaw, 1995). Many fish and crustacean species have been shown to ingress into and take advantage of the abundant food resources of intertidal mudflats (Kanou et al., 2005; Vinagre et al., 2006). In fact, Mérona et al. (2001) found that fish often focus on exploiting resources that are effectively accessible. Various foraging adaptations have been observed in fishes that effectively obtain such resources in estuaries, e.g. the morphological adaptations of the mouth and/or digestive tract that enable them to benefit from the high availability of detritus (Novakowski et al., 2007; Agostinho et al., 2008; Bennemann et al., 2011). On the other hand, a number of studies on other fish habitats have revealed that predation has a significant effect on the dynamics of the prey fish population (Planes & Lecaillon, 2001; Webster, 2002), as well as decreasing species diversity (Caley, 1993; Eggleston et al., 1997).

2.6 Mudflat productivity and connectivity to other coastal habitats

The high productivity of the intertidal mudflats results from the inputs of autochthonous and allochthonous nutrients/materials. The tidal flats receive nutrient, detritus and plankton derived from adjacent land and open sea, utilizing the energy/material input and in turn exporting it off-shore (Reise, 1985). On the other hand, the autochthonous production by local phytoplankton and microphytobenthos helps to enrich the mudflat productivity (Guarini et al., 2000; Blanchard et al., 2006). Microphytobenthos are photosynthetic microorganisms living on surface sediment that are capable of provide ample food resources to many shallow water ecosystems (Heip et al., 1995; MacIntyre et al., 1996; Underwood & Kromkamp, 1999). Assemblages of microphytobenthos often appear as brown and greenish film on the mudflat surface during low tide (Underwood, 2002). Compared to the subtidal area, intertidal mudflats have higher production (McLusky et al., 1992; Elliott & Taylor, 1989). Moreover, the biomass of microphytobenthos often exceeds that of the phytoplankton in the water column in some shallow ecosystems (MacIntyre et al., 1996; McLusky & Elliott, 2004). However, Lee et al. (2011) confirmed that primary production of microphytobenthos on subtropical intertidal sandflats is restricted to emmersion periods, likely due to the water turbidity prevented photosynthesis during immersion (Cayocca et al. 2008). The benthic microalgae, together with allochthonous carbon from adjacent sources in turn help support many benthic consumers (Herman et al., 1999), such as crabs (Dittman, 1993) and molluscs (Boehs et al., 2004).

Through connectivity with other adjacent ecosystems, intertidal mudflats are able to received allochthonous nutrient and materials via riverine discharge (Junk et al., 1989; Teoh et al., 2016; Garcia & Pessanha, 2018) and outwelling from mangroves (Kruitwagen et al., 2010). Carbon outwelling from mangrove habitat depends on abiotic factors such as the tidal amplitude, geomorphology and hydrology of coastal environments (Nagelkerken & van der Velde, 2004; Lugendo et al., 2007; Li et al., 2018). For example, higher rainfall in tropical estuaries has been associated with an increase in primary productivity due to the input of allochthonous detritus from freshwater discharge (Junk et al., 1989; Campos et al., 2015). In shorelines that are subjected to large tidal amplitude or tidal action, seawater retracts completely from the mangroves with the outgoing tide, and this can influence the degree of carbon outwelling to adjacent systems (Bouillon et al., 2008). However, stable isotope studies have shown little contribution of mangrove carbon to the nutrition of secondary consumers in adjacent habitats since mangrove carbon is more refractory than expected (Rodelli et al., 1984; Newell et al., 1995; Bouillon et al., 2008; Nagelkerken et al., 2008). On the other hand, Hatcher et al. (1989) suggested that mangrove detritus outwelled to the large offshore area will have little nutritional impact to consumers. This contention appears to be supported locally. Thong & Sasekumar, (1984) who studied the diet of fish fauna in offshore Angsa Bank, observed mangrove leaf litter that drifted at least 10 km from the Selangor coast, but detritus only contributed 9% by stomach volume despite its occurrence in 55 fish species. Meanwhile, several other studies have attested to the major contribution of microphytobenthos rather than mangrove carbon to consumers in other intertidal mudflats (Middelburg et al., 2000; Bouillon et al., 2002).

Carbon outwelling between mangrove and other ecosystems can also be achieved through biotic factors such as the ontogenetic migration of fish or macrofauna, and via trophic relay, which is carbon export through a series of predator-prey interactions (Bouillon & Connolly, 2009). Due to the fact that coastal biotopes such as mangroves, seagrass meadows and coral reefs do co-occur, the mudflat often acts as a corridor for fish to travel between these habitats, particularly during ontogenetic migration (Clark & Pessanha, 2015). The connectivity between mudflats and other adjacent biotopes will in turn affect the community structure and assemblage as a result of fish migration and vagrant activities (Unsworth et al., 2008; Kundu et al., 2012).

Figure 2.3 sums up and illustrates a local example of the connectivity between the intertidal mudflat coastal mangrove and nearshore waters, with respect to their ecological functions and fisheries support.

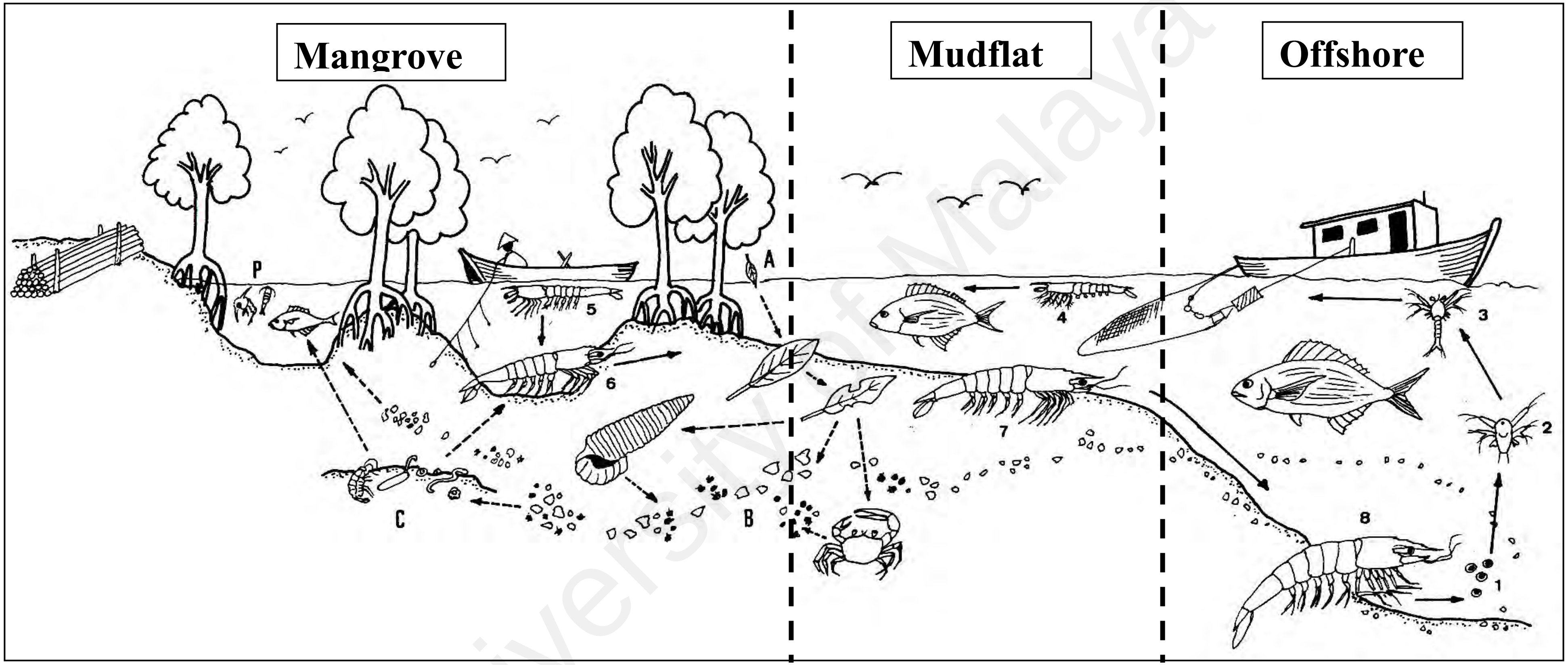

Figure 2.3 Composite picture of mudflat food web connection with adjacent systems (not drawn to scale, adapted from Chong et al. (2012a). **(A)** Mangrove leaf fall contributes to the pool of leaf litter which is broken down to fragments (as detritus) and outwelled to the mudflat area. **(B)** Plant fragments and faeces of macrofauna are further broken down by microorganisms, or are consumed by iliophagous fishes, shrimps, shellfishes and benthic meiofauna in the mudflat. **(1-8)** Illustrating the ontogenetic migration of penaeid shrimps between habitats, where the postlarvae settle in the mangrove (*Penaeus* spp.) or/and mudflat (*Parapenaeopsis* spp.), grow into juveniles in these nursery areas, before they migrate into deeper offshore waters to spawn on adulthood. Fish species (e.g. *Epinephelus, Lutjanus, Pomadasys* spp.) do the same, but many make use of the mudflat as feeding area and migration corridor to other marine habitats.

2.7 Deciphering fish trophodynamics: stomach content and stable isotope approach

In the past, dietary analysis was done through stomach content examination assessed by several methods, such as the occurrence, numerical, volumetric and gravimetric methods (Hynes, 1950; Hyslop, 1980). Each method has its own flaw and bias, e.g. the volumetric and gravimetric methods tend to overestimate the importance of large, but less frequently eaten food items (Hellawell & Abel, 1971), On the other hand, the numerical method overestimates by counting small food items that occur in high frequency (Hart et al., 2002). However, these methods have developed to calculate compound indices incorporating several measurements that provide a better representation of dietary importance (Pinkas et al., 1971; Liao et al., 2001). One of the more widely used compound indices is the index of relative importance or IRI (Pinkas et al., 1971). In this method, the percent frequency of occurrence of each prey category is multiplied by the sum of the percentage volume (or weight) and percentage number. By incorporating these measurements into a single measure, it appears to provide a more accurate description of dietary importance and also facilitate comparative studies. Despite being the only means of obtaining details of the type and number of prey items taken (Sydeman et al., 1997), many authors have criticized gut content analysis since only a snapshot view of the true diet is presented and contents may be difficult to identify (Gearing, 1991; Polis & Strong, 1996). Moreover, it is tedious and impractical to quantify the diet composition of many consumers in a community.

To tackle the problem of quantifying dietary information, numerous species can be grouped using a feeding guild, which is defined as a group of species that overlapped significantly in their exploitation of the same resources (Root, 1967). Trophic guild analysis is known to be a valuable tool in understanding the functional structure of complex ecosystems, particularly the marine ecosystem (Garrison & Link, 2000;

Bulman et al., 2001; Then, 2008; Kellnreiter et al., 2012; Varghese et al., 2014; Whitehouse et al., 2016). An example is the study by Delariva et al. (2013) which demonstrated the changes in fish guild structure as a result of impoundment effects on an aquatic ecosystem in Iguazu River, Brazil and Argentina. Classifying organisms into their respective guild also allows for the construction of a simplified food web from an otherwise complex web of interactions without significant changes of its salient properties (Sugihara et al., 1997; Gauzens et al., 2013). Under the rationale of comparative studies, Elliott et al. (2007) has provided seven broad categories of estuarine fishes, based on the feeding mode functional guild, which include detritivore, herbivore, omnivore, zooplanktivore, zoobenthivore, piscivore, and miscellaneous/opportunist.

Stable isotope analysis (SIA) is another approach to improve trophic interpretation based on the conventional dietary analysis (Jepsen & Winemiller, 2002; Claudino et al., 2013; Abrantes et al., 2013). Stable isotope analysis is a versatile tool for answering questions in biogeochemistry, plant and animal physiology, resource use and diet composition, trophic-level estimation and food-web functioning (Fry, 2006). In biogeochemistry or ecology studies, stable isotope analysis makes use of the small natural variations in stable isotope ratios resulting from physical, chemical and biological processes that cause isotopic fractionation (Craig, 1953). Carbon and nitrogen are two of the most commonly use isotopes to elucidate trophic structure and energy flow in the food web. The method analyzes the ratio of naturally-occurring carbon isotopes (i.e. $^{13}C/^{12}C$) or nitrogen ($^{15}N/^{14}N$) of the tissues of primary producers and consumers (Fry, 2006). The tissue isotope ratios reflect the actual assimilation of organic matter by the consumers over time, thus providing the long-term dietary information of the consumers (Gearing, 1991). The stable isotope compositions are expressed in terms of delta (δ) values in unit per mil (‰), i.e. parts per thousand differences from a standard.

The stable carbon isotope ratios (typically written as $\delta^{13}C$) of autotrophs primarily result from the differences in isotopic composition of the inorganic carbon substrate used and the photosynthetic pathway (C3 or C4) utilized (Smith & Epstein, 1970). An example such as mangrove plant that generally has a relatively low $\delta^{13}C$ value due to strong discrimination against ^{13}C by the C3 photosynthesis pathway (Loneragan et al., 1997; Bouillon et al., 2000), whereas a C4 plant such as saltmarsh grass will have relatively higher $\delta^{13}C$ value (Farquhar et al., 1989; Deegan & Garritt, 1997). Compared to autotrophs (e.g. diatoms) in the marine environment, isotopic discrimination against ^{13}C is lower (i.e. higher $\delta^{13}C$ value) due to its lower diffusion rate and other sources of dissolved inorganic carbon in the water (Dejours, 1988; Mook et al., 1974). Consequently, based on the principle of ―you are what you eat" (DeNiro & Epstein, 1976), these carbon isotope ratios are then reflected in the tissue of animals consuming these autotrophs. However, enrichment of the isotope value in the animal tissue will usually happen due to isotopic discrimination during the assimilation and excretion process (DeNiro & Epstein, 1976; Olive et al., 2003). Enrichments of $\delta^{13}C$ in animals are typically around 1 ‰ per trophic level (Michener & Lajtha, 2007; Sweeting et al., 2007a). Thus, one can trace the origin of the primary source consumed, provided that the difference in $\delta^{13}C$ value between primary sources are significant (Fry, 2006).

The stable nitrogen isotope also plays a role in deciphering food webs, where the stable nitrogen isotope ratios ($\delta^{15}N$) of animals are used to estimate their trophic positions in a trophic pathway (Minagawa & Wada, 1984). Animals at the higher trophic level will often have enriched $\delta^{15}N$ value due to the preferred excretion of ^{14}N when an organism consumed another organism (DeNiro & Epstein, 1981; Peterson &

Fry, 1987). However, trophic fractionation (either enrichment or depletion of isotope ratio value between prey and predator) of nitrogen can be influenced by a number of environmental and physiological factors such as trophic levels, taxa and metabolic rates (McCuthan et al., 2003; Vanderklift & Ponsard, 2003). Nonetheless, while fractionation of 3 ‰ is a mean for the considerable variation in fractionation values (Vander Zanden & Rasmussen, 2001), various other fractionation values for certain specific groups of organisms have been proposed by various researchers (McCuthan et al., 2003; Sweeting et al, 2007a,b; Caut et al., 2009). Using these isotopic data, researchers can construct a mass-balance mixing model to quantify the relative contribution of different food sources to the mixture (Peterson & Fry, 1987; Phillips & Gregg, 2001). For dealing with the uncertainties pertaining to fractionation values, the Bayesian mixing model in stable isotope analysis has the advantage of specifying a priori the standard deviation around the diet tissue discrimination factor to account for the uncertainty, thus allowing a better estimate of the relative contribution of each source (Moore & Semmens, 2008; Stock & Semmens, 2016; Parnell et al., 2010).

Many researchers have made use of the stable isotope approach to decipher the foodweb structure and trace the trophic energy back to the primary source(s) that fuels the ecosystem (Papiol et al., 2013; Bui & Lee, 2014; Perkins et al., 2014; Linnebjerg et al., 2016). In a temperate estuarine mudflat in Netherland, Middelburg et al. (2000) using the stable isotope approach elucidated the crucial role played by the microphytobenthos in moderating the carbon flow. In contrast, the use of stable isotopes was able to resolve the supporting role played by adjacent habitats in the supply of allochthonous carbon sources to a subtropical mudflat in Australia (Melville & Connolly, 2005). The first tropical trophodynamics study based on the dual (C, N) stable isotope approach was conducted in Malaysia to elucidate the contribution of two primary carbon sources (mangrove and phytoplankton) to the coastal fauna (Rodelli et al., 1984). Although the mudflat fauna were not specifically sampled or studied by these authors, this study is the first to state that mangrove detritus once outwelled into the coastal waters is basically refractory to biological assimilation. The second significant study that used the triple (C, N, S) stable isotope approach to resolve the issue of mangrove contribution to penaeid prawn nutrition was also conducted in Malaysia (Newell et al., 1995). These authors found decreasing utilization of mangrove detritus (vs. phytoplankton) from the mangrove swamp to offshore waters, not due to species or ontogenetic differences in the utilization of mangrove detritus (from radiotracer feeding experiments), but rather the abundance of detritus within the mangrove swamp. This study also alluded to the importance of benthic microalgae production in the coastal mudflats. These two seminal studies using stable isotopes to elucidate mangrove and coastal trophodynamics were carried out in Klang Strait waters, the study area and subject of the present PhD study.

CHAPTER 3: METHODOLOGY

3.1 Sampling site description

The study areas were located on the most extensive mudflat in the state of Selangor, west coast of Peninsular Malaysia (N 3°19.175 and E 101°13.446). The Klang mudflat continuously flanks the eastern seaboard of the Klang Strait, spanning about 55 km from Kapar to Sekinchan in the north, being interrupted only at the mouths of three major rivers: Tengi River, Kuala Selangor River and Buloh River (Figure 2.1). The mudflat covers about 8000 ha and extends between 1-2 km from the sea to the shoreline where fragmented mangrove forests still remained, particularly at the south of the Selangor estuary and the river mouth of Kuala Selangor River. The mangrove forests at the river mouth were mainly dominated by *Avicennia alba* and *Sonneratia* sp. (Sasekumar et al., 2012). Aside from the mangrove forest along the coastal fringe of the mudflat, no visible seagrass meadow or macroalgal patches can be found in the mudflat area.

The tidal regime at the Klang Straits is typically semidiurnal with mean high water springs of 5.09 m and mean low water spring of 0.98 m, resulting in maximum mean tidal amplitudes of about 4.2 m during spring tide (National Hydrographic Center 2018). The flood current flows southeast but the stronger ebb current flows northwest. During spring flood tide, the entire Klang mudflat are submerged under water, whereas during ebb tide, mudflats are exposed as far as to 2 km away from the mangrove-fringed shoreline.

The weather in the Klang mudflat is characterized by two alternating seasons or periods due to the winter or Northeast Monsoon (NEM) (November to March), and the summer or Southwest Monsoon (SWM) (May to September), with inter-monsoon periods in between. The onset of the NEM is characterized by very heavy rainfall but dry spells follow during the later part. The SWM however starts with relatively less rainfall until later when the monsoon —breaks” between July and September and heavy rainfall may result due to the convergence of low-level easterly and southwesterly winds over the Sumatran region (Cheang, 1988). Although the SWM signifies drier weather, there is no distinct wet or dry season in the study area.

Within the Klang mudflat area, two study sites were selected for this study: Bagan Pasir (BP) and Bagan Sungai Buloh (SB). The BP site was located at the mudflat south of Tanjung Karang town and close to the Tengi River mouth (N 3°23.738 and E 101°09.440), whereas the SB site was located at the mudflat south of the Buloh River mouth (N 3°15.268 and E 101°16.742). The SB mudflat is well known as an extensive cockle culture site, in contrast to the BP mudflat which is more pristine and not known to harbor any extensive cockle culture activity.

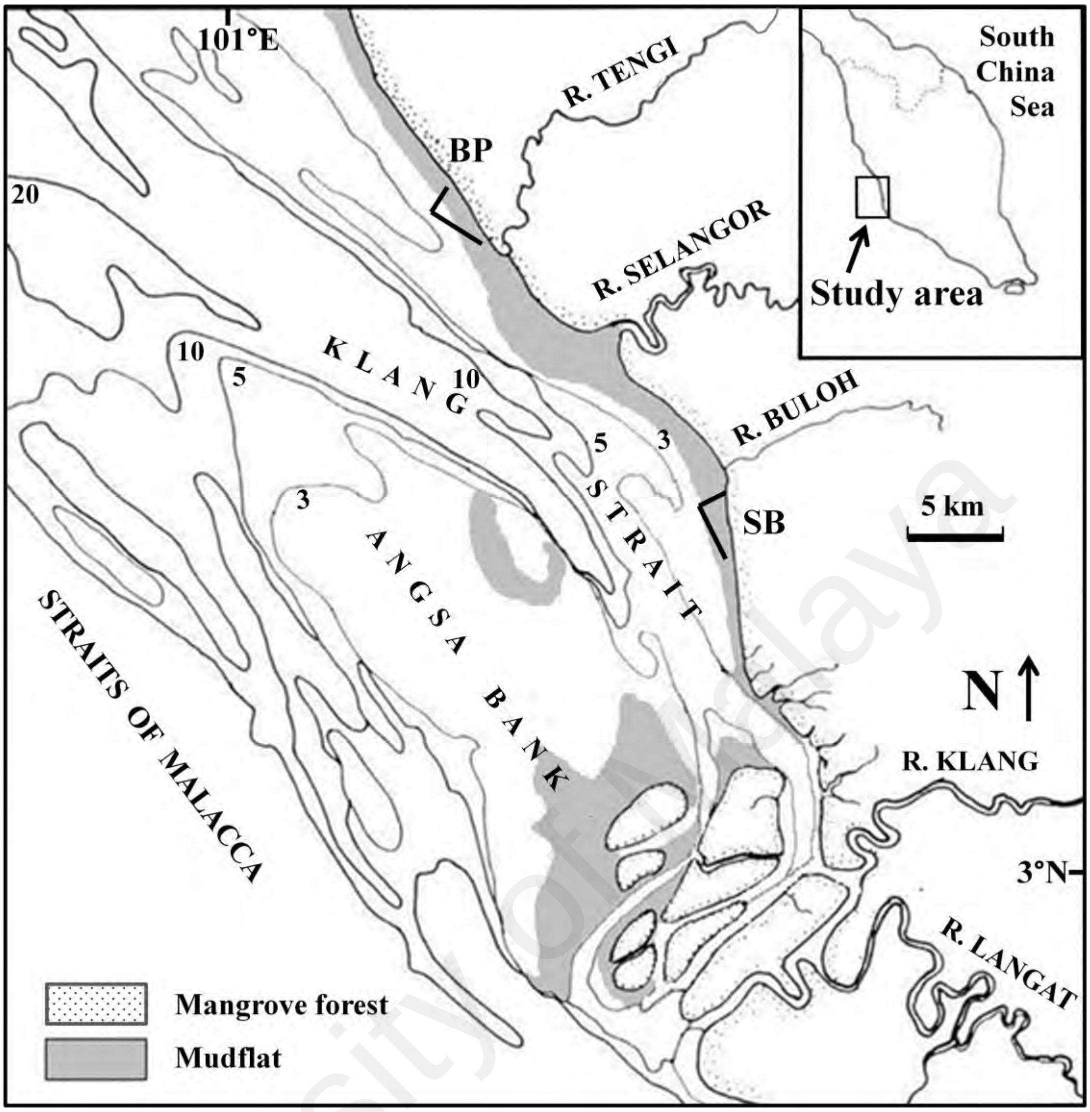

Figure 3.1 Map showing the study sites at Klang Strait, Peninsular Malaysia. Study sites labeled as BP (Bagan Pasir) and SB (Bagan Sungai Buloh) are marked with Ł” symbols depicting the enclosure net used as sampling gear. R denotes river. Isobaths in metres.

3.2 Field sampling

3.2.1 Routine sampling of fish and invertebrates

The fish community structure of the mudflat was investigated by monthly samplings on two mudflat sites (BP and SB). For each site, monthly samplings were carried out for a total of 26 months from September 2011 to November 2013, covering two alternating periods of the NEM (November to March) and SWM (April to September). In order to standardize the sampling conditions, all monthly samplings were conducted during the day time (10:00 am to 2:00 pm) on the spring tide of each month. Vagile fish and invertebrates in the mudflat were trapped by a traditional fishing net or barrier net (*belat lengkong*) and gill nets during ebb tide. Sampling using the barrier net was conducted with two representative fixed sites (BP and SB) set up as replicates every month except in May 2013 for both sites and October 2013 for SB when field works were suspended due to extremely rough weather. Samplings using gill nets were conducted monthly with three replicates for 18 months from September 2011 until February 2013.

In the local commercial fishery, the barrier net is designed to catch vagile fish and invertebrates on the mudflat when they retreat to the sea during spring ebb tide. This commercial gear operates about six days each during two spring tides of the month. The pre-gear operation began near high slack in water of closest at 800 m away from the mangrove fringe and not more than 1.5 m in depth, where the net stakes were manually driven into the mud to form an approximately ‗L' configuration with its long wing deployed along the direction of ebb flow (southwesterly) and the shorter wing deployed nearly perpendicular and as close as 400 m to the mangrove fringe. The GPS coordinates at both ends and vertex of the net were recorded using a handheld Garmin Rino 130. The set barrier net enclosed a large triangular area calculated to vary from 1.5 to 4.0 ha using great circle distance formula (Weisstein, 2014a). Fish were trapped mainly at the net's vertex during the subsequent ebb run when water had completely receded from the mudflat. Fish were then taken out from the cod-end bag (mesh size 1.5" or 3.81 cm) at the net's vertex using a scoop net and subsampled (1/2, ¼, or 1/8) when the catch was too large. All catch samples were kept in ice filled ice-chests, and on returning to the laboratory, the samples were immediately kept in a deep freezer (-20 °C) before subsequent analysis.

While the barrier nets were able to sample most of the fish species that ingressed into the mudflat over a large area during high tide, the gear could not be deployed at the subtidal edge of mudflat due to deeper water. Thus, a gill net of 1.25” (3.175 cm) mesh size was used to sample the fishes at the subtidal edge of the mudflat, where most of the fish and shrimps retreated to during the ebb tide. Three replicates of long gill net which measured 1.8 m in depth and 300 m in length were set obliquely or parallel to the shoreline at the subtidal area during the ebb tide, and allowed to passively fish for one hour. The fishing time was taken from the instance the gill net was deployed into the water until the time the net was completely retrieved from the water. Location of each net replicates was taken using GPS (Garmin Rino 130). All catches from the gill nets were collected without subsampling, kept in ice filled ice-chests and frozen immediately (-20 °C) upon returning to the lab for subsequent analysis.

3.2.2 Periodic-diel sampling

For the purpose of investigating the effects of site (BP, SB), diel light cycle (day, night), moonlight phase (new moon, full moon), and (rainfall) period (dry, wet) on the fish community structure and diet, additional barrier net samplings were conducted. The reason why the rainfall effect (i.e. wet and dry period) of two different monsoons was selected is because previous studies had shown the lowest and highest rainfall occurred during the SWM and NEM, respectively.

Barrier net samplings to address the above factors were conducted at the two mudflat sites, BP and SB, during the wettest period (November 2013 and March 2014) and the driest period (June and September 2014). At the stated months, samplings were conducted during day (10.00 am to 2.00 pm) and night (10.00 pm to 2.00 am) on the new moon and full moon phase of each month. Day and night samplings thus addressed the diel light factor while new moon and full moon samplings addressed the moonlight phase factor. The configurations and sample collection methods of the deployed barrier net were similar to that of the routine monthly samplings described above.

3.2.3 Measurements of physical parameters

Before fish sampling (monthly and diel) was made, water parameters (salinity, pH, temperature and dissolved oxygen concentration) were measured *in-situ* at depth of 0.5m during high slack by a multi-parameter sonde (Model YSI 556). Water depth of the mudflat was measured by a hand-held Speedtech echo sounder (Model SM-5). When the shore was exposed during low tide, the sediment samples were cored using a soil corer (32mm diameter x 140mm length). The retrieved sediment was then cut to give 0.0 to 2.0 cm surface sediment layer and kept in individual pill bottles. Sediment samples from both sites were then brought back to the lab for subsequent analyses of chlorophyll *a* content, particulate organic content and particle size. Rainfall data during the sampling period of the study were obtained from the Malaysian Meteorological Department; the rainfall measurements were recorded at the Sungai Buloh Estate, located 15 km to the southeast of Kuala Selangor river mouth (Figure 2.1).

3.2.4 Sample collection for stable isotope analysis

The potential primary producers namely phytoplankton and microphytobenthos on the mudflat, as well as allochthonous inputs such as mangrove leaves and sediment detritus were collected for stable isotope analysis at each site in January 2013. During flood tide, approximately 5 L of surface sea water containing seston was obtained by pooling 1 L of water samples from various locations for better representation. Water samples were collected during high tide and sieved through a 153-µm plankton net before being kept in plastic bottles. A total of three samples of pooled subsamples of seston were collected per site. Three samples of surface phytoplankton each at both sites were also collected using a 10-µm plankton net placed at the side of a drifting boat for

10 min. The codend contents were then poured through a 125-μm Endecott sieve to filter out any zooplankton and kept in plastic bottles. Drifting senescent mangrove leaves were collected by using a scoop net. When the mudflat was exposed during ebb tide, surface sediments (0 - 20 mm depth) were scrapped for microphytobenthos and kept in 50 mL bottles (three replicates in each site). Mudflat mollusks and polychaetes were hand-picked or dug out as representative prey samples for SIA. Nine replicates of upper 20 mm of sediment cores were also taken from each site for SIA using an acrylic soil corer (320 mm diameter and 2200 mm length).

Fresh specimens of representative fish or invertebrate species were separately taken after sampling for stable isotope analysis. These included various fish species from the various feeding guilds. Potential prey such as bivalves, decapods and polychaetes from the by-catch of the barrier net were also sampled for stable isotope analysis. All biological samples, except the scrapped microphytobenthos, were immediately kept in an ice chest after sampling and frozen in a freezer at -20 °C upon arrival in the laboratory. The seston samples were passed through a 53-μm Endecott sieve to obtain two size fractions prior to freezing. The scrapped microphytobenthos were however kept cool on the boat. In the laboratory, the live microphytobenthos were immediately processed for cell extraction (see below).

All specimens for stable isotope analysis were opportunistically collected many times whenever possible to meet the target sample size, or when the need arise.

3.3 Laboratory analysis

3.3.1 Sample sorting and measurement

Upon thawing, all catch samples in the laboratory were sorted, and the fish, shrimp and other invertebrates were identified to the species level whenever possible using the following published taxonomic keys: Munro (1974), De Bruin et al. (1994), Mohsin and

Ambak (1996), and Carpenter and Neim (1998a; 1998b). For fish, all specimens were counted by species, towel-dried, measured (standard length, mm) and weighed (W, g). Maximum standard length of each fish species was obtained from Fishbase (Froese & Pauly, 2018).Size class of individual fish was determined by using Nagelkerken and van der Velde‘s (2002) method, where each individual was ascribed to one of three size classes: small (< 1/3 of the species‘ maximum length), medium (1/3 to 2/3 of the species‘ maximum length), and large (> 2/3 of the species‘ maximum length). Subsequently, the stomach of each fish specimen was removed by cutting the anterior and posterior end of the stomach joining the oesophagus and spiral intestine respectively. Removed stomachs were then preserved in 80 % denatured alcohol for subsequent gut content analysis.

For invertebrates, the standard measurements of carapace length (crustaceans) and shell length (molluscs) were made where necessary. Only the total number and total weight (g) of each shrimp species were recorded for monthly samplings.

3.3.2 Fish stomach content analysis

Where possible, up to 10 individuals from the dominant size class of each species were taken from monthly samples from each site for stomach content analysis. Stomachs were dissected out and preserved in 80% alcohol. Gut fullness (GF) was estimated by eye (Chong 1977) and classified arbitrarily as empty (0), ¼ filled (1), ½ filled (2), ¾ filled (3) and full (4).

The contents of each stomach were sorted and identified to the lowest taxon possible with the aid of a stereomicroscope and inverted microscope. Generally, it was possible to group the food items into their taxonomic category with few exceptions. The diverse group of decapods was categorized broadly as shrimps (include penaeids, sergestids and mysids), crabs and hermit crabs. Planktonic stages of decapods (e.g.

zoea, megalopa, postlarva) were distinguished from their adult counterparts. Bits of organic material were regarded as detritus. Other stomach items that were relatively rare were grouped as ~~–o~~thers".

The quantification of each prey item was expressed numerically (counting the number of prey items) and volumetrically. Volume of prey items were estimated visually with the aid of a gridded 1 ml Sedgwick-Rafter cell (20 mm x 50 mm), where the volume of each small food item or parts of it was estimated using to the area coverage of the item in the rafter cell (Chong, 1977). For larger food items such as fish, crab and penaeid prawn, the water displacement method was used to estimate the volume (Hyslop, 1980). The food item(s) was completely submerged with a known volume of distilled water in a 5-ml measuring cylinder. The displaced volume is equal to the volume of the food item(s) measured.

3.3.3 Sample preparation for stable isotope analysis

Fish species belonging to eight trophic guilds identified from the cluster analysis of quantified prey categories (see data analysis below) were selected for SIA. At least three replicates from the dominant size class of fish species used in stomach content analysis were analyzed. For all selected fish species, only the muscles on the dorsal part of the fish were removed using a scalpel. For the identified invertebrates such as bivalves and crustaceans, muscle tissues were dissected from their exoskeleton or shells.

The fractionate frozen seston samples (> 53 µm) were thawed and small crustaceans including the zoeal larvae, copepods and sergestid shrimps were sorted out under a stereo microscope for SIA. The < 53 µm fractionated seston samples were filtered onto a precombusted glass fibre filter paper (GFC) and rinsed several times with distilled water. Thawed phytoplankton samples were processed by transferring small quantities at a time in a petri dish and observing under an inverted microscope. Contamination of phytoplankton subsamples was minimized by pipetting out or removing unwanted plant detritus, organic flocs and other non-microalgal elements. The remaining, mainly microalgal cells, were then concentrated by loading the cells onto a small area of the precombusted GFC filter paper, before gently rinsing several times with distilled water using a squirt bottle.

The freshly collected microphytobenthos from the field were immediately extracted from the sediment using the modified phototaxis method described by Du et al. (2010). The sediment samples were poured onto three individual dark-coloured containers to a height of 20 mm. A 100 µm mesh net was laid on top of the sediment, followed by a 10 mm - thick layer of precombusted sand grains (125 – 250 µm grain size) rinsed with 20 salt water. The petri dishes were then placed under a single 120 cm long 85 lumen/watt fluorescent lamp for two hours. The top layer of precombusted sand plus the phototactically attracted microphytobenthos was then removed and wet sieved through a 105 µm Endecott sieve using distilled water to obtain an aqueous mixture of concentrated microphytobenthos cells. The microphytobenthos samples were then washed through a 10 µm mesh net several times to reduce contamination by clay particles.

Collected senescent mangrove leaves were thoroughly rinsed with distilled water. The collected sediment core samples were homogenized and sub-samples were taken to represent the sediment particulate organic matter (sPOM).

All biological, filtered seston and sediment samples in aluminium boats (fashioned from aluminium foil) were oven-dried at 60°C to constant weight. Samples were then sealed in individual plastic bags and then sent to the Marine Biological Laboratory (MBL), Woods Hole, USA, for stable C and N isotope analyses.

3.3.4 Stable C and N isotope analysis

At the MBL, the dried samples were ground to fine powder before they were combusted to N_2 and CO_2 gasses by an Europa ANCA-SL (automated nitrogen carbon analysis for solids and liquids) elemental analyzer. The GFC filter papers containing the loaded phytoplankton were cut out for similar analysis. The stable C and N isotope ratios were determined by a Europa 20-20 mass spectrometer. Results were expressed in standard δ notation, and values were determined based on the following equations:

$$\delta^{13}C, ‰ = [(^{13}C/^{12}C)_{sample} / (^{13}C/^{12}C)_{standard,\ PDB} - 1] \times 1000$$

$$\delta^{15}N, ‰ = [(^{15}N/^{14}N)_{sample} / (^{15}N/^{14}N)_{standard,\ air} - 1] \times 1000$$

The standard reference materials for carbon and nitrogen in stable isotope analysis were Peedee Belemnite (PDB) and N_2 in air, respectively. The precision of the spectrophotometer was ±0.1 ‰ for both measurements of $\delta^{13}C$ and $\delta^{15}N$.

3.3.5 Sediment analysis

Nine mudflat sediment samples at each BP and SB sites were analyzed for sediment particle size, particulate organic matter (POM) and chlorophyll a biomass.

Sediment samples for particle size analysis and total organic matter content were dried in an oven at 60 °C for a week. Approximately 100 g of the dried sediment samples were immersed in a 6 % hydrogen peroxide overnight to remove organic matter, and then in sodium hexametaphosphate solution (6.2 g/L aqueous) overnight to disperse the sediment agglomerate (Holme & Mclntyre, 1971). Particle size of the treated samples were subsequently analysed by a Coulter 230L Particle Size Analyzer. The soil particle groups were categorized according to the Wentworth grade scale (Buchanan, 1984) as described in Table 2.1.

The organic matter content of the sediment was estimated by subtracting the weight of combusted sediment (at 500°C for 6 hours in a muffle furnace) from the weight of dried sediment (at 60°C for at least three days in an oven) (Holme & Mclntyre, 1971).

Table 3.1 Categories of sediment based on particle size.

Particle size class (µm)	**Categories**
0 - < 3.9	Clay
3.9 - < 15.6	Fine silt
15.6 - < 62.0	Coarse silt
62.0 - < 125	Very fine sand
125 - < 250	Fine sand
250 - < 500	Medium sand
500 - < 1000	Coarse sand
1000 - < 2000	Very coarse sand

For the determination of sediment chlorophyll *a* concentration, two samples of wet sediment each of 1-2 g were prepared, one placed inside a pre-weighed 10ml plastic Falcon^{TM} tube and the other placed in an aluminium boat. The Falcon^{TM} tube and aluminium boat containing the wet sediment were then weighed to the nearest 4 decimal points. Acetone was then added into the Falcon^{TM} tube and the sediment mixture was kept in 20°C freezer for at least 12 hours to allow extraction of chlorophyll. The chlorophyll *a* concentration was then measured using a Turner Fluorometer (Model 10AU) within 24-hour after extraction. The aluminium boat containing the wet sediment was dried in the oven (60°C) for at least three days to remove moisture. The dried sediment together with the aluminium foil was then weighed to the nearest 4 decimal points. The water content of the sediment was then estimated by subtracting the weight of dried sediment from the weight of wet sediment. Sediment chlorophyll *a* concentration expressed as microgram (µg) relative to dry weight (DW) of sediment in gram (i.e. µg/g DW) was calculated using the formula in Lorenzen (1967) as follow:

$$\text{Chl } a = \frac{\frac{\mathrm{F_0/F_a\ max}}{\mathrm{F_0/F_a\ max{-}1}} \cdot \mathrm{K_x(F_0 - F_a)}}{\text{dry weight of sediment (in gram)}}$$

where F_0 is fluorometer fluorescence reading before hydrochloric acid treatment,

F_a is fluorometer fluorescence reading after the hydrochloric acid treatment,

K_x is the calibration factor, determined for the fluorometer.

Mean reading of three pseudo-replicates for each sample of wet sediment were taken to increase precision.

3.4 Data and statistical analysis

3.4.1 Rainfall, water parameter and sediment analysis

Monthly averages of the daily rainfall at Sungai Buloh Estate station recorded by the Malaysian Meteorological Department were calculated for four years (2010-2013). The dry or wet period of each sampling month was determined based on the standardized precipitation index (SPI), where precipitation of below average (SPI < 0) was regarded as dry period while precipitation of above average (SPI > 0) was regarded as wet period. The SPI was calculated using the following equation:

$$\text{SPI} = \frac{X_i - X}{SD}$$

where X_i is the total rainfall of the *i*th month; X is the mean monthly rainfall over a 4-year timescale; and SD is the standard deviation of the monthly rainfall total (McKee et al., 1993).

Univariate analysis using one-way ANOVA were performed to test the null hypothesis of no significant difference in water parameter studied (salinity, pH, temperature and dissolved oxygen concentration) among factor levels. The investigated factors (and levels) were site (SB, BP), monsoon (NEM, SWM), period (dry, wet), moon phase (new moon, full moon) and diel (day, night). A two-way (site and monsoon) ANOVA was applied to data collected from the routine monthly samplings, while a four-way (site, period, moon phase and diel) ANOVA was applied to data collected from the periodic-diel samplings. Results on chlorophyll-*a* concentration, particle size and POM of sediment were compared for significant differences between sites using one-way ANOVA. Prior to the ANOVA analysis, all variables tested and square root transformed for normality and homogeneity of variances. In the event that transformation was not helpful, the non-parametric Kruskal-Wallis test was used for significant test. A Significance level at $p = 0.05$ was applied for all tests. The STATISTICA software package version 8.0 was used for all ANOVA analyses.

3.4.2 Fish community structure and distributions

a) ***Standing stock***

The abundance and biomass of fish and invertebrates at Kuala Selangor mudflat were calculated for monthly and diel samplings based on the area enclosed by the barrier net. The abundance (A_i) of each species (*i*th species) expressed as number ha^{-1} was calculated by using the following equation:

$$A_i = \frac{N_i}{A_b} r$$

where N_i is the total number of *i*th species of fish/invertebrate; A_b is the enclosed area and r is the raising factor due to subsampling.

Biomass (B_i) of each species (*i*th species) expressed as kg ha^{-1} was calculated by using the following equation:

$$B_i = \frac{G_i}{A_b} r$$

where G_i is the total weight of ith species of fish/invertebrate; A_b is the enclosed area and r is the raising factor due to subsampling. The enclosed area of the barrier net was estimated by using a three point GPS determination of the coordinates of its two ends and vertex. Based on the great circle distance formula (Weisstein, 2014a), the distance among the three point GPS were calculated. These distances were then applied to Heron‘s formula (Weisstein, 2014b) to calculate the area for an irregular triangle (the enclosed area of the barrier net).

The great circle distance between any two of three GPS points (1, 2, 3) was calculated from

$d = a \cos^{-1} [\cos \delta_1 \cos \delta_2 \cos (\lambda_1 - \lambda_2) + \sin \delta_1 \sin \delta_2]$, where

a is equatorial radius of earth ≈ 6378km,

δ is latitude in radians, i.e. degree * $\pi/180$, and

λ is longitude in radians.

The area (A) for an irregular triangle was then calculated viz.

A = square root $(s*(s-d_1)*(s-d_2)*(s-d_3))$, where

$s = (d_1 + d_2 + d_3)/2$

Monthly fish and shrimp abundance and biomass data were accumulated and grouped by site (BP and SB) and season (SWM and NEM). Whereas in diel sampling, fish abundance and biomass data were subjected to the following factors (levels): site (BP, SB), period (dry, wet), moon phase (new moon, full moon) and diel (day, night).

For fish and shrimp specimens collected by gill nets at the subtidal edge of mudflat, their abundance and biomass were calculated monthly based on the net size (area) and the fishing time. Unlike the enclosure trap which estimates absolute abundance, the passive gill net provides only relative abundance. The relative abundance of each species (jth species) was calculated as catch per unit effort (nCPUE_j), expressed as numbers meter square^{-1} hour^{-1} (N m^{-2} h^{-1}), based on the following equation:

$$\text{nCPUE}_j = \frac{N_j}{A_g * T} r$$

where N_j is the total number of jth species of fish/shrimp; A_g is the area of gill net, T is duration of the net setting and r is the raising factor due to subsampling.

Relative biomass (bCPUE_j) of each species (jth species) expressed as g meter^{-2} square^{-1} hour^{-1} (g m^{-2} h^{-1}) was calculated by the following equation:

$$\text{bCPUE}_i = \frac{G_j}{A_g * T} r$$

where bCPUE_j is the total weight of jth species of fish/shrimp; A_g is the area of gill net, T is duration of the net setting and r is the raising factor due to subsampling. The area of the gill net used was 300 m x 1.8 m.

All standing stock data from the barrier net (monthly and diel studies) and gill net (monthly studies) catches were subjected to similar but independent multiway ANOVA analyses. Two-way ANOVA analysis was performed to test for significant differences in standing stocks as influenced by the investigated factors (site and monsoon). Prior to the analyses, the assumption of homogeneity of variance was tested. Skewed data were transformed using square root transformation to homogenize the variance. Following unsuccessful transformation, Kruskal-Wallis test was used for significance testing.

Significance level at *p* = 0.05 was applied for all tests to determine significant difference.

b) ***Species richness, diversity and community structure***

The community structure of fish in Klang mudflats were described and analyzed by using the biotic indices, Shannon-Wiener diversity index (Shannon, 1948) and Pielou‘s evenness (Pielou, 1969), and multivariate analyses. Abundance data for both barrier nets (monthly and diel studies) and gill nets (monthly studies) were used for the following analyses.

Both biotic indices were determined for each factor level of respective data set using the DIVERSE routine of PRIMER software version 6.1.13 (PRIMER-E Ltd, Plymouth, United Kingdom) (Clarke & Gorley, 2006; Anderson et al., 2008). The non-parametric Kruskal-Wallis test was used to test for significant differences in both indices among their respective factors.

Distance-based permutational multivariate analysis of variance (PERMANOVA) in the PRIMER software was performed on transformed data. Prior to multivariate analysis, all fish abundance data were square rooted to downweigh the contribution of dominant species (Clarke & Warwick, 2001). The Bray-Curtis dissimilarity distance was used to test the null hypothesis of no differences in fish assemblage between the stated levels for each factor of respective data set. Each factor was analysed as fixed factors with two levels each using 4999 permutations. The null hypothesis of no difference in dispersions among factors was tested using test of homogeneity of dispersions (PERMDISP) (Anderson et al., 2008), followed by post hoc pair wise test if the test was significant. A null hypothesis indicated no differences in dispersions among the tested groups. Following pair wise tests on abundance data between and within each factor by PERMANOVA, the similarity percentage (SIMPER) tests were carried out on pairs with significant p values to identify the significant distinguishing fish species. Species that fulfilled the criteria $\bar{\delta}_i/\mathrm{SD} > 1$ and $\%\bar{\delta}_i > 3\%$ (where $\bar{\delta}_i$ is the overall dissimilarity between two groups and SD is the standard deviation) were arbitrarily accepted as important contributors to dissimilarity among each factor.

Following multivariate analysis, non-metric multidimensional scaling (nMDS) were utilized to visualize the dispersion of samples of both monthly results (abundance) of barrier nets and gill nets on a two-dimensional ordination. A stress value is an indicator of goodness-of-fit between the distance values represented in the ordination and the corresponding similarity rankings. Stress value of less than 0.2 is considered acceptable for use in two-dimensional ordination to represent real data (Clarke & Warwick, 2001). Pearson correlation coefficient of > 0.40 was superimposed to display weight loadings of fish species relative to ordination axes.

The groupings or patterns of the periodic-diel studies were however visualized on a constrained ordination using canonical analysis of principal coordinates (CAP), which maintained factor site, period, moon phase and diel (Clarke & Gorley, 2006). Null hypothesis of no difference between groups, formed by combining each factor was tested using 4999 random permutations. An appropriate subset of canonical axes (m) for the CAP analysis was determined by maximizing the leave-one-out allocation success (Anderson & Willis, 2003). A Spearman correlation coefficient of >0.40 was used as an arbitrary limit to display potential correlation between individual species abundance relative to the canonical axes. Meanwhile, multivariate analyses (BIO-ENV procedure) for the fish standing stock data in relation to the environmental data (water temperature, salinity, pH and dissolved oxygen) were also conducted. However, no significant relationships between them were shown.

3.4.3 Diet data analysis

Composition of stomach content was described using percentage volume (%V), percentage number (%N) and percentage frequency of occurrence (%FO) (Hyslop, 1980). For %V, individual stomach contents were emptied into a 1 mm x 1 mm x 1 mm Sedgwick-Rafter cell and sorted by food item types before the volume of each food item was estimated. The diet of each fish species was then described using the Index of Relative Importance (IRI) expressed as a percentage (%IRI) for better interpretation (Pinkas et al., 1971, Cortés, 1997). Food items that could not be counted were given a value of 1 for %N to offset distortion of IRI (Abdurahiman et al., 2010). The %IRI of each prey item was calculated as follow:

Index of Relative Importance, $\%IRI_i = (\%N_i + \%V_i) \times \%FO_i$

where $\%N_i$, $\%V_i$ and $\%FO_i$ respectively represents the percentage number, volume and frequency of occurrence of prey i.

In order to identify the major trophic guilds of the mudflat fish community collectively, hierarchical group average cluster analysis based on the Bray-Curtis similarity matrices (Bray & Curtis, 1957) of %IRI values, pooled for fishes from both BP and SB sites, was performed. Species with < 10 individuals were excluded from the analysis. Similarity profile analysis (SIMPROF) with 5 % significance level and 4999 permutations was conducted to identify significant clustering groups as trophic guilds. Prior to the clustering, the %IRI data were square-root transformed to downweigh the contribution of dominant prey items (Clarke & Warwick, 2001).

Additionally, non-metric multidimensional scaling (nMDS) was utilized to visualize the separation of predator species on a two-dimensional ordination plot. A Pearson correlation coefficient of > 0.40 was superimposed to display the weight loading of prey items relative to the ordination axes. The Similarity Percentage analysis (SIMPER) was then used to identify the top prey taxa contributing to forming the trophic guilds (Clarke, 1993).

To examine the spatiotemporal variation in fish diets for each trophic guild, a total of 34 species of fish (species with at least five samples on each factors), which comprised 64.2 % of the total species sampled, were subjected to PERMANOVA analysis for diet differences between sites (BP and SB) and monsoon periods (NEM and SWM) (Anderson et al., 2008). Prior to these tests, the data set was prepared by calculating the %IRI for every five randomly selected samples of each species, an approach suggested by Pardo et al. (2015). The data were then square-root transformed and the Bray-Curtis similarity index between fish species was calculated. Each factor was analyzed as fixed factors using 4999 permutations. Following significant results, SIMPER analysis was conducted to identify the prey taxa that contributed most to dissimilarities between factors.

Pearson correlation analyses were used to examine the relationship between fish species (shrimp feeder guilds) and shrimp species. Using monthly collected data, abundance of shrimp species was correlated to abundance of fish species on the mudflat. . Correlation analyses were performed using STATISICA 8 (StatSoft, Tulsa, USA).

3.4.4 Statistical analysis of stable isotope data

The mean and standard deviation of quantified stable isotopic values were calculated for selected species. A scatter plot derived from the mean $\delta^{13}C$ and $\delta^{15}N$ values of all predator fish species, prey and primary producers were constructed to give an overview of the isotopic trophic structure of the Klang mudflats. Analysis of variance (ANOVA) was performed on the isotopic data matrix to determine if there were significant differences between the trophic guilds. Following the rejection of the null hypothesis of no significant difference between trophic guilds, post-hoc pairwise tests were conducted to identify the significantly different pairs. ANOVA analyses were performed using STATISICA 8 (StatSoft, Tulsa, USA.

a) *Estimation of trophic position*

To date, selecting the most appropriate trophic enrichment factor (TEF) has remained one of the toughest challenges in stable isotope analysis (Phillips et al. 2014). While some researchers have suggested a fixed TEF of 3.0 to 3.4‰ as appropriate for nitrogen diet-tissue fractionation ($\Delta\delta^{15}N$) (Vander Zander & Rasmussen, 2001; Post, 2002; Sweeting et al., 2007b), some recent meta-analyses showed evidence of a narrowing $\Delta\delta^{15}N$ when moving up the trophic level (Caut et al., 2009; Hussey et al., 2014a). In response to this problem, Hussey et al. (2014a;b) developed a scaled $\Delta\delta^{15}N$ framework to estimate the trophic position (TP). For this work, this same approach was employed to estimate the TP of all consumers.

The scaled $\Delta\delta^{15}N$ approach uses the following formula:

$$\mathrm{TP_{consumer}} = \frac{\log_e(\delta^{15}\mathrm{N_{lim}} - \delta^{15}\mathrm{N_{primary\ consumer}}) - \log_e(\delta^{15}\mathrm{N_{lim}} - \delta^{15}\mathrm{N_{TP}})}{k} + \mathrm{TP_{primary\ consumer}}$$

where

$$k = -\log_e\left(\frac{\beta_0 - \delta^{15}\mathrm{N_{lim}}}{-\delta^{15}\mathrm{N_{lim}}}\right)$$

$$\delta^{15}\mathrm{N_{lim}} = \frac{-\beta_0}{\beta_1}$$

$\mathrm{TP_{consumer}}$ is the estimated trophic position of the consumer, $\delta^{15}\mathrm{N_{consumer}}$ is the mean $\delta^{15}N$ value of consumer, and $\delta^{15}\mathrm{N_{primary\ consumer}}$ is the value of a representative baseline at

TP 2 or the primary consumer. In this study, the herbivorous copepod *Parvocalanus crassirostris* was assigned as the baseline representative at TP 2 due to its lowest isotopic nitrogen value (8.4 ‰) and fed dominantly by most fish species. Values for the constants, β_0 (5.92) and β_1 (-0.27) were used based on a hierarchical meta-analysis that included 59 experimental studies (Hussey et al., 2014a).

b) *Determination of relative Contribution of primary sources using mixing model*

The relative contribution of the three primary sources, mangroves, microphytobenthos and phytoplankton, to consumers in Klang mudflats were determined using the Bayesian isotopic mixing model MixSIAR (Moore & Semmens, 2008; Stock & Semmens, 2016). No other primary sources such as seagrass and macroalgae were considered since their meadows are not known to occur in the study area (Bujang et al., 2006). Carbon and nitrogen isotopic signatures were corrected from the basal sources up to each consumer based on their respective TEF. For δ^{13}C, we used following equation adapted from Vander Zanden and Rasmussen (2001):

$$\delta^{13}\mathrm{C}_{adjbasal} = \delta^{13}\mathrm{C}_{basal} - (TP_{consumer} - 1)\,\Delta\delta^{13}\mathrm{C}$$

where $\delta^{13}C_{\mathrm{adjbasal}}$ is the adjusted δ^{13}C value of basal source, $\delta^{13}C_{\mathrm{basal}}$ is the initial basal source δ^{13}C value, TP_{consumer} is the assigned trophic position of consumers based on the scaled approach and $\Delta\delta^{13}$C is the TEF value. A $\Delta\delta^{13}$C value of 1.0 ± 0.5 ‰ was adopted from published literature (Vander Zander & Rasmussen, 2001).

Based on the meta-analysis by Hussey et al. (2014a), we assumed a narrowing discrimination of nitrogen fractionation when moving up the trophic levels instead of the conventional constant value. Here, we readjusted the basal source δ^{15}N value with respect to each consumer by using the scaled $\Delta\delta^{15}$N approach, and the equation becomes:

$$\delta^{15}\mathrm{N}_{adjbasal} = \delta^{15}\mathrm{N}_{lim} - (\delta^{15}\mathrm{N}_{lim} - \delta^{15}\mathrm{N}_{basal})e^{-k*(TP_{consumer} - TP_{base})}$$

where $\delta^{15}N_{adjbasal}$ is the adjusted basal $\delta^{15}N$ value, $\delta^{15}N_{basal}$ is the initial basal sources $\delta^{15}N$ value, and $\delta^{15}N_{lim}$ is the saturating isotope limit as TP increased, as defined in Hussey et al. (2014a). Our first attempt in the use of this equation to readjust the basal source isotope to respective consumer TP did not give satisfactory results. Specifically, the TEF values for $\delta^{15}N$ value from TP1 to TP2 were higher than expected, resulting in all $\delta^{15}N$ values of consumers not falling within the adjusted basal source triangle. Therefore, we adjusted the initial basal source $\delta^{15}N$ value stepwise; first, by using a fixed $\Delta\delta^{15}N$ value of 2.2 ± 0.3 ‰ (McCutchan et al., 2003) for herbivores/omnivores i.e. from TP1 to TP2, and then using variable $\Delta\delta^{15}N$ values for higher trophic levels to readjust the basal source value to the respective consumer. In this way, the resulting adjusted basal source triangles were able to fit in all consumer $\delta^{15}N$ values.

Following corrections of the means and standard deviations of $\delta^{13}C$ and $\delta^{15}N$ values of basal sources and consumers, the adjusted data were used as inputs into the Bayesian mixing model. The model was run for 100,000 iterations with the first 50,000 iterations discarded. Relative contribution of each basal source was reported as median with 95% credible interval. Stable isotope mixing model analysis was performed using the MixSIAR package within the R software version 3.4.0 (Stock & Semmens, 2016, R Core Team, 2017).

CHAPTER 4: RESULT AND DISCUSSION - ENVIRONMENTAL CHARACTERISTICS OF THE KLANG STRAIT MUDFLAT

4.1 Rainfall

The monthly rainfalls for the year 2010 – 2013 (four years), as recorded by the nearest meteorological station to the study area are plotted in Figure 4.1. Total rainfall ranged from 13.6 mm to 375.0 mm per month, with the highest recorded in March 2010 during the NEM while the lowest amount was recorded in July 2013 during the SWM. The mean monthly rainfall for four years was 152.9 ± 85.5 mm.

The SPI of monthly total rainfall over a 4-year timescale are presented in Figure 4.2. The average SPI was -1.85. The wettest months were observed during January, March and November during the NEM. The driest months were June and July, during the middle of SWM. Based on the SPI of four years of rainfall data, the period November to January was generally regarded as the wettest part of the year, whereas the period June - July during the SWM was the driest.

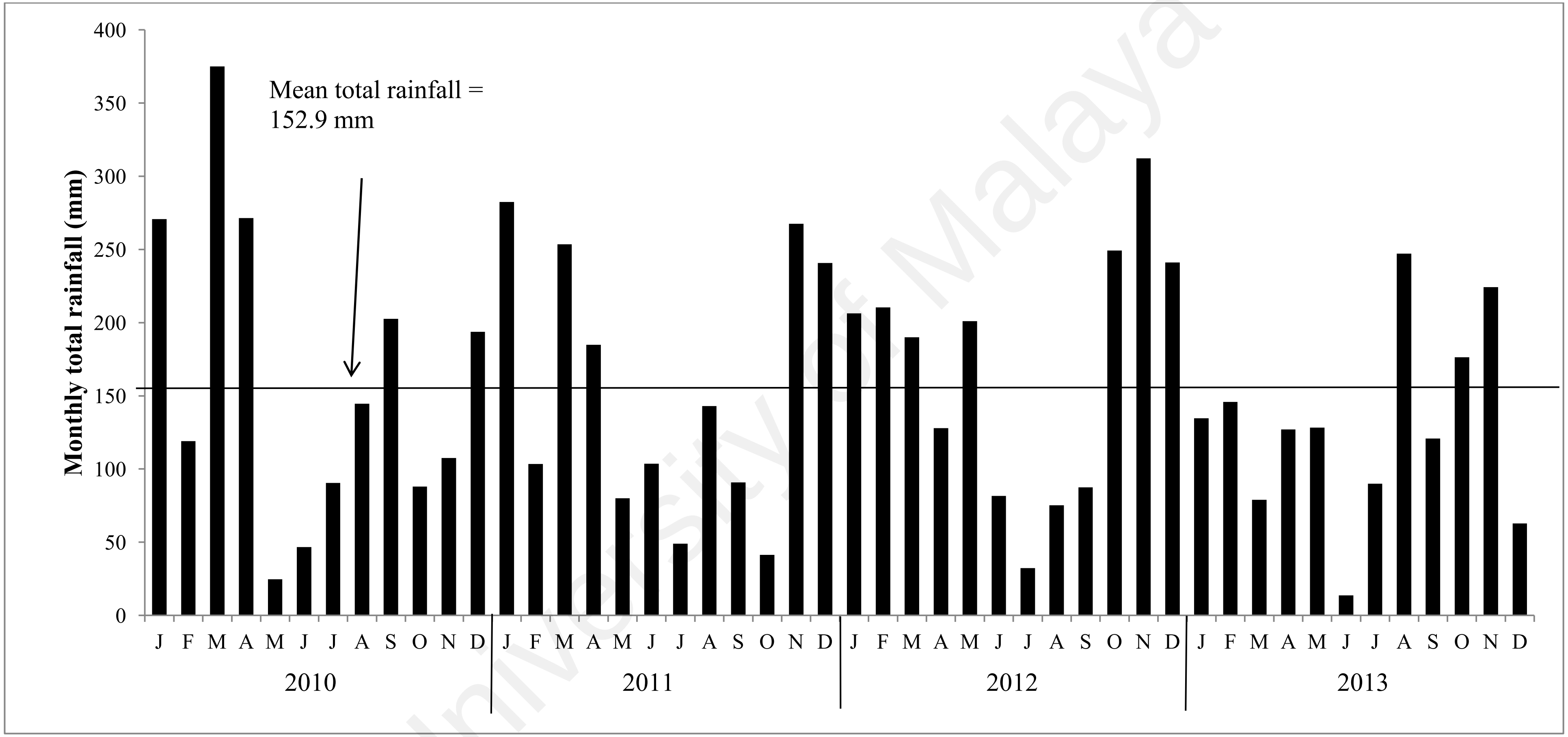

Figure 4.1 Monthly total rainfall (mm) by month for the year 2010 – 2013, recorded at the Sungai Buluh Estate rainfall station, Malaysian Meteorological Department.

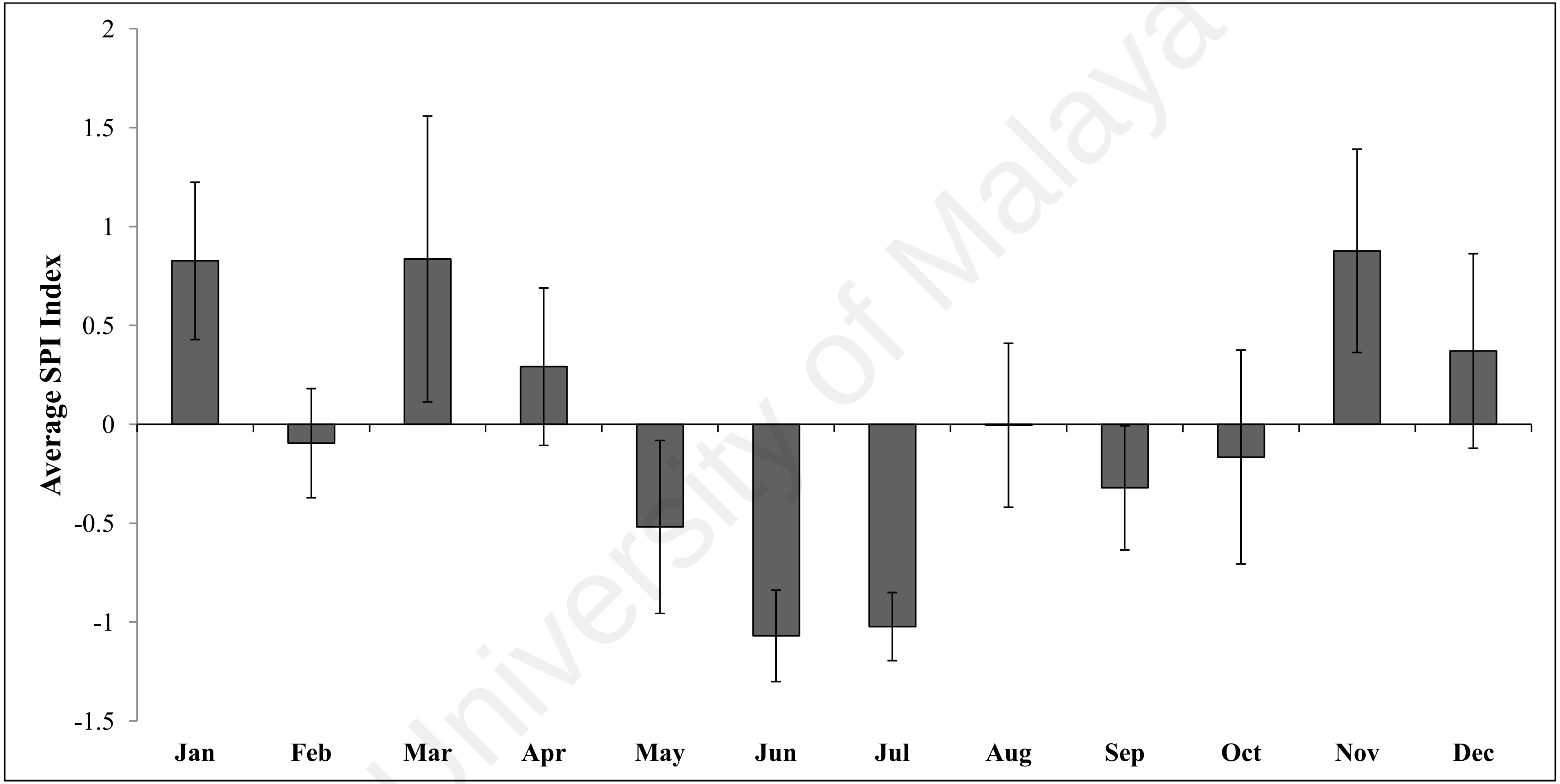

Figure 4.2 Monthly standard precipitation index (SPI) with 1 standard error (whiskers) based on deviation from the monthly rainfall data averaged across four years. SPI < 0 is regarded as dry period whereas SPI > 0 is regarded as wet period.

4.2 Water parameters

4.2.1 Site

For monthly routine sampling, recorded water temperature in BP ranged from 28.9 °C to 31.2 °C with a mean of 29.9 ± 0.6 °C (Figure 4.3). The highest temperature was recorded in April 2012 while the lowest was recorded in February 2013. In SB, water temperature ranged between 28.6 °C and 30.6 °C with mean 29.7 ± 0.5 °C. Mean water temperatures were not significantly different between sites ($p > 0.05$; $F_{1,49} = 1.3$) (Table 4.1). Mean water salinity at BP and SB were recorded at 32.2 ± 1.6 and 32.0 ± 1.3 respectively. The highest water salinity (33.8) at SB was recorded in October 2011 and lowest (26.6) in February 2013. At BP, recorded water salinity ranged between 26.0 and 33.9, with highest during November 2011 and lowest during February 2013. Water pH showed similar means of 7.8 ± 0.3 and 7.8 ± 0.4 for both BP and SB respectively, with the highest recorded at BP during April 2013 (8.6) and lowest recorded during November 2011 (7.11). At SB, pH ranged from 7.11 during December 2011 to 8.5 during March 2013. Although not significant, SB had a higher mean dissolved oxygen concentration (5.7 ± 3.7 mg/l) than BP (5.4 ± 0.9 mg/l).

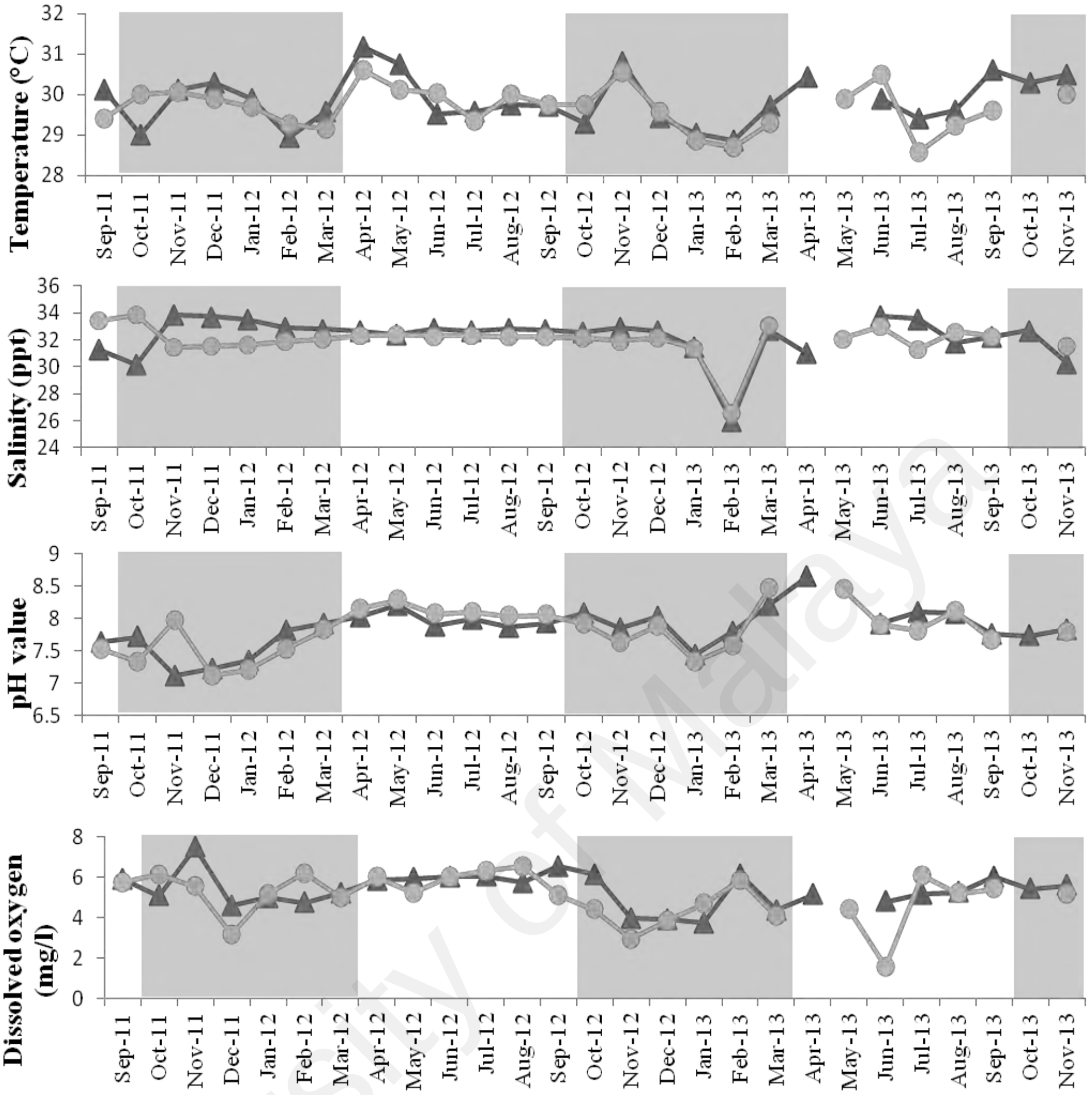

Figure 4.3 Monthly mean values of water parameters (temperature, salinity, pH value and dissolved oxygen) recorded at sampling site Bagan Pasir (dark grey, triangle) and Bagan Sungai Buloh (light grey, circle) over monthly sampling from September 2011 until November 2013. Shaded column indicates Northeast monsoon while non-shaded column indicates Southwest monsoon (standard deviation omitted for clarity).

Table 4.1 Summary results of ANOVA analysis on water temperature, salinity, pH value and dissolved oxygen concentration between factors in monthly sampling and diel sampling. Numbers in bold indicate significant difference at p < 0.05. (BP Bagan Pasir, SB Bagan Sungai Buloh, SWM southwest monsoon, NEM northeast monsoon, *n* number of samples, SD standard deviation)

Sampling		**Monthly sampling**				**Diel sampling**							
Factor		**Site**		**Season**		**Site**		**Period**		**Moon phase**		**Diel**	
Level		**BP**	**SB**	**SWM**	**NEM**	**BP**	**SB**	**Dry**	**Wet**	**Full**	**New**	**Day**	**Night**
n		26	25	24	27	16	16	16	16	16	16	16	16
Temperature (°C)	Mean	29.9	29.7	29.9	29.7	30.1	30.1	30.2	30.0	**29.8**	**30.4**	**29.8**	**30.4**
	±SD	0.6	0.5	0.6	0.6	0.8	0.8	1.0	0.6	0.7	0.8	0.9	0.6
Salinity	Mean	32.2	32.0	32.4	31.8	32.2	32.0	**32.7**	**31.5**	31.8	32.5	32.3	32.0
	±SD	1.6	1.3	0.7	1.9	1.3	1.5	1.2	1.4	1.4	1.3	1.2	1.6
pH	Mean	7.8	7.8	**8.0**	**7.7**	7.8	7.9	7.7	8.0	7.8	7.9	8.0	7.7
	±SD	0.3	0.4	0.2	0.3	0.6	0.6	0.8	0.4	0.8	0.4	0.6	0.6
Dissolved oxygen concentration (mg/l)	Mean	5.4	5.7	5.5	5.5	5.1	5.1	5.4	4.8	5.2	5.0	5.0	5.2
	±SD	0.9	1.2	1.0	1.4	0.9	1.1	1.1	0.6	0.9	1.0	0.8	1.1

For periodic-diel sampling, water temperatures recorded in both BP and SB were rather similar, ranging from 28.6 °C to 31.9 °C with a mean of 30.1 ± 0.8 °C at BP, and from 28.6 °C to 31.6 °C with a mean of 30.1 ± 0.8 °C at SB (Figure 4.4). The BP mudflat recorded a mean water salinity of 32.2 ± 1.3 whereas SB mudflat had a mean of 32.0 ± 1.5. In BP, water pH recorded a mean value of 7.8 ± 0.6 and 7.9 ± 0.6 at SB mudflat. Both BP and SB mudflats had similar mean dissolved oxygen, recorded at 5.1 ± 0.9 mg/l and 5.1 ± 1.1 mg/l, respectively. ANOVA test showed no significant differences between BP and SB for all physical parameters recorded during periodic-diel samplings.

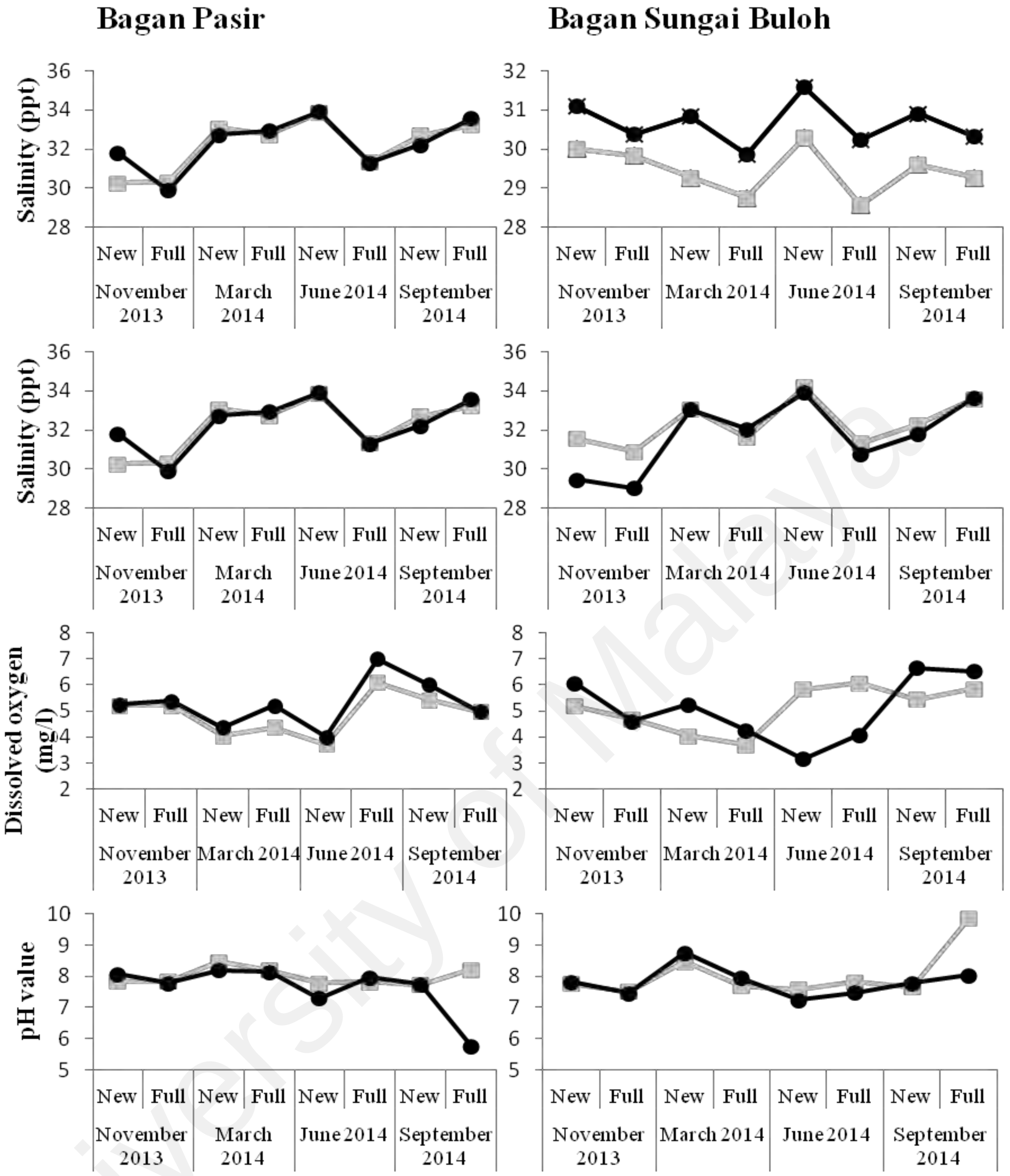

Figure 4.4 Mean values of water parameters (temperature, salinity, pH value and dissolved oxygen) recorded at sampling sites Bagan Pasir and Bagan Sungai Buloh at daytime (light grey, square) and nighttime (black, circle) during 24 hours sampling over new moon and full moon lunar phases of two wet periods (November 2013 and March 2014) and two dry periods (June and September 2014).

4.2.2 Monsoon

Recorded Water temperatures during the NEM gave a mean of 29.6 ± 0.6 °C (Table 4.1), with the highest in November 2012 at 30.8 °C and lowest in February 2013 at 28.7 °C (Figure 4.3). During the SWM, water temperature ranged from 28.6 °C (July 2013) to 31.2 °C (April 2012) with a mean of 29.9 ± 0.6 °C. Both November 2011 and February 2013 marked the highest and lowest salinities recorded in NEM respectively, with mean value at 31.8 ± 1.9. During SWM, mean water salinity was 32.4 ± 0.7. Maximum salinity was marked at 33.8 during September 2012 and a minimum at 31.1 during April 2013. Both monsoon seasons also recorded similar dissolved oxygen concentrations, which were 5.5 ± 1.0 in SWM and 5.5 ± 1.4 in NEM.

The maximum dissolved oxygen concentration was recorded at BP during November 2011 (7.5 mg/l) while the minimum was observed at SB during June 2013 (1.6 mg/l). While there were no significant differences in water temperature, salinity and dissolved oxygen between the monsoon seasons, the water during the SWM season was significantly more alkaline (pH 8.0 ± 0.2) than in the NEM season (7.7 ± 0.3) ($p < 0.05$; $F_{1,49} = 14.22$). However, no significant site x monsoon interaction effects was found for water pH. The highest water pH was recorded during April 2013 at BP (8.6).

4.2.3 Dry-wet period

In the periodic-diel sampling, water temperature in the dry period had a mean of 30.2 ± 1.0 °C while in the wet period the mean was 30.0 ± 0.6 °C (Table 4.1). ANOVA test on water temperature showed no significant difference between dry and wet period ($p > 0.05$; $F_{1,16} = 1.22$). Water salinity only showed significant differences where the wet period (31.5 ± 1.4) has significantly lower ($p < 0.05$; $F_{1,16} = 4.73$) water salinity as opposed to dry period (32.7 ± 1.5). The highest water salinity was recorded during the dry period in June 2014 (34.2) while the lowest was recorded in the wet period in November 2013 (29.0) (Figure 4.4). During the wet period, the pH value was 8.0 ± 0.4, higher than the dry period at 7.7 ± 0.8 despite being not significantly different ($p > 0.05$; $F_{1,16} = 1.41$). In terms of water dissolved oxygen concentration, the wet period (4.8

± 0.6 mg/l) had lower dissolved oxygen concentration than the dry period (5.4 ± 1.1 mg/l), although not significantly different ($p > 0.05$; $F_{1,16} = 2.19$).

4.2.4 Moonphase

Mean water temperature during the new moonphase (30.4 ± 0.8 °C) was significantly higher than full moonphase (29.8 ± 0.7 °C) ($p < 0.05$; $F_{1,16} = 10.82$; Table 4.1). Both the highest (31.9 °C) and lowest (28.6 °C) temperatures were recorded in the same month of June 2014 (Figure 4.4). The water salinity, pH and dissolved oxygen recorded during new moonphase were 32.5 ± 1.3, 7.8 ± 0.8 and of 5.0 ± 1.0 mg/l, respectively, whereas during full moonphase were 31.8 ± 1.4, 7.9 ± 0.4 and 5.2 ± 0.9 mg/l, respectively. No significant differences were observed between the two moonphases for these physical parameters.

4.2.5 Diel

In periodic-diel sampling, water temperature during daytime (29.8 ± 0.9 °C) was significantly lower than in the night time (30.4 ± 0.6 °C) ($p < 0.05$; $F_{1,16} = 10.94$; Table 4.1). The highest water temperature was recorded at 31.9 °C while the lowest at 28.6 °C (Figure 4.4). In terms of water salinity, day time and night time recorded a mean water salinity of 32.3 ± 1.2 and 32.0 ± 1.6, respectively. Although not significantly different ($p > 0.05$; $F_{1,16} = 1.79$), the pH value of water during daytime (8.0 ± 0.6) was more alkaline than during night time (7.7 ± 0.6). The water dissolved oxygen concentration during the day and night time was recorded at 5.0 ± 0.8 mg/l and 5.2 ± 1.1 mg/l, respectively. No significant differences were observed ($p > 0.05$; $F_{1,16} = 0.23$).

4.3 Sediment parameters

The organic matter content in sediment, expressed as percentage weight composition of organic matter relative to dry weight of sediment, was significantly ($p < 0.05$; $F_{1,25} = 6.93$) higher in SB (10.1 ± 0.6 %) compared to BP (7.1 ± 1.6 %) (Table 4.2). Sediment organic matter content in SB ranged from 9.0 % to 11.2 %, whereas sediment in BP had organic matter content that ranges from 5.1 % to 10.6 %.

SB recorded significantly higher ($p < 0.05$; $F_{1,70} = 3.89$) mean sediment chlorophyll *a* content at 9.9 ± 2.8 µg/g DW as opposed to BP (5.8 ± 1.8 µg/g DW). Highest and lowest sediment chlorophyll *a* content recorded at SB was 16.4 µg/g DW and 6.3 µg/g DW respectively, while in BP, chlorophyll *a* content in sediment ranged from 3.1 to 8.9 µg/g DW.

In terms of particle size, sediment in both sites consisted of five categories of sand particle (Figure 4.5) according to the Wentworth grade scale: clay (< 3.9 µm), fine silt (3.9 - < 15.6 µm), coarse silt (15.6 - < 62.0 µm), very fine sand (62.0 - < 125 µm) and fine sand (125 - < 250 µm). SB had significantly higher clay and fine silt content (clay 16.1 ± 2.0 %; fine silt 17.3 ± 2.3 %) than BP (clay 9.5 ± 2.3 %; fine silt 10.6 ± 3.1 %) ($p < 0.05$; $F_{1,76} = 1.45$; $F_{1,76} = 6.50$, respectively). On the other hand, BP had significantly higher mean percentage of coarse silt (58.4 ± 8.0 %) than SB (46.0 ± 4.2 %) ($p < 0.05$; $F_{1,76} = 3.43$). Both very fine sand and fine sand category were not significantly different between both sites ($p > 0.05$), where BP had 17.6 ± 9.7 % of very fine sand and 3.9 ± 3.2 % of fine sand, whereas SB had a mean of 17.4 ± 3.4 % of very fine sand and 3.3 ± 2.5 % of fine sand.

Table 4.2 Summary results of ANOVA test, sample size, mean and standard deviation (SD) of sediment organic matter content and sediment chlorophyll content at Bagan Pasir (BP) and Bagan Sungai Buloh (SB).

	Sample size *(n)*	**BP (mean ± SD)**	**Sample size *(n)***	**SB (mean ± SD)**	**p-value**
Sediment organic matter (%)	12	7.08 ± 1.61	15	10.13 ± 0.61	$p < 0.05$
Sediment Chlorophyll-*a* (µg/gDW)	18	5.77 ± 1.76	25	9.94 ± 2.79	$p < 0.05$

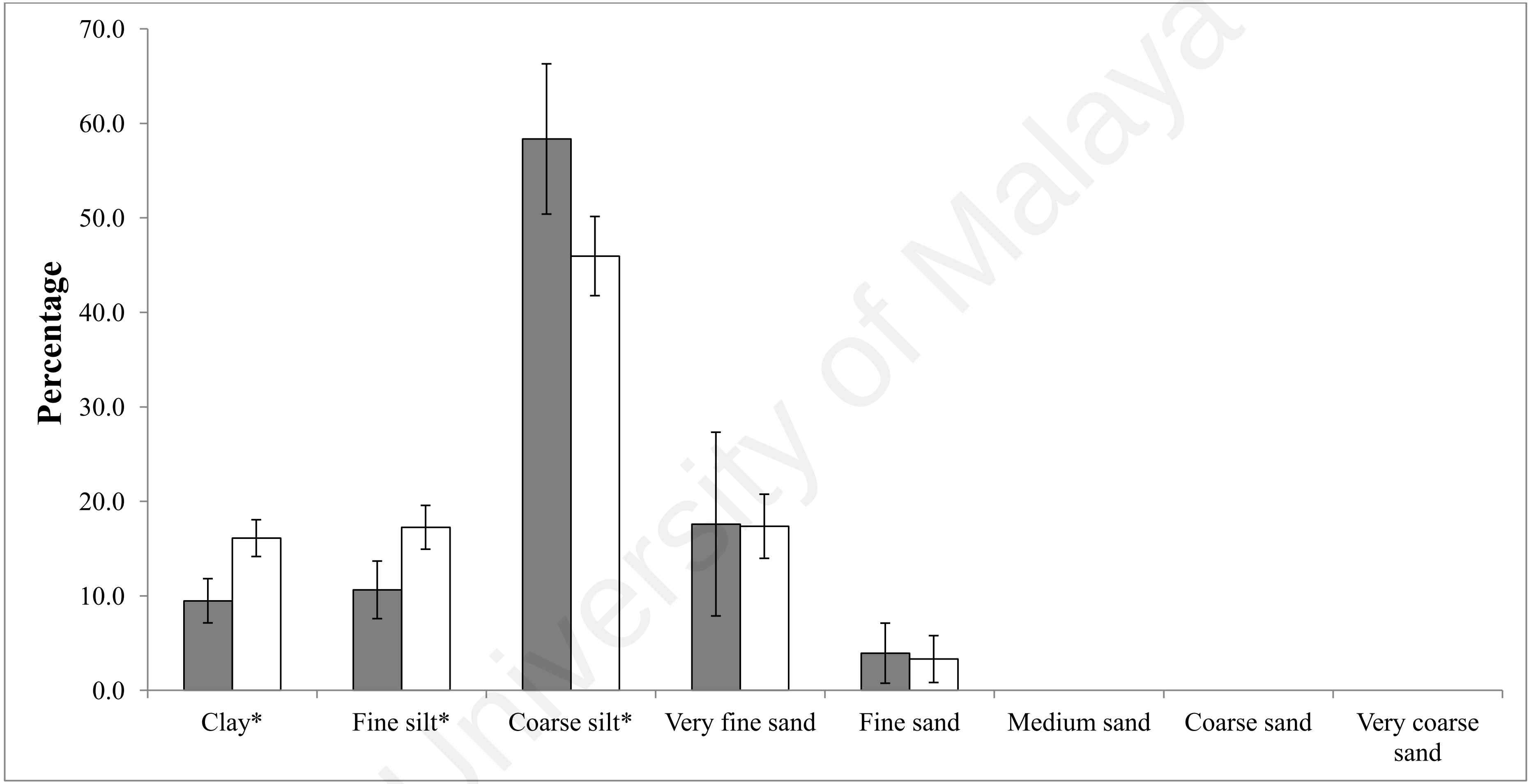

Figure 4.5 Mean compositions of sediment particle size based on Wentworth grade scale (Table 2.1) at Bagan Pasir (dark column) and Bagan Sungai Buloh (light column), with standard deviation as error bar. _*‘ notation on each category indicates significant difference between sites.

4.4 Discussion

In this study, the water parameters of Klang Strait mudflat in the overall are rather similar to the previously reported results on Klang Strait. Water salinity and temperature in the Klang Strait mudflat in the overall do not appear to fluctuate widely over time (month), ranging between 26 and 34, and between 29 and 32 °C. Chong (1993) and Zgozi (2000) also found that both water salinity and temperature in Klang Strait had little differences (6) between months, with monthly mean salinities that varied between 27.5 to 33.3 while mean temperature ranged between 29 and 31 °C.

Compared to the true estuarine environment of the Selangor River that drains into Klang Strait, the vertical salinity fluctuation at mid-estuary varied by at least 15 (Nelson, 2012). In this study, vertical measurements of water parameters on the mudflat were not made because of the shallow water. However, Chong (1993) who made vertical salinity measurements described the water in Klang Strait as vertically well-mixed and not stratified. Apparently, the dilution of the upper surface water, i.e. within the upper 6-8 m, but was very small (up to 2 only), and this diluted but unstable layer extended up to several kilometres offshore. The farshore (15 km) waters however had very slightly higher salinity (1.6 change per 10 km) than near shore. The Klang Strait, an extension of the Malacca Strait, is thus considered a mild, well-mixed estuary. This is despite the strait receiving an estimated total montly discharge of 120 cumec from the three main rivers of Langat (39 cumec), Klang (27 cumec) and Selangor (54 cumec) (Chong et al., 2005). However, observations made by Ibrahim (1988) based on salinity, and Bird et al. (2000) based on sediment plumes suggest that most of the freshwater (and sediment) discharged by the Klang and Langat exit, via the southern approach of Klang Strait, into the Malacca Straits. Hence, more than half of the total freshwater inflow into the main Klang Strait comes from the Selangor, and to some extent, the

Tengi (21 cumec) which discharges into its northern approach. This volume of riverine discharge is thus expected to be substantially diluted by the higher salinity water of the Malacca Strait due to the strong tidal and wave effects.

Changes in water temperature and pH can be drastic as a result of anthropogenic activities such as the thermal discharge from power plants that receive seawater to cool down its superheated power turbines (Poornima et al., 2005; Ferry-Graham et al., 2008; Coulter et al., 2014). Chew et al. (2015) conducted a comparative study of the impact of Kapar power station (see Fig 2.1) on the zooplankton community in Klang Strait before and after three decades of operation of the power plant. They found post-impact of the surrounding surface seawater temperature that were raised by 0.58 °C (from 29.34 ± 1.09 °C to 29.92 ± 0.66 °C) while the water pH dropped by 0.32 (from 8.06 ± 0.01 to 7.74 ± 0.05). Concomitantly, the copepod community has shifted to an abundance of more small-bodied copepod species. Compared to the current study at both BP and SB mudflat, water temperature was similar to Chew et al. (2015)'s recent measurements at 31.2 ± 0.5 °C, but our water pH at SB (7.8 ± 0.4) was slightly more alkaline.

The hydrodynamic conditions and bathymetry that promote water mixing in Klang Strait is also reflected by the rather stable measurements of the dissolved oxygen and water pH, which averaged at 5.2 ± 1.0 mg/l and 7.8 ± 0.3, respectively. These results in Klang Strait mudflat match the results of Chong et al. (2005) who reported strait-wide mean dissolved oxygen of 5.4 ± 0.9 mg/l and mean pH of 8.1 ± 0.2, and of Zgozi (2000) who however recorded mean dissolved oxygen of 5.8 ± 0.6 mg/l but a more alkaline pH value of 8.3 ± 0.1. In this study, water pH was more acidic during the NEM likely due to the greater influence of terrestrial riverine input. Fluvial discharge of suspended sediments that feed the coastal mudflat also comes mainly from the Selangor and Tengi rivers that amount to 0.5 million tonnes per year and 0.05 million tonnes per year, respectively (Chong et al., 2005). The high amount of suspended sediment in the water column accounts for the high turbidity in Klang Strait waters which varied between 11 - 80 NTU for monthly values (Zgozi, 2000).

Bottom sediment characteristics at both BP and SB mudflats differed significantly; the BP mudflat contained relatively higher percentage of larger soil particles (more silt and sand) than SB mudflat (Figure 4.5). The finer sediments at SB mudflat had higher percentage of organic particles and chlorophyll *a* content than at BP. Similar observation were also made by Zgozi (2000) and Chong et al. (2005), where the northern side of Kuala Selangor River featured higher percentage of fine sand and very fine sand whereas the southern side have higher clay and silt percentage. Despite the mudflat‘s homogenous appearance, Eeo (2018) reported sediment variability along the southern Klang mudflat (Jeram) due to wave and tidal effects as modulated by the prevailing climatic (wind) condition. During the SWM season, the wave effect appears weak due to the southeasterly winds blow mainly from land to sea (see Figure 2.2) resulting stronger erosive power of flood stream on the mudflat at Jeram. The prevailing northwesterly wind during the NEM season however has a large wind fetch thus forming larger waves that converge on the Selangor shore (Fitri et al., 2015) and transport fine sediment along the shore.

Fine-grained sediments generally correlate with higher organic content as compared to coarse sediment (Köster & Meyer-Reil, 2001), potentially providing ample food resources to the benthic organisms. Our results on sediment analysis supported this statement; the finer sediments at SB mudflat had higher percentage of organic particles and chlorophyll *a* content than in BP mudflat. At SB, Teoh et al. (2016) found that chlorophyll *a* concentration increased substantially from the north to south which was attributed to the high discharge of nutrients from Buloh River. Moreover, the chlorophyll *a* concentration in both water column and surface sediment were found to be correlated, suggesting tidally-induced exchange of microalgal cells across the sediment–water interface (Teoh et al., 2016). The shallow water and strong vertical mixing also contributed to the high water turbidity.

As a conclusion, Klang Strait mudflat exhibited distinct dry and wet period as shown by rainfall data. Despite the apparent dry and wet period, the overall water parameters (salinity, temperature, dissolved oxygen concentration and pH) in Klang Strait mudflat were rather stable and relatively marine, both spatially and temporally. Water parameters were generally homogenous between full and new moon phase and between day and night time. On the other hand, southern part of the Selangor River (SB) mudflat had finer sediment particles and higher organic matter and chlorophyll *a* content than the northern (BP), alluded by higher riverine discharge and existing shoreline processes due to the vertical mixing by tide and wave effects of monsoonal seasons.

CHAPTER 5: RESULTS AND DISCUSSION - FISH COMMUNITY OF KLANG STRAIT MUDFLAT

5.1 Mudflat fish community structure

5.1.1 Species composition

A total number of 26,252 fish were sampled in the mudflat during the study period from September 2011 to November 2014 comprising 120 species belonging to 46 families. The family Sciaenidae was the most speciose family (13 species), followed by Ariidae (11 species) and Carangidae (10 species) (Table 5.1). Monthly day-time sampling in the intertidal mudflat area using the enclosure trap recorded a total of 104 species of fish (18,553 individuals) while during periodic diel (November 2013, March, June and September 2014) sampling yielded 100 species of fish (7,699 individuals). Both sampling regimes yielded 85 common species of fish. However, 16 species of fish that were sampled during the periodic diel sampling were not recorded in the monthly day sampling (Table 5.1). On the other hand, 19 species sampled in the monthly day sampling were not sampled during the periodic diel sampling. Three fish species (*Cynoglossus arel, Ilisha macrogaster* and *Trachinothus blochii*) were found explicitly during the night time of periodic diel sampling, while five species species (*Carangoides malabaricus Gerres erythrourus, Paramugil parmatus, Leptomelanosoma indicum* and *Siganus vermiculatus*) captured in the monthly day sampling were absent in the periodic diel sampling.

Table 5.1 Checklist of fish species (with their respective local name and code used throughout the thesis) collected in Klang mudflat and adjacent subtidal area during monthly and periodic diel samplings.

Family	Species	Code	Local name	Monthly sampling (day)	Periodic diel sampling		Subtidal area (day)
					Day	Night	
Ambassidae	*Ambassis gymnocephalus*	Agym	Bald glassy	X	X	X	X
Ariidae	*Arius arius*	Ariu	Threadfin sea catfish	X	X	X	
	Arius maculatus	Amac	Spotted catfish	X	X	X	X
	Arius microcephalus	Amic	Squirrelheaded catfish	X			
	Arius oetik	Aoet	Lowly catfish	X	X	X	
	Arius venosus	Aveno	Veined catfish	X	X	X	X
	Cryptarius truncatus	Ctrun	Spoonsnouted catfish	X	X	X	X
	Hexanematichthys sagor	Hsag	Sagor catfish	X	X	X	X
	Nemapteryx caelata	Ncae	Engraved catfish	X	X	X	X
	Nemapteryx nenga	Nnen	Kata		X	X	
	Osteogeneiosus militaris	Omil	Soldier catfish	X	X		X
	Plicofollis argyropleuron	Pagy	Longsnouted catfish	X	X	X	X
Batrachoididae	*Allenbatrachus grunniens*	Agru	Grunting toadfish	X			X
Belonidae	*Strongylura strongylura*	Sstr	Spottail needlefish	X	X	X	X
	Tylosurus crocodilus	Tcroc	Hound needlefish	X	X		X
Carangidae	*Alectis indica*	Aind	Indian threadfish				X
	Alepes djedaba	Adje	Shrimp scad				X
	Atropus atropos	Aatr	Cleftbelly trevally				X
	Carangoides malabaricus	Cmal	Malabar trevally	X		X	X
	Megalaspis cordyla	Mcord	Torpedo scad				X
	Parastromateus niger	Pnig	Black pomfret				X
	Scomberoides commersonnianus	Scom	Talang queenfish	X	X	X	X
	Scomberoides tala	Stal	Barred queenfish		X		X
	Scomberoides tol	Stol	Needlescaled queenfish	X	X		X
	Trachinothus blochii	Tblo	Snubnose pompano			X	
Chirocentridae	*Chirocentrus dorab*	Cdora	Dorab wolf-herring				X
	Chirocentrus nudus	Cnudu	Whitefin wolf-herring	X			X
Cichlidae	*Oreochromis mossambicus*	Omos	Mozambique tilapia	X	X	X	

Table 5.1, continued

Clupeidae	*Anodontostoma chacunda*	Acha	Chacunda gizzard shad	X	X	X	X
	Escualosa thoracata	Ethr	White sardine	X	X	X	X
	Hilsa kelee	Hkel	Kelee shad	X			X
	Opisthopterus tardoore	Otar	Tardoore	X	X	X	X
Cynoglossidae	*Cynoglossus arel*	Carel	Largescale tonguesole			X	
	Cynoglossus bilineatus	Cbil	Fourlined tonguesole	X	X	X	X
	Cynoglossus cynoglossus	Ccyn	Bengal tonguesole	X	X	X	X
	Cynoglossus lingua	Clin	Long tonguesole	X	X	X	X
	Cynoglossus puncticeps	Cpun	Speckled tonguesole	X	X	X	
Dasyatidae	*Brevitrygon walga*	Bwal	Scaly whipray	X	X	X	
	Dasyatis bennetti	Dben	Bennett's stingray	X	X	X	
	Dasyatis zugei	Dzug	Pale-edged stingray	X	X	X	X
	Himantura pastinacoides	Hpas	Round whipray	X			
	Himantura uarnak	Huar	Honeycomb stingray	X			X
	Neotrygon kuhlii	Nkuh	Blue-spotted stingray	X			
	Taeniura lymma	Tlym	Ribbontail stingray		X		
Drepaneidae	*Drepane longimana*	Dlong	Concertina fish	X	X	X	
	Drepane punctata	Dpun	Spotted sicklefish	X	X	X	X
Eleotridae	*Butis koilomatodon*	Bkoi	Mud sleeper	X			
Elopidae	*Elops machnata*	Emach	Tenpounder				X
Engraulidae	*Coilia dussumieri*	Cdus	Goldspotted grenadier anchovy	X	X	X	X
	Setipinna taty	Stat	Scaly hairfin anchovy	X	X	X	X
	Stolephorus baganensis	Sbag	Bagan anchovy	X	X	X	X
	Stolephorus tri	Stri	Spined anchovy	X	X		X
	Thryssa hamiltonii	Tham	Hamilton's anchovy	X	X	X	X
	Thryssa kammalensis	Tkam	Kammal anchovy	X	X	X	X
	Thryssa mystax	Tmys	Moustached thryssa	X	X	X	
Ephippidae	*Ephippus orbis*	Eorb	Orbfish				X
	Platax teira	Ptie	Longfin batfish	X	X		
Gerreidae	*Gerres erythrourus*	Gery	Deep-bodied mojarra	X		X	X
	Gerres filamentosus	Gfila	Whipfin silver-biddy				X
Gobiidae	*Boleophthalmus boddarti*	Bbod	Boddart's goggle-eyed goby	X			
	Odontamblyopus rubicundus	Odrub	Eel goby	X			

Table 5.1, continued

	Oxuderces dentatus	Oden	Crocodile-face goby		X	X	
	Taenioides nigrimarginatus	Tnig	Blackfin eel goby	X	X	X	
	Trypauchen vagina	Tvag	Burrowing goby	X	X		
Haemulidae	*Plectorhinchus gibbosus*	Pgib	Harry hotlips		X		
	Pomadasys kaakan	Pkaa	Javelin grunter	X	X	X	X
	Pomadasys maculatus	Pmac	Saddle grunt		X		
Hemiramphidae	*Hemiramphus far*	Hfar	Black-barred halfbeak	X	X	X	X
Hemiscylliidae	*Chiloscyllium hasselti*	Chas	Indonesia bambooshark		X	X	
	Chiloscyllium indicum	Cind	Slender bambooshark	X			
	Chiloscyllium plagiosum	Cpla	Whitespotted bambooshark	X			
Kurtidae	*Kurtus indicus*	Kind	Indian hump head	X	X	X	X
Latidae	*Lates calcarifer*	Lcal	Barramundi	X			X
Leiognathidae	*Leiognathus brevirostris*	Lbre	Shortnose ponyfish	X	X	X	X
	Secutor insidiator	Sins	Pugnose ponyfish	X	X	X	X
	Secutor ruconius	Sruc	Deep pugnose ponyfish	X			X
Lobotidae	*Lobotes surinamensis*	Lsuri	Tripletail	X	X	X	X
Mugilidae	*Ellochelon vaigiensis*	Evaig	Squaretail mullet	X	X	X	X
	Paramugil parmatus	Ppar	Broad-mouthed mullet	X		X	X
	Planiliza melinopterus	Pmel	Otomebora mullet	X	X	X	X
	Planiliza subviridis	Psub	Greenback mullet	X	X	X	X
Mullidae	*Upeneus sulphureus*	Usulp	Sulphur goatfish	X	X	X	X
Muraenesocidae	*Congresox talabonoides*	Ctala	Indian pike conger		X	X	X
Platycephalidae	*Platycephalus indicus*	Pind	Bartail flathead	X	X		X
Plotosidae	*Plotosus canius*	Pcan	Gray eel-catfish	X	X	X	
	Plotosus lineatus	Plin	Striped eel-catfish		X		
Polynemidae	*Eleutheronema tetradactylum*	Etet	Fourfinger threadfin	X	X	X	X
	Leptomelanosoma indicum	Lind	Indian threadfin	X		X	X
	Polydactylus sextarius	Psex	Blackspot threadfin		X		
	Polynemus paradiseus	Ppara	Paradise threadfin		X	X	
Pristigasteridae	*Ilisha elongata*	Ielo	Elongate ilisha	X	X	X	X
	Ilisha macrogaster	Imac	Kalimantan ilisha			X	
	Ilisha melastoma	Imel	Indian ilisha	X	X	X	X
Scatophagidae	*Scatophagus argus*	Sarg	Spotted scat	X	X	X	X

Table 5.1, continued

Sciaenidae	*Aspericorvina jubata*	Ajub	Prickly croaker	X	X	X	X
	Dendrophysa russelii	Druss	Goatee croaker	X	X	X	X
	Johnius belangerii	Jbela	Belanger's croaker	X	X	X	X
	Johnius borneensis	Jborn	Sharpnose hammer croaker	X	X	X	X
	Johnius carouna	Jcaro	Caroun croaker	X	X	X	X
	Johnius carutta	Jcaru	Karut croaker	X			X
	Johnius trachycephalus	Jtrac	Leaftail croaker		X	X	
	Johnius weberi	Jwebe	Weber's croaker				X
	Nibea soldado	Nsal	Soldier croaker	X	X	X	X
	Otolithes ruber	Orub	Tigertooth croaker	X	X	X	X
	Otolithoides biauritus	Obir	Bronze croaker	X	X	X	X
	Panna microdon	Pmic	Panna croaker	X	X	X	X
	Pennahia anea	Pane	Donkey croaker	X	X	X	X
	Protonibea diacanthus	Pdia	Blackspotted croaker	X			
Scombridae	*Rastrelliger brachysoma*	Rbra	Short mackerel	X			X
	Scomberomorus commerson	Scomm	Narrow-barred Spanish mackerel	X			
	Scomberomorus guttatus	Sgut	Indo-Pacific king mackerel				X
Serranidae	*Epinephelus sp.*	Epi sp.	Grouper	X	X		
Siganidae	*Siganus canaliculatus*	Scana	White-spotted spinefoot	X	X		
	Siganus vermiculatus	Sverm	Vermiculated spinefoot	X		X	
Sillaginidae	*Sillago sihama*	Ssih	Silver sillago	X	X	X	X
Soleidae	*Synaptura commersonnii*	Sycom	Commerson's sole	X	X	X	X
Sphyraenidae	*Sphyraena putnamae*	Sput	Sawtooth barracuda	X			
Stromateidae	*Pampus argenteus*	Parg	Silver pomfret	X	X	X	X
	Pampus chinensis	Pchi	Chinese silver pomfret	X	X	X	X
Syngnathidae	*Doryichthys boaja*	Dboa	Long-snouted pipefish	X			
Synodontidae	*Harpadon nehereus*	Hneh	Bombay duck	X	X	X	
Terapontidae	*Terapon jarbua*	Tjar	Jarbua terapon	X	X	X	
	Terapon theraps	Tthe	Largescaled terapon	X	X	X	X
Tetraodontidae	*Dichotomyctere fluviatilis*	Dflu	Green puffer	X	X	X	X
	Lagocephalus lunaris	Lluna	Lunartail puffer	X	X		X
	Takifugu oblongus	Tobl	Lattice blaasop	X	X	X	X
Toxotidae	*Toxotes jaculatrix*	Tjac	Banded archerfish		X	X	

Table 5.1, continued

	Toxotes microlepis	Tmic	Smallscale archerfish	X	X	X	
Triacanthidae	*Triacanthus nieuhofii*	Tnei	Silver tripodfish	X	X		X
Trichiuridae	*Lepturacanthus savala*	Lsava	Savalai hairtail	X	X	X	X
	Trichiurus lepturus	Tlep	Largehead hairtail	X	X	X	X
Total number of species				104	92	83	87
					100		

5.1.2 Univariate species diversity comparison

a) *Monthly day-time catches in mudflat*

A total number of 92 and 84 fish species were recorded in the SB and BP mudflat, respectively (Table 5.2). The calculated Margalef‘s species richness index in SB (D = 4.2 ± 1.1) was significantly higher than in BP (D = 2.9 ± 0.7) ($p < 0.05$; $F_{1,49} = 2.48$),. Shannon-Wiener‘s diversity index in SB (H‘ = 2.2 ± 0.3) was also significantly higher than in BP (H‘ = 1.8 ± 0.5) ($p < 0.05$; $F_{1,49} = 1.96$). However, Pielou‘s evenness for both sites (BP, J‘ = 0.57 ± 0.16; SB, J‘ = 0.64 ± 0.07) showed no significant differences ($p > 0.05$; $F_{1,49} = 4.58$). For the monsoon season, no significant difference was observed between SWM and NEM ($p > 0.05$) for all diversity indices at both sites (Table 5.2).

Table 5.2 Means (± SD) of various diversity indices of fish community of Klang mudflat, tested between sites (BP vs. SB) and between monsoon seasons (SWM vs. NEM) using ANOVA. Numerals in bold indicate significant difference at $p < 0.05$. n = number of monthly samples collected by enclosure trap. BP = Bagan Pasir; SB = Bagan Sungai Buloh. n = number of samples.

Tested Index/parameter		**Intertidal mudflat**			
		Site		**Monsoon**	
Levels		**BP**	**SB**	**SWM**	**NEM**
Sample size, n		26	25	24	27
Number of species, s		84	92	86	94
Margalef‘s index, D	Mean	**2.93**	**4.16**	3.51	3.55
	± SD	0.73	1.14	1.32	0.95
Shannon-Wiener diversity index, H'	Mean	**1.8**	**2.2**	1.98	2.01
	± SD	0.48	0.34	0.45	0.48
Pielou‘s evenness, J'	Mean	0.57	0.64	0.62	0.59
	± SD	0.16	0.07	0.13	0.13

b) *Periodic diel catches in mudflat*

A total of 82 and 89 species of fish were found in the SB and BP mudflat, respectively (Table 5.3). Dry period recorded a total of 85 species of fish whereas wet period recorded a total of 87 species. A total number of 85 and 89 species of fish recorded during the full moon phase and new moon phase, respectively. In daytime, 93 species of fish were found while night time recorded 83 species of fish. In term of Margalef‘s species richness between sites, SB (D = 4.9 ± 1.1) showed significantly higher species richness than BP (D = 3.3 ± 0.9) ($p < 0.05$; $F_{1,30} = 1.53$). Although not significantly different ($p > 0.05$), the wet period (D = 4.2 ± 1.1) recorded higher Margalef‘s species richness than dry period (4.0 ± 1.4). Both factors, moon light and diel, also had no significant effects on Margalef‘s species richness ($p > 0.05$); D was recorded at 4.0 ± 1.4 during the full moon phase, 4.2 ± 1.2 during the new moon phase, 4.2 ± 1.2 during day time and 4.0 ± 1.4 during night time. As for Shannon-Wiener diversity index, BP and SB mudflat recorded a mean H‘ value of 2.1 ± 0.5 and 2.3 ± 0.4 respectively. Dry period recorded a mean H‘ value of 2.2 ± 0.5 whereas H‘ in the wet period was 2.3 ± 0.4. New moon phase had H‘ index of 2.3 ± 0.4 whereas in full moon phase H‘ was 2.2 ± 0.5. The day time H‘ index was 2.3 ± 0.4 while the night time H‘ index was 2.2 ± 0.5. There were no significant differences in the diversity indices (D, H‘) between the tested levels for the factor period (dry, wet), moon light (full moon, new moon) and diel (day, night) ($p > 0.05$). In terms of Pielou‘s evenness, no significant differences were observed as well between the tested levels of the factor site (BP = 0.6 ± 0.1, SB = 0.7 ± 0.1), period (dry = 0.6 ± 0.1, wet = 0.7 ± 0.1), moon light (full moon = 0.6 ± 0.1, new moon = 0.7 ± 0.1) and diel (day = 0.7 ± 0.1, night = 0.6 ± 0.1) ($p > 0.05$).

Table 5.3 Means (± SD) of various diversity indices of fish community of Klang mudflat, tested between sites (BP vs. SB), periods (dry vs. wet), between moon lights (full moon vs. new moon) and between diels (day vs. night) using ANOVA. Numeral in bold indicate significant difference at $p < 0.05$. BP = Bagan Pasir; SB = Bagan Sungai Buloh. n = number of samples.

Factors		**Site**		**Period**		**Moon light**		**Diel**	
Levels		**BP**	**SB**	**Dry**	**Wet**	**Full**	**New**	**Day**	**Night**
Sample size, n		16	16	16	16	16	16	16	16
Number of species, s		82	89	85	87	85	89	93	83
Margalef‘s index, D	Mean	**3.32**	**4.86**	3.99	4.18	4.01	4.17	4.23	3.95
	±SD	0.92	1.14	1.44	1.13	1.38	1.22	1.19	1.39
Shannon-Wiener diversity index, H'	Mean	2.11	2.30	2.17	2.25	2.16	2.25	2.26	2.16
	±SD	0.47	0.41	0.51	0.38	0.49	0.41	0.35	0.53
Pielou‘s evenness, J'	Mean	0.64	0.66	0.64	0.66	0.64	0.66	0.65	0.64
	±SD	0.12	0.11	0.13	0.09	0.13	0.09	0.08	0.14

5.1.3 Fish Community structure: spatial and temporal variability

a) *Monthly day sampling*

The multivariate analysis of variance (PERMANOVA) showed that fish composition in the intertidal area differed significantly between sites (BP and SB) and monsoon periods (NEM and SWM) ($p < 0.05$) (Table 5.4). Marginally significant interaction appeared between the factors ($p = 0.045$). Subsequent pair-wise analysis indicated significant difference between BP and SB within each monsoonal season; both monsoons significantly differed only at SB but not BP. The PERMDISP routine showed homogeneous dispersion for both factors of sites ($F_{2,49} = 0.059$, $p = 0.059$) and monsoon seasons ($F_{2,49} = 0.286$, $p = 0.632$), indicating significant differences in fish community are not due to variation in dispersion.

Table 5.4 PERMANOVA results comparing the composition of fish community structure among and across site (BP and SB) and monsoon season (NEM and SWM) in Klang mudflat. Significant differences in bold.

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms.
Site	1	10635	10635	7.4722	**0.0002**	4978
Monsoon	1	4158.3	4158.3	2.9216	**0.0020**	4977
SitexMonsoon	1	2608.3	2608.3	1.8326	**0.0454**	4975
Residual	47	66896	1423.3			
Total	50	84400				

The non-metric multidimensional scaling (MDS) ordination showed a rather clear distinction between BP (square) on the left and SB (circle) on the right, as opposed to the monsoon season (filled and empty symbol) (Figure 5.1). The ordination plot however had a high stress value of 0.22, which could be due to the significant interaction effect between site and monsoon season. The fish species Kammal anchovy *Thryssa kammalensis* and spoonsnouted catfish *Cryptarius truncatus* appeared to be associated with BP, whereas the Bartail flathead *Platycephalus indicus,* Chacunda gizzard shad *Anodonstoma chacunda,* tigertooth croaker *Otolithes ruber* and Chinese pomfret *Pampus chinensis* were highly associated to SB. The Bengal croaker *Johnius bornensis* and scaly whipray *Brevitrygon walga* were positively correlated to NEM, contrary to the Bengal tonguesole *Cynoglossus cynoglossus* and veined catfish *Arius venosus* which were more correlated with SWM.

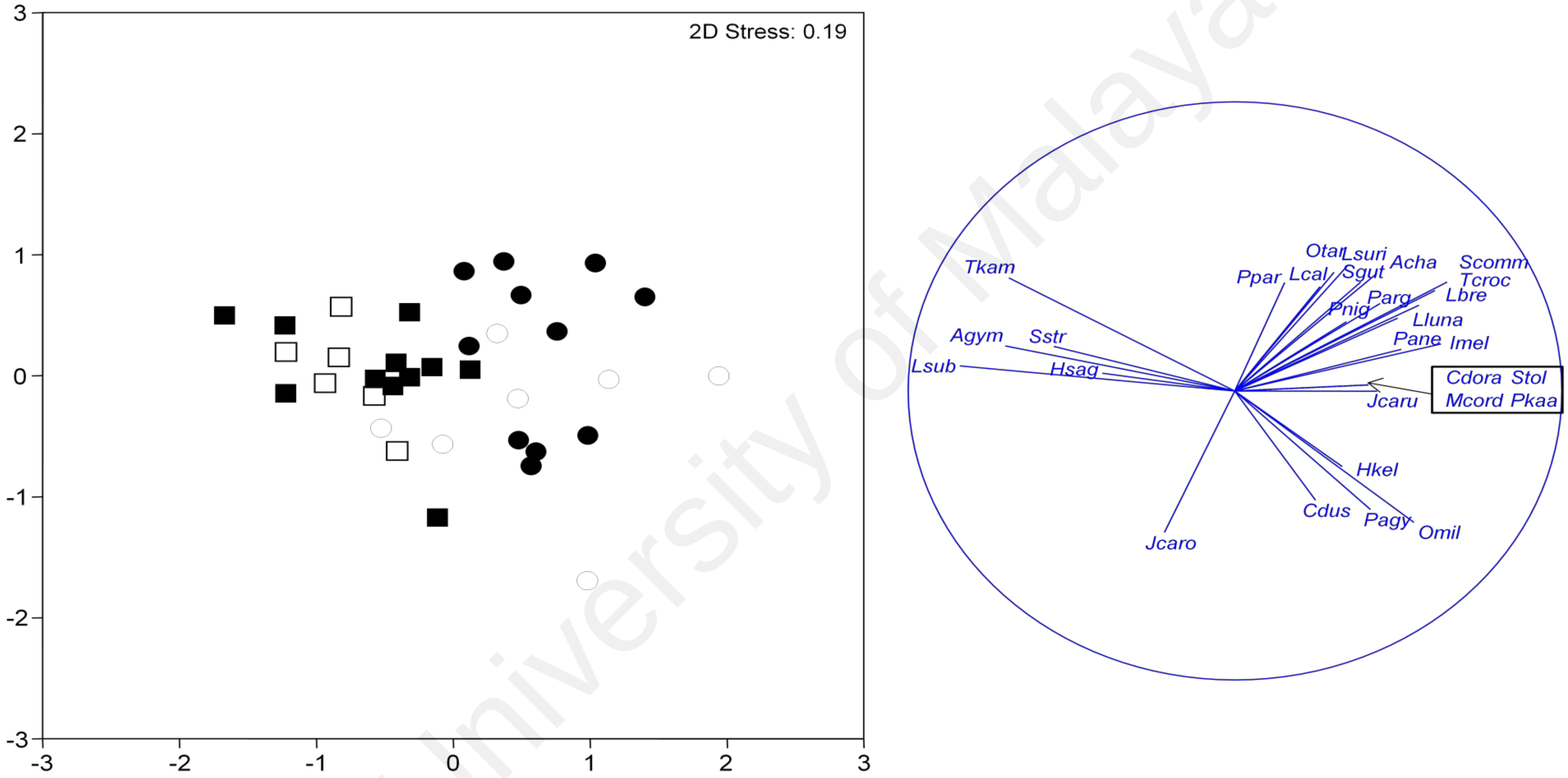

Figure 5.1 Non-metric multidimensional scaling (nMDS) ordination plot based on intertidal mudflat fish abundance, comparing the fish assemblage of Bagan Pasir (square), Bagan Sungai Buloh (circle), northeast monsoon (filled symbol) and southwest monsoon (empty symbol). Line vectors indicating fish species corresponded with strength and direction of Pearson correlation (> 0.40) to the ordination.

The similarity percentage analysis (SIMPER) revealed that average dissimilarities between BP and SB and between NEM and SWM were 59.89 % and 55.13 %, respectively. The dissimilarity between sites was mainly contributed by Kammal anchovy, Caroun croaker, Sagor catfish (*Hexanematichthys sagor*) and scaly hairfin anchovy (Table 5.5). The engraulid *T. kammalensis* showed higher relative abundance in BP whereas the others were found more in SB. The main contributors in the separation between NEM and SWM were *J. carouna, T. kammalensis, H. sagor* and *O. ruber*. Both *J. carouna* and *T. kammalensis* had rather similar relative abundance in both monsoons; *H. sagor* was found more in NEM whereas *O. ruber* had higher relative abundance in SWM.

Table 5.5 Summary results of SIMPER analysis showing the fish species fulfilled the criteria of dissimilarity/standard deviation (SD) > 1.0 and percentage contribution to dissimilarity > 3.0 % as important contributors to the dissimilarity between the factor sites (BP = Bagan Pasir; SB = Bagan Sungai Buloh) and monsoons (NEM = Northeast monsoon; SWM = Southwest monsoon) in the Klang mudflat. The relative abundance of each species is expressed as the percentage of total fish abundance for each factor.

Species	**Relative abundance (%)**		**Dissimilarity/ SD**	**Contribution to dissimilarity (%)**
Average dissimilarity = 59.89 %	**BP**	**SB**		
Thryssa kammalensis	30.49	7.49	1.66	7.70
Johnius carouna	20.22	21.94	1.32	6.84
Hexanematichthys sagor	2.26	12.95	1.27	5.61
Setipinna taty	0.43	4.22	1.05	3.12
Average dissimilarity = 55.13 %	**NEM**	**SWM**		
Johnius carouna	22.04	20.19	1.38	7.68
Thryssa kammalensis	19.16	19.26	1.16	6.02
Hexanematichthys sagor	8.1	6.97	1.24	3.96
Otolithes ruber	1.57	4.51	1.12	3.07

b) *Periodic diel sampling*

The fish composition examined according to four influencing factors differed significantly between their levels, i.e. for site (BP, SB), period (dry, wet) and diel (day, night) ($p < 0.05$; Table 5.6). However, there were no significant difference between full and new moon samples for the factor moon light ($p > 0.05$). There were also no significant interactions among factors at all levels ($p > 0.05$).

Table 5.6 PERMANOVA results comparing the composition of fish assemblage among and across site (BP and SB), period (dry and wet), moon light (new moon and full moon) and diel light cycle (day-night). Significant differences in bold.

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms
Site	1	10188	10188	7.0161	**0.0002**	4984
Period	1	2748.6	2748.6	1.8928	**0.0328**	4982
Moon light	1	1121.9	1121.9	0.77262	0.6916	4981
Diel	1	2674.6	2674.6	1.8419	**0.0390**	4984
Site x Period	1	1532.9	1532.9	1.0556	0.3780	4971
Site x Lunar	1	1739.7	1739.7	1.1981	0.2858	4988
Site x Diel	1	1250.1	1250.1	0.86087	0.5956	4975
Period x Lunar	1	1509.3	1509.3	1.0394	0.4002	4983
Period x Diel	1	1280.2	1280.2	0.88164	0.5728	4980
Lunar x Diel	1	1043.7	1043.7	0.71877	0.7524	4980
Site x Period x Lunar	1	1345.3	1345.3	0.92641	0.5178	4979
Site x Period x Diel	1	1286.4	1286.4	0.88586	0.5662	4981
Site x Lunar x Diel	1	1425.4	1425.4	0.98157	0.4680	4981
Period x Lunar x Diel	1	1024.1	1024.1	0.70524	0.7606	4983
Site x Period x Lunar x Diel	1	1208.6	1208.6	0.8323	0.6264	4983
Residual	16	23234	1452.1			
Total	31	54613				

The test of homogeneity of dispersions showed no significant dispersion for site ($p = 0.545$), period ($p = 0.803$), moon light ($p = 0.810$) and diel ($p = 0.308$). This result, together with PERMANOVA results showed that the fish community structure did not show dispersion effect but differed significantly within the factors (site, period and diel). Community structure under new moon and full moon phase was not significantly different among and within level; therefore, the moon light factor was omitted in subsequent constrained CAP analyses.

The separation of species community between sites (BP, SB), period (dry, wet) and diel (day, night) was visualized in constrained CAP ordination results (Figure 5.2). Null hypothesis of no differences between the six groups of fish (for each level) due to the effect of site, period and diel light was rejected (p <0.05) based on CAP permutational test. This result was also consistent with the previous PERMANOVA test (Table 5.11). The leave-one-out allocation success was maximized at m = 8, where 40.63% ($\bar{\delta}^2$ = 0.88) of the samples were allocated to the correct group. The spread along the first canonical axis separated the fish community at BP mudflat (squares, right) from the fish community at SB mudflat (circles, left) whereas the second canonical axis separated those from the dry-wet period (wet at top, dry at bottom) and diel light regime (day on top, night at bottom). Distinct groups of fish were identified from CAP analysis (Figure 5.2b) with abundances significantly correlated (Spearman correlation > 0.40) with site, period and diel light. Abundance of seven species of fish namely *A. chacunda*, *Kurtus indicus*, *Upeneus sulphureus*, *Dasyatis zugeii*, *Leiognathus brevirostris, Pampus argenteus* and *Coilia dussumieri* were significantly associated with SB mudflat, while BP mudflat were characterized by fish composition comprising mainly *T. kammalensis, Ambassis gymnocephalus, Scatophagus argus, Strongylura strongylura, Hemiramphus far, Plotosus canius, Planiliza subviridis* and *Stolephorus baganensis*. There were seven species of fish whose abundance were significantly associated with wet period and day time (*Takifugu oblongus, Aspericorvina jubata, Johnius belangerii, Plicofollis argyropleuron, Planiliza melinopterus, H. sagor* and *O. ruber*), and three species of fish were found significantly associated with dry period and night time (*Congresox talabonoides, Ilisha melastoma and Nibea soldado*).

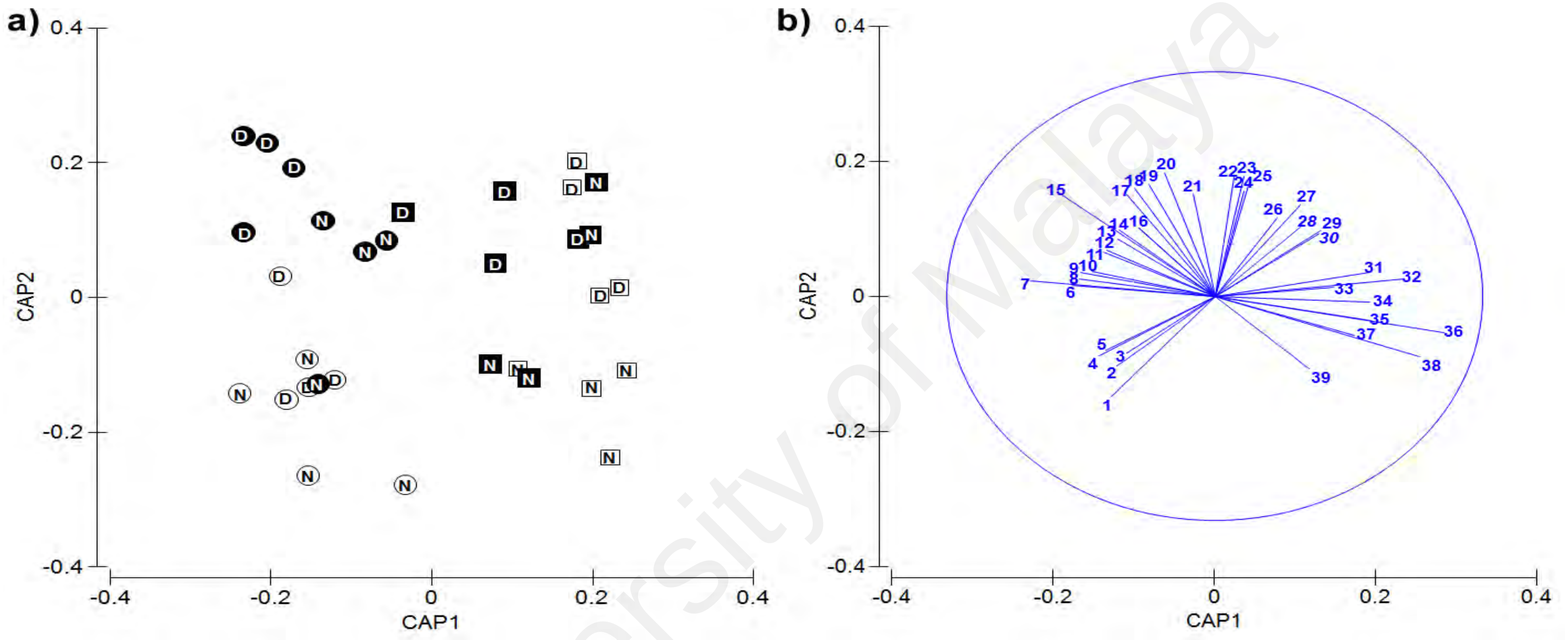

Figure 5.2 Canonical analysis of principal coordinates (CAP) ordination of fish abundance data (a) with corresponding strength and direction of Spearman correlation >0.40 of fish species shown as line vectors (b). Square = Bagan Pasir mudflat; circle = Bagan Sungai Buloh mudflat; filled symbol = wet period; empty symbol = dry period; D = day time; N = night time. Fish species include *Congresox talabonoides*[1], *Ilisha melastoma*[2], *Toxotes jaculatrix*[3], *Oreochromis mossambicus*[4], *Harpadon nehereus*[5], *Coilia dussumieri*[6], *Pampus argenteus*[7], *Leiognathus brevirostris*[8], *Dasyatis zugei*[9], *Upeneus sulpureus*[10], *Kurtus indicus*[11], *Anodontostoma chacunda*[12], *Opisthopterus tardoore*[13], *Pampus chinensis*[14], *Lagocephalus lunaris*[15], *Scomberomorus tol*[16], *Platycephalus indicus*[17], *Dasyatis bennenti*[18], *Otolithes ruber*[19], *Hexanematichthys sagor*[20], *Liza melinoptera*[21], *Plicofollis argypleuron*[22], *Takifugu oblongus*[23], *Aspericorvina jubata*[24], *Johnius belangerii*[25], *Eleutheronema tetradactylum*[26], *Drepane punctata*[27], *Synaptura commersonnii*[28], *Nemapteryx caelata*[29], *Tetraodon fluviatilis*[30], *Plotosus canius*[31], *Scatophagus argus*[32], *Stolephorus baganensis*[33], *Hemiramphus far*[34], *Strongylura strongylura*[35], *Thryssa kammalensis*[36], *Liza subviridis*[37], *Ambassis gymnocephalus*[38], and *Nibea soldado*[39].

SIMPER analysis indicated that four species of fish (*T. kammalensis, J. carouna, H. sagor* and *A. gymnocephalus*) showed most differences between levels of site, period, moon light and diel (%$\bar{\delta}_I$> 3% and $\bar{\delta}_i$ /SD > 1) (Table 5.7). Relative abundance of all four species was higher in BP than SB mudflat. Both Kammal anchovy and Caroun croaker had higher abundance at full moon (moonlit night) during the dry period compared to new moon and wet period. On the other hand, Sagor catfish and bald glassy were more abundant at new moon during the wet period compared to full moon during the dry period. Both Caroun croaker and Sagor catfish recorded higher abundance during daytime while *T. kammalensis* and *A. gymnocephalus* had higher abundance at night time.

Table 5.7 Summary results of SIMPER analysis showing the fish species during periodic diel sampling that fulfilled the criteria of dissimilarity/standard deviation (SD) > 1.0 and percentage contribution to dissimilarity > 3.0 % as important contributors to the dissimilarity between levels in the factor site (BP = Bagan Pasir and SB = Bagan Sungai Buloh), period (dry and wet), moon light (new moon and full moon) and diel light (daytime and night time). The relative abundance of each species is expressed as the percentage of total fish abundance for each factor.

Species	**Relative abundance (%)**		**Dissimilarity/ SD**	**Contribution to dissimilarity (%)**
Average dissimilarity = 63.53 %	**BP**	**SB**		
Thryssa kammalensis	32.07	6.38	1.45	12.65
Johnius carouna	13.23	24.96	1.41	5.39
Hexanematichthys sagor	4.35	9.84	1.19	3.87
Ambassis gymnocephalus	4.64	1.38	1.22	3.77
Average dissimilarity = 59.50 %	**Dry**	**Wet**		
Thryssa kammalensis	23.85	14.59	1.13	10
Johnius carouna	22.45	15.74	1.3	5.72
Hexanematichthys sagor	3.57	10.63	1.32	4.48
Ambassis gymnocephalus	2.97	3.06	1.05	3.04
Average dissimilarity = 58.59	**Full moon**	**New moon**		
Thryssa kammalensis	21.55	16.89	1.12	10.02
Johnius carouna	20.7	17.48	1.29	5.77
Hexanematichthys sagor	6.53	7.66	1.19	4.12

Ambassis gymnocephalus	2.74	3.28	1.07	3.11
Average dissimilarity = 59.43	**Day**	**Night**		
Thryssa kammalensis	16.01	22.44	1.16	9.85
Johnius carouna	26.14	12.04	1.31	6.27
Hexanematichthys sagor	6.12	8.08	1.34	4.29
Ambassis gymnocephalus	1.3	4.73	1.07	3.15

5.2 Mudflat fish community structure

The mean monthly fish abundance in SB mudflat was 2744 ± 948 ind. ha^{-1} and 4722 ± 698 ind. ha^{-1} in BP mudflat (Table 5.8). In terms of the monsoon season, NEM recorded a higher mean monthly abundance of 5152 ± 1068 ind. ha^{-1} than SWM (2178 ± 362 ind. ha^{-1}). ANOVA results showed that the mean total fish abundance from monthly sampling was significantly higher at NEM compared to SWM ($p < 0.05$; $F_{1,49} = 6.94$). Fish abundance in SB and BP however did not show significant difference ($p > 0.05$; $F_{1,49} = 1.40$). The highest monthly fish abundance at both sites were recorded in NEM, i.e., January 2012 (16,473 ind. ha^{-1}) for BP and November 2012 (24,337 ind. ha^{-1}) for SB (Figure 5.3). The Caroun croaker contributed the most to both density peaks, accounting for about 66 % of total fish abundance in January 2012 at BP and 38 % in November 2012 at SB.

Table 5.8 Standing stocks of fishes collected in intertidal mudflat during monthly and periodic diel samplings. Numbers in bold indicate significant difference at $p < 0.05$. BP = Bagan Pasir; SB = Bagan Sungai Buloh; SWM = Southwest monsoon; NEM = Northeast monsoon; SE = standard error.

Area/Sampling		**Monthly day-time sampling**				**Periodic diel sampling**							
Factor		**Site**		**Season**		**Site**		**Period**		**Moon light**		**Diel**	
Level		**BP**	**SB**	**SWM**	**NEM**	**BP**	**SB**	**Dry**	**Wet**	**Full**	**New**	**Day**	**Night**
Abundance (N/ha)	Mean	4722	2744	**2178**	**5152**	**4086**	**1035**	2869	2252	2701	2420	2346	2776
	±SE	698	948	362	1068	670	159	710	517	704	535	390	791
Biomass (kg/ha)	Mean	**113.7**	**62.6**	65.3	109.4	73.2	16.2	38.3	51.1	45.3	44.1	39.5	49.9
	±SE	29.6	29.5	29.4	29.8	13.3	2.1	12.9	10.9	10.9	13.1	9.6	14
Average weight per fish (g/N)	Mean	28.23	20.9	28.46	21.23	18.9	18.56	21.1	16.36	18.19	19.27	15.41	22.05
	±SE	5.49	3.4	5.58	3.27	2	2.25	2.5	1.75	2.25	2.25	1.5	2.25

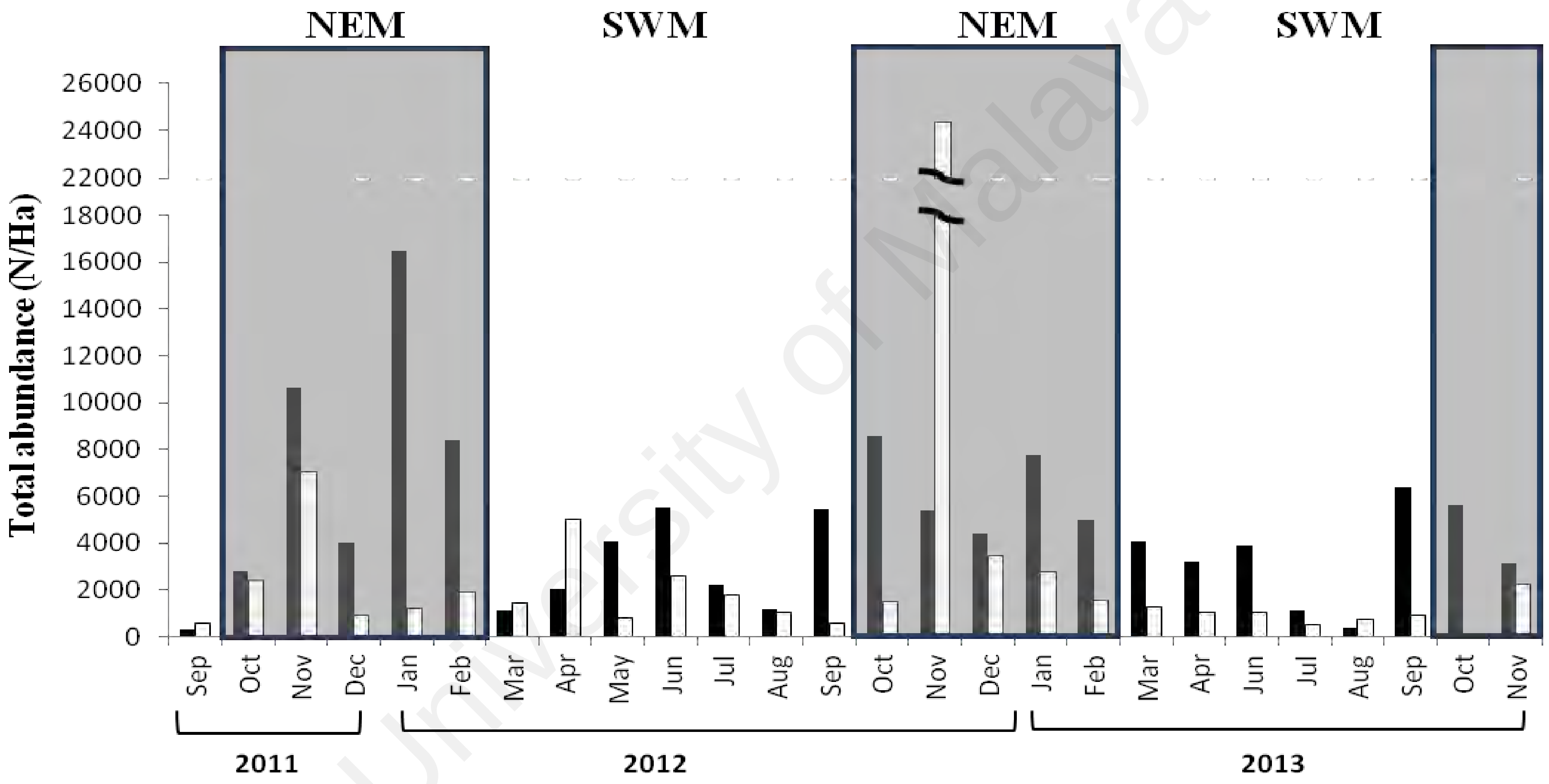

Figure 5.3 Monthly and seasonal abundance of total fish stock in the Klang mudflat, from September 2011 to November 2013. Shaded area indicate NEM period. Filled bar = Bagan Pasir mudflat; empty bar = Bagan Sungai Buloh mudflat.

In terms of mean fish stock biomass, BP had significantly higher ($p < 0.05$; $F_{1,49} = 4.86$) mean biomass (113.7 ± 29.6 g/ha) than SB (62.6 ± 29.5 g/ha), but no significant difference ($p > 0.05$; $F_{1,49} = 0.87$) was found between monsoon seasons (SWM 65.3 ± 29.4 g/ha; NEM 109.4 ± 29.8 g/ha). The highest fish stock biomass (531.2 kg/ha) was recorded in September 2012 and the lowest biomass (15.9 kg/ ha) in August 2013 for BP. In SB, the highest (554.7 kg/ ha) and lowest (5.6 kg/ha) biomass were obtained in November 2012 and May 2012, respectively (Figure 5.4). The high biomass of fish during these months was attributed to large catches of ariids (> 90%).

Sciaenidae was the most important fish family during monthly day-time samplings (Table 5.9), represented by six species that made up of approximately 40 % of the total catch. In terms of abundance, the Caroun croaker, Kammal anchovy and Sagor catfish were the three most important fish species caught in the intertidal mudflat during monthly samplings. However in terms of stock biomass, Caroun croaker and Kammal anchovy remained as the two highest, followed by the spotted catfish (*Arius maculatus*).

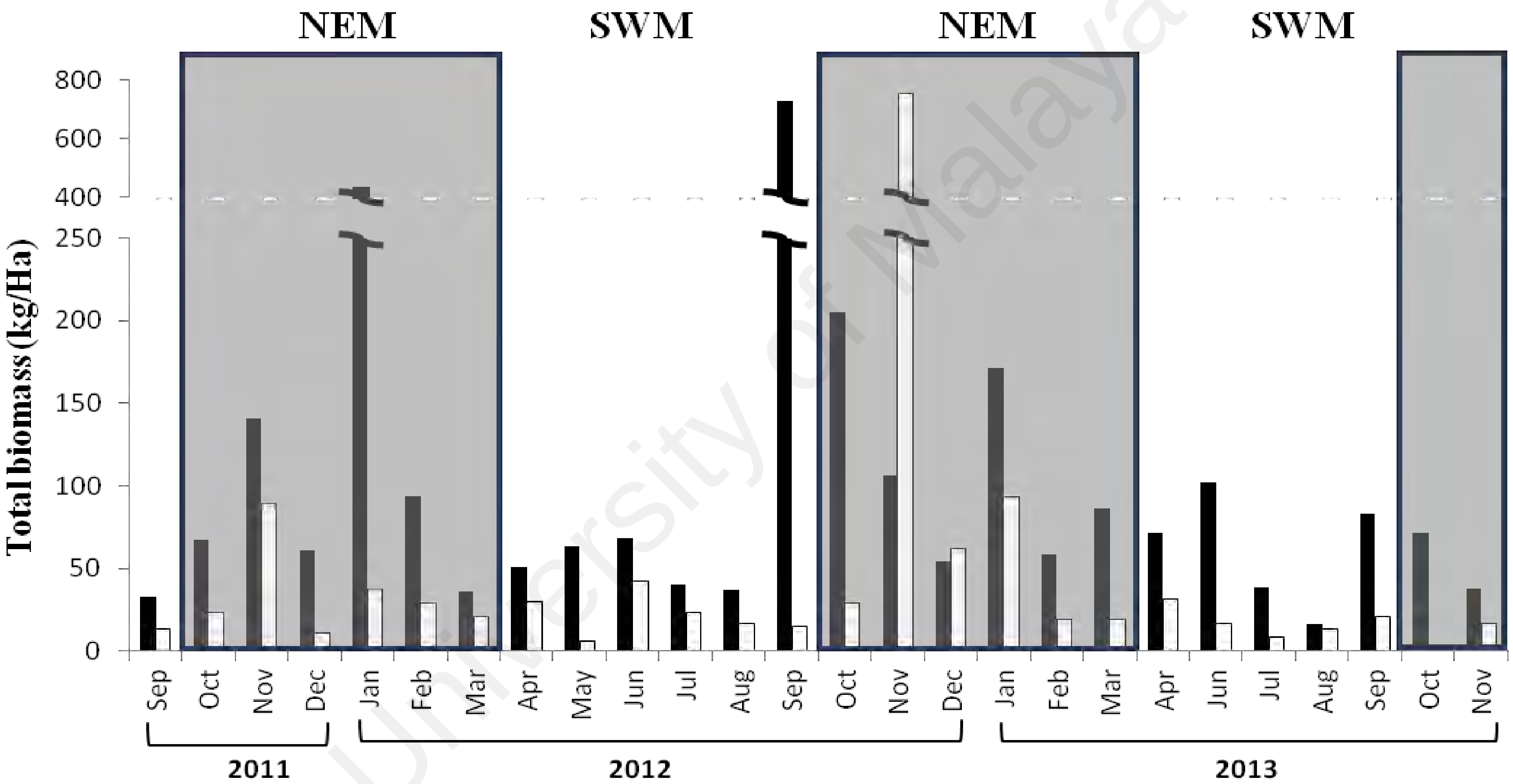

Figure 5.4 Monthly and seasonal total fish stock biomass in Klang mudflat, from September 2011 to November 2013. Shaded area indicate NEM period. Filled bar = Bagan Pasir mudflat; empty bar = Bagan Sungai Buloh mudflat.

Table 5.9 Catch summary of fish collected in intertidal mudflat using enclosure trap during monthly day-time samplings. Code for each fish species can be found on Table 5.1. * Valid N refers to actual number of measurements taken on each fish species. Bold figures make up of 90 % of total monthly abundance or biomass cumulatively. 0.0 value denotes less than 0.1 %.

Species code	Monthly mean		N*	Standard length (cm)				Weight (g)			
	N/Ha	g/Ha		Min	Max	Mean	SD	Min	Max	Mean	SD
Jcaro	**1245.3**	**26236.00**	1944	3.5	25.5	11.94	2.58	0.42	191.5	20.46	14.53
Tkam	**812.5**	**5504.35**	1281	5	12.5	9.65	0.96	0.79	118.4	7.32	3.85
Hsag	**191.7**	**1771.09**	949	4.1	36.4	9.73	4.75	0.84	1096.76	17.49	64.06
Amac	**132.0**	**8350.39**	139	5	188.42	14.93	16.05	0.88	319.32	43.77	66.53
Psub	**121.3**	**3028.35**	867	5.7	31.7	12.88	3.23	1.49	258.69	27.06	22.01
Orub	**95.2**	**1484.14**	603	4.1	32.5	11.06	5.48	0.59	283.86	24.13	46.19
Ccyn	**89.9**	**1119.37**	493	1.7	38.7	11.78	4.99	1.42	170.24	15.38	26.03
Lbre	**60.1**	346.51	332	3.1	9.8	7.88	1.08	0.34	14.9	6.42	2.28
Jbela	**55.9**	**1740.13**	257	8.4	19.4	13.95	1.94	4.18	102.82	32.5	15.86
Agym	**55.8**	360.35	354	3.7	9	7.19	0.9	1.1	9.19	4.66	1.42
Pmic	**54.0**	**1067.53**	437	4.2	30	11.94	5.93	0.59	249.87	26.78	45.4
Etet	**51.6**	**961.34**	533	6.0	27.9	12.47	2.86	1.34	247.12	16.76	16.06
Otar	**49.1**	**1174.79**	172	4.6	18.4	12.31	3.65	0.7	51.24	15.75	13.43
Dflu	**43.8**	**756.52**	192	2.6	14.5	7.35	2.8	0.53	99.94	20.21	23.08
Stat	**43.1**	318.63	360	1.5	21	10.65	2.35	1.78	324.83	13.22	34.21
Ctrun	**41.3**	**7240.16**	63	6.5	35.7	23.56	8.04	3.33	400.7	129.72	92.87
Pcan	**37.8**	**3111.02**	215	8.2	43.1	23.24	7.67	3.07	678.2	102.17	114.62
Parg	**35.0**	**1062.60**	163	5.7	20.1	11.93	2.75	3.25	137.37	27.18	20.75
Jborn	**33.8**	728.88	67	6	14.2	8.96	1.52	2.03	50.88	12.47	11.91
Cpun	**33.6**	295.99	170	7.2	42.3	10.76	2.77	2.39	233.53	9.69	17.47
Hfar	**33.1**	516.95	134	10.1	24.7	15.54	2.58	2.87	26.38	11.62	5.76
Sstr	**30.9**	**1181.35**	291	18.5	38.9	27.56	3.17	4.13	113.56	36.19	15.07
Ajub	**29.7**	500.96	258	3.7	16.6	11.64	2.76	0.42	55.23	19.91	12.13
Nsal	**29.1**	**1321.21**	221	5.1	28.5	12.57	6.06	0.83	304.82	36.89	56.34
Bwal	29.0	676.00	52	12.3	46.4	22.22	6.91	8.04	393.28	52.51	88.14
Ncae	27.8	**3285.72**	117	5.1	37.8	17.95	8.29	0.84	495.08	91.43	91.12
Cbil	26.7	611.99	229	7.1	33.4	14.21	4.76	2.41	257.66	24.08	40.04
Pagy	21.7	**2347.84**	272	4.1	33.4	18.59	6.67	0.72	405.64	94.54	77.84

Table 5.9, continued

Clin	20.8	**898.10**	287	1.6	38.0	19.43	8.73	2.25	363.37	40.85	50.2
Tobl	19.1	135.68	265	2	22	6.09	2.98	0.3	358.24	10.52	34.09
Sarg	17.8	586.88	78	2	16	8.89	3.59	0.74	140.03	30.3	27.28
Pmel	17.7	182.34	210	5.7	17.6	8.98	1.7	2.85	55.55	10.7	7.07
Tthe	17.6	72.10	118	4.3	12.8	6.47	1.53	1.01	31.36	4.64	4.98
Cdus	12.9	96.92	49	10	16.2	13.86	1.25	6.34	17.64	11.53	2.53
Dpun	11.2	239.83	97	3.1	13.5	7.7	2.71	0.33	81.36	18.81	16.67
Druss	11.2	223.06	152	5.2	16	10.26	2.46	1.44	56.82	15.06	11.72
Aoet	10.7	52.42	39	9.5	12	10.33	0.57	7.78	16.57	10.51	2.18
Dzug	8.5	**765.49**	66	14.9	59	30.07	12.65	5.94	424.56	35.66	50.25
Sbag	7.9	39.76	89	5	11.4	8.76	1.3	0.81	13.15	5.71	2.62
Sruc	6.5	19.49	47	3	9.1	5.81	1.39	0.42	9.46	3.1	1.28
Tlep	6.2	142.18	45	19.4	43.4	31.2	6.04	4.07	49.24	21.39	12.55
Dben	5.8	**1314.53**	7	28.7	48.9	37.36	7.01	47.57	99.13	68.42	21.17
Obir	4.9	238.50	21	9.1	25	15.7	4.05	7.41	176.46	39.68	35.99
Lluna	4.5	68.02	101	4.5	19	7.87	2.33	1.42	123.63	14.03	16.12
Pchi	4.3	69.79	61	3.6	15.5	7.27	3.04	0.43	167.62	16.19	27.99
Aveno	4.0	26.64	1	11.5				21.3			
Acha	3.5	62.59	46	6.8	12.7	9.18	1.7	2.92	30.84	10.29	6.44
Huar	3.1	383.95	10	14.5	21.1	19	2.18	9.27	23.19	16.06	3.79
Ssih	3.0	94.38	40	7.6	18.7	16.67	1.94	1.8	57.58	30.95	9.12
Evaig	2.9	93.29	46	6.3	29.8	13.13	4.04	3.54	318.07	38.12	46.6
Hpas	2.9	**2138.08**	1	31.2				219.18			
Ethr	2.4	11.05	22	6	10.6	8.28	1.47	1.6	11.55	5.78	3.02
Pkaa	2.4	44.76	30	6.5	14.9	10.38	2.18	4.03	56.42	19.81	13.8
Dlong	2.2	37.96	10	3.7	9.7	8.31	1.88	1.21	27.44	19.21	8.55
Imel	1.9	13.06	24	7.1	12.1	9.33	1.45	3.42	19.25	8.03	3.9
Omos	1.9	75.82	33	3	20	11.92	3.77	7.12	157.39	41.33	38.27
Lcal	1.7	70.11	3	24	40.5	30.5	8.79	172.8	895.95	444.33	393.78
Tnei	1.7	71.76	18	8.8	22.3	18.67	2.97	7.5	156.66	88.64	32.68
Omil	1.6	151.07	5	11.5	26.2	21.56	6.72	9.35	146.76	97.83	67.84
Tcroc	1.6	135.29	3	38.2	51.9	43.63	7.28	81.98	168.06	115.24	46.26
Hneh	1.6	7.56	32	7	17.1	11.98	3.7	0.67	23.83	5.82	5.16
Pind	1.5	32.56	23	11.3	20.7	15.5	2.32	9.2	63.08	24	12.48

Table 5.9, continued

Usulp	1.4	9.03	30	5.6	11	7.78	1.28	1.59	21.7	6.45	5.32
Tnig	1.2	19.18	11	14.1	32	23.99	4.97	3.9	26.21	14.83	7.63
Tham	1.1	10.02	38	10.4	12.3	11.08	0.45	1.43	13.84	8.92	5.64
Tmic	1.0	37.75	22	4.5	23.4	10.16	4.73	2.05	280.75	34.42	61.05
Lind	0.9	102.42	7	8.6	44.5	24.73	12.28	4.98	601.41	163.31	210.62
Kind	0.8	8.25	10	6.4	9.9	8.26	1.23	3.5	13.97	7.98	3.63
Stri	0.8	5.80	12	8.5	11.2	10.36	1.07	1.67	12.57	8.12	3.92
Scana	0.7	2.33	8	3.8	8.8	5.94	1.65	0.71	7.32	2.77	2.15
Sycom	0.7	32.94	10	13	24	18.03	4.04	11.23	128.56	42.28	39.47
Lsuri	0.6	140.91	7	14.2	36	22.22	7.52	60.04	908.42	270.53	293.2
Ariu	0.6	7.87	8	9.2	11.3	10.23	0.95	8.79	18.38	12.35	3.98
Pane	0.4	10.28	8	4.6	14.5	9.58	4.3	1.62	41.97	18.54	19.67
Sins	0.4	7.43	3	5.1	6	5.4	0.52	2.3	4.22	2.94	1.11
Cmal	0.4	6.34	1	4.3				0.76			
Tjar	0.3	4.53	3	9	10.7	9.9	0.85	11.13	18.08	14.66	3.48
Tvag	0.3	4.49	11	11	28.5	20.34	5.49	4.41	35.77	18.65	9.46
Ptie	0.3	27.21	4	11.1	16.2	14.43	2.27	53.89	145.45	112.01	40.24
Ielo	0.2	2.25	7	9	12.2	10.57	0.97	5.51	12.31	9.12	2.49
Rbra	0.2	0.71	3	7.6	8.6	8	0.53	3.41	4.51	3.95	0.55
Cnudu	0.2	2.19	1	23.7				55.75			
Stol	0.2	0.48	6	6.1	7.6	6.95	0.52	2.24	3.44	2.84	0.46
Ppar	0.2	27.26	21	10.9	26.5	16.15	4.27	14.16	222.83	60.04	61.32
Orub	0.2	3.93	2	9.7	10	9.85	0.21	3.96	6.79	5.38	2.02
Amic	0.1	27.93	1	27				215.31			
Tlym	0.1	12.42	1					102.21			
Tmys	0.1	1.01	4	9.4	12.5	10.68	1.42	5.71	12.8	8.31	3.17
Lsava	0.1	2.91	7	30.5	38	34	2.68	22.33	40	27.37	6.16
Pdia	0.1	4.21	1	15.3				38.29			
Cpla	0.1	0.62	2	11.5	12.6	12.05	0.78	4.15	6.42	5.29	1.61
Jcaru	0.1	0.31	1	13.4				26.6			
Hkel	0.1	6.78	4	17.8	20	18.53	1.06	67.09	104.84	78.58	17.69
Gery	0.1	0.72	1	8.5				8.98			
Bkoi	0.1	0.08	1	4.5				1.18			
Sverm	0.1	0.07	1	4.5				1.22			

Table 5.9, continued

Cind	0.1	0.28	1	11.6				5.12			
Scomm	0.0	0.42	2	12.8	21	16.9	5.8	13.56	70.71	42.14	40.41
Dboa	0.0	0.05	1	14.2				1.02			
Nkuh	0.0	11.78	1	49.55				268.6			
Scom	0.0	0.05	3	5.6	10.2	7.13	2.66	1.4	9.53	4.11	4.69
Epi sp.	0.0	3.88	1	18.4				127.8			
Bbod	0.0	1.02	1	17				34.06			
Agru	0.0	2.48	1	17				98.29			
Sput	0.0	0.75	1	20				32.93			
Total species mean	35.7	821.4		9.8	24.5	14.2		19.4	163.3	37.3	

In the periodic diel sampling, the mean fish stock abundance and biomass was significantly higher in BP (4086 ± 670 ind.ha^{-1}; 73.2 ± 13.3 kg/ha) than in SB (1035 ± 159 ind.ha^{-1}; 16.2 ± 2.1 kg/ha) mudflat ($p < 0.05$) (Table 5.8). However, there was no significant differences observed between levels for period (dry, wet), moon phase (new, full) and diel (day, night) factors, as well as their interaction effects ($p > 0.05$). In terms of fish abundance, the dry period recorded a mean of 2869 ± 710 ind. ha^{-1} whereas the wet period recorded 2252 ± 517 ind. ha^{-1}. The full moon phase (2701 ± 704 ind. ha^{-1}) had higher mean fish abundance than the new moon or dark phase (2420 ± 535 ind. ha^{-1}) but difference was not significant. On the other hand, mean fish abundance at day time was 2346 ± 390 ind. ha^{-1} while night time had higher mean fish abundance of 2776 ± 791 ind. ha^{-1}. Fish biomass appeared to be higher during the wet period (51.1 ± 10.9 kg/ha) compared to dry period (38.3 ± 12.9 kg/ha), and during night time (49.9 ± 14.0 kg/ha) compared to day time (39.5 ± 9.6 kg/ha). Both new (44.1 ± 13.1 kg/ha) and full moon (45.3 ± 10.9 kg/ha) phases had rather similar mean fish biomass observed.

5.3 Mudflat fish size and maturity

If all fish sampled from the mudflat were pooled together, 50.4 % of it belonged to the small size class (i.e. < 1/3 of the species‘ maximum length), 38.4 % from the medium size class (1/3 to 2/3 of the species‘ maximum length) and 11.2 % from the large size class (> 2/3 of the species‘ maximum length). Of the total of 131 fish species present in the mudflat, sixty-nine species had mainly individuals of the small size category (Table 5.10); nine of these were carangids and eight were sciaenids. Forty-eight fish species had mainly individuals of the medium size range category, while only 13 fish species had higher number of individuals that belonged to the large size category. Fish species that were often found in the large sized category included the

Bagan anchovy (*S. bagannensis*) and spined anchovy (*Stolephorus tri*), Chacunda gizzard shad (*A. chacunda*) and white sardine (*E. thoracata*).

Table 5.10 Summary of fish size (SL) based on pooled data of fish collected from intertidal mudflat during monthly and periodic diel samplings. Code for each fish species can be found on Table 5.1. * Valid N refers to actual number of measurements taken on each fish species. Size class of fish species are reported as a percentage relative to total individuals of each species. Size class of each fish species was determined by using Nagelkerken and van der Velde‘s (2002)‘s method, where each individual was ascribed to one of three size classes: small (< 1/3 of the species‘ maximum length), medium (1/3 to 2/3 of the species‘ maximum length), and large (> 2/3 of the species‘ maximum length).

Family	Code	N*	Size range (cm)		Size category (%)		
			Min	Max	Small	Medium	Large
Ambassidae	Agym	947	3.7	9	29.2	70.8	0.0
Ariidae	Ariu	17	7.3	11.3	100.0	0.0	0.0
	Amac	397	4.4	188.42	81.6	18.4	0.0
	Amic	2	23.1	28.1	0.0	100.0	0.0
	Aoet	203	7.2	19.2	2.0	97.0	1.0
	Aveno	191	4.0	18.5	43.1	56.9	0.0
	Ctrun	92	6.5	35.7	20.5	60.3	19.2
	Hsag	1639	4.1	36.4	96.1	3.6	0.2
	Ncae	292	4.0	37.8	58.5	40.4	1.1
	Nnen	10	8.1	11.2	60.0	40.0	0.0
	Omil	19	11.5	26.2	0.0	94.4	5.6
	Pagy	548	4.1	33.4	59.6	40.4	0.0
Batrachoididae	Agru	1	17.0		0.0	50.0	50.0
Belonidae	Sstr	854	5.5	38.9	0.3	41.1	58.6
	Tcroc	5	33.8	51.9	75.0	25.0	0.0
Carangidae	Cmal	9	3.0.	4.1	100.0	0.0	0.0
	Scom	8	4.7	10.2	100.0	0.0	0.0
	Sctal	1	4.3	7.0	100.0	0.0	0.0
	Stol	8	5.9	7.6	90.0	10.0	0.0
	Tblo	2	3.5	5.1	100.0	0.0	0.0
Chirocentridae	Cnudu	1	23.7		100.0	0.0	0.0
Cichlidae	Omos	96	3	20	88.9	11.1	0.0
Clupeidae	Acha	67	5.2	12.7	64.8	35.2	0.0
	Ethr	72	6	10.6	0.0	34.8	65.2
	Hkel	4	17.8	20	0.0	14.3	85.7
	Otar	250	4	18.4	15.9	62.1	22.1
Cynoglossidae	Carel	1	35.3		0.0	100.0	0.0
	Cbil	351	7.1	33.4	80.1	18.8	1.2
	Ccyn	792	1.7	38.7	0.8	85.9	13.2
	Clin	452	1.6	38	41.5	47.8	10.7
	Cpun	419	0.6	42.3	98.8	0.4	0.8
Dasyatidae	Bwal	153	5.3	46.4	87.0	12.0	0.9
	Dben	13	9.5	48.9	100.0	0.0	0.0
	Dzug	98	8.5	59	95.5	3.4	1.1
	Hpas	1	31.2		85.7	14.3	0.0
	Huar	10	14.5	21.1	60.5	32.6	7.0
	Nkuh	1	49.55		100.0	0.0	0.0
	Tlym	2	18.7	21.5	0.0	100.0	0.0
Drepaneidae	Dlong	28	2.8	9.7	100.0	0.0	0.0
	Dpun	281	1.7	13.5	100.0	0.0	0.0

Table 5.10, continued

Eleotridae	Bkoi	1	4.5		0.0	100.0	0.0
Engraulidae	Cdus	96	10	16.2	0.0	59.1	40.9
	Stat	779	1.5	21	0.2	71.6	28.2
	Sbag	157	3.8	11.4	0.0	20.2	79.8
	Stri	14	8.5	11.2	0.0	7.7	92.3
	Tham	59	6.4	17.7	45.5	54.5	0.0
	Tkam	2336	2.3	12.5	0.6	99.0	0.4
	Tmys	14	7.9	12.5	0.0	66.7	33.3
Ephippidae	Ptie	10	2.8	16.2	100.0	0.0	0.0
Gerreidae	Gery	2	6.4	8.5	14.3	85.7	0.0
Gobiidae	Bbod	1	17		0.0	100.0	0.0
	Odrub	2	9.7	10	0.0	100.0	0.0
	Oden	5	7.5	12.2	0.0	20.0	80.0
	Tnig	39	12.2	32	0.00	2.94	97.06
	Tvag	13	11	28.5	0.0	18.2	81.8
Haemulidae	Pgib	2	12	12.6	100.0	0.0	0.0
	Pkaa	82	4.9	14.9	100.0	0.0	0.0
	Pmac	2	3.8	5.8	100.0	0.0	0.0
Hemiramphidae	Hfar	200	6.2	24.7	67.9	32.1	0.0
Hemiscylliidae	Chas	14	7.1	17.3	100.0	0.0	0.0
	Cind	1	11.6		100.0	0.0	0.0
	Cpla	2	11.5	12.6	100.0	0.0	0.0
Kurtidae	Kind	23	4.5	9.9	0.0	92.9	7.1
Latidae	Lcal	3	24	40.5	0.0	100.0	0.0
Leiognathidae	Lbre	383	3.1	9.8	2.3	97.7	0.0
	Sins	5	5.1	6	0.0	100.0	0.0
	Sruc	56	3	15.5	3.8	94.2	1.9
Lobotidae	Lsuri	9	14.2	36	83.3	16.7	0.0
Mugilidae	Evaig	100	6.3	29.8	97.1	2.9	0.0
	Ppar	22	10.9	26.5	0.00	92.31	7.69
	Pmel	316	5.3	17.6	97.2	2.8	0.0
	Psub	1873	2.9	33.5	77.5	21.1	1.4
Mullidae	Usulp	43	5.3	11.6	79.4	20.6	0.0
Muraenesocidae	Ctala	5	39.4	41.2	0.0	100.0	0.0
Platycephalidae	Pind	54	9.9	20.7	100.0	0.0	0.0
Plotosidae	Pcan	374	8.2	43.1	91.9	8.1	0.0
	Plin	1	17		0.0	100.0	0.0
Polynemidae	Etet	905	4.7	27.9	10.9	87.9	1.2
	Lind	10	6.7	44.5	73.33	26.67	0.00
	Psex	13	8.4	9.7	0.00	100.00	0.00
	Ppara	2	9.5	15	50.00	50.00	0.00
Pristigasteridae	Ielo	12	8	12.2	100.0	0.0	0.0
	Imac	2	9.6	11.1	0.0	0.0	100.0
	Imel	119	4.2	13.5	4.4	43.9	51.8
Scatophagidae	Sarg	192	2	16	98.2	1.8	0.0
Sciaenidae	Ajub	598	2.7	21.5	10.4	59.2	30.4
	Druss	419	4.2	16	60.3	39.7	0.0
	Jbela	452	6	19.4	3.6	96.4	0.0
	Jborn	82	6	15.4	84.9	9.6	5.5
	Jcaro	3370	3.5	25.5	24.9	74.8	0.3
	Jcaru	1	13.4		0.0	100.0	0.0
	Jtrac	1	18		0.0	0.0	100.0
	Nsal	267	5.1	28.5	93.7	6.3	0.0
	Orub	1210	3.7	32.5	100.0	0.0	0.0
	Obir	104	9.1	25	100.0	0.0	0.0
	Pmic	832	3.4	30	83.1	16.9	0.0
	Pane	21	4.6	14.5	62.5	37.5	0.0
	Pdia	1	15.3	0	100.0	0.0	0.0

Table 5.10, continued

Scombridae	Rbra	3	7.6	8.6	21.43	78.57	0.00
	Scomm	2	12.8	21	88.68	11.32	0.00
Serranidae	Epi sp.	2	15.6	18.4	-	-	-
Siganidae	Scana	9	3.8	8.8	100.0	0.0	0.0
	Sverm	2	4		100.0	0.0	0.0
Sillaginidae	Ssih	93	7.6	35.6	25.4	74.6	0.0
Soleidae	Sycom	37	7.7	24	47.6	28.6	23.8
Sphyraenidae	Sput	1	2.8	8.2	100.0	0.0	0.0
Stromateidae	Parg	310	3.8	20.1	100.0	0.0	0.0
	Pchi	178	2	15.5	100.0	0.0	0.0
Syngnathidae	Dboa	1	14.2		0.0	100.0	0.0
Synodontidae	Hneh	56	7	17.1	94.6	5.4	0.0
Terapontidae	Tjar	7	6	12.3	85.7	14.3	0.0
	Tthe	242	3.5	12.8	98.9	1.1	0.0
Tetraodontidae	Dflu	435	2.6	14.5	52.8	46.3	0.9
	Lluna	123	4.4	19	99.1	0.9	0.0
	Tobl	510	1.8	26	98.1	1.4	0.5
Toxotidae	Tjac	9	4.6	14.1	33.3	33.3	33.3
	Tmic	28	4.5	23.4	16.7	54.2	29.2
Triacanthidae	Tnei	74	7.3	22.3	9.5	66.7	23.8
Trichiuridae	Lsava	15	20	38	30.00	70.00	0.00
	Tlep	67	19.4	43.4	51.0	49.0	0.0
Total/Mean		26252			52.2	36.9	10.9

5.4 Fish species in subtidal waters adjacent to mudflat

Day-time gill net sampling in the adjacent subtidal area where mudflat fishes are expected to retreat to during ebb tide yielded a total of 87 species of fish (see Table 5.1). Compared to the mudflat, 76 species were found in both areas. This was 87.4% of the total subtidal fish species or 68 % of the intertidal mudflat‘s fish species. There were 11 species of fish found exclusively in subtidal area i.e. not sampled in the mudflat. On the other hand, 29 species found in the mudflat were not sampled by the gill net in the subtidal area (Table 5.1).

For the subtidal area, monthly bCPUE values from gill nets indicated that SB (50.4 ± 5.3 g/m^2/hour) recorded a significantly higher value than BP (23.0 ± 4.0 g/ha/hour, $p < 0.05$; $F_{1,34} = 18.65$) (Table 5.11). However in terms of nCPUE, no significant difference was observed between BP (0.61 ± 0.07 ind./m^2/hour) and SB (1.60 ± 0.61 ind./m$^{2/}$hour) ($p > 0.05$; $F_{1,34} = 2.82$). Both fish biomass and density were not significant different between SWM (34.9 ± 5.4 g/m^2/hour; 0.68 ± 0.10 ind. ha^{-1} hour^{-1}) and NEM (38.4 ± 5.7 g/m^2/hour; 1.38 ± 0.50 ind./m$^{2/}$hour) ($p > 0.05$).

Table 5.11 Standing stocks in catch per unit effort (CPUE) of fishes collected in the adjacent subtidal area, off Klang mudflat during monthly samplings. Numbers in bold indicate significant difference at $p < 0.05$. BP = Bagan Pasir; SB = Bagan Sungai Buloh; SWM = Southwest monsoon; NEM = Northeast monsoon; SE = standard error.

Factor		**Site**		**Monsoon**	
Level		**BP**	**SB**	**SWM**	**NEM**
nCPUE	Mean	0.61	1.60	0.68	1.38
(N/m^2/hour)	±SE	0.07	0.61	0.10	0.50
bCPUE	Mean	**23.0**	**50.4**	34.9	38.4
(g/m^2/hour)	±SE	4.0	5.3	5.4	5.7

Similar to the observations made for the mudflat, highest bCPUE for both sites was recorded during the NEM period, which was February 2012 (64.5 g/m^2/hour) at BP and November 2012 (88.7 g/m^2/hour) at SB (Figure 5.5). As for nCPUE, BP catch was the highest in February 2013 (1.22 ind./m$^{2/}$hour) whereas highest SB catch was in October 2012 (11.47 ind./m$^{2/}$hour), both during NEM season (Figure 5.6). The extremely high fish catch on October 2012 at SB was due to the high abundance of two species, the Tardoore, *Opisthopterus tardoore* (47.4 %) and Kammal anchovy (40.7 %). Both Tardoore and Kammal anchovy also contributed the highest in terms of the total CPUE (Table 5.12). Kammal anchovy comprised approximately 25 % of total catch in relative abundance, followed by Taardore (20 %) and scaly hairfin anchovy *Setipinna taty* (10 %). On the other hand, longsnoutted catfish *P. argyropleuron* recorded the highest in terms of relative biomass (15 %), followed by Taardore (7 %) and Caroun croaker (7 %).

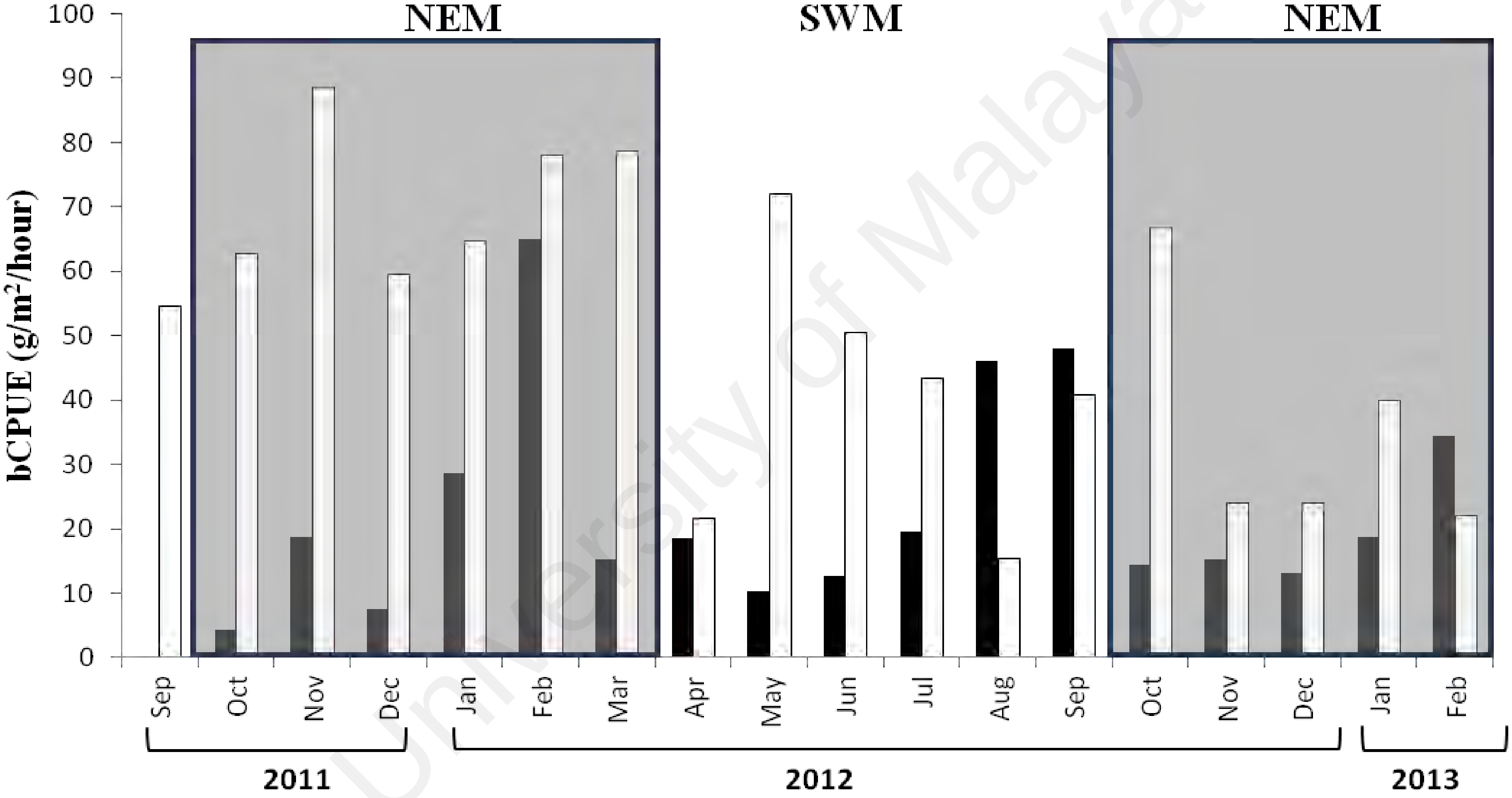

Figure 5.5 Monthly and seasonal catch per unit effort (bCPUE) of fish in the subtidal area, off Klang mudflat, from September 2011 to November 2013. Shaded area indicate NEM period. Filled bar = Bagan Pasir mudflat; empty bar = Bagan Sungai Buloh mudflat.

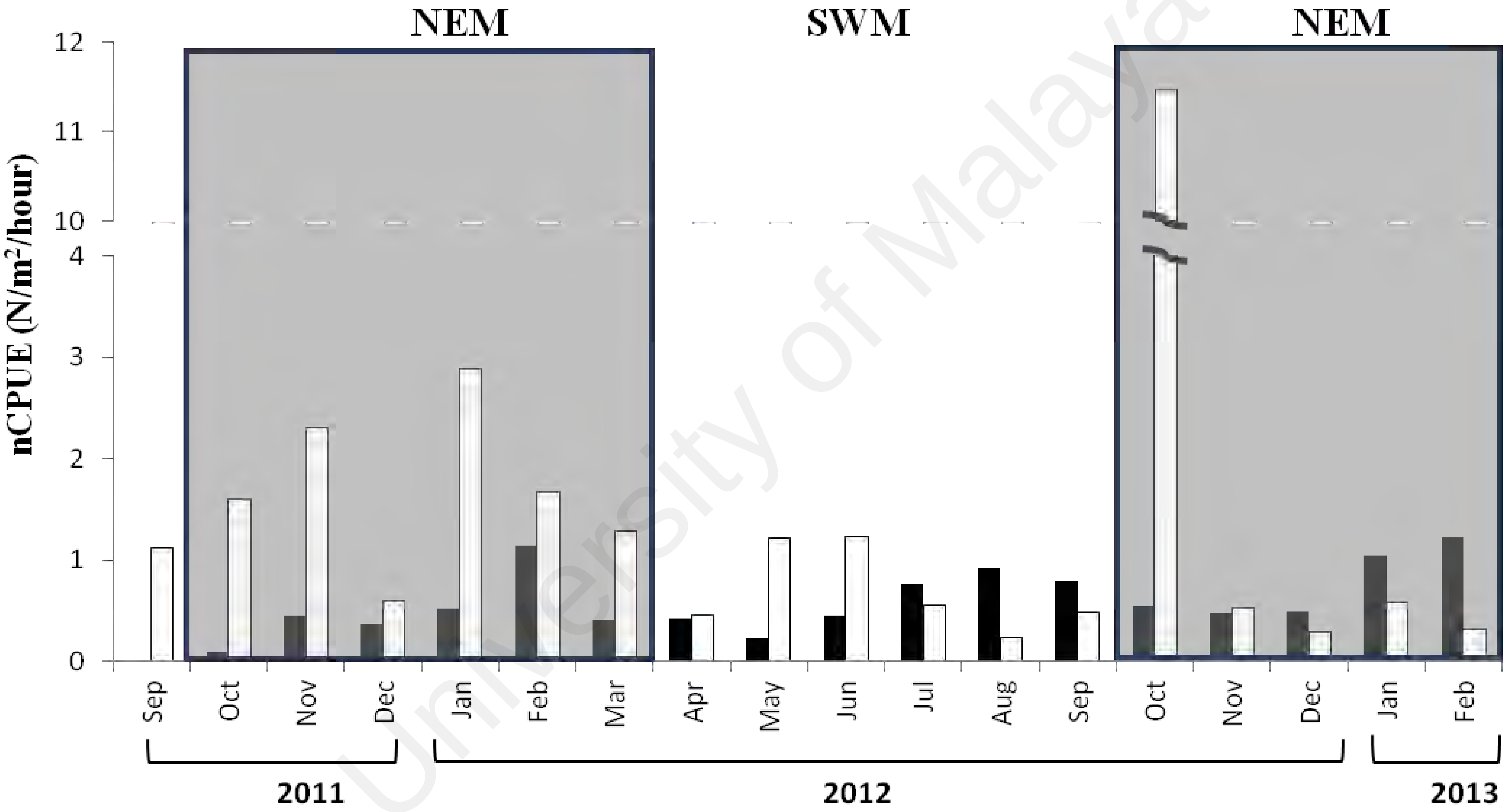

Figure 5.6 Monthly and seasonal catch per unit effort (nCPUE) of fish in the adjacent subtidal area, off Klang mudflat, from September 2011 to November 2013. Shaded area indicate NEM period. Filled bar = Bagan Pasir mudflat; empty bar = Bagan Sungai Buloh mudflat.

Table 5.12 Catch summary and size (SL) of fish collected in the adjacent subtidal area, off Klang mudflat using gill net during monthly day samplings. Full name to code for each fish species can be found in Table 5.1. * Valid N refers to actual number of measurements taken on each fish species. Bold figures make up of 90 % of total monthly relative abundance (nCPUE) and biomass (bCPUE) cumulatively.

Species code	**Monthly mean**		**N**	**Standard length (cm)**				**Weight (g)**			
	N/m^2 /hour	**g/m^2 /hour**		**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**
Tkam	**0.2771**	**1.3405**	853	5.5	11	8.56	0.67	1.81	18.02	8.45	1.95
Otar	**0.2173**	**2.6917**	521	7.2	18.1	14.26	1.68	3.84	69.44	35.01	10.95
Stat	**0.1104**	**2.1812**	603	6.3	15.4	11.46	1.36	1.66	43.68	18.74	6.31
Jcaro	**0.0939**	**2.4417**	605	5.7	18.8	11.16	1.74	3.72	206.29	28.13	16.81
Pagy	**0.0465**	**5.5670**	374	8.2	34.5	18.70	4.36	8.23	680.82	130.32	106.48
Psub	**0.0343**	**1.6686**	308	7.5	19.9	13.78	1.24	9.64	255.29	49.12	18.34
Acha	**0.0265**	**1.2174**	248	9.5	16.5	11.73	1.43	24.21	99.8	45.68	13.57
Hsag	**0.0222**	**0.9077**	74	4.5	48.1	14.72	7.90	1.38	2317.23	109.23	282.77
Amac	**0.0213**	**1.6819**	76	10	29.8	16.53	3.64	17.95	384.52	88.51	63.88
Hkel	**0.0212**	**1.3898**	129	11.9	16.1	14.15	0.82	4.26	110.92	67.22	14.69
Jbela	**0.0206**	**0.9063**	182	4.7	18.4	12.45	3.33	2.13	130.99	46.79	30.34
Etet	**0.0171**	**1.9932**	164	8	35.3	18.47	5.77	7.38	414.63	133.73	106.09
Cdus	**0.0167**	0.1684	169	8.2	15.9	12.21	1.37	3.46	21.22	10.07	3.31
Sruc	**0.0163**	0.2093	149	5.4	9.2	7.87	0.45	5.58	16.72	12.82	1.66
Omil	**0.0144**	**2.2307**	138	15.9	28.2	22.02	2.79	19.68	387.69	154.90	69.45
Orub	**0.0107**	**1.7303**	104	5	27.1	20.73	3.41	2.84	353.82	156.79	60.49
Lbre	**0.0106**	**0.2306**	103	5.9	7.8	6.78	0.36	4.99	12.22	8.32	1.32
Ncae	**0.0102**	**0.9097**	87	4.2	35.4	14.19	7.20	0.44	518.94	77.19	89.81
Ctrun	0.0078	**0.8101**	47	10.1	29.2	17.77	4.57	18.59	325.68	106.89	78.54
Jcaru	0.0072	**0.3022**	41	9.6	16.3	12.90	1.32	19.03	118.52	43.10	15.88
Imel	0.0059	0.2137	58	7.1	19.7	12.89	2.19	7.08	97.41	36.16	15.97
Agym	0.0059	0.0290	53	3.9	6.7	5.70	0.56	2.35	6.94	4.88	1.17

Table 5.12, continued

Parg	0.0057	**0.2656**	55	5.5	17.6	9.53	2.33	8.72	269.11	46.94	42.00
Sbag	0.0052	0.0419	53	4	9.9	7.84	1.06	0.8	15.07	8.08	2.83
Scom	0.0051	**0.4468**	50	13.2	34.7	18.01	4.56	33.19	431.83	86.85	69.73
Pmic	0.0047	**0.4763**	47	8.8	23.9	18.66	3.96	10.59	181.68	98.49	50.74
Ajub	0.0046	0.1342	122	4.5	14.6	10.97	1.83	1.81	76.69	26.85	11.74
Sarg	0.0033	0.2037	30	5.8	18.2	10.15	2.57	12.62	232.16	63.83	48.31
Nsal	0.0028	**0.2590**	28	6.6	22	15.98	4.78	6.83	207.35	103.21	64.59
Sstr	0.0025	0.1810	21	21	39.2	29.60	5.04	19.79	186	76.55	37.68
Clin	0.0024	0.1263	24	9.4	33.9	20.98	5.12	7.29	151.88	54.12	31.21
Jborn	0.0024	0.1894	30	7.8	18.5	15.27	2.62	10.68	157.01	88.62	39.34
Evaig	0.0021	0.1006	20	12.4	16	13.75	0.89	38.14	76.53	48.88	9.75
Ielo	0.0021	0.0851	20	11.4	15.1	14.01	1.05	22.58	54.81	41.35	9.09
Sins	0.0016	0.0231	16	7.6	8.5	8.07	0.24	12.06	16.45	14.02	1.02
Cbil	0.0015	0.0456	15	9.8	22.9	14.79	4.64	6.87	84.17	29.53	25.97
Lluna	0.0015	0.1275	15	6.5	18.2	12.35	3.19	10.55	237.18	82.61	69.58
Ppar	0.0014	0.1449	14	14.3	20.1	16.74	1.61	59.17	153.45	100.59	23.98
Sgut	0.0014	**0.4555**	15	24.3	39.8	31.72	5.53	132.67	560.82	329.19	157.07
Druss	0.0013	0.0495	13	8	13.6	11.63	1.55	10.18	59.73	37.01	13.62
Rbra	0.0011	0.0880	11	14.8	16.8	15.81	0.61	60.14	96.68	77.76	12.14
Tnei	0.0010	0.0389	10	10.8	13.9	12.45	0.89	23.62	46.89	37.84	7.37
Adje	0.0010	0.0538	4	5.4	6.6	5.88	0.51	5.41	10.08	7.02	2.08
Usulp	0.0010	0.0507	10	9.4	14.7	12.94	1.73	23.35	65.93	49.26	14.75
Aveno	0.0010	0.0527	1	16.9				49.12			
Stri	0.0010	0.0099	10	7	9.4	8.42	0.80	5.08	12.89	9.59	2.65
Tthe	0.0010	0.0046	10	4.5	7	5.38	0.89	2.74	8.59	4.51	2.05
Tlep	0.0009	0.0495	9	24.6	46.9	40.14	6.36	23.92	91.49	53.40	19.73
Aatr	0.0009	0.0314	3	9.6	11.5	10.23	1.10	23.6	43.7	32.01	10.44

Table 5.12, continued

Ccyn	0.0009	0.0627	9	9.7	30.4	23.22	6.37	5.42	137.35	67.74	41.86
Pane	0.0008	0.0383	9	9.1	16.5	12.44	2.46	18.57	106.1	47.82	29.14
Dpun	0.0008	0.0279	8	6.6	8.8	7.83	0.69	19.48	49.39	33.86	9.52
Tcroc	0.0007	**0.2679**	7	44.6	62.3	56.50	6.23	113.04	560.55	372.08	146.03
Lind	0.0007	0.0568	8	10.5	42.7	17.30	10.51	26.71	1062.37	201.83	349.36
Tobl	0.0007	0.0480	7	6.5	12.2	10.87	1.99	16.13	113.91	66.57	30.81
Gery	0.0006	0.0207	6	9.1	11.1	9.67	0.74	22.65	47.88	33.57	8.16
Pind	0.0005	0.0564	8	17.2	24.5	19.21	2.34	49.76	125.24	68.53	25.42
Stal	0.0005	0.0330	5	15.3	19	16.64	1.41	50.45	94.76	64.07	18.33
Ssih	0.0005	0.0235	5	14.9	17.9	16.12	1.21	36.12	56.59	45.68	8.92
Tham	0.0005	0.0130	5	6.3	16.5	10.78	4.46	3.74	61.27	25.23	26.56
Pchi	0.0005	0.0191	5	6.5	11.4	8.66	1.80	11.78	94.58	37.19	33.78
Kind	0.0005	0.0071	5	8.3	9.7	8.84	0.53	11.74	18.27	13.86	2.63
Mcord	0.0004	0.0463	4	18.7	20.8	19.50	0.93	105.94	122.43	112.51	7.21
Aind	0.0004	0.0029	10	9.7	16.9	13.54	2.53	18.01	100.29	52.28	32.72
Cnudu	0.0003	0.0243	3	19	24.5	21.67	2.75	39.93	128.27	78.82	45.11
Pnig	0.0003	0.0068	3	8	9	8.47	0.50	16.29	29.17	22.14	6.52
Lsuri	0.0003	**0.2697**	3	15.3	40.7	26.10	13.12	132.29	2115.18	873.86	1081.79
Sycom	0.0003	0.0148	4	15.3	19.9	17.55	1.88	25.56	76.42	46.44	21.42
Ethr	0.0003	0.0022	3	7	9.1	7.83	1.12	6.24	8.27	7.10	1.05
Dflu	0.0003	0.0455	3	12.2	14.7	13.77	1.37	123.05	171.36	147.32	24.16
Pmel	0.0003	0.0417	1	21.2				160.13			
Eorb	0.0002	0.0071	2	8	8.2	8.10	0.14	32.03	36.88	34.46	3.43
Hfar	0.0002	0.0050	2	14.9	23.6	19.25	6.15	16.31	32.67	24.49	11.57
Lcal	0.0002	0.1425	1	25.3				323.06			
Cdora	0.0002	0.0386	2	29.9	31.6	30.75	1.20	167.92	207.05	187.49	27.67
Ctala	0.0002	0.0311	2	43.1	61.4	52.25	12.94	93.01	208.87	150.94	81.93

Table 5.12, continued

Obir	0.0002	0.0233	2	16.6	21.1	18.85	3.18	72.35	153.53	112.94	57.40
Huar	0.0002	0.0113	2	11.2	12.8	12.00	1.13	47.72	61.8	54.76	9.96
Dzug	0.0001	0.0060	1	14.3				58.42			
Lsava	0.0001	0.0075	1	46.6				73.16			
Gfila	0.0001	0.0074	1	12.8				72.27			
Jwebe	0.0001	0.0038	1	12				36.87			
Cmal	0.0001	0.0023	1	9.8				22.19			
Emach	0.0001	0.0365	1	324.6				354.79			
Agru	0.0001	0.0249	1	21				242.39			
Stol	0.0001	0.0065	1	17.4				62.81			
Pkaa	0.0001	0.0050	1	12.3				48.98			

Of the total of 5885 individuals of fish sampled from the subtidal edge off Klang Strait mudflat, 43.2 % of it belonged to the medium size class (1/3 to 2/3 of the species‘ maximum length), 31.8 % from the small size class (i.e. < 1/3 of the species‘ maximum length) and 25 % from the large size class (Table 5.13). Among the 87 species of fish found in the subtidal area, thirty-eight species had mainly individuals of the medium size category, twenty-six species had mainly small size range category and twenty three species had mainly large size range category. Fish species that often found in large sized category are such as the clupeids *E. thoracata, O. tardoore* and *Hilsa keele*, engraulids such as the *S. taty, S. baganensis, S. tri*, and the polynemids *E. tetradactylum*.

Table 5.13 Summary of fish size (SL) based on data of fish collected from subtidal edge of Klang Strait mudflat during monthly and periodic diel samplings. Code for each fish species can be found on Table 5.1. * Valid N refers to actual number of measurements taken on each fish species. Size class of fish species are reported as a percentage relative to total individuals of each species. Size class of each fish species was determined by using Nagelkerken and van der Velde‘s (2002)‘s method, where each individual was ascribed to one of three size classes: small (< 1/3 of the species‘ maximum length), medium (1/3 to 2/3 of the species‘ maximum length), and large (> 2/3 of the species‘ maximum length).

Family	Code	N*	Size range (cm)		Size category		
			Min	Max	Small	Medium	Large
Ambassidae	Agym	53	3.9	6.7	26.4	73.6	0.0
Ariidae	Amac	76	10	29.8	38.2	61.8	0.0
	Aveno	1	16.9	16.9	0.0	0.0	100.0
	Ctrun	47	10.1	29.2	23.4	72.3	4.3
	Hsag	74	4.5	48.1	60.8	36.5	2.7
	Ncae	87	4.2	35.4	42.5	55.2	2.3
	Omil	138	15.9	28.2	0.0	95.7	4.3
	Pagy	374	8.2	34.5	25.4	61.0	13.6
Batrachoididae	All gru	1	21	21	0.0	0.0	100.0
Belonidae	Sstr	21	21	39.2	0.0	27.6	72.4
	Tcroc	7	44.6	62.3	0.0	14.3	85.7
Carangidae	Aind	4	5.4	6.6	100.0	0.0	0.0
	Adje	10	9.7	16.9	60.0	40.0	0.0
	Aatr	3	9.6	11.5	0.0	100.0	0.0
	Cmal	1	9.8	9.8	100.0	0.0	0.0
	Mcord	4	18.7	20.8	100.0	0.0	0.0
	Pnig	3	8	9	100.0	0.0	0.0
	Stal	5	15.3	19	0.0	100.0	0.0
	Stol	1	17.4	17.4	0.0	100.0	0.0
Chirocentridae	Cdora	2	29.9	31.6	0.0	100.0	0.0

Table 5.13, continued

	Cnudu	3	19	24.5	0.0	100.0	0.0
Clupeidae	Ano cha	248	9.5	16.5	0.0	91.9	8.1
	Ethr	3	7	9.1	0.0	0.0	100.0
	Hkel	129	11.9	16.1	0.0	14.7	85.3
	Otar	521	7.2	18.1	0.0	27.1	72.9
Cynoglossidae	Cbil	15	9.8	22.9	66.7	33.3	0.0
	Ccyn	9	9.7	30.4	0.0	11.1	88.9
	Clin	24	9.4	33.9	13.0	82.6	4.3
	Dzug	1	14.3	14.3	100.0	0.0	0.0
	Huar	2	11.2	12.8	100.0	0.0	0.0
	Dpun	8	6.6	8.8	100.0	0.0	0.0
Elopidae	Emach	1	324.6	324.6	0.0	0.0	100.0
Engraulidae	Cdus	169	8.2	15.9	0.0	82.2	17.8
	Stat	603	6.3	15.4	0.0	19.8	80.2
	Sbag	53	4	9.9	0.0	3.8	96.2
	Stri	10	7	9.4	0.0	0.0	100.0
	Tham	5	6.3	16.5	60.0	40.0	0.0
	Tkam	853	5.5	11	0.0	99.5	0.5
Ephippidae	Eorb	2	8	8.2	0.0	100.0	0.0
Gerreidae	Gery	6	9.1	11.1	0.0	100.0	0.0
	Gfila	1	12.8	12.8	0.0	100.0	0.0
	Pkaa	1	12.3	12.3	100.0	0.0	0.0
Hemiramphidae	Hfar	2	14.9	23.6	50.0	50.0	0.0
Kurtidae	Kind	5	8.3	9.7	0.0	0.0	100.0
Latidae	Lcal	1	25.3	25.3	0.0	100.0	0.0
Leiognathidae	Lbre	103	5.9	7.8	0.0	100.0	0.0
	Sins	16	7.6	8.5	0.0	0.0	100.0
	Sruc	149	5.4	9.2	0.0	0.0	100.0
Lobotidae	Lsuri	3	15.3	40.7	66.7	33.3	0.0
Mugilidae	Evaig	20	12.4	16	100.0	0.0	0.0
	Ppar	14	14.3	20.1	0.0	92.9	7.1
	Pmel	1	21.2	21.2	0.0	0.0	100.0
	Psub	308	7.5	19.9	32.6	65.5	1.9
Mullidae	Usulp	10	9.4	14.7	0.0	100.0	0.0
Muraenesocidae	Ctala	2	43.1	61.4	50.0	50.0	0.0
Platycephalidae	Pind	8	17.2	24.5	100.0	0.0	0.0
Polynemidae	Etet	164	8	35.3	0.0	36.2	63.8
	Lind	8	10.5	42.7	87.5	12.5	0.0
Pristigasteridae	Ielo	20	11.4	15.1	100.0	0.0	0.0
	Imel	58	7.1	19.7	0.0	17.4	82.6
Scatophagidae	Sarg	30	5.8	18.2	93.3	6.7	0.0
Sciaenidae	Ajub	122	4.5	14.6	1.6	36.9	61.5
	Druss	13	8	13.6	7.7	92.3	0.0
	Jbela	182	4.7	18.4	17.7	81.2	1.1
	Jborn	30	7.8	18.5	16.7	6.7	76.7
	Jcaro	605	5.7	18.8	6.9	88.9	4.1
	Jcaru	41	9.6	16.3	0.0	100.0	0.0
	Jwebe	1	12	12	0.0	0.0	100.0
	Nsal	28	6.6	22	78.6	21.4	0.0
	Orub	104	5	27.1	25.0	43.3	31.7
	Obir	2	16.6	21.1	100.0	0.0	0.0
	Pmic	47	8.8	23.9	14.9	85.1	0.0
	Pane	9	9.1	16.5	11.1	88.9	0.0
Scombridae	Rbra	11	14.8	16.8	0.0	100.0	0.0
	Scomm	50	13.2	34.7	88.0	12.0	0.0
	Sgut	15	24.3	39.8	13.3	86.7	0.0
Sillaginidae	Ssih	5	14.9	17.9	0.0	100.0	0.0
Soleidae	Sycom	4	15.3	19.9	0.0	0.0	100.0

Table 5.13, continued

Stromateidae	Parg	55	5.5	102	96.4	0.0	3.6
	Pchi	5	6.5	11.4	100.0	0.0	0.0
Terapontidae	Tthe	10	4.5	7	100.0	0.0	0.0
Tetraodontidae	Dflu	3	12.2	14.7	0.0	0.0	100.0
	Lluna	15	6.5	18.2	80.0	20.0	0.0
	Tobl	7	6.5	12.2	100.0	0.0	0.0
Triacanthidae	Tnei	10	10.8	13.9	0.0	100.0	0.0
Trichiuridae	Lsava	1	46.6	46.6	0.0	100.0	0.0
	Tlep	9	24.6	46.9	11.1	88.9	0.0
Total/Mean		5885			31.8	43.2	25.0

5.5 Discussion

The Klang coastal mudflat features a dynamic environment where the intertidal mudflat is inundated twice during high tide and exposed twice during low tide. Despite this environmental variability, a total of 116 species that ingressed into the intertidal mudflat during high tide was recorded. The high number of species recorded appeared to be common for most tropical estuarine systems (Blaber, 1997). Two studies from two decades ago (Chong et al., 1990; Sasekumar & Chong, 1991) at sites near SB using similar sampling gears recorded 70 and 21 fish species respectively. The lower numbers are attributed to the limited sampling periods of both studies. Another study by Chong et al. (2012b) at the Matang coastal mudflat, located farther north of the current study site, recorded at least 97 species of fish caught by using gill nets, beam and otter trawls in a mixed day and night sampling regime, over a period of 19 months. Although species richness of fish utilizing the Klang mudflats is high, the fish species are dominated by a few families: sciaenids, ariids and engraulids. This observation is quite consistent with the previous studies in the same area (Chong et al., 1990; Sasekumar & Chong, 1991).

A global comparison also showed that the present findings showed relatively higher species richness compared to similar habitats elsewhere (see Table 2.1). For examples, 31 fish species were sampled seasonally using gill net in a tropical mudflat of the Indian

Sundarbans (Chaudhuri et al., 2013); 39 species were sampled seasonally using fyke net, gill net and beach seine in a southern Australia mudflat (Hindell & Jenkins, 2004); 20 species were sampled during day and night time by using a beach seine in the Tama River mudflat in central Japan, (Kanou et al., 2005); 51 species were sampled seasonally using a beach seine in a Hong Kong mudflat (Tse et al., 2008); and 66 species were recorded from diel and seasonal sampling using beach seine in a tropical mudflat in north-eastern Brazil (Garcia & Pessanha, 2018). Although these results may be partly due to differences in terms of sampling gear, sampling effort and/or temporal variance, the present study indicated the importance of the Klang tropical mudflat in supporting a highly diverse fish community that utilizes the habitat.

In terms of standing stock, previous studies in the Klang mudflat recorded a mean fish biomass of 10.53 kg/ha (Sasekumar & Chong, 1991) using similar sampling gear, and 5.96 kg/ha (Chong et al., 1990) using trawl net. The latter study also reported mean biomass of the juvenile fish stock in the adjacent Klang mangrove of 17.7 kg/ha. These figures are generally lower compared to those found in the current study (see Table 5.4) which ranged from 5.5 kg/ha to 554.7 kg/ha. Meanwhile, the study by Chong et al. (2012a) at the Matang coastal mudflat using a small beam trawl estimated total faunal standing stock biomass of 21.23 to 34.89 kg/ha; approximately 87% of the biomass comprised of invertebrates such as molluscs and anomurans.

In the Klang Strait mudflat, the majority of caught individuals (50.4 %) were considered of small sized. With individual‘s size length less than 1/3 of their maximum length, these fishes are likely still a juvenile fish (Nagelkerken & van der Velde, 2002). On the other hand, anchovies such as the Bagan anchovy, spined anchovy and white sardine are often found as large sized categroy. These are small-sized species that could be mature fishes in the mudflat. The functional role of intertidal mudflat as shallow nursery habitat for small and juvenile fish was discussed in some studies (Morrison et al., 2002; Kanou et al., 2005). Juvenile fish take advantageous on the ample food resources in mudflat and shallow water habitat to avoid predators. However, Nip & Wong (2010) deemed that intertidal mudflat is unsuitable as refugia for juvenile fish due to the higher piscivory rate in the mudflat area as opposed to adjacent mangrove area. Habitats with high predator density are prone to reaching their maximum carrying capacity (Morris, 2003). A decline in population growth can occur when carrying capacity of a habitat is reached (Goss-Custard et al., 2001). Nevertheless, the high portion of small fish in this study likely reflected the relevance of Klang Strait mudflat as an important feeding or nursery area.

The fish community of the Klang Strait mudflat appeared to be heterogeneous spatially. In particular, the SB mudflat located on the southern part of Selangor River had higher species richness and diversity compared to the BP mudflat (northern part of Selangor River). More fish species, particularly the catfishes were associated with the SB mudflat. Although BP mudflat had lower species diversity, it is characterized by higher fish abundance and biomass, dominated by fish species such as the Caroun croaker and Kammal anchovy. Different localities, areas and regions of the mudflat appeared to serve as feeding or nursery areas to different or certain groups of fishes (Gibson et al., 2002; Stevens, 2006). Significant differences in an estuary‘s community structure is common when the habitats are different, such as between upstream and downstream (Thiel et al., 1995), and between mudflat and adjacent mangrove (Tse et al., 2008; Nip & Wong, 2010). However, in intertidal mudflats, spatial differences in community structure often related to the depth-related and seasonal variables (Gibson, 1973; Hernández et al., 2002; Griffiths et al., 2003). Differences in topography and gradient of water depth were related to fish body size and distribution of prey species, where larger piscivorous fish has lower density in the upper reaches of the intertidal area while smaller fishes migrate higher on the mudflat to avoid predation (Paterson & Whitfield, 1996; Gibson et al., 2002; Baker & Sheaves, 2005). In this study, fishes in SB mudflat were more of large bodied, as opposed to BP mudflat that has high abundance of small fodder fish.

Both SB and BP mudflat did not display any significant differences in their water parameters (i.e. salinity, temperature, dissolved oxygen and pH) (Section 4.4). The mudflats also appeared homogeneous and without apparent vegetation. This can be attributed to differences in substrate texture and mudflat productivity (Section 4.3). Sediment particle size analyses of both sites indicated that BP mudflat contained relatively higher percentage of the larger soil particles (more silt and sand) than SB mudflat (Figure 4.5), whereas the finer sediments at SB mudflat had higher percentage of organic particles and chlorophyll *a* content than BP mudflat. Fine-grained sediments generally carry a higher organic content compared to coarse sediment (Köster & Meyer-Reil, 2001). High organic matter may also indicate higher food availability in sediment that can support benthic feeders such as the pomfrets, scats and mullets were observed to be found more in the SB mudflat (Figure 5.1). On the other hand, many researchers also have shown that high organic matter content and low hydrodynamic properties of finer-sediment habitats favor higher densities, diversities and richness of macrobenthic species (Alongi, 1990; Gray & Elliott, 2009; Hossain, 2011), which in turn support most of the benthic macrofeeders such as catfishes and tongue soles. Coincidentally, both longsnouted catfish and Sagor catfish are more prominent in the SB than BP site.

Compared to BP, SB is more anthropogenically disturbed due to its location as an extensive blood cockle culture bed (2500 ha) that are artificially seeded by local fisherman throughout the year. Generally, bivalve culture beds can influence the local system in three ways namely food and waste production, disturbance through harvesting activities, and alteration of physical structure such as substrate (Dumbauld et al., 2009). Several manipulative studies on bivalves have demonstrated that the physical structure of the bivalve itself played larger role than the bivalve‘s biological activities in engineering the local habitat (Bódis et al., 2014; Dumbauld et al., 2009; Ricciardi et al., 1997). Densely cultured bivalve shells can create nooks and crannies on and among them, allowing sediments to accumulate within the matrix, thus forming different microhabitats and increasing habitat heterogeneity (Mohammed, 1992; Lohse, 1993; Borthagaray & Carranza, 2007). This may also explain the high species diversity of fish as observed at SB and may contribute to the relatively higher POM content in the sediments (Gutierrez et al., 2003). The presence of large amount of cockles may also attracts their natural predators such as gastropods (Vermeij, 1980; Broom, 1985), which in turn attracted more fishes particularly the tongue soles and puffer fish (Figure 5.1) to ingress into mudflat for predation.

The wet period of the monsoon with significantly lower salinity (Section 4.2.3) appears to have more fish species in the mudflat compared to the dry period (Figure 5.2). Fishes such as sciaenids (*J. carouna, O. ruber, J. belangerii*, and *A. jubata*) and catfishes (*H. sagor* and *P. argyropleuron*) were more prominent during the wet period. In particular, the Caroun croaker‘s density peaked during the wet period between October 2012 and January 2013. In contrast, the spoonsnouted catfish *C. truncatus* and soldier croaker *N. soldado* were more abundant during the dry period, particularly at BP. The high occurrence of the soldier croaker was similarly observed during the drier period (June–September) on the west coast of India (Ansari et al., 1995). A study by Pang (1990) in Sarawak, East Malaysia revealed that the maturation process for both *C. truncatus* (total length 300–340 mm) and *Nemapteryx caelata* (220–260 mm) could start in August and reached its peak from December to January. In the present study, *C. truncatus* similarly recorded a peak density during September and *N. caelata* in

November. Most specimens of these two species had a size range of 220 to 330 mm during these periods, which indicate that both catfish ingressed into the mudflat as mature stages. However, it is not known whether the catfish spawned in the mudflat; only gonadal and larval studies could confirm this. Nevertheless, many small juveniles of *N. caelata* were recorded subsequently in January and February though not for *C. truncatus* which may indicate that the latter spawn farther offshore or in the deeper water of the estuary. Other than for feeding or spawning, the movement of fish may also be a result of wind forcing. Several studies had revealed that fish movement and larval recruitment were positively correlated with wind force and direction (Findlay & Allen, 2002; Thorrold et al., 1994).

Differences in diel (ie. day and night) utilization of the mudflat may be partially explained by the trophic ecological role played by individual species (Morrison et al., 2002; Castillo-Rivera et al., 2010). In the present study, the majority of fish species that were found to be abundant in the mudflat area during day time were predatory fishes such as Caroun croaker, tardoore, fourfinger threadfin, tigertooth croaker, and Belanger‘s croaker. These visual predatory fish may hunt their prey during daylight as shown in previous studies (Salini et al., 1998; Eskandary et al., 1999). On the other hand, small fodder fish such as bald glassy occurred abundantly in the mudflat at night. This is consistent with the findings of previous studies (Martin & Blaber, 1983; Krumme et al., 2015) which reported that ambassids feed and occur mainly during the night. The present study also recorded that the ambassids were abundant especially during the NEM season (November to January). According to Chew et al. (2012), common mangrove and mudflat fish species such as ariids, engraulids, and ambassids feed primarily on copepods. They also reported that copepod and phytoplankton density peaked during the wetter months (November and February) of the NEM season (Chew & Chong, 2011). In contrast, several studies showed that ambassids are scarce in the mudflat as compared to mangrove forest (Tse et al., 2008) as they prefer sheltered (Shao & Chen, 2003) and structurally complex habitats (Laegdsgaard & Johnson, 2001). However, the present study shows that ambassids utilizing the shallow coastal mudflat at night may indicate nocturnal feeding to avoid visual predators. On the other hand, ambassids, like other marine stragglers, irregularly visit the coastal mudflat without any apparent estuarine requirement (Elliot & Dewailly, 1995; França et al., 2008).

Moon light intensity has been reported to have an impact on community composition and breeding of fish (Horký et al., 2006; Ikegami et al., 2014; Krumme et al., 2015) and invertebrates (Nascimento et al., 1991; Camargo et al., 2002; Bentley et al., 1999). Fishes such as the silver pomfret *P. argenteus* at different geographical regions exhibited breeding periods that are correlated with the moon phases (Almatar et al., 2004). The ambient light produced from moonlight is known to facilitate visual predator‘s migration and predation (Poisson et al., 2010). Moon phase in the present study (new moon vs. full moon) however appeared to have no discernible effect on the mudflat fish species in Klang Strait. This is likely due to the high turbidity (ranging 0.3 to 0.5 m secchi disc depth) of the mudflat waters so that moon light may offer little advantage to visual predators. Turbid shallow waters provide protection to young fish from predators (Blaber, 2000; McLusky & Elliot, 2004), which is further enhanced by darkness provided by the new moon (Krumme et al., 2015). The effect of moon light may however have a more pronounced effect on the molting and spawning of local shrimp species compared to fish species (Pushparajan et al., 2012; Ramarn et al., 2014). Berry and Chew (1973) also recorded that littorinid gastropods on the mangrove trees of west coast Malaysia spawn their eggs only during the alternating full moon.

The adjacent subtidal area off the mudflat was sampled for its fish species in order to assess its connectivity with the mudflat in term of fish movement. Almost 90% of the fish species sampled in the subtidal area were those also found in the intertidal mudflat and fish sizes largely overlapped despite using two different sampling gears. Also, the top five most abundant species in the barrier net catches were also in the top nine species of the gill net catches. This affirms the notion that fish ingression and egression reflect the ―expansion and contraction" of the fish population in the mudflat and immediate subtidal waters. However, this study also shows that about 28 % of the fish species in the mudflat (29 species) did not belong to the subtidal waters. This may suggest fish exiting into the nearby estuaries or tidal inlets during ebb tide, or that the gill net missed them due to chance, fish behavior or net selectivity (Hamley, 1975; Argent & Kimmel, 2005). Interestingly, the remaining 10 % of the subtidal fish species not recorded in the intertidal mudflat comprised of largely predatory fishes.

The effects of gill net selectivity on fish catch are well known (Hamley, 1975; Argent & Kimmel, 2005). In our case, the gill net (2.5" mesh size) used however sampled both pelagic fishes as well as most of the demersal fishes since the gill net reached the sea bottom or was very close to it. The 2.5"-mesh gill net is probably the most suitable gill net to sample outgoing fishes at the deeper subtidal edge of the mudflat as this study had demonstrated. Preliminary samplings using gill nets of 1"- and 5"-mesh size and trammel net gave poorer and less diverse catches. Nevertheless, the 2.5" gill net did not sample the flatfishes, glassfishes and gobies. Another limitation of the gill net, besides providing qualitative data like fish species, is that only semi-quantitative or relative abundance data (CPUE) could be obtained. Unfortunately, the CPUE is only useful to compare among similar data but cannot be compared with the abundance data obtained from the barrier net.

In conclusion, the fish community of Klang mudflat consisted of largely small- to medium-sized fish which were almost all juvenile fish. Only the small-sized species had adults in the mudflat. The SB mudflat comprised of higher diversity (100 species) of fish, but Ariidae, Clupeidae, Engraulidae, and Tetraodontidae were the numerically dominant families. In contrast, BP‘s fish community consisted of 90 species of fish, with high abundance from mainly the family Cynoglossidae, Plotosidae, and Ambassidae. The fish community structure also varied temporally. Most species however occurred throughout the year. More fishes (abundance) were found during the NEM than SWM. Species composition differed between the dry and wet period and between day and night; however, there was no difference between full and new moon. Daytime had more species of predatory fish, while nighttime had large numbers of small fishes.

CHAPTER 6: RESULTS AND DISCUSSION - TROPHODYNAMICS OF MUDFLAT FISH COMMUNITY

6.1 Trophic guilds

A total of 3875 stomachs belonging to 68 species and 32 families of fishes were examined in this study, with 535 empty stomachs excluded from analysis. Only 53 fish species (77.9 % of total fish species) with sufficient sample size ($n \geq 10$ per species) were selected for subsequent description of their diet (Table 6.1; Table 6.2). Among the selected fish species, *Sillago sihama* recorded the highest percentage of empty stomach (45.2 %), whereas lowest percentage of empty stomach was recorded by *Pomadasys kaakan* (1.9 %). The overall mean gut fullness of all species was 1.8 ± 0.4. Mean gut fullness of each species ranged from the lowest of 1.14 for *Anodonstoma chacunda* to the highest of 2.86 for *Dichotomyctere fluviatilis*.

Table 6.1 List of 53 fish species sampled in the Klang Strait mudflats with fish size, gut fullness and number of prey item categories found. The total number of stomachs examined (n), number of non-empty stomachs (GF or gut fullness > 0), mean gut fullness (1 = ¼ filled; 2 = ½ filled; 3 = ¾ filled; 4 = full), range and mean length of fish are indicated. Codes for each species are used throughout this study.

Feeding guild	Species name	n	GF > 0	Mean gut fullness	Size range		Mean SL (cm)	Number of prey item categories found
					(cm)	Category		
Iliophages (IL)	*Anodontostoma chacunda*	22	15	1.1 ± 1.0	5.1-6.9	Small	5.8 ± 0.6	3
	Ellochelon vaigiensis	18	15	1.8 ± 1.5	9.6-15.2	Small	12.3 ± 1.6	5
	Oreochromis mossambicus	27	18	1.3 ± 1.2	5.8-12.0	Small	9.3 ± 2.3	4
	Pampus argenteus	115	99	1.6 ± 1.1	5.9-14.6	Small	8.0 ± 1.7	7
	Pampus chinensis	46	36	1.4 ± 1.0	4.2-11.0	Small	7.4 ± 1.5	11
	Planiliza melinopterus	31	26	1.5 ± 1.0	6.5-9.8	Small	7.6 ± 0.8	8
	Planiliza subviridis	158	142	1.7 ± 1.1	5.4-13.3	Small	10.6 ± 2.0	3
	Scatophagus argus	52	48	2.4 ± 1.3	5.6-13.8	Small	9.9 ± 1.9	2
Copepods feeders (CO)	*Ambassis gymnocephalus*	106	89	1.5 ± 1.0	5.4-9.5	Medium	6.0 ± 0.5	7
	Escualosa thoracata	33	30	2.0 ± 1.2	6.6-9.6	Large	8.1 ± 0.9	7
	Leiognathus brevirostris	58	51	1.6 ± 1.0	5.8-7.8	Medium	6.8 ± 0.4	5
Shrimp/teleost feeders (ST)	*Otolithes ruber*	190	166	2.1 ± 1.3	6.5-22.5	Small	13.7 ± 5.3	3
	Platycephalus indicus	14	12	2.4 ± 1.5	6.5-16.1	Small	13.5 ± 3.5	3
	Scomberomorus commerson	17	14	1.8 ± 1.3	14.3-21.7	Small	16.3 ± 2.1	8
	Strongylura strongylura	123	104	1.8 ± 1.4	13.5-26.6	Medium	23.1 ± 3.1	13
Shrimp/decapod feeders (SD)	*Ephippus orbis*	16	12	1.7 ± 1.6	5.7-8.2	Small	7.2 ± 0.9	11
	Ilisha elongata	17	16	2.2 ± 1.3	6.2-15.1	Small	11.5 ± 3.0	8
	Johnius belangerii	102	95	2.3 ± 1.2	9.1-17.8	Medium	12.7 ± 1.9	13
	Johnius carouna	195	160	1.6 ± 1.3	8.4-15.5	Medium	11.3 ± 1.5	3
	Pomadasys kaakan	103	101	2.4 ± 1.2	6.6-14.2	Small	10.0 ± 2.0	8
Shrimp/zooplankton feeders (SZ)	*Alepes djejaba*	16	11	1.9 ± 1.6	8.2-14.1	Medium	10.2 ± 2.0	11
	Thryssa kammalensis	168	124	1.4 ± 1.2	5.5-9.8	Medium	8.5 ± 0.8	3
Shrimps feeders (SH)	*Brevitrygon walga*	23	22	2.1 ± 1.1	6.9-16.4	Small	10.0 ± 2.5	4
	Coilia dussumieri	72	63	1.4 ± 0.9	7.3-13.2	Medium	10.7 ± 1.6	6
	Dendrophysa russelii	98	90	1.7 ± 1.1	8.4-14.5	Medium	10.6 ± 1.5	10
	Eleutheronema tetradactylum	149	128	2.3 ± 1.4	6.6-14.5	Medium	10.8 ± 1.8	7
	Harpadon nehereus	23	16	1.5 ± 1.4	5.9-13.0	Small	10.6 ± 2.0	5
	Ilisha melastoma	91	81	2.2 ± 1.3	5.8-11.6	Medium	9.1 ± 1.7	12
	Johnius borneensis	19	17	1.8 ± 1.0	7.6-15.4	Small	11.5 ± 2.8	8
	Leptomelanosoma indicum	15	12	2.5 ± 1.9	13.1-22.5	Small	16.7 ± 3.6	8
	Nibea soldado	104	101	1.8 ± 1.1	7.1-18.5	Small	12.6 ± 3.9	6
	Opisthopterus tardoore	138	126	2.0 ± 1.2	13.3-18.1	Medium	15.4 ± 1.0	8

Table 6.1, continued

	Panna microdon	140	107	1.5 ± 1.2	10.1-19.9	Medium	15.1 ± 3.1	6
	Setipinna taty	180	125	1.2 ± 1.1	10.2-14.5	Large	12.1 ± 1.0	8
	Stolephorus baganensis	44	32	1.6 ± 1.4	6.8-9.7	Large	8.0 ± 0.7	3
	Terapon theraps	18	13	1.2 ± 1.0	4.2-7.6	Small	5.7 ± 1.3	11
	Thryssa hamiltonii	43	36	1.9 ± 1.2	9.0-17.7	Medium	10.8 ± 2.1	5
	Upeneus sulphureus	28	26	2.4 ± 1.2	5.2-9.6	Small	7.3 ± 1.5	8
Polychaete feeders (PO)	*Drepane punctata*	78	72	2.3 ± 1.2	5.8-15.1	Small	8.8 ± 2.4	6
	Sillago sihama	31	17	1.2 ± 1.3	13.0-16.5	Large	14.8 ± 1.2	12
Mixed macrobenthos feeders (MX)	*Arius maculatus*	89	79	2.2 ± 1.3	5.7-14.3	Small	10.9 ± 2.6	14
	Cryptarius truncatus	20	18	2.3 ± 1.3	15.0-27.0	Medium	19.5 ± 4.1	11
	Cynoglossus cynoglossus	98	91	1.5 ± 0.9	7.5-12.3	Medium	9.8 ± 1.2	9
	Cynoglossus lingua	69	57	1.5 ± 1.1	15.3-29.5	Medium	22.2 ± 4.7	7
	Dichotomyctere fluvialitis	28	27	2.9 ± 1.1	6.0-11.0	Medium	8.6 ± 1.6	14
	Hexanematichthys sagor	104	101	2.4 ± 1.2	4.6-14.6	Small	9.2 ± 2.7	7
	Lagocephalus lunaris	25	23	2.0 ± 1.1	6.1-12.5	Small	8.1 ± 1.7	8
	Nemapterys caelata	92	90	2.0 ± 1.1	6.5-13.8	Small	10.8 ± 1.9	10
	Osteogeneiosus militaris	23	18	1.6 ± 1.3	16.5-25.8	Medium	21.3 ± 2.5	13
	Plicofollis argyropleuron	146	139	1.8 ± 1.1	16.8-31.6	Medium	21.3 ± 3.3	8
	Plotosus canius	97	92	2.2 ± 1.0	9.1-32.3	Small	19.5 ± 5.7	11
	Takifugu oblongus	28	23	1.4 ± 0.9	2.4-10.9	Small	4.9 ± 2.1	11
	Triacanthus nieuhofii	31	29	2.1 ± 1.1	9.7-17.5	Medium	12.6 ± 2.1	6

Table 6.2 Diet of 53 fish species from the Klang mudflats, organized by dietary trophic guilds and expressed as Index of Relative Importance (% IRI) for 17 prey categories. _others‘ comprised 5 minor prey categories including asteroids, holothuroids, limulids, insects and cirripedes. n indicates number of non empty stomachs examined. * indicated the 34 species subjected to PERMANOVA analysis of fish diet between sites (BP and SB) and between monsoon seasons (NEM and SWM). 0.0 value denotes less than 0.1%IRI.

Species name	n	microalgae	tintinids	copepods	amphipods	decapod	zoeae	shrimps	fish	bnrachyurans	anomurans	isopods	gastropods	bivalves	cephalopods	polychaetes	nematodes	detritus	others
Iliophages (IL)																			
Anodonstoma chacunda	15	99.5	0.5																
*Planiliza melinopterus**	26	74.8	1.7															23.5	
*Planiliza subviridis**	142	91.4	1.4	0.1														7.1	
Ellochelon vaigiensis	15	91.4	0.1	1.9	0.1													6.5	
Oreochromis mossambicus	18	96.9	2.9		0.2														
*Pampus argenteus**	99	56.8	1.1	19.2	0.2		2.9	0.2		0.3								19.4	
*Pampus chinensis**	36	80.6	5.1	3.1			2.0			3.4						2.2		3.6	
*Scatophagus argus**	48	19.5	2.4	0.8			2.7	0.0	0.1	0.1	0.0	0.0				0.3		74.1	
Copepods feeders (CO)																			
*Ambassis gymnocephalus**	89	0.0		94.4	0.9		1.3	0.6			2.7							0.0	
*Escualosa thoracata**	30			92.8	1.5		0.5	5.0						0.2					
*Leiognathus brevirostris**	51			90.1			1.2	0.7			1.1			5.3		0.2		1.4	
Shrimp/teleost feeders (ST)																			
*Otolithes ruber**	166			0.0			0.0	74.1	25.2	0.1	0.0	0.0	0.0	0.0	0.5		0.0	0.0	
Platycephalus indicus	12							44.4	48.0									7.7	
Scomberomorus commerson	14							7.9	91.7	0.4									
*Strongylura strongylura**	104							47.2	45.5	0.7	0.0	0.0		0.0			6.5	0.0	
Shrimp/decapod feeders (SD)																			
Ephippus orbis	12							44.0		13.4	42.6								
Ilisha elongata	16			2.9			2.1	61.8	3.8	23.1	4.3			0.8				1.2	
*Johnius belangerii**	95							31.3	0.2	26.6	37.9		0.7	0.0		3.2		0.0	
*Johnius carouna**	160			2.5			1.2	52.3	5.5	11.2	20.6		0.2	4.6	0.0	1.9	0.0	0.1	0.0

Table 6.2, continued

*Pomadasys kaakan**	101		2.4			80.9	0.0	5.0	4.8	0.5	3.7	0.1	0.0	2.4		0.1	
Shrimp/zooplankton feeders (SZ)																	
Alepes djejaba	11		20.2			69.5							10.3				
*Thryssa kammalensis**	124	0.0	38.6		0.0	57.5	0.1	3.5	0.1		0.0	0.0			0.0	0.2	
Shrimps feeders (SH)																	
Brevitrygon walga	22			0.2		93.1	0.1	5.0	0.0			0.8		0.7		0.1	
*Coilia dussumieri**	63					93.8	2.2	3.0					0.9				
*Dendrophyssa russelii**	90		1.0		0.7	84.1	0.2	12.5	0.0					0.5	0.0	0.8	0.1
*Eleutheronema tetradactylum**	128		0.0		0.0	96.0	3.4	0.4		0.0	0.0	0.0		0.0	0.0	0.0	
Harpadon nehereus	16					96.0	3.5					0.5					
*Ilisha melastoma**	81		0.7	0.0		97.0	0.6	1.5	0.0					0.0		0.2	
Johnius borneensis	17		0.9			83.5	4.5	1.5	0.2	6.9				0.3		2.2	
Leptomelanosoma indicum	12					89.3	10.0	0.2					0.3			0.2	
*Nibea soldado**	101		0.1		0.0	92.5	5.6	0.8	0.7	0.0	0.0	0.0		0.0		0.1	0.0
*Opisthopterus tardoore**	126		3.2		0.2	95.8	0.6	0.0	0.1	0.0						0.0	
*Panna microdon**	107					94.2	4.5	0.4	0.2				0.5		0.1		
*Setipinna taty**	125		0.0		0.6	98.8	0.0	0.5	0.0					0.0		0.1	
*Stolephorus baganensis**	32				0.1	98.6	0.1	0.4				0.9					
Terapon theraps	13	0.9				93.8	0.8	0.4	2.0				1.4	0.7			
*Thryssa hamiltonii**	36		0.7			95.5	0.3	2.3		0.6						0.6	
Upeneus sulphureus	26		2.2			89.6	3.7	1.1				3.0				0.4	
Polychaete feeders (PO)																	
*Drepane punctata**	72	2.1	0.2			6.7		0.0	0.2	0.1	0.4	0.1		90.2	0.0	0.0	0.0
Sillago sihama	17		6.9				0.3	6.6	9.2					76.7		0.4	
Mixed macrobenthos feeders (MX)																	
*Arius maculatus**	79		2.2	0.1	0.1	3.8	0.6	5.6	0.1	0.0	0.0	83.4		2.1	0.0	1.9	0.1
Cryptarius truncatus	18					0.2	1.6	9.4	0.3			84.5		3.3		0.4	0.1
*Cynoglossus cynoglossus**	91	0.2	3.7		6.2	3.7	4.1	30.8	0.0			8.7		3.2		39.3	0.0
*Cynoglossus lingua**	57	1.4	2.3		3.0	1.5		37.4	3.1		4.4	9.2		7.2		30.3	0.1
*Hexanematichthys sagor**	101				4.0	28.2	17.6	9.5	10.0	0.4	3.5	3.5	0.0	2.4	0.1	20.4	0.5
Lagocephalus lunaris	23						4.7	84.8	0.4	0.2	6.7	0.7	0.4			2.1	
*Nemapterys caelata**	90		0.0			3.5	24.0	32.6	3.5	0.7	0.0	1.2		6.5	0.3	27.6	0.0
Osteogeneiosus militaris	18					0.7		6.2				77.6		0.5		14.9	0.2

Table 6.2, continued

*Plicofollis argyropleuron**	139			2.9	1.1	14.3	0.1	0.8	60.2	0.3	3.6	0.2	15.3	1.1
*Plotosus canius**	92			2.3	0.0	66.9	3.0	0.0	17.7		5.5	0.0	4.5	0.0
Takifugu oblongus	23		0.0	1.6	1.1	20.0		19.5	43.3				14.5	
*Dichotomyctere fluvialitis**	27			0.0	0.2	0.1		5.1	43.9				0.6	50.1
*Triacanthus nieuhofii**	29	10.7	0.6	0.1		22.1	5.4		44.8		13.2		0.6	2.5

The diet of 53 species of fish encompassed a total of 77 different prey items. To aid interpretation of the diet data, the large number of prey types were amalgamated into 17 broad prey categories (Table 6.3), based on the higher taxa they belonged to. Microalgae as prey item such as the centric diatom *Coscinodiscus* sp. was consumed more (64.6 %) than the pennate diatom *Pleurosigma* sp. (34.4 %). Among the shrimps as prey, the penaeid prawn or Jinga shrimp (*Metapenaeus affinis*) was the most common (57.8 %), followed by sergestid shrimps, *Acetes* spp. (33.1 %). Fish species that were often found as prey were the engraulids such as Kammal anchovy and Bagan anchovy and sciaenids such as the Caroun croaker and Panna croaker. Rare prey items that were lumped into the category of “others” included the chaetognaths, cirripids, echinoderms, foraminiferan, holothurids, insects, limulids and other unidentified materials. Collectively, they comprised 1.07 % of overall fish diet. Majority of the prey items were benthic invertebrates.

Table 6.3 List of 69 food items amalgamated into 17 broad prey categories, with their percentage index of relative importance to overall fish diet and number of fish species consuming the particular prey categories.

Prey categories	Food items	Consumed by number of fish species	% Index of Relative Importance	
			Mean	**Rank**
Microalgae	*Pleurosigma* sp. *Coscinodiscus* sp. *Nitzschia* sp. *Triceratium* sp. Unidentified microalgae	17	11.62	2
Tintinids		8	0.29	13
Copepods	*Arcatia* sp. *Parvocalanus crassirostris*	30	7.65	5
Amphipods		8	0.06	17
Zoea decapods	Crab larvae Shrimp larvae	22	0.55	12
Shrimps	Caridean Unidentified Caridean shrimp Penaeidae *Metapenaeus affinis* *Metapenaeus brevicornis* *Parapenaeopsis hardwickii*	45	40.09	1

Table 6.3, continued

	Sergestids *Acetes* spp.			
Fish	Ariidae Cynoglossidae *Cynoglossidae* sp. Engraulidae *Stolephorus* sp. *Thryssa kammalensis* *Thryssa* sp. Gobiidae *Oxuderes dentatus* Platicephalidae Sciaenidae *Johnius carouna* *Nibea soldado* *Otolithes ruber* *Panna microdon* Trichiuridae *Trichiurus lepturus* Eggs Scales Larvae Unidentified fish parts	37	5.95	7
Brachyurans	Leucosiidae *Philyra olivacea* Ocypodidae *Macrophthalmus* sp. Pinnotheridae *Xenophthalmus pinnotheroides* Portunidae *Charybdis feriatus* *Portunus pelagicus* Dorripidae *Neodorippe callida*	42	8.76	4
Anomurans	*Diogenes* sp. Unidentified anomuran	32	2.88	9
Isopods		14	0.18	15
Gastropods	Nassaridae *Nassarius jacksoniasus* *Nassarius olivaceus* *Nassarius bellulus*	17	0.85	11
Bivalves	Arcidae *Tegillarca granosa* Crassostrea Mytillidae *Arcuatula senhousia* *Mytillus* sp. *Perna viridis* Tellinidae Veneridae *Pelecyora trigona* Unidentified bivalve	28	9.24	3
Cephalopods	Sepia sp. Octopus sp.	11	0.27	14
Polychaetes	Eunicidae *Marphysa mossambica* Nereidae Pectinidae	26	4.28	8

Table 6.3, continued

	Sabellalidae Terebellidae			
Nematodes		13	0.14	16
Detritus		42	6.12	6
Others	Chaetognatha Cirripedia Echinoderm Foraminiferan Holothuroidea Insectoid Limulidae Unidentified materials	16	1.07	10

Among the prey categories, shrimps recorded the highest %IRI (40 %), followed by microalgae (11.7 %) and bivalves (9.3 %). Among the 53 fish species analyzed, shrimps as prey were found in the stomachs of most fish species (45 species), while predominantly consumed by 27 fish species (50.9 %) (see Table 6.2). Penaeid prawns (51.7 %IRI) and the sergestid shrimps (42.3 %IRI) formed the bulk of this prey category. The most common species of penaeid prawns encountered in the stomachs were Jinga shrimp, and yellow shrimp *Metapenaeus brevicornis* while spear shrimp *Parapenaeopsis hardwickii* was rarely encountered. Meanwhile *Acetes* spp. formed the bulk of sergestids.

Both the prey category of crabs and detritus were fed by same number of fish species (42). Fish as prey were dominated by the engraulids and sciaenids, whereas arids, cynoglossids, platycephalids and trichiurids were rare and only found in a total of four fish stomachs (*Takifugu oblongus*, *Nibea soldado*, *Platycephalus indicus* and *Chirocentrus nudus*, respectively). The average number of broad prey categories for each species was seven; catfishes generally fed on most types of prey (14), whereas the clupeid Chacunda gizzard shad only fed on two types of prey (microalgae and tintinnids).

Cluster analysis of the 17 prey categories using SIMPROF ($p < 0.05$) revealed eight distinct trophic guilds (Figure 6.1). These guilds were assigned as iliophages (IL, 8 species), copepod feeders (CO, 3 species), shrimp feeders (SH, 16 species), shrimp and teleost feeders (ST, 4 species), shrimp and zooplankton feeders (SZ, 2 species), shrimp and decapod feeders (SD, 5 species), polychaete feeders (PO, 5 species) and mixed macrobenthos feeders (MX, 13 species). The latter consumed multiple prey taxa namely the copepods, decapods zoeae and larvae, shrimps, fish, brachyuran, anomuran, isopod, gastropod, bivalves, cephalopods, polychaetes, nematodes, detritus and others, in no particular order.

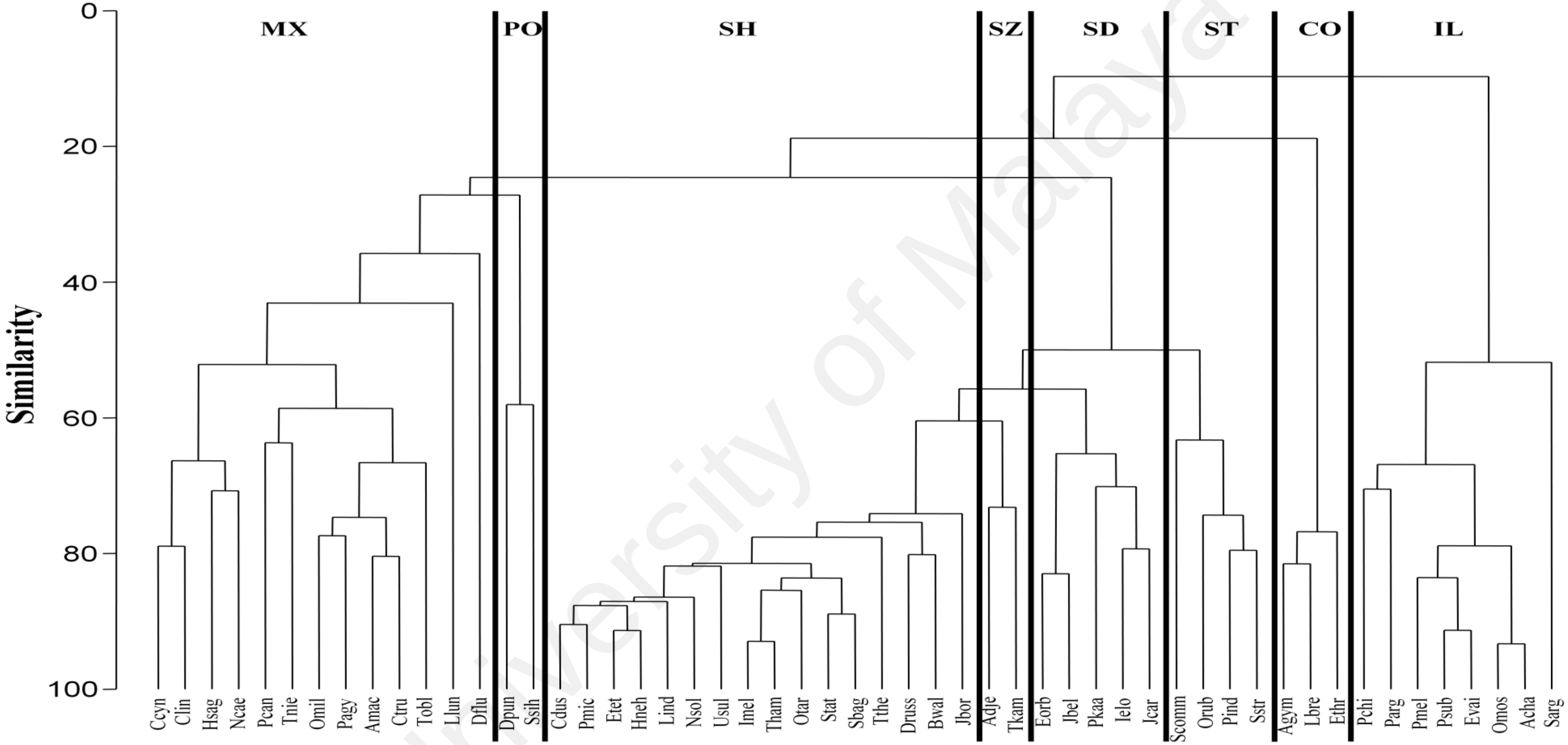

Figure 6.1 Clustering results by SIMPROF as shown in a dendrogram. Fish species were clustered based on the Bray-Curtis similarity matrix of % Index of Relative Importance of prey items. Clusters defining the eight feeding guilds are labeled as IL (iliophages), CO (copepod feeders), ST (shrimp and teleost feeders), SD (shrimp and decapod feeders), SZ (shrimp and zooplankton feeders), SH (shrimp feeders), PO (polychaete feeders), MX (mixed macrobenthos feeders). Refer Table 5.1 for code of each fish species.

The assignment of fish species into the eight trophic guilds was supported by the nMDS ordination results overlaid with vectors of prey importance (Figure 6.2). As observed, fish species in the same guild were generally located closer to each other in the ordination with their respective main prey vector. Fish species that were located closer to the ordination centroid indicate higher diet diversity (generalist feeders), as opposed to species located farther away from the centroid, i.e. those having diets of one or few prey categories (potential specialist feeders). Fish species of the guilds IL, CO and MX were shown to occupy the ordination space forming distinct clusters. In contrast, fish species of the guilds SH, ST, SZ and SD shared a common dominant prey group, that is shrimps. Apart from the SH guild where shrimp was the single most dominant food, the dissimilarity among the other guilds was related to their ingestion of secondary prey, such as teleosts, copepods, anomurans and brachyurans.

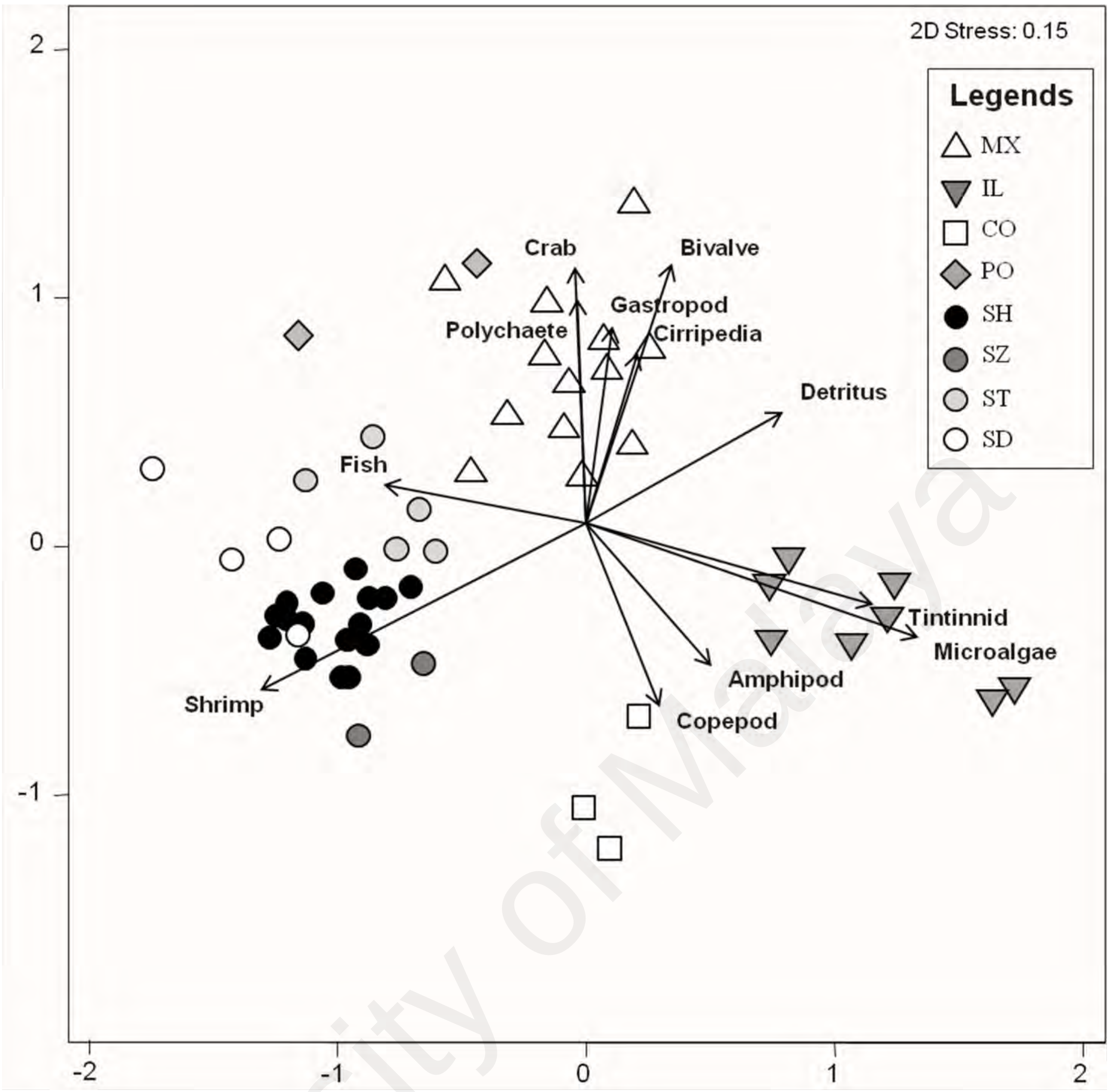

Figure 6.2 Non-metric multidimensional scaling (nMDS) ordination of the dietary similarity among 53 examined fish species from Klang Strait mudflats. The ordination is overlaid with prey importance vectors (arrows). Abbreviations in legends: MX, mixed macrobenthos feeders; IL, iliophages; CO, copepod feeders; PO, polychaete feeders; SH, dominantly shrimp feeders; SZ, shrimp and zooplankton feeders; ST, shrimp and fish feeders; SD, shrimp and other decapod feeders.

6.1.1 Iliophages (IL)

Iliophages are species that typically frequent muddy bottoms to feed on the superficial layer of organic particles or matter. The eight members of the IL guild were mainly microalgal feeders from families Cichlidae (Mozambique tilapia), Clupeidae (Chacunda gizzard shad), Mugilidae (squaretail mullet *Ellochelon vaigiensis*, greenback mullet and Otomebora mullet *Planiliza melinopterus*), Scatophagidae (spotted scat) and Stromateidae (Chinese silver pomfret and silver pomfret). Diatoms (68.8 %IRI) and detritus (20.1 %IRI) formed most important resource for this guild (Figure 6.3). Majority of the diatoms consumed consisted of *Coscinodiscus* (62.3 %IRI) and *Pleurosigma* (32.5 %IRI). Diet of the IL guild members also included zooplankton such as amphipods, copepods, zoeae and tintinnids, but these were of very low importance (8.5 %IRI collectively). SIMPER analysis revealed an average similarity within IL guild of 68.8%, contributed mainly by microalgae (74.4 % similarity), detritus (12.8 %) and tintinids (8.3 %). In the nMDS ordination biplot, members of the IL guild were located close to each other and near the ‗microalgae' prey vector (Figure 6.2). The vectors for tintinnids and amphipods were also correlated to IL fishes, especially the silver pomfret.

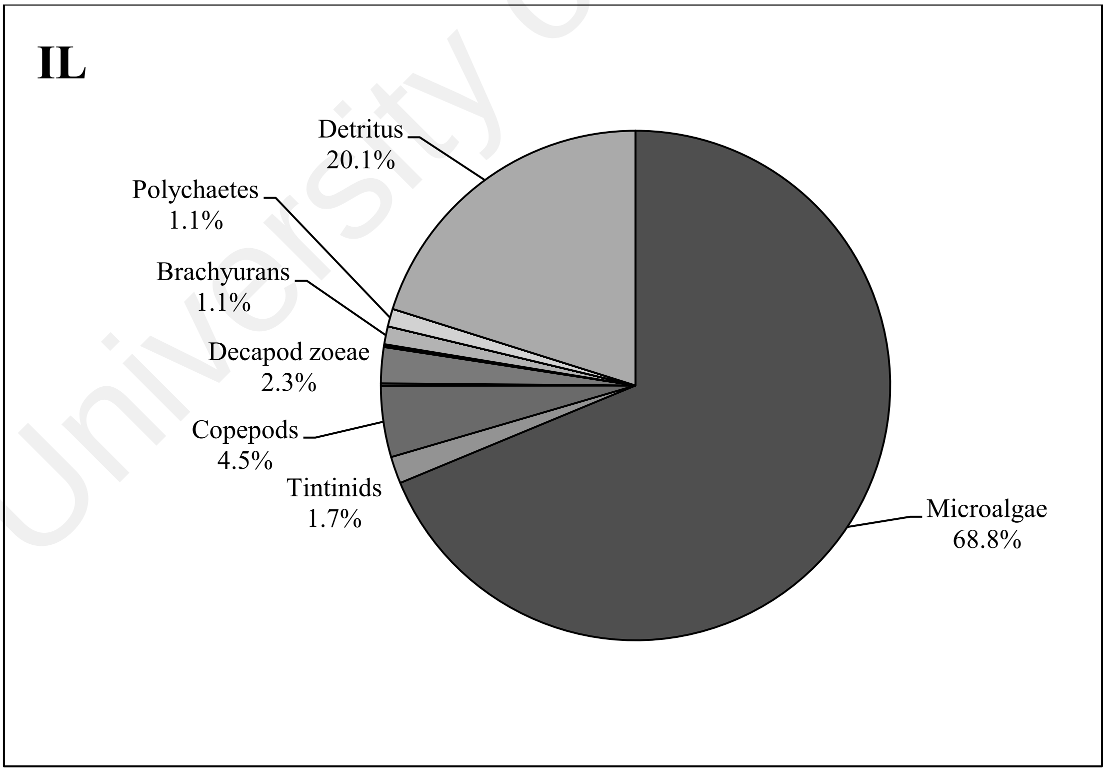

Figure 6.3 Percentage contributions (%IRI) of various prey categories in the iliophage (IL) guild.

a) *Anodonstoma chacunda*

A total of 22 stomachs of Chacunda gizzard shad *A. chacunda* were examined, where 15 individuals had non-empty stomach with gut fullness of 1.1 ± SD 1.0. Its mean gut fullness was also the lowest among all the IL fishes. Gizzard shad only fed on two types of prey categories, that is the microalgae (99.5 %IRI) and tintinids (0.5 %IRI). The diatom *Coscinodiscus* formed the bulk of microalgae diet (86.7 %IRI).

b) *Planiliza melinoptera*

For the mullet *Planiliza melinopterus*, 26 out of 31 individuals were examined with a mean gut fullness of 1.5 ± SD 1.0. The other 5 individuals had empty stomachs. Microalgae formed the major food type (74.8 %IRI), followed by plant-based detritus (23.5 %IRI) and tintinids (1.7 %IRI). Within the microalgae prey category, *Coscinodiscus* (54.8 %IRI) and *Pleurosigma* (24.7 %IRI) were mainly ingested.

c) *Planiliza subviridis*

A total of 158 stomachs of mullet *Planiliza subviridis* were examined, where 89.9% of the stomachs were found non-empty with mean gut fullness of 1.7 ± SD 1.1. While microalgae comprised the majority of the diet (91.4 %IRI), the mullet also ingested detritus (7.1 %IRI) and other insignificant items such as tintinids (1.4 %IRI) and copepods (0.1 %IRI). Similar to *P. melinopterus*, *Coscinodiscus* diatom (66.2 %IRI) formed the bulk of microalgae, followed by *Pleurosigma* (31.2 %IRI).

d) *Ellochelon vaigiensis*

Only 15 out of 18 individuals of *E. vaigiensis* stomach were non-empty. Mean gut fullness was 1.8 ± SD 1.5. While microalgae remained as the dominant prey category

(91.4 %IRI), *E. vaigiensis* also consumed zooplankton such as copepods (1.9 %IRI), tintinids (0.1 %IRI) and amphipods (0.1 %IRI), although in insignificant portions.

e) *Oreochromis mossambicus*

A total of 27 individuals of the brackish water dwelling tilapia *Oreochromis mossambicus* was examined with mean gut fullness of 1.3 ± SD 1.2. Only nine individuals were found with empty stomachs. This species ingested mainly microalgae (96.9 %IRI) and small amount of tintinids (2.9 %IRI) and amphipods (0.2 %IRI).

f) *Pampus argenteus*

A total of 115 stomachs of silver pomfret *Pampus argenteus* were examined, with 99 individuals of non empty stomach and mean gut fullness of 1.6 ± SD 1.1. Microalgae comprised almost one half of the silver pomfret‘s diet (56.8 %IRI), whereas the other half consisted of plant detritus (19.4 %IRI), zooplankton such as copepods (19.2 %IRI), decapod zoeae (2.9 %IRI), tintinnids (1.1 %IRI) and amphipods (0.2 %IRI) and a very small amount of crabs (0.3 %IRI) and shrimps (0.2 %IRI).

g) *Pampus chinensis*

The 46 individuals of Chinese pomfret *Pampus chinensis* were examined and showed mean gut fullness of 1.4 ± SD 1.0. This species of pomfret fed on more microalgae (80.6 %IRI) compared to its sister species, the silver pomfret *Pampus argenteus*. Other food items that were also ingested were the tintinnids (5.1 %IRI), plant detritus (3.6 %IRI), small crabs (3.4 %IRI), copepods (3.1 %IRI), polychaetes (2.2 %IRI) and decapod zoeae (2.0 %IRI).

h) ***Scatophagus argus***

A total of 52 stomachs of spotted scat *Scatophagus argus* were examined, with 48 individuals that recorded mean gut fullness of 2.4 ± SD 1.3. Detritus (74.1 % IRI) was the dominant food item in the spotted scat, followed by microalgae (19.5 %IRI) and a wide variety of food items with low significance (less than 3 %IRI). Despite the low microalgae contribution, SIMPROF analysis showed that the scat‘s diet was not significantly distinct from the other members in the IL guild.

6.1.2 Copepod feeders (CO)

Three species of fish assigned to the CO guild by SIMPROF analysis were *Ambassis gymnocephalus*, *Escualosa thoracata* and *Leiognathus brevirostris*. Besides copepod as the most important prey category (90.4 % IRI) within the guild, bivalves (2.7 %IRI) and small shrimps (2.1 %IRI) were also consumed (Figure 6.4). SIMPER analysis showed that copepods contributed 80.8 % of diet similarity within the guild. Decapod zoeae and small planktonic shrimps contributed 7.2 % and 6.8 % to similarity within the guild respectively. Members of the CO guild were distinctly located from other guilds in the nMDS ordination, being closest to the ‗copepod' prey vector (Figure 6.2).

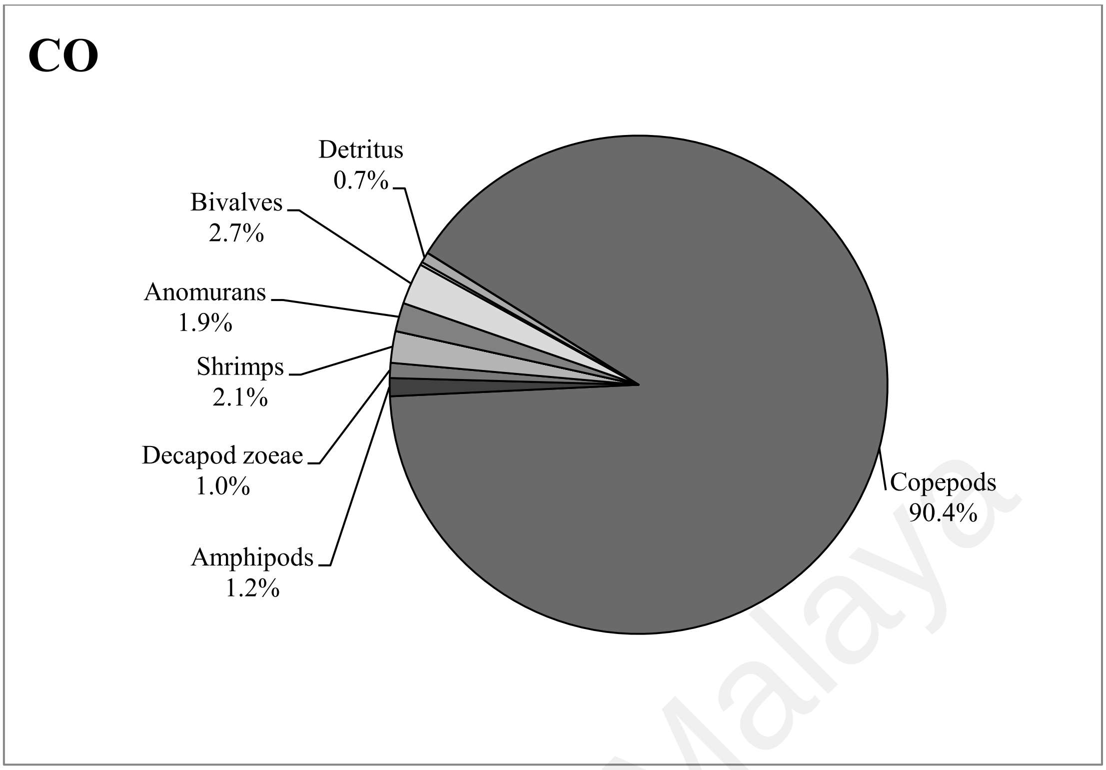

Figure 6.4 Percentage contributions (%IRI) of various prey categories in copepod feeders (CO) guild.

a) *Ambassis gymnocephalus*

A total of 106 stomachs of bald glassy *Ambassis gymnocephalus* were examined, where 89 of the stomachs were found non-empty with mean gut fullness of 1.5 ± SD 1.0. Aside from the main diet contribution from copepods (94.4 %IRI), 37 individuals of bald glassy were found to feed on other crustaceans such as anomurans (2.7 %IRI), decapod zoeae (1.3 %IRI), amphipods (0.9 %IRI) and sergestid shrimps (0.6 %IRI). Important copepod prey included *Parvocalanus crassirostris* and *Acartia* spp.

b) *Escualosa thoracata*

Of the 33 white sardine *Escualosa thoracata* examined, 30 individuals were sampled with a mean gut fullness of 2.0 ± SD 1.2. Copepod remained as the dominant prey category (92.8 %IRI), followed by sergestid shrimps (5.0 %IRI) and amphipods (1.5 %IRI).

c) *Leiognathus brevirostris*

A total of 58 stomachs of shortnose ponyfish *Leiognathus brevirostris* were examined, with mean gut fullness of 1.6 ± SD 1.0 based on 51 non-empty stomachs. Although copepod was the dominant prey category (90.1 %IRI), this species fed on wider range of prey categories, which included the other crustaceans such as sergestid shrimps, hermit crabs and decapod zoeae (collectively 4.0 %IRI), bivalves (5.3 %IRI) and detritus (1.4 %IRI).

6.1.3 Shrimp feeders (SH)

A total of 16 species of fish feeding primarily on shrimps (89.4 %) formed the shrimp feeder guild (SH) (Figure 6.5). This guild comprised of four species of sciaenids (*Dendrophyssa russelii, Johnius borneensis, Nibea soldado* and *Panna microdon*), four species of engraulids (*Coilia dussumieri, Setipinna taty, Stolephorus baganensis* and *Thryssa hamiltonii*), two species of polynemids (*Eleutheronema tetradactylum* and *Leptomelanosoma indicum*), two species of clupeids (*Ilisha melastoma* and *Opisthopterus tardoore*), one dasyatid (*Brevitrygon walga*), one synodontid (*Harpadon nehereus*), one terapontid (*Terapon theraps*) and one mullid (*Upeneus sulphureus*). Mean gut fullness for fishes of the SH guild was 1.8 ± 0.4. Both *S. taty* and *H. nehereus* had the highest percentage of empty stomachs within the guild (30.6 % and 30.4 %, respectively), whereas *Nibea soldado* had the lowest percentage of empty stomach, with only three individuals of fish (2.9 %). SIMPER analysis on the SH guild indicated that shrimps contributed 83.5% to intraguild similarity, followed by fish (6.8%) and brachyurans (5.3%).

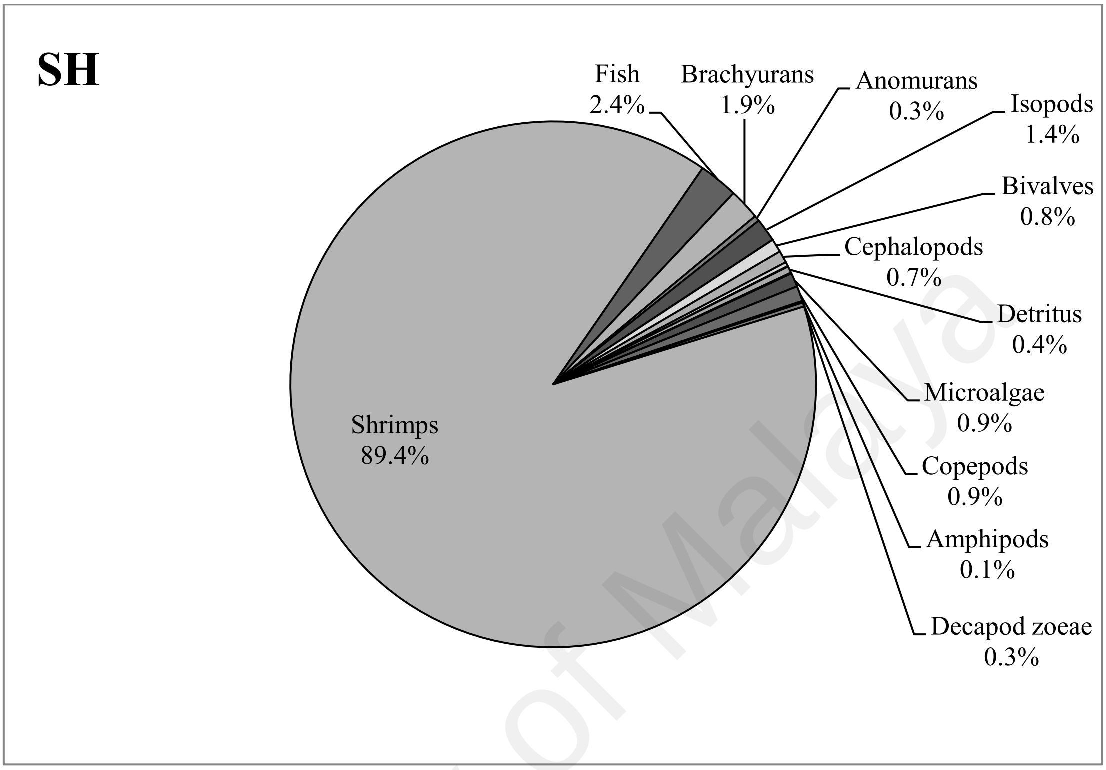

Figure 6.5 Percentage contributions (%IRI) of various prey categories in shrimp feeders (SH) guild.

a) ***Brevitrygon walga***

A total of 23 stomachs of the scaly whipray *Brevitrygon walga* were examined, with only one empty stomach individual and mean gut fullness of 2.1 ± SD 1.1. Shrimps comprised the most of the scaly whipray‘s diet (93.1 %IRI), followed by brachyurans (5.0 %IRI), bivalves (0.8 %IRI), polychaetes (0.7 % IRI) and amphipods, fish, anomurans and detritus collectively formed 0.4 %IRI.

b) *Coilia dussumieri*

The 72 individuals of Goldspotted grenadier anchovy *Coilia dussumieri* were examined and showed mean gut fullness of 1.4 ± SD 0.9. Only 9 individuals had empty stomachs. This species of engraulid only fed on four prey categories, namely shrimps (80.6 %IRI), brachyurans (3.0 %IRI), fish (2.2 %IRI) and cephalopods (0.9 %IRI). Small penaeid prawns (67.3 %) were commonly found in the anchovy stomachs.

c) *Dendrophyssa russelli*

Of the 98 individuals of Goatee croaker *Dendrophyssa russelii* examined, 90 individuals with non-empty stomachs gave a mean gut fullness of 1.7 ± SD 1.1. Shrimps remained as the dominant prey category (84.1 %IRI), followed by brachyurans (12.5 %IRI) and rarely copepods, decapod zoeae, fish, anomurans, polychaetes, nematodes, detritus and cirripids (collectively 3.4 %IRI).

d) *Eleutheronema tetradactylum*

A total of 149 stomachs of the fourfinger threadfin *Eleutheronema tetradactylum* were examined, where 128 (85.9 %) of the stomachs were non-empty with mean gut fullness of 2.3 ± SD 1.4. While shrimps comprised the majority of the diet (96.0 %IRI), the threadfin also ingested fish (3.4 %IRI) and rare prey items such as copepods, decapods zoeae, brachyurans, isopods, gastropods, bivalves, polychaetes and nematodes (0.6 %IRI). Penaeid prawns such as Jinga shrimp, yellow shrimps and white shrimps are the major prey items

e) *Harpadon nehereus*

Sixteen out of the 23 individuals of examined Bombay duck *Harpadon nehereus* stomachs were non-empty. Mean gut fullness was 1.5 ± SD 1.4. This species ranked the second highest in terms of percentage of empty stomachs (30.4 %). Although shrimps remained as the dominant prey category (96.0 %IRI), the Bombay duck also consumed smaller quantity of fish (3.5 %IRI) and bivalves (0.5 %IRI).

f) *Ilisha melastoma*

The Indian ilisha *Ilisha melastoma* had 81 non-empty stomachs out of 91 stomachs examined. Mean gut fullness were 2.2 ± SD 1.3. This species fed mainly on shrimps (97.0 %IRI). The shrimp prey category and consisted of mainly small penaeid prawns (78.4 %) such as the Jinga shrimp and spear shrimp. Other prey items with lesser importance were the brachyurans (1.5 %IRI), copepods (0.7 %IRI) and fish (0.6 %IRI).

g) *Johnius borneensis*

A total of 19 stomachs of sharpnose hammer croaker *Johnius borneensis* were examined, with mean gut fullness of 1.8 ± SD 1.0 from 17 non-empty stomachs. This species fed on eight type of prey items, with shrimps as the most dominant prey category (83.5 %IRI), followed by isopods (6.9 %IRI), fish (4.5 %IRI), plant detritus (2.2 %IRI), brachyurans (1.5 %IRI), copepods (0.9 %IRI), polychaetes (0.3 %IRI) and anomurans (0.2 %IRI). The main portion of shrimp prey of sharpnose hammer coaker consisted of penaeid prawns (55.5%), particularly the Jinga shrimp *M. affinis.*

h) *Leptomelanosoma indicum*

Twelve out of 15 individuals of Indian threadfin *Leptomelanosoma indicum* had non-empty stomachs, giving a mean gut fullness value at 2.5 ± SD 1.9. While shrimps particularly the penaeid prawns such as *F. merguensis* and *M. brevicornis* remained as the dominant prey category (83.5 %IRI), the Indian threadfin also consumed fish (10.0 %IRI), mainly the engraulids such as Kammal anchovy and Bagan anchovy.

Brachyurans and cephalopods were also consumed but in small quantities (collectively 0.5 %IRI).

i) *Nibea soldado*

Of the 104 individuals of soldier croaker *Nibea soldado* examined, 101 individuals had non-empty stomachs with a mean gut fullness of 1.8 ± SD 1.1. The soldier croaker had the lowest percentage of empty stomach (2.9 %). While shrimps remained as the dominant prey category (92.5 %IRI), this species also fed on a wide variety of prey items such as fish (5.6 %IRI), brachyurans (0.8 %IRI), anomurans (0.7 % IRI), and rarely on copepods, decapod zoeae, isopods, gastropods, bivalves, polychaetes and plant detritus (collectively 1.1 %IRI).

j) *Opisthopterus tardoore*

A total of 138 stomachs of the Taardore *Opisthopterus tardoore* were examined, of which 126 (91.3 %) of the stomachs were found to be non-empty with mean gut fullness of 2.0 ± SD 1.2. Shrimps comprised the majority of the diet (95.8 %IRI), followed by copepods (3.2 %IRI), fish (0.6 %IRI) and decapod zoeae (0.2 %IRI). More sergestid shrimps (*Acetes* spp.) were consumed than penaeid prawns.

k) *Panna microdon*

The 140 individuals of Panna croaker *Panna microdon* that were examined gave a mean gut fullness of 1.5 ± SD 1.2. Only 33 individuals had empty stomachs. This species of sciaenid fed on six prey categories, namely the shrimps (94.2 %IRI), fish (4.5 %IRI), cephalopods (0.5 %IRI), brachyurans (0.4 %IRI), anomurans (0.2 %IRI) and nematodes (0.1 %IRI). Penaeid prawns (64.5 %) were commonly found in the stomachs.

l) *Setipinna taty*

A total of 180 stomachs of the scaly hairfin anchovy *Setipinna taty* were examined, where 125 (69.4 %) of the stomachs were found non-empty with mean gut fullness of 1.2 ± SD 1.1. Among the sampled fish species in the SH guild, the scaly hairfin anchovy had the highest percentage of empty stomachs at 30.6 %. Shrimps were the most important prey items (98.8 %IRI), consisted of mainly sergestid shrimps *Acetes* spp. (66.3 %) and small penaeid prawns (27.7 %). Other prey items included copepods, decapod zoeae, brachyurans, anomuran and fish but in very insignificant quantities (collectively 1.1 %IRI).

m) *Stolephorus baganensis*

The Bagan anchovy *Stolephorus baganensis* were examined for 44 samples; with 32 of them having non-empty stomachs. Mean gut fullness were 1.6 ± SD 1.4. Similar to the scaly hairfin anchovy, this species fed on high percentage of shrimps (98.6 %IRI). Other prey items with lesser importance were the bivalves (0.9 %IRI), brachyurans (0.4 %IRI), fish (0.1 %IRI) and decapod zoeae (0.1 %IRI).

n) *Terapon theraps*

Only 18 stomachs of largescaled terapon *Terapon theraps* were examined, and five of them had empty stomachs. The mean gut fullness was 1.2 ± SD 1.0. Shrimps were the most important food (93.8 %IRI), followed by anomurans (2.0 %IRI), cephalopods (1.2 %IRI), microalgae (0.9 %IRI), fish (0.8 %IRI), polychaetes (0.7 %IRI) and brachyurans (0.4 %IRI).

o) *Thryssa hamiltonii*

Of the 43 individuals of Hamilton‘s anchovy *Thryssa hamiltonii* examined, 36 individuals had non-empty stomachs that gave a mean gut fullness of 1.9 ± SD 1.2. This species only fed on six prey categories, namely the shrimps (95.5 %IRI), brachyuran (2.3 %IRI), copepods (0.7 %IRI), bivalves (0.6 %IRI), plant detritus (0.6 %IRI) and fish (0.3 %IRI).

p) *Upeneus sulphureus*

A total of 28 stomachs of the sulphur goatfish *Upeneus sulphureus* were examined, of which only two were empty. The mean gut fullness was 2.4 ± SD 1.2. Shrimps comprised the most of its diet (89.6 %IRI), followed by fish (3.7 %IRI), bivalves (3.0 %IRI), copepods (2.2 %IRI), brachyurans (1.1 %IRI) and plant detritus (0.4 % IRI).

6.1.4 Shrimp/teleost feeders (ST)

The ST guild consisted of *Otolithes ruber*, *P. indicus*, *Scomberomorus commerson* and *Strongylura strongylura*. Mean gut fullness for this guild was 2.0 ± SD 0.3, which was among the highest compared to other guilds. The flathead *P. indicus* had the highest mean gut fullness at 2.4 ± 1.5, followed by the tigertooth croaker *O. ruber* (2.1 ± SD 1.3). These fish preyed mainly on other teleosts (51.2 %IRI) and shrimps (42.3 %IRI) (Figure 6.6). Prey fish comprised of mainly small engraulids, particularly the *Thryssa* spp. Caroun croaker as prey was also found in the stomach of the spottail needlefish. Prey shrimp consisted of mainly penaeid prawns.

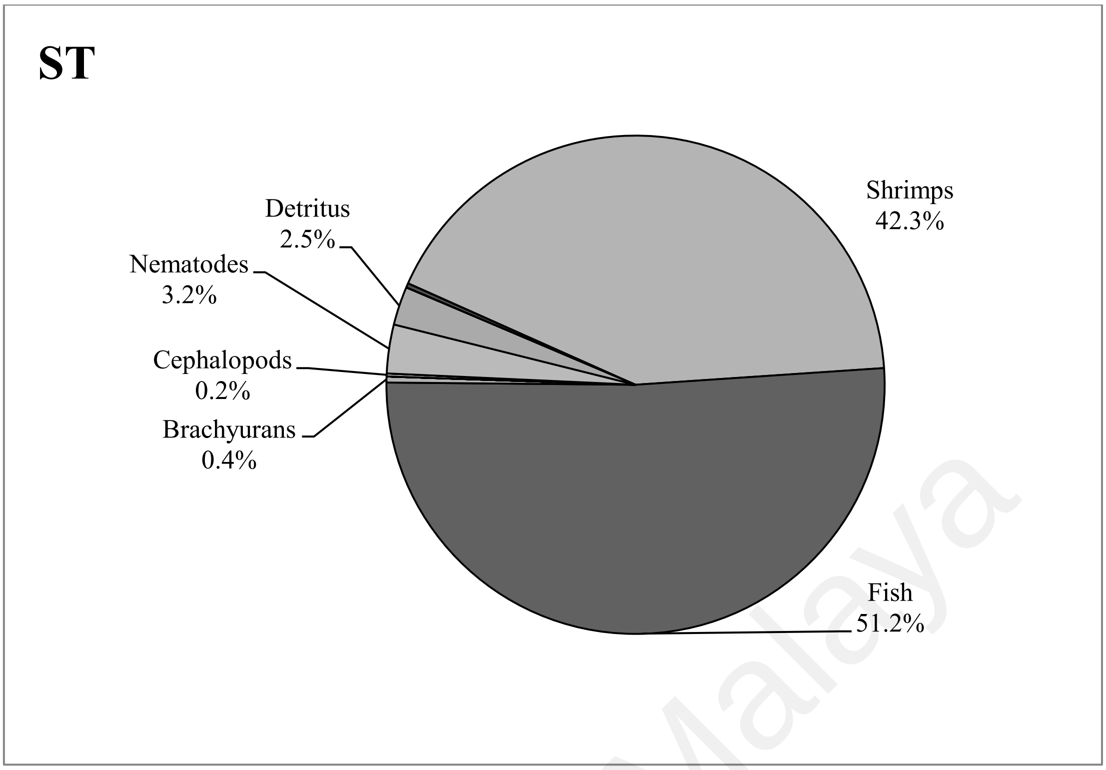

Figure 6.6 Percentage contributions (%IRI) of various prey categories in shrimp/teleost feeder (ST) guild.

a) *Otolithes ruber*

A total of 190 stomachs of Tigertooth croaker *O. ruber* were examined, of which 166 stomachs (87.4 %) were found non-empty with mean gut fullness of 2.1 ± SD 1.3. The tigertooth croaker fed on the most type of prey items (12 types). Shrimps were the most important prey items (74.1 %IRI), followed by fish (25.2 %IRI), cephalopods (0.5 %IRI) and brachyurans (0.1 %IRI). Penaeid prawns were common prey.

b) *Platycephalus indicus*

Only 14 individuals of the bartail flathead *P. indicus* were examined, of which 12 individuals had non-empty stomachs with a mean gut fullness of 2.4 ± SD 1.5. This species fed on both fish and shrimps of almost equal importance, 48.0 %IRI and 44.4

%IRI, respectively. Prey fish found in the stomachs of the flathead included the *Thryssa* spp. unidentified sciaenids and interestingly, platycephalids. Since there is no record of cannibalism within the Platycephalidae, it is possible that the prey platycephalids were forced into its mouth swallowed during trapping.

c) *Scomberomorus commerson*

A total of 17 stomachs of the narrow-barred Spanish mackerel *S. commerson* were examined, of which 14 individuals had non-empty stomach with a mean gut fullness of 1.8 ± SD 1.3. Compared to other fish species in the ST guild, the Spanish mackerel fed primarily on fish (91.7 %IRI). Engraulids and sciaenids were commonly found in the stomachs. Shrimps (7.9 %IRI) and brachyurans (0.4 %IRI) were also consumed.

d) *Strongylura strongylura*

The 123 individuals of the spottail needlefish *S. strongylura* were examined and showed a mean gut fullness of 1.8 ± SD 1.4. Another 19 individuals had empty stomachs. Similar to the bartail flathead, this species fed on both shrimps (47.2 %IRI) and fish (45.5 %IRI) in almost equal importance. Other prey items of low importance (7.3 %IRI) were also fed; these included nematodes, brachyurans, anomurans, isopods and bivalves.

6.1.5 Shrimp/zooplankton feeders (SZ)

The two examined members of the SZ guild were the shrimp scad *Alepes djedaba* and Kammal anchovy *Thryssa kammalensis* which fed mainly on shrimps and zooplankton. These species fed on a high proportion of shrimps (59.3 %) particularly the sergestids, and copepods (27.5 %) such as the *Acartia* sp. and *Parvocalanus* *crassirostris* (Figure 6.7). Mean gut fullness for SZ guild were recorded at 1.8 ± SD 0.8. On the other hand, SIMPER analysis revealed an average similarity of 73.2%. The entirety of the similarity was contributed by shrimps (62.8 %) and copepods (37.2 %).

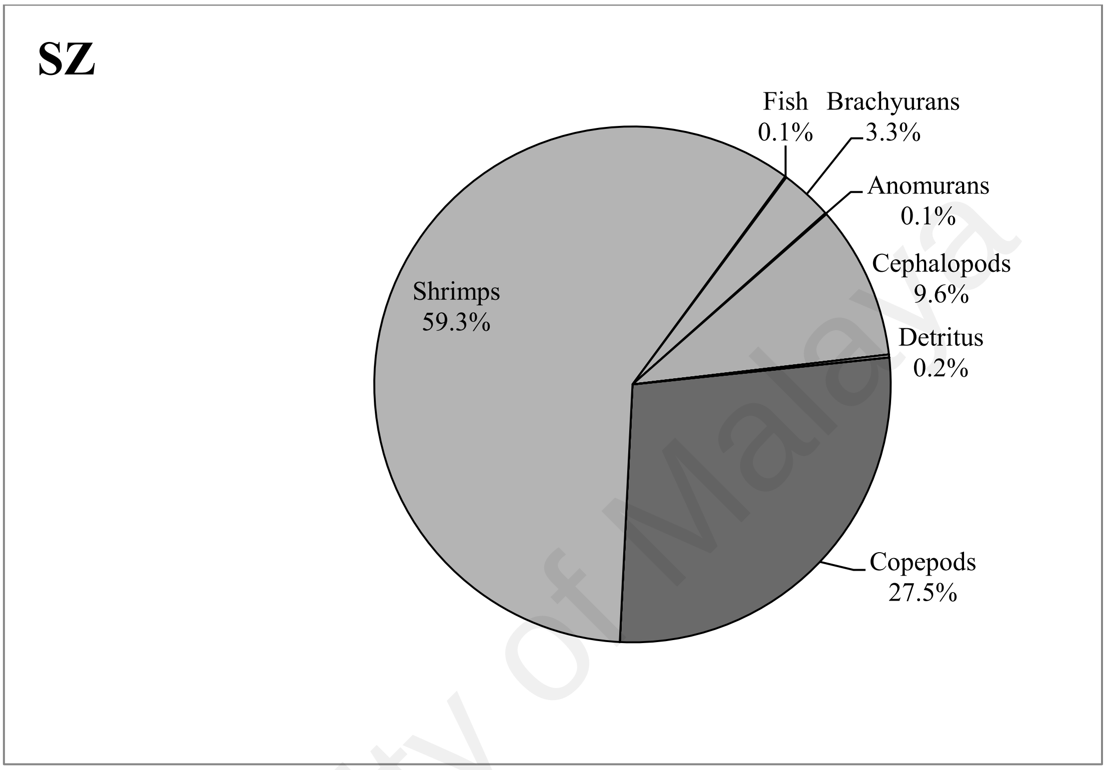

Figure 6.7 Percentage contributions (%IRI) of various prey categories in the shrimp/zooplankton feeder (SZ) guild.

a) *Alepes djejaba*

A total of 16 stomachs of shrimp scad *A. djejaba* were examined, recording a mean gut fullness of 1.9 ± SD 1.6 from 11 stomachs with food. The diets of shrimp scad consisted of only shrimps (69.5 %IRI), copepods (20.2 %IRI) and cephalopods (10.3 %IRI).

b) *Thryssa kammalensis*

A total of 168 stomachs of Kammal anchovy were examined, of which 124 of them had mean gut fullness of 1.4 ± SD 1.2. The Kammal anchovy appeared to feed on a broader range of prey (11 types of prey category) compared to *A. djedaba* (3 types). Shrimps (57.5 %IRI) and copepods (38.6 %IRI) were the most important prey items, followed by others in less significant proportions including brachyurans, anomurans, decapod zoeae, fish larvae, gastropods, bivalves, nematodes, microalgae and detritus.

6.1.6 Shrimp/decapod feeders (SD)

Five species of fish examined, namely *Ephippus orbis*, *P. kaakan*, *Ilisha elongata*, *Johnius belangerii* and *Johnius carouna*, formed the SD guild. This guild fed mainly on shrimps (51.6 %), anomurans (21.0 %) and brachyurans (15.1 %) (Figure 6.8). Similar with ST guild, the mean gut fullness was the highest among shrimp-based trophic guilds (2.0 ± 0.4). The dominant prey for this guild was also supported by the SIMPER analysis, where shrimps contributed 44.9% to similarity, followed by the brachyuran crabs (21.7%) and hermit crabs (21.1%).

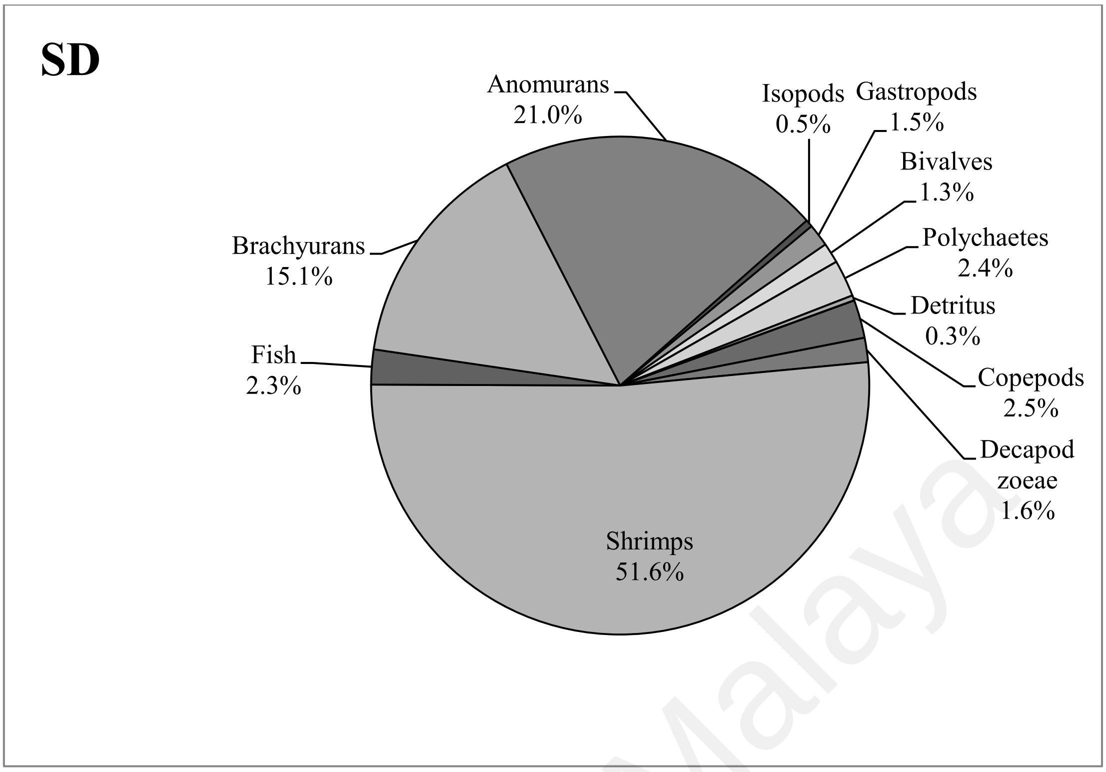

Figure 6.8 Percentage contributions (%IRI) of various prey categories in shrimp/decapod feeder (SD) guild.

a) *Ephippus orbis*

Only 16 individuals of orbfish *E. orbis* were examined, with four of them had empty stomachs and mean gut fullness of 1.7 ± SD 1.6. The orbfish appeared to feed on the three dominant prey items only, with more emphasis on shrimps (44.0 %IRI) and anomurans (42.6 %IRI) than the brachyurans (13.4 %IRI). The spear shrimp *P. hardwickii* and hermit crab *Diogenes* sp. were commonly found in the stomachs of the orbfish.

b) *Ilisha elongata*

The 16 individuals of elongate ilisha *I. elongata* that were examined had mean gut fullness of 2.2 ± SD 1.3. Only one individual had empty stomach. While shrimps remained as the most important prey (61.8 %IRI), the elongate ilisha also fed on brachyurans (23.1 %IRI), and anomurans (4.3 %IRI), fish (3.8 %IRI), copepods (2.9 %IRI), decapod zoeae (2.1 %IRI), plant detritus (1.2 %IRI) and bivalves (0.8 %IRI).

c) ***Johnius belangerii***

A total of 102 stomachs of grey croaker *J. belangerii* were examined with mean gut fullness of 2.3 ± SD 1.2 and seven individuals with empty stomachs. The grey croaker fed on rather even proportions of hermit crabs (37.9 %IRI), shrimps (31.3 %IRI) and brachyurans (26.6 %IRI), and very low proportions of polychaetes, gastropods, teleosts and detritus (collectively 4.2 %IRI).

d) ***Johnius carouna***

Among 195 individuals of Caroun croaker *J. carouna* examined, 160 individuals had non-empty stomachs with mean gut fullness of 1.6 ± SD 1.3. The Caroun croaker fed on most types of prey categories (13) compared to other species of the SD guild. Shrimps were the most important prey items, constituting half of the Caroun croaker‘s diet (52.3 %IRI). Anomurans were the second most important (20.6 %IRI), followed by brachyurans (11.2 %IRI), fish (5.5 %IRI) and bivalves (4.6 %IRI). The other prey categories included copepods, decapod zoeae, polychaetes, gastropods, cephalopods, nematodes, cirripids and plant detritus (5.8 %IRI, collectively).

e) ***Pomadasys kaakan***

A total of 103 stomachs of javelin grunter *P. kaakan* were examined, of which 101 of them had mean gut fullness of 2.4 ± SD 1.2. Compared to other fish species of the SD guild, the javelin grunter‘s diet had a higher percentage of shrimps (80.9 %IRI). Sergestid shrimps (*Acetes* spp.) formed the bulk of prey shrimps (74.3 %). Other prey items of lesser importance included the brachyurans (5.0 %IRI), anomurans (4.8 %IRI), gastropods (3.7 %IRI), copepods (2.4 %IRI), polychaetes (2.4 %IRI), isopods (0.5 %IRI), bivalves, cephalopods fish and plant detritus (collectively 0.3 %IRI).

6.1.7 Polychaete feeders (PO)

Two species of fish examined fed primarily on benthic polychaetes, namely the spotted sicklefish *Drepane punctata* and northern whiting *S. sihama*. While polychaetes formed the bulk of prey consumed (79.6 %), the two members of the PO guild also fed on other benthic invertebrates such as shrimps (6.4 %IRI), anomurans (4.5 %), copepods (3.4 %) and brachyurans (3.1 %) (Figure 6.9). The northern whiting had 14 empty stomachs out of 31 examined individuals, with mean gut fullness of 1.2 ± SD 1.3. From a sample of 78 individuals examined, the spotted sicklefish had a mean gut fullness of 2.3 ± SD 1.2 based on 72 non-empty stomachs. Both species of fish predated on two major polychaete families, Sabellariidae and Pectinariidae. Additional families included Terebellidae and Eunicidae in the diet of the spotted sicklefish and northern whiting, respectively. Both fish species of the PO guild are located apart from each other in the nMDS ordination, reflecting diet differences in their choice of other prey (Figure 6.2). Spotted sicklefish appeared to feed on especially polychaetes (90.2 %IRI) and shrimps (6.7 %IRI), but shrimps was absent in the other species. While the northern whiting fed on lowerproportion of polychaetes (76.7 %IRI) than *D. punctata*, it additionally fed on more anomurans (9.2 %IRI), copepods (6.9 %IRI) and brachyurans (6.6 %IRI).

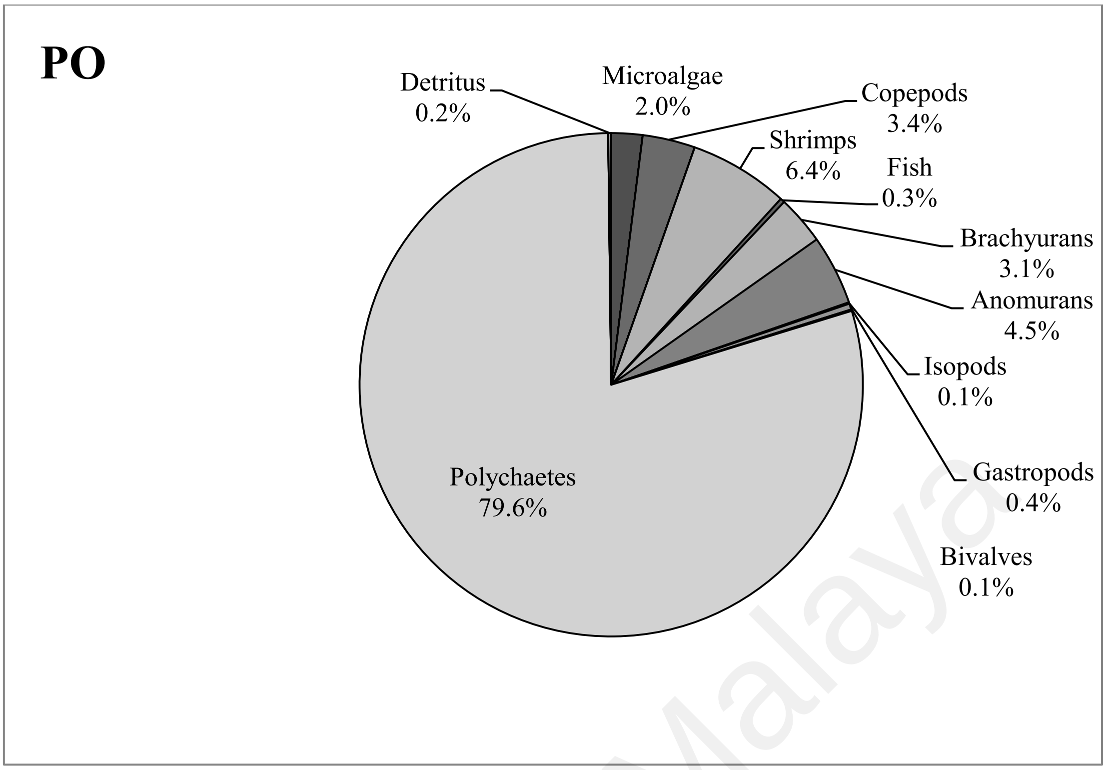

Figure 6.9 Percentage contributions (%IRI) of various prey categories in polychaete feeders (PO) guild.

6.1.8 Mixed macrobenthos feeders (MX)

The remaining 13 species of fish (24.5 %) made up the MX guild, which were benthic generalist feeders. Members of the MX guild consisted of six species of catfish (*Arius maculatus, Cryptarius truncatus, Hexanematichthys sagor, Nemapteryx caelata, Osteogeneiosus militaris* and *Plicofollis argyropleuron*), three species of pufferfish (*Dichotomyctere fluvialitis, Lagocephalus lunaris* and *Takifugu oblongus*), two species of tongue sole (*Cynoglossus cynoglossus* and *Cynoglossus lingua*), one species of tripod fish (*Triacanthus nieuhofii*) and one species of eel catfish (*Plotosus canius*). These species of fish fed on an average of 10 prey categories each, primarily bivalves (33.4 %IRI), brachyurans (23.7 %IRI), detritus (12.0 %IRI), teleosts (5.0 %IRI), cirripedes (4.5 %IRI), shrimps (3.7 %IRI), polychaetes (4.3 %IRI) and gastropods (4.0 %IRI) (Figure 6.10). SIMPER analysis of the MX guild revealed an average similarity of

53.2%, with bivalves contributing the most to diet similarity (30.8 %), followed by brachyurans (26.1 %) and detritus (15.7 %).

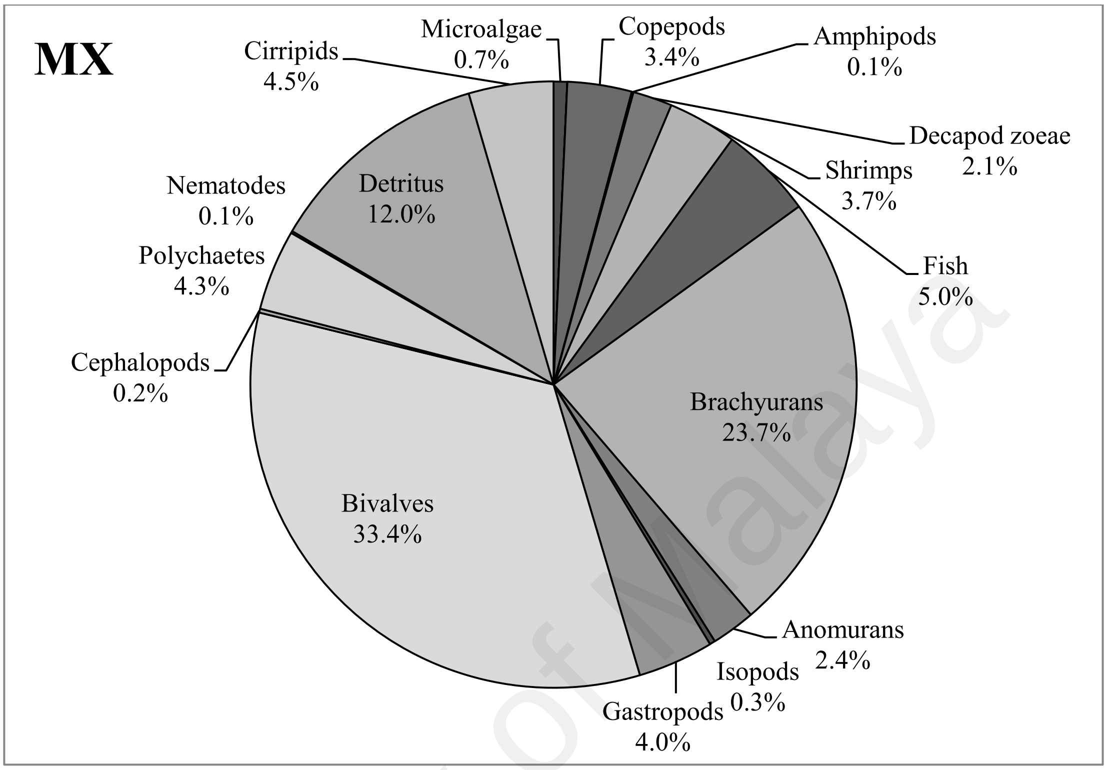

Figure 6.10 Percentage contributions (%IRI) of various prey categories in mixed macrobenthos feeders (MX) guild.

a) *Arius maculatus*

A total of 89 samples of *A. maculatus* were examined, of which 79 individuals had non-empty stomach with a mean gut fullness of 2.2 ± SD 1.3. It fed on a total of 14 prey types that were dominated by bivalves (83.4 %IRI) and followed by crabs (5.6 %IRI). *Pelecyora trigona* (Venus clam) appeared to be the dominant prey items among the consumed bivalves (58.5 %IRI). An average of about 80 individuals of *P. trigona* can be found in the stomachs. Other bivalve prey included the Asian date mussel *Arcuantula senhousia* and *Mytillus* sp., and rarely, the blood cockle *Tegillarca granosa*. Crabs as prey included the crucifix crab *Charybdis feriatus*, pinnotherids and dorripids.

The polychaetes of family Terebellidae were also found in the stomachs of *Arius maculatus*.

b) *Cryptarius truncatus*

The 18 stomachs of catfish *C. truncatus* recorded a mean gut fullness of 2.3 ± SD 1.3, with two empty stomachs. This species of catfish fed on a total of eight prey types, but similar to *A. maculatus*, it fed mainly on bivalves (84.5 %IRI), followed by brachyurans (9.4 %IRI). The bivalves comprised tellinid and venerid clams, while the brachyurans were portunids and pinnotherids.

c) *Hexanematichthys sagor*

A total of 104 stomachs of the Sagor catfish were examined and only three individuals had empty stomachs. Mean gut fullness was 2.4 ± SD 1.2. The Sagor catfish appeared as true generalist feeder, feeding on wide variety of prey items (13 types). Shrimps formed the highest composition (28.2 %IRI), followed by detritus (20.4 %IRI), teleosts (17.6 %IRI), anomurans (10.0 %IRI) and brachyurans (9.5 %IRI). Larger individuals (SL > 20 cm) were found to feed on penaeid prawns such as *Metapenaeus* spp. and fish such as *J. carouna* and *Thryssa* spp. Individuals with intermediate size (SL = 10 - 20 cm) fed on wide variety of preys such as the terebellids, pinnotherids, dorripids, sergestids and diogenids. Small individuals (SL < 10 cm) were found to mostly feed on plant detritus, decapod zoeae and sergestid shrimps.

d) *Nemapteryx caelata*

Total number of the engraved catfish *N. caelata* stomachs examined was 92 with two empty stomachs. Mean gut fullness was 2.0 ± SD 1.1. The diet of the engraved catfish consisted of mainly crabs (32.6 %IRI), detritus (27.6 %IRI) and fish (24.0 %IRI). Crabs of the Ocypodidae (36.8 %IRI) and Pinnotheridae (31.4 %IRI) were mostly consumed.

e) *Osteogeneiosus militaris*

Only 23 stomachs of the soldier catfish *O. militaris* were examined, with five of them empty. The mean gut fullness was 1.6 ± SD 1.3. Among members of the MX guild, the soldier catfish consumed the lowest number of prey type (6). Bivalves was the dominant food ingested (77.6 %IRI), followed by detritus (14.9 %IRI) and brachyurans (6.2 %IRI).

f) *Plicofollis argyropleuron*

A total of 139 out of 146 stomachs of the longsnouted catfish *P. argyropleuron* examined revealed a mean gut fullness of 1.8 ± SD 1.1. Its diet proportions were rather similar to the soldier catfish, comprising of bivalves (60.2 %IRI), detritus (15.3 %IRI) and brachyurans (14.3 % IRI). Both Tellinidae and Vereridae clams formed the majority of the bivalves consumed.

g) *Lagocephalus lunaris*

Among the 25 individuals of lunartail pufferfish *L. lunaris* examined, two of them had empty stomachs. Mean gut fullness was 2.0 ± SD 1.1. The lunartail pufferfish was the only member of MX guild that fed primarily on crabs (84.8 %IRI) such as pinnotherids. Gastropods (6.7 %IRI) and teleosts (4.7 %IRI) were also ingested. However, mainly teleost scales were consumed.

h) *Takifugu oblongus*

A total of 28 stomachs of the lattice blaasop *T. oblongus* were examined, with 23 of them non-empty giving a mean stomach fullness of 1.4 ± SD 0.9, the lowest among members of the MX guild. The diet of *T. oblongus* consisted of bivalves (43.3 %IRI), brachyurans (20.0 %IRI), gastropods (19.5 %IRI) and plant detritus (14.5 %IRI). Fish, shrimps and decapod zoeae were also ingested but in insignificant proportions.

i) *Dichotomyctere fluviatilis*

There was only one empty stomach from the 28 stomachs of green puffer, *D. fluviatilis* examined. The green puffer had the highest mean gut fullness among the members of the MX guild (2.9 ± SD 1.1). Barnacles formed the half of the green puffer‘s diet (50.1 %IRI), followed by bivalves (43.9 %IRI) and gastropods (5.1 %IRI). Interestingly, the occurrences of barnacle as diet were very rare in the stomachs of other examined fish species.

j) *Cynoglossus cynoglossus*

The Bengal tongue sole *C. cynoglossus* were examined for 98 individuals; 91 of them had non-empty stomachs. Mean gut fullness were 1.5 ± SD 0.9. This species fed mainly on plant detritus (39.3 %IRI) and brachyurans (30.8 %IRI). Other prey items with lesser importance were the bivalves (8.7 %IRI), decapod zoeae (6.2 %IRI), teleosts (4.1 %IRI), shrimps (3.7 %IRI), copepods (3.7 %IRI) and polychaetes (3.2 %IRI).

k) *Cynoglossus lingua*

A total of 69 stomachs were examined, with 57 non-empty stomachs and a mean gut fullness of 1.5 ± SD 1.1. The diet of long tongue soles was similar to the Bengal tongue sole, consisting of primarily brachyurans (37.4 %IRI) and detritus (30.3 %IRI).

l) *Triacanthus nieuhofii*

Stomachs of A total of 31 individuals of tripodfish *T. neiuhofii* were examined, with mean gut fullness of 2.1 ± SD 1.1. Bivalves were the most important food of tripod fish (44.8 %IRI), followed by brachyurans (22.1 %IRI), polychaetes (13.2 %IRI) and copepods (10.7 %IRI). Other food items such as anomurans, cirripids, fish and detritus appeared sporadically in its diet but were insignificant in terms of relative importance.

m) *Plotosus canius*

Out of 97 stomachs of the eel catfish *Plotosus canius* examined, 92 contained food with mean gut fullness of 2.2 ± SD 1.0. The crabs especially the leucosiids formed the majority of the eel catfish diets (66.9 %IRI). The bivalves were observed as the second most important food (17.7 %IRI) which consisted of mainly mytillids.

6.1.9 Other fish species

The stomach contents from 15 other fish species that were not included in the trophic guild analysis due to low sample size (n < 10 non-empty stomachs) were also examined. The numbers of non empty stomachs per species ranged from 3 to 9 for a total of 86 individuals. The trophic guild for each of these fish species was tentatively assigned based on the two most important prey items found in their stomachs based on %IRI. The guild characterization for these species should be treated as preliminary until further studies are conducted.

The 15 fish species fall into five feeding guilds described above, and one additional guild not described before (Table 6.4). A single species, the cleftbelly trevally *Atropus atropos* was found to feed heavily on copepods but also on cephalopods, based on six stomachs examined. It was tentatively assigned to the copepod feeders (CO) guild. Four species of fish was assigned as shrimp feeders (SH) due to high reliance on shrimp diet (> 90 %IRI). They included three species of Carangidae (*Alectis indica*, *Scomberoides tol* and *Scomberoides tala*) and one species of Polynemidae (*Polydactylus sextarius*). Five species fed more heavily on fish and were assigned as shrimp/teleost feeders (ST) including the hound needlefish (*Tylosurus crocodilus crocodilus*), Savalai hairtail (*Lepturacanthus savala*), tripletail (*Lobotes surinamensis*), Donkey croaker (*Pennahia anea*) and short mackerel (*Rastrelliger brachysoma*). The shrimp/decapod feeders (SD) consisted of John‘s snapper (*Lutjanus johnii*) and Jarbua terapon (*Terapon jarbua*). While brachyuran crabs were the top prey item for these species (50 - 70 % IRI), these fish species were also found to feed on other prey items such as shrimps and fish. The longfin batfish *Platax teira* fed mainly on detritus (68.0 %IRI) and brachyurans (30.6 %IRI) were considered mixed macrobenthos feeders (MX). The two species of archer fish, the banded archerfish *Toxotes jaculatrix* and the smallscale archerfish (*Toxotes microlepis*) which fed on insects (29 - 87 %IRI) also took in other preys like small decapods and fish. Both were assigned to a new feeding guild, the Insects/miscellaneous feeders (IM).

Table 6.4 Diet expressed as Index of Relative Importance (% IRI) for 13 prey categories and mean gut fullness of 15 less common fish species from Klang mudflats (not included in trophic guild analysis). N indicates number of non empty stomachs examined.

Species name	**Common name**	**N**	**Mean gut fullness**	**copepods**	**shrimps**	**fish**	**bnrachyurans**	**anomurans**	**isopods**	**bivalves**	**cephalopods**	**polychaetes**	**detritus**	**insectoid**
Copepod feeders (CO)														
Atropus atropos	Cleftbelly trevally	6	2.2 ± 1.3	43.3		5.3			1.4		50.0			
Shrimp feeders (SH)														
Polydactylus sextarius	Blackspot threadfin	5	2.8 ± 1.1		100									
Scomberoides tol	Needlescaled queenfish	5	4.0 ± 0.0		98.7	0.7						0.6		
Alectis indica	Indian threadfish	7	3.1 ± 1.5		97.9		2.1							
Scomberoides tala	Barred queenfish	7	2.3 ± 1.3		93.7	5.4	0.9							
Shrimp/teleost feeders (ST)														
Tylosurus crocodilus crocodilus	Hound needlefish	3	2.3 ± 1.2			100								
Lepturacanthus savala	Savalai hairtail	5	2.0 ± 1.2		1.5	98.5								
Lobotes surinamensis	Tripletail	3	3.3 ± 1.2		11.0	89.0								
Pennahia anea	Donkey croaker	5	3.2 ± 0.4		23.4	76.6								
Rastrelliger brachysoma	Short mackarel	9	2.8 ± 1.6			85.7					14.3			
Shrimp/decapod feeders (SD)														
Lutjanus johnii	John‘s snapper	5	4.0 ± 0.0		40.6		59.4							
Terapon jarbua	Jarbua terapon	8	3.4 ± 0.7		24.6	10.8	53.3	7.2		0.9				3.1
Mixed macrobenthos feeders (MX)														
Platax teira	Longfin batfish	6	2.2 ± 1.5				30.6	1.4					68.0	
Insect/miscellaneous feeders (IM)														
Toxotes jaculatrix	Banded archerfish	9	2.7 ± 1.2		7.9	1.0	4.5							86.5
Toxotes microlepis	Smallscale archerfish	3	2.3 ± 0.6				71.1							28.9

6.2 Spatial and temporal variability in diet

PERMANOVA analysis indicated that six species of fish showed significant dietary difference between sites ($p < 0.05$) and eight species showed significant difference between monsoon periods ($p < 0.05$) (Table 6.5). SIMPER analysis indicated that crustaceans accounted for most of the diet differences especially between sites (Table 6.5). At SB, both *E. tetradactylum* and *N. soldado* appeared to consume more fish as prey whereas *A. gymnocephalus* and *L. brevirostris* consumed a greater variety of prey taxa (anomurans, amphipods and zoeae) as opposed to only copepods consumed at BP by the latter two species (Table 6.5). Anomurans, brachyurans and copepods were the top three prey taxa that contributed to the diet difference in *P. kaakan* between BP and SB; fish at SB consumed more anomurans while those at BP consumed more brachyurans and copepods. Brachyurans also contributed the most to the site differences in the diet of *S. taty*, where more brachyurans were consumed at SB than BP. In terms of gut fullness, t-test indicated that both species of the Thryssa anchovies appeared to had significantly higher mean gut fullness in SB ($p < 0.05$), indicating higher predation or feeding rate in SB. Contrary to that, *D. punctata* and *P. argyropleuron* recorded higher mean gut fullness in BP ($p < 0.05$) (Table 6.6).

Table 6.5 Summary list of fish species (feeding guild shown in brackets) with significant diet difference ($p < 0.05$) between sampling sites (BP and SB) and between monsoon periods (SWM and NEM). Only the top three prey taxa that contributed most to diet dissimilarity were shown. The average pooled percentage IRI values are given for each level of the tested factor (i.e. site or monsoonal season). MX, mixed macrobenthos feeders; IL, iliophages; CO, copepod feeders; SH, dominantly shrimp feeders; SZ, shrimp and zooplankton feeders; SD, shrimp and other decapod feeders.

Species	**Prey (% dissimilarity)**	**% IRI**	
		BP	**SB**
Ambassis gymnocephalus (CO)	Hermit crab (33.2)	0.45	11.41
	Zoea (17.3)	1.07	4.58
	Amphipoda (16.6)	1.36	3.10
Leiognathus brevirostris (CO)	Bivalve (27.2)	0.00	19.37
	Copepod (20.7)	97.90	56.69
	Detritus (13.6)	0.15	5.31
Pomadasys kaakan (SD)	Anomuran (19.3)	17.72	0.00
	Copepod (16.0)	0.00	8.11
	Brachyuran (16.0)	3.00	18.28
Eleutheronema tetradactylum (SH)	Fish (40.9)	0.32	7.67
	Brachyuran (19.5)	0.77	2.12
	Shrimp (9.3)	98.36	89.43
Nibea soldado (SH)	Teleost (20.0)	1.58	13.52
	Brachyuran (16.8)	0.21	7.05
	Anomuran (15.7)	0.23	5.46
Setipinna taty (SH)	Brachyuran (34.9)	3.61	0.25
	Detritus (19.6)	3.18	0.00
	Zoea (17.8)	0.61	0.00

Species	**Prey (% dissimilarity)**	**% IRI**	
		SWM	**NEM**
Pampus chinensis (IL)	Zoea (27.5)	35.05	0.32
	Microalgae (18.3)	52.80	57.13
	Detritus (15.5)	0.00	14.43
Thryssa kammalensis (SZ)	Copepod (30)	21.87	42.76
	Shrimp (21.9)	72.07	48.91
	Brachyuran (20.0)	3.94	7.61
Opisthopterus tardoore (SH)	Copepod (30.3)	7.34	1.85
	Teleost (26.8)	0.00	2.35
	Zoea (14.4)	1.33	0.59
Setipinna taty (SH)	Brachyuran (32.8)	1.79	0.15
	Zoea (19.7)	0.00	2.01
	Detritus (16.4)	0.48	0.00
Cynoglossus cynoglossus (MX)	Shrimp (18.5)	0.00	17.08
	Bivalve (13.5)	15.45	1.84
	Brachyuran (12.6)	15.45	26.28
Nemapteryx caelata (MX)	Brachyuran (21.8)	55.01	10.93
	Teleost (15.7)	4.54	24.05
	Detritus (14.4)	9.59	39.98
Plicofollis argypleuron (MX)	Brachyuran (16.6)	33.84	7.86
	Bivalve (14.4)	29.94	45.94
	Shrimp (11.9)	10.72	1.97
Plotosus canius (MX)	Polychaete (23.7)	17.09	0.41
	Bivalve (18.1)	19.42	16.70
	Shrimp (16.1)	7.61	0.00

Table 6.6 List of selected fish species from each trophic guild with number of non empty stomach examined, mean and standard deviation (SD) of gut fullness compared between site BP and SB, and their *p*-value from t-test. Numeral in bold indicate significant difference ($p < 0.05$).

Species name	**BP**		**SB**		***p* value**
	Number	**Mean and SD**	**Number**	**Mean and SD**	
Iliophages (IL)					
Pampus argenteus	41	1.76 ± 1.20	74	1.53 ± 1.04	0.286
Pampus chinensis	21	1.52 ± 1.12	25	1.36 ± 0.91	0.587
Planiliza melinoptera	10	1.00 ± 0.94	21	1.71 ± 0.96	0.061
Planiliza subviridis	89	1.64 ± 1.04	69	1.77 ± 1.10	0.456
Scatophagus argus	27	2.44 ± 1.25	25	2.40 ± 1.32	0.901
Copepods feeders (CO)					
Ambassis gymnocephalus	51	1.57 ± 0.94	55	1.44 ± 1.12	0.514
Escualosa thoracata	17	1.76 ± 0.90	16	2.31 ± 1.45	0.199
Leiognathus brevirostris	21	1.43 ± 0.75	37	1.62 ± 1.09	0.474
Shrimp/teleost feeders (ST)					
Otolithes ruber	85	2.25 ± 1.29	105	2.04 ± 1.34	0.279
Strongylura strongylura	67	1.64 ± 1.57	56	1.98 ± 1.10	0.176
Shrimp/decapod feeders (SD)					
Johnius belangerii	45	2.36 ± 1.15	57	2.30 ± 1.25	0.813
Johnius carouna	85	1.55 ± 1.16	110	1.69 ± 1.32	0.446
Pomadasys kaakan	68	2.44 ± 1.19	35	2.23 ± 1.19	0.392
Shrimp/zooplankton feeders (SZ)					
Thryssa kammalensis	92	1.14 ± 1.03	76	1.72 ± 1.25	**0.001**
Shrimps feeders (SH)					
Coilia dussumieri	33	1.52 ± 1.00	39	1.33 ± 0.90	0.420
Dendrophyssa russelii	42	1.69 ± 1.00	56	1.70 ± 1.13	0.978
Eleutheronema tetradactylum	64	2.11 ± 1.39	85	2.42 ± 1.41	0.178
Ilisha melastoma	42	2.00 ± 1.31	49	2.31 ± 1.36	0.278
Nibea soldado	53	1.72 ± 1.08	51	1.84 ± 1.05	0.547
Opisthopterus tardoore	49	1.96 ± 1.17	89	1.97 ± 1.15	0.973
Panna microdon	62	1.53 ± 1.29	78	1.46 ± 1.22	0.741
Setipinna taty	62	1.16 ± 0.85	118	1.19 ± 1.18	0.882
Stolephorus baganensis	22	1.41 ± 1.47	22	1.86 ± 1.39	0.298
Thryssa hamiltonii	8	0.88 ± 0.99	35	2.17 ± 1.18	**0.006**
Polychaete feeders (PO)					
Drepane punctata	41	2.68 ± 1.33	36	1.83 ± 1.00	**0.002**
Mixed macrobenthos feeders (MX)					
Arius maculatus	45	2.36 ± 1.43	44	2.14 ± 1.23	0.441
Cynoglossus cynoglossus	51	1.41 ± 0.94	47	1.55 ± 0.93	0.456
Cynoglossus lingua	35	1.71 ± 1.20	34	1.24 ± 0.96	0.072
Dichotomyctere fluvialitis	13	3.00 ± 1.08	15	2.73 ± 1.22	0.549
Hexanematichthys sagor	51	2.22 ± 1.14	53	2.49 ± 1.28	0.250
Nemapterys caelata	48	2.13 ± 1.14	44	1.86 ± 1.07	0.261
Plicofollis argyropleuron	70	2.24 ± 1.08	76	1.49 ± 0.96	**0.000**
Plotosus canius	54	2.11 ± 1.00	43	2.37 ± 1.07	0.219
Triacanthus nieuhofii	6	2.33 ± 1.03	25	2.08 ± 1.12	0.617

In term of monsoonal season, prey fish and copepods were consumed by tardoore, *O. tardoore*, where the former prey were consumed throughout the year but more during SWM, while the latter were only consumed during NEM. Two catfish species *N. caelata* and *P. argyropleuron*, and the scaly hairfin anchovy appeared to prey on brachyurans more during the SWM than NEM. The tongue sole *C. cynoglossus* were observed to consume more shrimps in their diet during the NEM, in contrast to the eel catfish *P. canius* which fed more on shrimps during SWM. The Kammal anchovy was also found to consume higher amount of pelagic shrimps during SWM, but more copepods during NEM. The Chinese pomfret *P. chinensis* also exhibited significant differences in its diet over the year where during the SWM, more decapod zoeae were consumed. As for fish mean gut fullness, SWM appeared to have more species of fish with higher mean gut fullness as opposed to NEM (Table 6.7). Three species of ariids (*H. sagor, N. caelata* and *P. argyropleuron*), *D. punctata, C. dussumieri* and tripodfish *T. nieuhofii* have higher mean gut fullness during SWM, whereas only two engraulids species (*S. baganensis* and *T. hamiltonii*) have higher mean gut fullness during NEM.

Table 6.7 List of selected fish species from each trophic guild with number of non empty stomach examined, mean and standard deviation (SD) of gut fullness compared between SWM and NEM, and their *p*-value from t-test. Numeral in bold indicate significant difference ($p < 0.05$).

Species name	**SWM**		**NEM**		***p* value**
	Number	**Mean and SD**	**Number**	**Mean and SD**	
Iliophages (IL)					
Pampus argenteus	40	1.78 ± 1.19	75	1.52 ± 1.04	0.237
Pampus chinensis	27	1.37 ± 0.93	19	1.53 ± 1.12	0.609
Planiliza melinoptera	12	1.33 ± 0.98	19	1.58 ± 1.02	0.513
Planiliza subviridis	75	1.57 ± 1.04	83	1.81 ± 1.08	0.168
Scatophagus argus	23	2.30 ± 1.26	29	2.52 ± 1.30	0.555
Copepods feeders (CO)					
Ambassis gymnocephalus	53	1.38 ± 0.97	53	1.62 ± 1.10	0.224
Escualosa thoracata	19	1.79 ± 0.92	14	2.36 ± 1.50	0.188
Leiognathus brevirostris	27	1.48 ± 0.8	31	1.61 ± 1.12	0.613
Shrimp/teleost feeders (ST)					
Otolithes ruber	70	2.27 ± 1.44	120	2.05 ± 1.24	0.266
Strongylura strongylura	58	1.76 ± 1.33	65	1.83 ± 1.44	0.774
Shrimp/decapod feeders (SD)					
Johnius belangerii	48	2.25 ± 1.12	54	2.39 ± 1.28	0.563
Johnius carouna	92	1.53 ± 1.28	103	1.72 ± 1.22	0.301
Pomadasys kaakan	48	2.21 ± 1.15	55	2.51 ± 1.22	0.201
Shrimp/zooplankton feeders (SZ)					
Thryssa kammalensis	80	1.33 ± 1.13	88	1.48 ± 1.2	0.401
Shrimps feeders (SH)					
Coilia dussumieri	38	1.66 ± 1.02	34	1.15 ± 0.78	**0.021**
Dendrophyssa russelii	52	1.79 ± 1.21	46	1.59 ± 0.88	0.354
Eleutheronema tetradactylum	63	2.40 ± 1.41	86	2.21 ± 1.41	0.423
Ilisha melastoma	42	2.10 ± 1.14	49	2.22 ± 1.49	0.648
Nibea soldado	51	1.84 ± 1.07	53	1.72 ± 1.06	0.547
Opisthopterus tardoore	60	2.02 ± 1.11	78	1.92 ± 1.19	0.639
Panna microdon	58	1.60 ± 1.34	82	1.41 ± 1.19	0.380
Setipinna taty	92	1.15 ± 1.05	88	1.20 ± 1.11	0.745
Stolephorus baganensis	25	1.20 ± 1.15	19	2.21 ± 1.58	**0.019**
Thryssa hamiltonii	19	1.47 ± 1.17	24	2.29 ± 1.20	0.030
Polychaete feeders (PO)					
Drepane punctata	38	2.63 ± 1.08	39	1.95 ± 1.34	**0.016**
Mixed macrobenthos feeders (MX)					
Arius maculatus	43	2.33 ± 1.19	46	2.17 ± 1.47	0.595
Cynoglossus cynoglossus	53	1.42 ± 0.91	45	1.56 ± 0.97	0.461
Cynoglossus lingua	35	1.51 ± 1.25	34	1.44 ± 0.96	0.786
Dichotomyctere fluvialitis	12	2.67 ± 1.37	16	3.00 ± 0.97	0.456
Hexanematichthys sagor	48	2.69 ± 1.21	56	2.07 ± 1.16	**0.009**
Nemapterys caelata	53	2.26 ± 1.08	39	1.64 ± 1.06	**0.007**
Plicofollis argyropleuron	66	2.11 ± 1.24	80	1.64 ± 0.89	**0.009**
Plotosus canius	53	2.21 ± 1.08	44	2.25 ± 0.99	0.842
Triacanthus nieuhofii	10	2.70 ± 0.95	21	1.86 ± 1.06	**0.042**

6.3 Shrimp (prawn) standing stock

Since shrimps made such a strong presence in the diet of most of the fish fishes examined, their abundance were examined in greater detail here to see whether shrimp abundance is correlated to fish abundance. In this study, a total of 11 species of prawns and shrimps were captured during monthly sampling from September 2011 to November 2013 (26 months), using the same enclosure trap and gill net at both study sites (Table 6.8).

Table 6.8 Checklist and catch summary of shrimp species with their respective local name collected in intertidal area of Klang mudflats during monthly samplings.

Family	Species	Local name	Mean stock abundance and biomass	
			N/Ha	g/Ha
Palaemonidae	*Macrobrachium equidens*	Rough river prawn	45.4	0.98
	Palaemon styliferus	Roshna prawn	217.4	11.70
Penaeidae	*Fenneropenaeus indicus*	Indian prawn	57.6	4.25
	Fenneropenaeus merguiensis	Banana prawn	55.5	3.67
	Metapenaeus affinis	Jinga shrimp	626.3	13.98
	Metapenaeus brevicornis	Yellow shrimp	146.3	2.83
	Metapenaeus ensis	Greasyback shrimp	0.5	0.01
	Parapenaeopsis coromandelica	Coromandel shrimp	33.1	0.05
	Parapenaeopsis hardwickii	Spear shrimp	152.7	3.59
	Parapenaeopsis sculptilis	Rainbow shrimp	10.8	0.32
	Penaeus monodon	Giant tiger shrimp	0.3	0.01
	Total number of species/ total stock abundance and biomass	11	1345.9	41.39

There were nine species of penaeid prawns (*Fenneropenaeus merguiensis, Fenneropenaeus indicus, M. affinis, M. brevicornis, Metapenaeus ensis, Parapenaeopsis sculptilis*, *P. hardwickii, Parapenaeopsis coromandelica* and *Penaeus monodon*) and two species of caridean prawns (*Macrobrachium equidens* and *Palaemon styliferus*) recorded from the mudflat (Table 6.8). Among these prawns, the Jinga shrimp *M. affinis* had the highest abundance (46 %) and biomass (34 %), followed by *P. styliferus* (16 % and 28 %, respectively).

In the intertidal mudflat area, the mean total shrimp abundance at SB and BP mudflat was estimated at 1491 ± 425 ind. ha^{-1} and 1212 ± 245 ind. ha^{-1} (mean and standard error) respectively, whereas mean biomass was recorded at 2.87 ± 0.57 kg ha^{-1} and 5.69 ± 1.67 kg ha^{-1}, respectively (Table 6.9). In terms of monsoon seasons, NEM had a mean abundance of 1352 ± 330 ind. ha^{-1} and mean biomass of 4.32 ± 1.07 kg ha^{-1} whereas SWM had a mean abundance of 1346 ± 361 ind.ha^{-1} and mean biomass of 4.17 ± 1.46 kg ha^{-1}. No significant differences ($p > 0.05$) were observed for both study sites and monsoon seasons. Three modes of shrimp abundance and biomass were recorded at SB mudflat during November 2011, January 2012 and September 2012 attributed to the high catches of *M. affinis* and *P. styliferus* (Figure 6.11, 6.12).

Table 6.9 Standing stocks of shrimps in the intertidal area of mudflat during monthly sampling. Numeral in bold indicate significant difference at $p < 0.05$. BP = Bagan Pasir; SB = Bagan Sungai Buloh; SWM = Southwest monsoon; NEM = Northeast monsoon; SE = standard error.

Factor		**Site**		**Monsoon**	
Level		**BP**	**SB**	**SWM**	**NEM**
Abundance	Mean	1212	1491	1346	1352
(N/ha)	±SE	245	425	361	330
Biomass	Mean	2.87	5.69	4.17	4.32
(kg/ha)	±SE	0.57	1.67	1.46	1.07

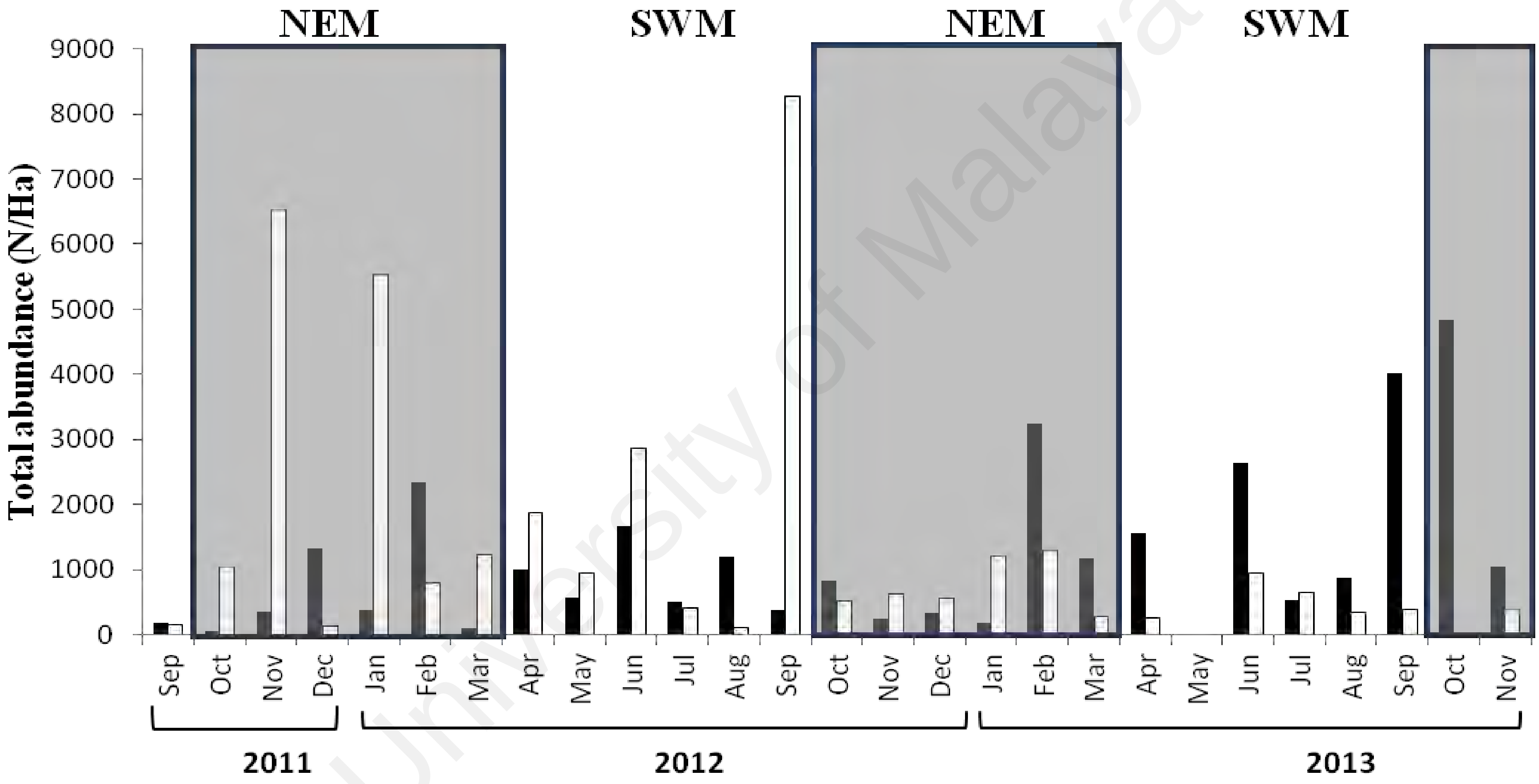

Figure 6.11 Monthly and seasonal variability of total shrimp abundance in the intertidal area of Klang mudflat, from September 2011 to November 2013. Shaded area indicate NEM period. Filled bar = Bagan Pasir mudflat; empty bar = Bagan Sungai Buloh mudflat.

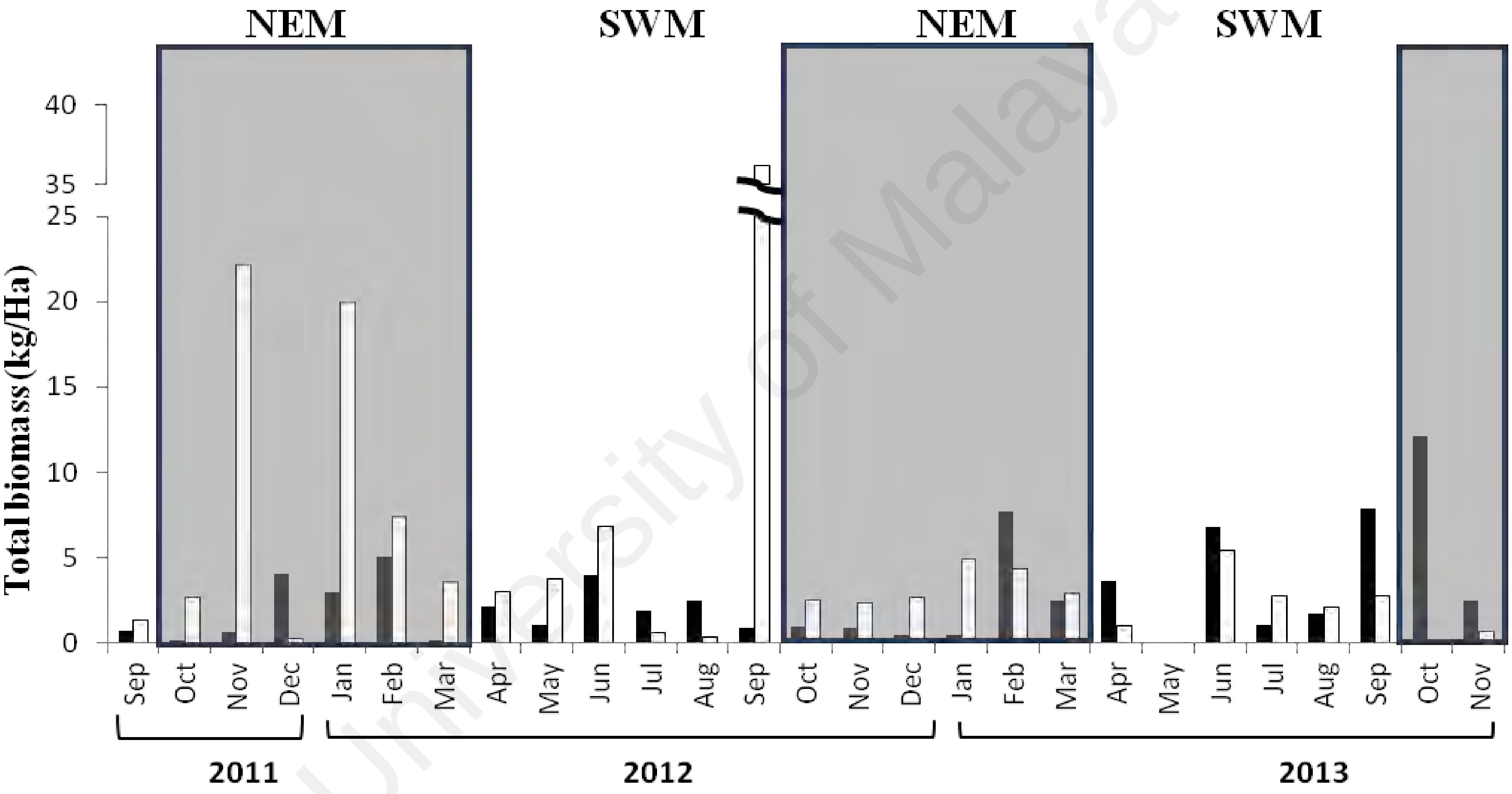

Figure 6.12 Monthly and seasonal variability of total shrimp biomass in the intertidal area of Klang mudflat, from September 2011 to November 2013. Shaded area indicate NEM period. Filled bar = Bagan Pasir mudflat; empty bar = Bagan Sungai Buloh mudflat.

6.4 Relationship between shrimp feeder and shrimp and abundance

Among the 16 species of shrimp feeders (SH) and 11 species of mixed shrimp feeders (ST, SZ and SD), 10 species of fish in the intertidal mudflat area showed significant positive correlations ($p < 0.05$) with at least one of the dominant shrimp species shown in Table 6.8. Only two species of fish were significantly correlated to a single species of shrimp whereas the rest were correlated with at least two shrimp species. In the overall, abundance of all shrimp feeders combined were significantly correlated to combined shrimp abundance ($p < 0.05$, $r = +0.45$). The goatee croaker *D. russelii* was significantly correlated ($p < 0.05$) with five species of penaeid prawns and one species of caridean shrimp. *F. indicus* ($r = +0.79$), *M. brevicornis* ($r = +0.68$) and *M. affinis* ($r = +0.63$) were prawn species that showed the highest positive correlation coefficients with the goatee croaker. The other three sciaenids the sharpnose hammer croaker, Belanger‘s croaker and soldier croaker however were more correlated with the caridean prawn *P. styliferus* ($r = +0.80$; $+0.74$; $+0.70$, respectively) and penaeid prawn *F. merguensis* ($r = +0.78$; $+0.76$; $+0.70$, respectively). The taardore also showed significantly high positive correlations with both *P. styliferus* ($r = +0.99$) and banana prawn ($r = +0.99$). The Rough River Prawn *M. equidens* were only correlated with Kammal anchovy ($r = +0.44$; $p < 0.05$). Meawhile, the Bombay duck was only correlated with rainbow shrimp *P. sculptilis* ($r = +0.31$; $p < 0.05$) whereas the Indian ilisha was positively correlated with the Jinga shrimp *M. affinis* ($r = +0.47$; $p < 0.05$). The spear shrimp *P. hardwickii* was however not significantly correlated ($p > 0.05$) with any examined fish species.

Table 6.10 Correlation coefficients between shrimp feeder species (row) and shrimp species (column) in intertidal area during monthly sampling. Only fish species with significant correlation are shown ($p < 0.05$).

Species name	***Palaemon styliferus***	***Macrobrachium equidens***	***Metapenaeus affinis***	***Metapenaeus brevicornis***	***Parapenaeopsis hardwickii***	***Parapenaeopsis sculptilis***	***Fenneropenaeus indicus***	***Fenneropenaeus merguiensis***
Shrimp feeders (SH)								
Brevitrygon walga	0.48							0.43
Dendrophysa russelii	0.33		0.68	0.73		0.31	0.79	0.34
Eleutheronema tetradactylum	0.63			0.39		0.37		0.62
Harpadon nehereus						0.31		
Ilisha melastoma			0.47					
Johnius borneensis	0.80			0.31				0.78
Nibea soldado	0.70							0.70
Opisthopterus tardoore	0.99			0.41				0.99
Shrimp/decapod feeders (SD)								
Johnius belangerii	0.74			0.30				0.76
Shrimp/zooplankton feeders (SZ)								
Thryssa kammalensis		0.44						

6.5 Discussion

The diet of 53 common fish species using the Klang Strait mudflats were described; this represented the half of the fish species richness and more than 90% of the total fish abundance sampled the Klang Strait mudflats. All species of fish examined have more non-empty stomachs, with some of the common species have mean gut fullness more than half, suggesting that feeding is an important activity of the fish that use the mudflat area. As mentioned above (Section 5.5), compared to refugia, the ample food resources of the Klang Strait mudflats are likely the major driving force for the fishes to ingress into.

The fish community in the Klang Strait mudflats can be grouped into eight major trophic guilds based on their diet preferences, which are the iliophages (IL), copepod feeders (CO), shrimp feeders (SH), shrimp and teleost feeders (ST), shrimp and zooplankton feeders (SZ), shrimp and decapod feeders (SD), polychaete feeders (PO) and mixed macrobenthos feeders (MX). An additional feeding guild (IM) is apparent, although its members like the archer fishes are more reprentative of the adjacent mangrove habitat or estuary. These fishes though not abundant may move into the mudflat during high tide. Being the most speciose guild, shrimp feeders make up about 30 % of the fish species, followed by the mixed macrobenthos feeders (25 %) and the iliophages (15 %). The Matang coastal mudflats, located about 180 km farther north of the current study site, also have eight trophic guilds of fish (Chong et al., 2012b). These include the herbivore–detritivores, natantia (shrimp) feeders, mollusk feeders, polychaete feeders, crab/hermit crab feeders, copepod feeders, piscivores, and mixed feeders.

The discernible trophic guilds in the Klang mudflats attest to some degree of food partitioning among the fish species where only a small fraction of their feeding niche overlaps. Food partitioning is among several adaptation strategies for predators to coexist with others within an area (Ross, 1986). However, it is expected that members of the same guild will have stronger interactions between each other (intraguild) as compared to with members of other guilds (Muñoz & Ojeda, 1997); thus, strong intraguild interactions may require alternative feeding strategies among species sharing the same trophic guild. Flexibility in feeding strategy is also required on shared resources by different species (Ley et al., 1994). Adaptations such as partition of habitat space (Potier et al., 2004), occupation of the habitat at different times (Young et al., 2010; Varghese et al., 2014) and abundance of shared food resources (Laptikhovsky et al., 2001) can help reduce species competition.

In the Klang Strait mudflat, the shared prey resources of a large number of fish species sampled (45 out of 53 species) were highly abundant, supporting the hypothesis that mudflat fishes coexist by sharing similar but abundant food resources. Specifically, the prey resources are the large stocks of penaeid and sergestid shrimps reported by others who have conducted similar works in the same study area (Marsitah & Chong, 2002; Azila & Chong, 2010). The present study estimated a mean (± standard error) stock density of shrimps of 1494 ± 425 ind ha^{-1} and 1212 ± 245 ind ha^{-1} at the Sungai Buloh (SB) and Bagan Pasir (BP) mudflats, consisting of mainly penaeid prawns (80.0 %). From the correlation analysis between shrimp feeders and shrimps‘ abundance, at least five species of penaeid shrimps and prawns are known to serve as critical food source to half of the fish species of shrimp feeders guild have further support this contention. On the other hand, sergestid shrimps are particularly important prey to the smaller or juvenile shrimp feeders in this study. Athough the abundance of sergestid shrimps were not sampled in this study, an earlier study estimated monthly catches of *Acetes* spp. in the Klang Strait mudflats at 68 (± 27 SE) m^{-3} (Mariana, 1993). In addition to serving as important prey resource for the highly diverse fish community, both the penaeid and *Acetes* shrimps support the state‘s production of 45,580 and 32,056 metric tonnes per year, respectively (Department of Fisheries Malaysia, 2016).

The apparent lack of seasonal difference in the diet of shrimp feeders suggests the constant presence of shrimp prey and their availability to the coastal fishes. Chong et al. (1996) reported continuous recruitment of postlarval penaeid prawns into Klang‘s coastal mangroves and mudflats which serve as major nursery or feeding areas. The present study also indicates the continuous presence of shrimps as prey throughout the year in the Klang mudflat (Figure 6.11, 6.12). No spatial and seasonal difference in shrimp availability was observed as well. Like penaeid shrimps, the recruitment of *Acetes* shrimps into the coastal areas on the west coast of Peninsular Malaysia appeared to be continuous throughout the year (Amin, 2009a;b). Similar to the Matang mudflat study (Chong et al., 2012b), studies from other regions also emphasized the importance of penaeid prawns to the local fish communities (Robertson, 1988; Brewer et al., 1995; Fujiwara et al., 2016). Most fishes will feed on frequently occurring prey in sufficient abundance rather than predate selectively, as they will focus on resources that are effectively accessible (Mérona et al., 2001). However, certain species of shrimps and prawns may not be easily available to certain fish species, particularly the burrowing shrimps such as the *Parapenaeopsis* and *Metapenaeus* shrimps (Chong et al., 1990; Chong et al., 1994; Primavera & Lebata, 1995; Marsitah & Chong, 2002). *Penaeus* prawn are active swimmer but not known to burrow as much (Primavera & Lebata, 1995), thus rendered the *Fenneropenaeus (Penaeus) merguiensis* in this study as an easier prey to many fish species compared to other shrimps. Burrowing species such as the rainbow shrimp *Parapenaeopsis sculptilis* appears to be fed mostly by goatee croaker that possessed chin barbel and fourfinger threadfin that possessed numerous pectoral filaments. Fish barbel and pectoral filaments are sensory appendages known to house taste bud of fish functioning in searching for food in murky environment (Joyce

& Chapman, 1978; Ogawa et al., 1997; LeClair & Topczewski, 2010). The juvenile and adult of penaeid prawns are good nutrient source to their predator due to their high energy content that rival other invertebrates such as polychaetes and gastropods (Thayer et al., 1973).

High abundance of prey can lead to a specialized diet as suggested by other workers (Crowder & Cooper, 1982; Amundsen et al., 1996). In the present study, two specialist polychaete feeders *D. punctata* and *S. sihama* relied on at least one polychaete family (Sabellaridae). In the Jeram mudflat just 3 km south of SB, sabellariids build very extensive, ephemeral polychaete reefs that survive from April to December but disintegrate thereafter (Eeo et al., 2017). Stomach contents of these fish sampled after reef disintegration period (January - March) showed a shift from sabellariid to errantia polychaetes. Another example of specialist feeders are such as the goatee croaker and fourfinger threadfin using their chin barbel and pectoral filament to sense burrowing rainbow shrimps. Zooplanktivores, or fishes that feed on copepods or other zooplankton can also be considered as specialist feeders due to their overwhelming dependence on single prey food (> 70 %IRI), a finding similarly reported by other researchers (Hajisamae et al., 2003; Cui et al., 2012). In the Klang Strait estuarine area, calanoid and cyclopoid copepods dominate the zooplankton community (Chew et al., 2015). In the present study, the calanoid copepods *Parvocalanus* constituted the major prey of the three species of copepods feeders (Raje et al., 1994; Blaber, 2000; Sebastian & Inasu, 2011; Chew et al., 2012). The dependence of ambassids on copepod food appears to limit their abundance to the wetter NEM when copepod abundance also peaked (Chew & Chong, 2011).

The mixed macrobenthos feeders comprising catfishes, pufferfishes and tongue soles that feed on a wide range of prey types demonstrate some degree of prey partitioning. Species of these families are often characterized as benthic or detritus feeders (Singh, 2003; Mazlan et al., 2008; Then, 2008). While members of the guild collectively feed on a large variety of prey, individual species appears to feed mainly on one or two particular prey type(s). Sympatric or similar-sized species tend to exhibit higher dietary overlap (Heithaus, 2004). However, they are able to co-exist by utilizing food sources that are abundant and feeding at different times or prey sizes (Bethea et al., 2004). In the present study, the four sympatric catfish species (*A. maculatus, C. truncatus, O. militaris* and *P. argyropleuron*) focus on benthic bivalves as their main prey, whereas two other catfish species (*H. sagor* and *N. caelata*) appear to be generalists, feeding variably on brachyurans, penaeid prawns, teleosts and detritus (see Table 6.1). The catfish *N. caelata* and *P. argypleuron* exhibited temporal diet difference; while more bivalves were fed by *P. argypleuron* during the NEM, more brachyurans were targeted by *N. caelata* and *P. argypleuron* during the SWM. Compared to the studies in the Matang estuary, the diets for the four sympatric catfish species were relatively similar where macrobenthos formed the bulk of their diets (Then, 2008; Chong et al., 2012b). However, no prominent association with temporal difference was observed for these species in Matang, indicating lesser intraguild competition compared to the Klang mudflat.

The eel catfish *P. canius* was observed to feed mainly on crabs particularly leucosiid crab in this study. This finding is in contrast to a previous study by Leh et al. (2012) at the Sungai Buloh mudflat which reported that the blood cockle *Tegillarca granosa* contributed about 40 % to eel catfish diet, followed by brachyurans. Interestingly, despite the reputation of the study location as an extensive cockle culture bed, only one out of 92 eel catfish stomachs examined contained blood cockle as prey item. However, the eel catfish in Matang mangroves was reported to feed mainly on *Acetes* shrimps and penaeid prawns (Then, 2008).

The grey mullet species (Mugilidae) are often referred to as illiophagous feeders or limno-benthophagous and derive their nutrition mainly from benthic microalgae and microfauna (Blaber, 1997; Laffaille et al., 2002). Microphytobenthos appeared to make up the bulk of the iliophage diet (Laffaille et al., 1998; Carpentier et al., 2014). The grey mullet‘s feeding behavior and lips are adapted for grazing on the sea bottom and the biofilm of any surface (Thomsom, 1966; Almeida, 2003). In the present study, *P. subviridis* and *P. melinoptera* were observed to feed mostly on *Coscinodiscus* and *Pleurosigma* diatoms. Since *Coscinodiscus* is largely pelagic in habit (Ubertini et al., 2012; Lucas et al., 2001), these large pelagic diatoms are likely deposited and resuspended by tidal currents in the mudflat (Tolhurst et al., 2003; Ubertini et al., 2012). Meanwhile, the known detritivorous and omnivorous spotted scat *S. argus* (Barry & Fast, 1992; Thimdee et al., 2004; Sivan & Radhakrishnan, 2011) were found to feed on more plant detritus in this study.

Several recent studies have provided evidence in support of the shallow-water refuge hypothesis; that, there is higher predation rate from piscivorous fishes and predator density within the putative refugia area of shallow water habitats such as the mudflats (Hammerschlag et al., 2010; Ryer et al., 2010; Tobin et al., 2013). Nevertheless, Sheaves (2001) pointed out that the often overlooked abundance of small piscivory fishes and opportunistic piscivory may have significant impact on the mortality of small and juvenile fish than previoiusly thought. In the present study, although common in the subtidal edge of the mudflat, large predatory fishes such as narrow-barred Spanish mackerel, and large sized Indian threadfin (> 30 cm) were occasionally found to enter the intertidal mudflat. Other predatory species such as the large hound needlefish, tripletail and mackerel, all fed primarily on fish, despite the shallow water depth and high turbidity suggested as ―refugial conditions" by other workers (Abrahams & Kattenfield, 1997; Ryer et al., 2010). The preys in questions are quite often the juvenile and/or small-sized fishes such as the engraulids and sciaenids. Often the abundance of large piscivory fish is very low relative to the total fish abundance (Morton et al., 1987; Ronnback et al., 1999; Paterson & Whitfield, 2000). In terms of abundance, the four fish species of the ST guild in this study constituted only an average of 3.5 % of total fish abundance throughout the samplings. Piscivorous fishes are thus a small component and are not expected to exert significant predation pressure on the mudflat fish community. However, 37 out of the 53 fish species examined fed on other teleosts to some degree (< 20 %IRI).

In conclusion, fish users of the Klang Strait mudflat can be grouped into eight trophic guilds based on their feeding habits which show varying degrees of food partitioning: iliophages (IL), copepod feeders (CO), shrimp feeders (SH), shrimp and teleost feeders (ST), shrimp and zooplankton feeders (SZ), shrimp and decapod feeders (SD), polychaete feeders (PO) and mixed macrobenthos feeders (MX). The dominant guild is made up of shrimp feeders that prey mostly on Penaeidae and Sergestidae. These abundant crustaceans constitute the predominant shared prey to most fish species are due to their constant presence and availability to the coastal fishes. Specialized feeding was identified among the fishes of polychaete feeders and copepod feeders guild. On the other hand, feeding partitioning via temporal partitioning and feeding on wide range of prey types was observed among the fishes of mixed macrobenthos feeders.

CHAPTER 7: RESULTS AND DISCUSSION - STABLE ISOTOPE ANALYSIS OF MUDFLAT COMMUNITY

7.1 Stable isotope of mudflat organisms

The carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) stable isotope matrix in the Klang mudflats were represented by 33 species of fish consumers, six prey taxa, and three basal food sources (Table 7.1). The fish consumers are the representative fish species from all eight identified trophic guilds (IL, CO, SH, SD, SZ, ST, PO and MX guild). The prey fauna were the main prey taxa identified from the diet analysis, which included bivalves, brachyurans, polychaetes, shrimps, copepods, fish larvae and decapod zoeae. The three primary energy or basal food sources were represented by microphytobenthos, phytoplankton and mangrove detritus.

Table 7.1 Stable isotope ($\delta^{13}C$, $\delta^{15}N$) values (mean ± standard deviation) of representative fish species in Klang Strait mudflat and median percent contribution (5th quartile and 95th quartile in brackets) of basal sources (mangrove, microphytobenthos, phytoplankton) to fish diet based on Bayesian mixing model. N, number of samples analysed; TP, trophic position.

Species/Taxa/Grouping	N	$\delta^{13}C$	$\delta^{15}N$	TP	%Mangrove	%MPB	%Phytoplankton
Iliophages (IL)							
Liza melinoptera	3	-17.60 ± 0.24	13.70 ± 0.06	3.58	10.5 (2.6 - 24.6)	30.3 (7.4 - 63.7)	57.1 (14.6 - 87.8)
Liza subviridis	8	-15.08 ± 0.27	12.97 ± 0.47	3.31	1.5 (0.3 - 5.5)	63.0 (49.0 - 80.0)	35.1 (17.0 - 49.8)
Pampus argentus	3	-15.95 ± 0.07	14.25 ± 0.92	3.80	2.8 (0.4 - 11.7)	44.2 (20.4 - 75.5)	52.2 (16.0 - 77.8)
Pampus chinensis	3	-16.10 ± 0.14	15.10 ± 0.00	4.17	4.2 (0.5 - 14.8)	35.9 (13.8 - 63.9)	59.3 (24.7 - 84.5)
Scatophagus argus	3	-18.00 ± 1.21	14.53 ± 0.38	3.92	24.1 (3.6 - 36.5)	40.9 (8.7 - 63.0)	33.6 (9.1 - 84.4)
Mean		-16.55 ± 1.22	14.11 ± 0.82		8.6 ± 9.3	42.9 ± 12.4	47.5 ± 12.3
Copepod feeders (CO)							
Ambassis gymnocephalus	3	-16.15 ± 1.48	14.60 ± 1.13	3.95	3.6 (0.4 - 16.8)	57.7 (14.4 - 87.1)	35.8 (6.3 - 83.6)
Escualosa thoracata	3	-15.81 ± 0.22	13.20 ± 0.40	3.39	2.3 (0.4 - 8.6)	53.3 (34.5 - 76.4)	43.9 (18.2 - 63.8)
Mean		-15.98 ± 0.24	13.90 ± 0.99		3.0 ± 0.9	55.5 ± 3.1	39.9 ± 5.7
Polychaete feeders (PO)							
Drepane punctata	3	-15.26 ± 0.35	14.06 ± 1.66	3.72	2.5 (0.3 - 9.6)	74.2 (49.6 - 92.5)	21.8 (4.6 - 48.1)
Sillago sihama	3	-14.32 ± 0.24	14.39 ± 0.20	3.86	1.7 (0.3 - 6.7)	74.5 (54.3 - 92.6)	22.9 (5.4 - 43.9)
Mean		-14.66 ± 0.48	15.12 ± 1.03		2.1 ± 0.6	74.4 ± 0.2	22.4 ± 0.8
Shrimp and teleost feeders (ST)							
Otolithes ruber	3	-14.90 ± 0.72	14.12 ± 1.82	3.75	1.9 (0.3 - 8.2)	80.1 (56.3 - 95.0)	16.5 (3.3 - 41.8)
Strongylura strongylura	6	-14.59 ± 0.49	15.54 ± 0.71	4.38	2.2 (0.3 - 8.8)	64.6 (43.4 - 86.4)	32.5 (9.0 - 54.7)
Mean		-14.75 ± 0.22	14.83 ± 1.00		2.1 ± 0.2	72.4 ± 11.0	24.5 ± 11.3
Shrimp and decapod feeders SD)							
Johnius belangerii	4	-14.60 ± 0.08	14.68 ± 0.28	3.98	1.8 (0.3 - 6.8)	63.2 (46.0 - 83.2)	34.6 (13.0 - 52.6)
Johnius carouna	4	-14.63 ± 0.21	14.20 ± 0.00	3.78	1.7 (0.3 - 6.5)	65.7 (49.4 - 85.7)	31.9 (11.0 - 49.0)
Pomadasys kaakan	3	-17.00 ± 0.05	14.10 ± 0.14	3.52	3.4 (0.4 - 13.8)	54.6 (24.2 - 84.2)	40.5 (9.1 - 74.1)
Mean		-15.41 ± 1.38	14.33 ± 0.31		2.3 ± 1.0	61.2 ± 5.8	35.7 ± 4.4
Shrimp and zooplankton Feeders (SZ)							
Thryssa kammalensis	3	-16.25 ± 0.21	13.65 ± 0.35	3.56	3.0 (0.4 - 11.7)	43.3 (21.5 - 70.5)	53.1 (21.2 - 76.6)
Mean		-16.25 ± 0	13.65 ± 0		3.0 ± 0	43.3 ± 0	53.1 ± 0
Shrimp feeders (SH)							
Brevitrygon walga	7	-14.56 ± 0.44	13.99 ± 0.47	3.69	1.5 (0.3 - 6.1)	69.7 (53.4 - 87.5)	28.0 (9.4 - 45.0)
Coilia dussumieri	3	-14.50 ± 0.57	15.25 ± 0.78	4.24	2.0 (0.3 - 8.4)	69.7 (45.6 - 91.4)	27.5 (6.0 - 52.1)
Dendrophyssa russelli	3	-14.80 ± 0.14	13.10 ± 0.28	3.36	1.7 (0.3 - 6.8)	74.3 (53.7 - 92.1)	23.1 (5.8 - 44.9)
Eleutheronema tetradactylum	5	-15.33 ± 0.14	13.36 ± 0.40	3.45	1.8 (0.3 - 6.9)	58.1 (41.9 - 77.3)	39.5 (19.2 - 56.6)
Ephippus orbis	3	-15.64 ± 0.06	13.88 ± 0.39	3.65	2.3 (0.4 - 9.8)	53.8 (32.5 - 80.1)	43.2 (14.4 - 65.8)
Leptomelanosoma indicum	3	-15.55 ± 0.07	15.50 ± 0.05	4.36	3.4 (0.4 - 12.4)	40.8 (19.3 - 67.5)	55.3 (22.9 - 79.1)

Table 7.1, continued

Nibea soldado	5	-14.76 ± 0.24	14.96 ± 0.28	4.11	1.9 (0.3 - 7.2)	57.7 (40.7 - 77.7)	39.8 (18.2 - 57.8)
Opithopterus taardore	3	-14.15 ± 0.07	14.30 ± 0.14	3.82	1.5 (0.3 - 6.3)	77.3 (57.4 - 93.4)	20.2 (4.8 - 40.6)
Panna microdon	5	-14.60 ± 0.66	14.12 ± 0.68	3.75	1.7 (0.3 - 6.7)	75.1 (55.8 - 92.9)	22.5 (5.0 - 42.8)
Setipinna taty	3	-14.20 ± 0.42	14.80 ± 0.14	4.04	1.7 (0.3 - 6.9)	74.0 (53.9 - 91.9)	23.3 (5.7 - 44.3)
Mean		-14.81 ± 0.53	14.33 ± 0.79		2.0 ± 0.6	65.1 ± 11.9	32.2 ± 11.6
Mixed macrobenthos feeders (MX)							
Arius maculatus	3	-15.63 ± 0.15	12.92 ± 0.94	3.29	3.2 (1.9 - 5.3)	60.4 (51.4 - 69.1)	36.1 (27.0 - 46.2)
Cynoglossus cynoglossus	3	-13.91 ± 1.17	12.19 ± 0.21	3.04	1.2 (0.2 - 4.8)	88.1 (70.7 - 97.2)	10.3 (1.9 - 27.7)
Cynoglossus lingua	3	-14.49 ± 0.93	12.04 ± 0.08	3.00	1.3 (0.2 - 5.4)	84.3 (64.9 - 96.2)	13.7 (2.6 - 33.4)
Hexanematichthys sagor	3	-16.02 ± 0.21	12.85 ± 0.22	3.27	2.3 (0.4 - 8.4)	51.0 (32.0 - 72.6)	46.1 (21.8 - 66.3)
Lagocephalus lunaris	3	-15.14 ± 0.36	13.52 ± 0.71	3.51	1.9 (0.3 - 7.8)	67 (45.9 - 89.2)	30.1 (7.2 - 52.9)
Plicofollis argypleuron	4	-15.65 ± 0.20	13.15 ± 0.24	3.37	2.0 (0.3 - 7.8)	54.5 (37.8 - 75.4)	42.8 (19.8 - 60.8)
Plotosus canius	4	-15.42 ± 0.51	12.42 ± 0.53	3.12	1.8 (0.3 - 6.9)	67.4 (49.0 - 87.1)	30.1 (9.4 - 49.6)
Triacanthus neiuhofii	3	-15.10 ± 0.17	13.55 ± 1.42	3.52	2.0 (0.3 - 8.0)	74.0 (50.3 - 92.7)	22.9 (5.0 - 48.2)
Mean		-15.17 ± 0.68	12.83 ± 0.57		2.0 ± 0.6	68.3 ± 13.3	29.0 ± 12.9

7.1.1 Primary and carnivorous fish consumers

A total of 121 individual fish were examined for their $\delta^{13}C$ and $\delta^{15}N$ values, selected from 33 species of fish covering the eight trophic guilds identified in this study (see Chapter 6): five species from the IL guild, two species from the CO guild, two species from the PO guild, two species from the ST, three species from the SD guild, one species from the SZ guild, 10 species from the SH guild and eight species from the MX guild (Table 7.1).

The mean isotopic values for all examined fish consumers were -15.32 ± 0.96 ‰ (ranged from -18.00 to -13.91 ‰) for $\delta^{13}C$ ratio and 13.96 ± 0.97 ‰ (ranged from 12.04 to 15.54 ‰) for $\delta^{15}N$ ratio (Figure 7.1). The mixed macrobenthos feeders of the MX guild showed the lowest mean $\delta^{15}N$ value at 12.83 ± 0.57 ‰, which was significantly lower ($p < 0.05$) than the SH (14.33 ± 0.79 ‰) and ST (14.83 ± 1.00 ‰) guilds. Similar to the observation on $\delta^{13}C$, PO guild also had the highest mean $\delta^{15}N$ value at 15.12 ± 1.03 ‰. The IL, CO and SZ guild showed rather similar mean $\delta^{15}N$ value (14.11 ± 0.81 ‰, 13.90 ± 0.99 ‰ and 13.65 ‰, respectively), while SD guild had higher (14.33 ± 0.31 ‰) despite insignificant differences.

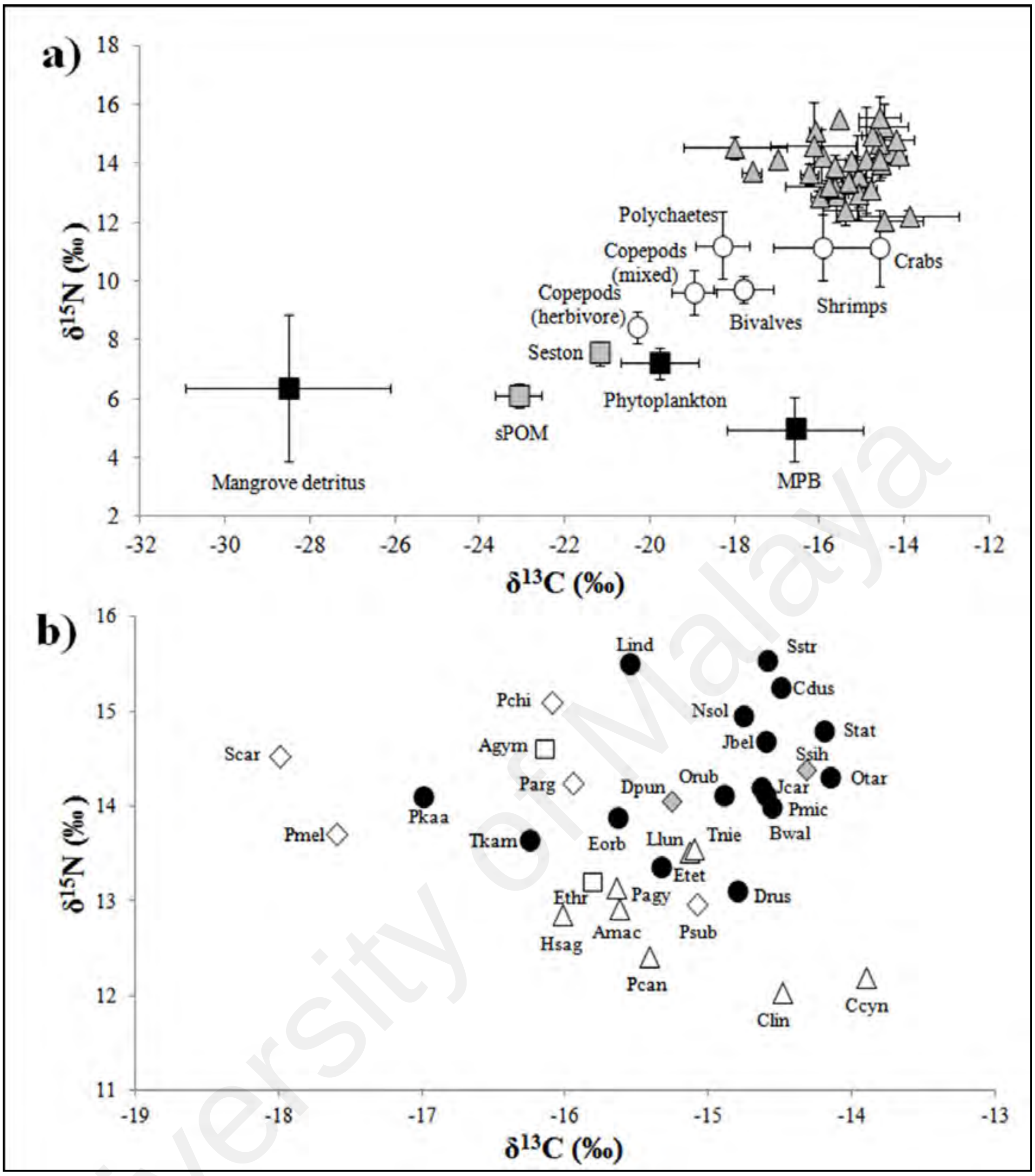

Figure 7.1 Scatter plots of unadjusted mean and standard deviation of stable isotopic ratios ($\delta^{13}C$ and $\delta^{15}N$) of **a)** fish (▲), prey invertebrates (○), primary producers (■) and others (■) in Klang Strait mudflat, and **b)** representative fish species of each feeding guild: IL (◇); CO (□); PO (◆); MX (△); S (●). For sake of simplicity all shrimp feeder guilds (ST, SD, SZ and SH) were grouped together as one (S) in this figure. Codes for fish species can be found on Table 6.2.

Fishes of the IL guild, which could be considered broadly as the primary fish consumers, generally had lower $\delta^{13}C$ values compared to fishes of other guilds, with two of its members *Scatophagus argus* (-18.00 ± 1.21 ‰) and *Planiliza melinopterus* (-

17.60 ± 0.24 ‰) having the most depleted $\delta^{13}C$ ratios amongst all the fishes. Another mullet *Planiliza subviridis* however recorded the highest $\delta^{13}C$ (-15.08 ± 0.27 ‰) and lowest $\delta^{15}N$ (12.97 ± 0.47 ‰) values amongst the IL guild members. Both pomfret species (*Pampus argenteus* and *Pampus chinensis*) had rather similar isotopic carbon value (-15.95 ± 0.07 ‰ and -16.10 ± 0.14 ‰), however the latter had higher isotopic nitrogen signatures (15.10 ± 0.00 ‰) than silver ponfret (14.25 ± 0.92 ‰).

Two members of the CO guild, *Ambassis gymnocephalus* and *Escualosa thoracata*, shared similar isotopic carbon values (-16.15 ± 1.48 ‰ and -15.81 ± 0.22 ‰, respectively), but differed in their isotopic nitrogen value. The former had higher $\delta^{15}N$ value (14.60 ± 1.13 ‰) than the latter (13.20 ± 0.40 ‰). Although two members in the PO guild fed primarily on polychaetes, their isotopic values differed; *Drepane punctata* had lower $\delta^{15}N$ (14.06 ± 1.66 ‰) and $\delta^{13}C$ (-15.26 ± 0.35 ‰) values than *Sillago sihama* ($\delta^{15}N$ = 14.39 ± 0.20 ‰; $\delta^{13}C$ = -14.32 ± 0.24 ‰).

Among all the dominant shrimp feeder guilds, *Pomadasys kaakan* from the SD guild had the most depleted $\delta^{13}C$ value (-17.00 ± 0.05 ‰), followed by *Thryssa kammalensis* (-16.25 ± 0.21 ‰) from the SZ guild. Both sciaenids (*Johnius belangerii* and *Johnius carouna*) from the SD guild had similar and more positive $\delta^{13}C$ value (-14.60 ± 0.08 ‰ and -14.63 ± 0.21 ‰, respectively). Meanwhile, other sciaenids from the SH and ST guild also had rather similar mean $\delta^{13}C$ value within the range of -14.5 to -15.0 ‰ (*Otolithes ruber*, -14.90 ± 0.72 ‰; *Dendrophyssa russelli*, -14.80 ± 0.14 ‰; *Nibea soldado*, -14.76 ± 0.24 ‰; *Panna microdon*, -14.60 ± 0.66 ‰). Within the SH guild, *Ephippus orbis* had the highest mean $\delta^{13}C$ value (-15.64 ± 0.06 ‰) while *O. taardore* were the lowest (-14.15 ± 0.07 ‰). For $\delta^{15}N$, values were highest for *Strongylura strongylura* (15.54 ± 0.71 ‰) from ST guild. Another member of ST guild only had mean $\delta^{15}N$ of (14.12 ± 1.82 ‰). Fishes from the SD guild had the lowest overall mean amongs the dominant shrimp feeder guilds at 14.33 ± 0.31 ‰ where *J. belangerii* had 14.68 ± 0.28 ‰, *J. carouna* had 14.20 ± 0.00 ‰ and *P. kaakan* had 14.10 ± 0.14 ‰. The lowest $\delta^{15}N$ were recorded by *D. russelli* (13.10 ± 0.28 ‰) from SH guild. The same guild also had *L. indicum* (15.50 ± 0.05 ‰) as one of the highest mean $\delta^{15}N$ value among all fish species examined.

Cynoglossus cynoglossus (MX guild) recorded the most enriched $\delta^{13}C$ value (-13.91 ± 1.17 ‰) among all fishes examined. On the other hand, the Sagor catfish *Hexanematichthys sagor* had the lowest $\delta^{13}C$ value (-16.02 ± 0.21 ‰) in the MX guild. In general, fishes of the MX guild had lower mean $\delta^{15}N$ value (12.83 ± 0.57 ‰) than other guilds. The $\delta^{15}N$ values of both tongue sole species were recorded to be amongst the lowest (*C. cynoglossus* = 12.04 ± 0.21 ‰; *Cynoglossus lingua* = 12.04 ± 0.08 ‰) compared to all other fishes. The silver tripodfish *Triacanthus neiuhofii* had the most positive $\delta^{15}N$ value (13.55 ± 1.42 ‰) recorded in the MX guild.

The ANOVA tests on the mean $\delta^{13}C$ and $\delta^{15}N$ values showed significant differences ($F_{7, 25} = 3.26$, $p < 0.05$; $F_{7, 25} = 3.87$, $p < 0.05$, respectively) among the trophic guilds. Subsequent post-hoc pair-wise tests indicated that only the mean $\delta^{13}C$ value of the IL guild, which was also the lowest among trophic guilds (-16.55 ± 1.22 ‰) was significantly lowered ($p < 0.05$) compared to the SH guild (-14.81 ± 0.53‰). Despite no significant difference compared to other guilds, PO guild recorded the highest mean $\delta^{13}C$ value (-14.66 ± 0.48 ‰) and followed by ST (-14.75 ± 0.22 ‰). The SZ, CO, SD and MX guild had mean $\delta^{13}C$ value of -16.25 ‰, -15.98 ± 0.24 ‰, -15.41± 1.38 ‰ and -15.17 ± 0.68 ‰, respectively.

7.1.2 Invertebrate prey

The prey fauna isotopic signatures were examined for a total of 55 samples, covering the bivalves, crabs, polychaetes, prawns, shrimps, copepods and fish larvae.

The isotopic signatures of these prey fauna ranged from -20.30 to -14.50 ‰ for $\delta^{13}C$ and from 8.40 to 11.95 ‰ for $\delta^{15}N$ (Table 7.2). Both $\delta^{13}C$ (-17.25 ± 1.58 ‰) and $\delta^{15}N$ (10.13 ± 1.00 ‰) values of the prey items were significantly more lower ($p < 0.05$, t-test) than their fish consumers. The flower crab *Portunus pelagicus* had the most enriched $\delta^{13}C$ value (-14.50 ± 0.14 ‰) whereas the herbivorous copepods (*Parvocalanus crassirostris*) had the lowest $\delta^{13}C$ value (-20.30 ± 0.13 ‰). Another species of crab *Xenophthalmus pinnotheroides* however showed a rather lower $\delta^{13}C$ value (-18.15 ± 0.11 ‰) than the flower crabs. Both the bivalves and polychaetes (ranged between -18.57 ‰ and -17.10 ‰) had lower $\delta^{13}C$ value whereas the prawns and shrimps were more enriched (ranged from -16.10 ‰ to -15.30 ‰), except for the river prawn *Macrobrachium equidens* (-17.10 ± 0.57 ‰) and *Fenneropenaeus merguiensis* (-18.10 ± 0.14 ‰).

In terms of $\delta^{15}N$ value, the most enriched were recorded by both the penaeid prawn *Fenneropenaeus indicus* (11.95 ± 0.49 ‰) and caridean prawn *M. equidens* (11.95 ± 0.35 ‰). Following them, fish larvae had mean value of 11.20 ± 1.14 ‰ while *Metapenaeus affinis* were 10.87 ± 0.95 ‰. The herbivorous copepods showed the lowest $\delta^{15}N$ value (8.40 ± 0.54 ‰), followed by sergestid shrimps, *Acetes japonicus* (9.10 ± 0.70 ‰).

Table 7.2 Stable isotope ($\delta^{13}C$, $\delta^{15}N$) values (mean ± standard deviation) of prey invertebrates in Klang Strait mudflat and median percent contribution (5th quartile and 95th quartile in brackets) of basal sources (mangrove, microphytobenthos and phytoplankton) based on Bayesian mixing model. N indicated number of samples analysed; TP indicated trophic position; ϕ indicated data taken from adjacent studies: *Acetes japonicus* (Tanaka et al. 2011).

Species/Taxa/Grouping	**N**	**$\delta^{13}C$**	**$\delta^{15}N$**	**TP**	**%Mangrove**	**%MPB**	**%Phytoplankton**
Bivalvia							
Meretrix meretrix	2	-17.10 ± 0.57	10.25 ± 0.07	2.47	3.8 (0.5 - 13.5)	38.0 (17.0 - 63.9)	57.6 (26.0 - 81.0)
Perna viridis	3	-18.57 ± 0.15	9.43 ± 0.55	2.25	8.0 (0.8 - 19.2)	29.8 (10.0 - 54.6)	61.6 (29.0 - 87.2)
Tegillarca granosa	4	-17.29 ± 0.58	9.68 ± 0.26	2.32	2.8 (0.4 - 10.7)	47.3 (30.3 - 68.9)	49.2 (23.2 - 68.1)
Brachyura							
Portunus pelagicus	3	-14.50 ± 0.14	10.35 ± 0.07	2.49	1.1 (0.2 - 4.6)	86.9 (70.2 - 96.4)	11.4 (2.4 - 28.3)
Xenophthalmus pinnotheroides	3	-18.15 ± 0.11	9.53 ± 0.07	2.28	5.0 (0.5 - 15.9)	34.0 (13.0 - 60.8)	60.3 (27.2 - 85.4)
Polychaeta							
Sabellaria jeramae	2	-17.80 ± 0.08	9.70 ± 0.18	2.32	3.8 (0.5 - 12.7)	37.4 (18.6 - 60.4)	58.2 (29.8 - 79.7)
Prawn and shrimp							
Acetes japonicus ϕ	2	-16.10 ± 0.10	9.10 ± 0.70	2.17	33.4 (23 - 47.6)	32.4 (11.6 - 51.0)	31.9 (10.2 - 59.9)
Fenneropenaeus indicus	3	-15.30 ± 0.42	11.95 ± 0.49	2.97	1.8 (0.3 - 7.2)	73.2 (52.8 - 92.0)	24.1 (5.6 - 45.2)
Fenneropenaeus merguiensis	3	-18.10 ± 0.14	9.75 ± 0.30	2.33	4.7 (0.5 - 15.5)	33.6 (12.5 - 60.0)	61.2 (27.9 - 85.8)
Macrobrachium equidens	3	-17.10 ± 0.57	11.95 ± 0.35	2.97	3.9 (0.5 - 14.4)	40.9 (16.6 - 68.4)	54.6 (20.8 - 81.3)
Metapenaeus affinis	3	-15.55 ± 0.65	10.87 ± 0.95	2.64	1.7 (0.2 - 6.7)	77.3 (57.1 - 93.7)	20.0 (4.4 - 41.0)
Metapenaeus brevicornis	3	-15.63 ± 0.21	10.13 ± 0.67	2.44	1.6 (0.3 - 6.1)	75.3 (56.2 - 92.5)	22.3 (5.3 - 42.3)
Copepod (herbivorous)							
Parvocalanus crassirostris	5	-20.30 ± 0.13	8.40 ± 0.54	2.00	21.4 (12.4 - 32.0)	31.1 (12.3 - 51.8)	48.3 (19.4 - 73.9)
Copepod (mixed)	11	-18.95 ± 0.54	9.60 ± 0.77	2.30	16.4 (5.0 - 27.4)	37.9 (13.7 - 58.2)	45.2 (18.3 - 81.0)
Fish larvae	5	-18.30 ± 0.64	11.2 ± 1.14	2.74	10.9 (0.6 - 27.6)	30.4 (5.3 - 64.5)	58.8 (11.6 - 92.9)

7.1.3 Primary producers

The surface phytoplankton samples were dominated by centric diatoms (~70 %) especially *Coscinodiscus* and *Thalassiosira* spp., whereas the microphytobenthos samples consisted of mainly pennate diatoms (~80 %) especially *Pleurosigma* spp. Senescent mangrove leaves had the lowest mean isotopic carbon signature (-28.52 ± 2.41 ‰, $p < 0.05$), followed by phytoplankton (-19.78 ± 0.91 ‰, $p < 0.05$) and microphytobenthos (-16.58 ± 1.61 ‰, $p < 0.05$), with no overlap between them (Table 7.3). ANOVA test showed significant differences in $\delta^{13}C$ values among the three primary producers ($F_{2, 15} = 79.08$, $p < 0.05$).

The seston fraction < 53 µm recorded $\delta^{13}C$ of -21.19 ± 0.20 ‰ and $\delta^{15}N$ of 7.57 ± 0.32 ‰, which were slightly more depleted and enriched than phytoplankton, respectively. The mudflat sPOM, assumed to be mixed mangrove detritus, settled or trapped seston, and microphytobenthos had $\delta^{13}C$ of -23.10 ± 0.56 ‰ and $\delta^{15}N$ of 6.1 ± 0.42 ‰. In terms of $\delta^{15}N$, although not significantly different, phytoplankton was the most enriched at 7.21 ± 0.54 ‰ compared to the other two primary sources. The microphytobenthos had a lower $\delta^{15}N$ value (4.96 ± 1.10 ‰) than mangrove (6.37 ± 2.49 ‰).

Table 7.3 Stable isotope ($\delta^{13}C$, $\delta^{15}N$) values (mean ± standard deviation) of three primary producers of Klang Strait mudflat.

Species/Taxa/Grouping	N	$\delta^{13}C$	$\delta^{15}N$
Mangrove leaves	6	-28.52 ± 2.41	6.37 ± 2.49
Microphytobenthos	6	-16.58 ± 1.61	4.96 ± 1.10
Phytoplankton	6	-19.78 ± 0.91	7.21 ± 0.54
Others			
Sediment POM (sPOM)	4	-23.10 ± 0.56	6.10 ± 0.42
Seston	6	-21.19 ± 0.20	7.57 ± 0.32

7.2 Trophic position (TP)

Using the scaled $\Delta\delta^{15}N$ framework, the estimated mean TP of consumers ranged from 2.00 to 4.25 (Table 7.1; Table 7.2). Invertebrate prey were among those that occupied the lowest TPs of the mudflat consumers studied, with values ranging from 2.0 (*P. crassirostris*) to 2.97 (*F. indicus* and *M. equidens*). The herbivorous copepods and sergestid shrimps were among the lowest in TP, followed by bivalves, polychaetes and crabs in the intermediate range, and finally the prawns and shrimps that occupied the higher end of the invertebrate‘s TP.

The majority of the fishes occupied the third (TP3) to fourth (TP4) trophic positions. Fishes of the MX guild generally occupied lower end of the TP‘s, which was from 3.00 to 3.51. The lowest were the tongue soles *C. lingua* (3.00) and *C. cynoglossus* (3.04). Fishes that occupied the intermediate ranges of TP (3.50 to 4.00) were mainly from the SD, SZ and CO guild. Fishes that occupied TP4 or above were the *P. chinensis* (IL), *S. strongylura* (ST) and *Coilia dussumieri*, *Leptomelanosoma indicum*, *N. soldado* and *Setipinna taty* (SH). Highest TP were recorded by *S. strongylura* (4.38). Members of the IL guild had the widest range of TP, from the lowest by *P. subviridis* (3.31) to highest *P. chinensis* (4.17).

7.3 Mixing model and relative contribution of basal sources

The Bayesian mixing model results showed a high dependence of the coastal mudflat consumers on carbon from microphytobenthos (median = 57.2 %) and phytoplankton (37.4 %) (Tables 7.1, 7.2). Median contribution of mangrove-derived carbon to all fishes however was generally low (1.2 % to 24.1 %). The median contribution of microphytobenthos and phytoplankton carbon however varied considerably among guilds, ranging from 28.3 % to 88.1 % for microphytobenthos and

10.3 % to 59.3 % for phytoplankton. The CO, PO, ST, SD, SH and MX guilds derived their carbon sources more from microphytobenthos than phytoplankton, but vice versa for the SZ guild. However, the IL guild appeared to derive their carbon equally from both phytoplankton (48.5 ± 13.4 %) and microphytobenthos (42.5 ± 13.0 %) sources.

For the IL guild, while both species of the mullet derived their carbon from phytoplankton and microphytobenthos, the *P. melinopterus* derived more carbon from phytoplankton (57.1 %) while *P. subviridis* relied more on microphytobenthos (63.0 %). The former also appeared to rely somewhat on mangrove source, presumably detrital matter (10.5 %). The tongue sole *C. cynoglossus* relied most on carbon from microphytobenthos (88.1 %) and least from mangrove (1.2 %). In contrast, the Chinese pomfret (*P. chinensis*) relied most on carbon from phytoplankton (59.3 %). Mangrove carbon source was most important to the IL guild (8.6 ± 9.3 %), with 24.1 % contribution to diet of the spotted scat (*S. argus*). Mangrove carbon contribution to the MX guild members was minimal (1.2 % - 3.2 %).

Among the benthic prey, crabs, *P. pelagicus* and *X. pinnotheroides*, derived highest carbon source from microphytobenthos and phytoplankton (86.9 % and 60.3 % respectively). The penaeid prawns *F. indicus*, *M. affinis* and *Metapenaeus brevirostris* were observed to utilize more carbon from microphytobenthos (> 70%). On the other hand, the penaeid *F. merguiensis* and caridean *M. equidens* relied more on carbon from phytoplankton (61.2 % and 54.6 %, respectively) while mangrove carbon contributed nearly 5%. The sergestid shrimp *A. japonicus* however appeared to derive their carbon equally from all three sources.

The polychaete *Sabellaria jeramae* received 58.2 % of carbon from phytoplankton and 37.4 % from phytoplankton. For the bivalves, *Tegillarca granosa* derived carbon from both phytoplankton (49.2 %) and microphytobenthos (47.3 %), while the major carbon source for *Perna viridis* and *Meretrix meretrix* was from phytoplankton (61.6 % and 57.6 %, respectively). The herbivorous copepod, *P. crassirostris*, derived nutrition mainly from phytoplankton carbon (48.3 %).

7.4 Discussion

In the absence of other significant basal sources of energy, this study considers only mangrove, phytoplankton and microphytobenthos as major carbon contributors to the Klang mudflat. The study shows that the major carbon contribution for both fish and invertebrate consumers comes from phytoplankton and microphytobenthos with low contribution from mangrove (see below). Despite turbid waters (ranging 0.3 to 0.5 m secchi disc depth), the hydrodynamic features of the shallow intertidal mudflat appear to encourage in-situ primary production on and above the mudflat. The availability of microphytobenthos production on the sediment is influenced by the tidal and light cycle (Jesus et al., 2005). During ebb tide, the primary production of surface microphytobenthos is accelerated when the mudflat is exposed to sunlight during ebb tide (Chai et al., 2012). The subsequent flood tide resuspends the microphytobenthos into the water column, and together with the phytoplankton production fuel the shallow water food web (Teoh et al., 2016) of the mud flat. Thus, the close bentho-pelagic coupling in the mudflat maintains the mudflat‘s primary productivity.

Stable nitrogen isotope analysis revealed that the food web of the nearshore waters on and adjacent to Klang Strait mudflats, consists of four to five trophic levels (Tables 7.1, 7.2). Trophic energy flows from three primary producers, via one or two consumer levels to tertiary consumers that included the shrimp-teleost feeders. Similar food web structure of four trophic levels was also reported for the Matang mudflat (Chong et al., 2012b) and the adjacent Matang mangrove estuary (Then, 2008). The trophic pathways to large animals such as birds and animals are however not considered in the present study; for instance, humpback dolphins (*Sousa chinensis*) which are known to feed on ariid and sciaenid fishes in Matang (Kuit et al., 2019) have been sighted in nearshore Klang waters. Thus, the humpback dolphin is at the fifth trophic level. Since, the mean length of the global marine food webs (47 examined) has been estimated at close to 4.0, with a range of 3.3 to 5.3 (Vander Zander & Fetzer, 2007), the mudflat‘s food web is quite long despite its transitory nature.

The calanoid copepod *P. crassirostris*, known for its herbivorous diet (Johnson & Allen, 2005; Chew et al., 2012), was taken as the baseline representative of primary consumer (i.e. TP = 2) in the present study. Other invertebrates such as omnivorous copepods, bivalves and polychaetes had slightly higher TPs (about 2.3), consistent with their omnivorous diet. The bivalves *P. viridis*, *T. granosa* and *M. meretrix* and polychaete *S. jeramae* which are known suspension and deposit feeders (Stanley, 1970; Dobbs & Scholly, 1986; Gosling, 2003; Dubois et al., 2009; Arapov et al., 2010), recorded very similar mean δ^{13}C and δ^{15}N values to those in the Klang mudflats. These invertebrates‘ δ^{13}C ratios indicate similar diet derived mainly from microphytobenthos as basal source, as opposed to the lower δ^{13}C ratios of mixed omnivorous copepods that derive their carbon source to some degree from mangrove (~20 %). The brachyuran crabs (*P. pelagicus* and *X. pinnotheroides*) and penaeid prawns (*F. indicus* and *M. affinis*) which showed higher TPs (~ 2.6) than herbivorous and omnivorous invertebrates suggest an omnivorous diet tending to carnivory.

The mudflat fish consumers are at higher trophic positions than the invertebrates, generally between the third and fourth levels. Species of the SH, CO, PO and IL guilds included specialized feeders that have wide-ranging TPs (3.0 - 4.4), compared to the MX guild with smaller TP range (3.0 - 3.5). Members of the MX guild are detritivores and benthic feeders with lower mean $\delta^{15}N$ values compared to other fishes. Despite members of the MX guild being located at the lower end of the fish trophic web, a study on fatty acids showed that some detritivorous fishes are able to harness high quality food sources such as decomposing microalgae from detritus (Mortillaro et al. 2015). In the present study, both species of tongue sole (*C. cynoglossus* and *C. lingua*) have quite enriched $\delta^{13}C$ but depleted $\delta^{15}N$ ratios suggesting the assimilation of dietary microphytobenthos carbon and nitrogen. Piscivores of the ST guild (*L. indicum* and *S. strongylura*) with the highest $\delta^{15}N$ ratios are at the highest trophic level, and are the top predators of the fish community in Klang Strait mudflat.

Interestingly, fishes of the IL guild have almost similar $\delta^{15}N$ values as other predatory fishes (e.g. CO, PO and SD guilds), with TPs that ranged from 3.31 to 4.17, despite a diet of mainly phytoplankton and microphytobenthos. The $\delta^{15}N$ ratio of *P. melinopterus* (9.5 ‰) and *S. argus* (11.0 ‰) in the present study are distinctly lower than that reported in Matang mangrove (13.7 ‰, 14.5 ‰ respectively) by Then (2008). This may be due to the assimilation of nitrogen from detritus or via detritus-feeding meiofauna such as foraminiferan and tintinnids (Masson & Marais, 1975; Gandhi, 2002), resulting in high variability of their isotopic N signatures.

Stable isotope analysis revealed that the majority of the consumers in Klang Strait mudflat have $\delta^{13}C$ values closer to the enriched end of their carbon signature range, i.e. -17.9 ‰ to -13.9 ‰ for the fishes (Table 7.1) and -20.3 ‰ to -14.6 ‰ for invertebrates (Table 7.2). These observations coupled with results of the Bayesian mixing model show that most fish consumers in the Klang mudflat rely heavily on microphytobenthos and phytoplankton production compared to allochthonous mangrove detritus. This is the first time that the trophic contribution of MPB and the lack thereof from mangrove detritus has been attested by stable isotope analysis for a vast, non-vegetated tropical mudflat close to the mangrove forest. This finding supports the hypothesis that the mudflat fish community in Klang Strait is supported by autochthonous rather than allochthonous (mangrove) carbon inputs. Similar conclusions have also been made for the Matang mudflat (Chong et al., 2012b) and other similar habitats (e.g. Middelburg et al., 2000; Bouillon et al., 2002).

The contribution from MPB and phytoplankton as basal food sources to mudflat consumers however appears equivocal. While the consumers may make use of both basal sources due to shallow water, close bentho-pelagic coupling of the phytoplankton and MPB community on the intertidal mudflat as a result of strong tidal mixing in shallow water is reiterated here (see Tolhurst et al., 2003; Ubertini et al., 2012). Evidence of this coupling in the present study sites are the strong positive correlation between the concentrations of chlorophyll-*a* in the water column and surface sediment (Teoh et al., 2016), and iliophages fishes feed on both pelagic and benthic species of microalgae.

Despite the generally low carbon contribution of mangrove detritus to consumers in the present study, some fishes display a relatively high degree of dependence on mangrove carbon, for example, the grey mullet *P. melinopterus* (10.5 %). Compared to the other sympatric mullet species *P. subviridis* with distinct differences in δ^{13}C value (-17.60 ± 0.24 ‰ vs -15.08 ± 0.27 ‰), *P. melinopterus* is more of an inshore or estuarine species (Then, 2008; Chong et al., 2012b) that is rarely observed at the subtitdal edge of the mudflat in this study. This reflects its depleted carbon isotope inshore which gradually become enriched when transiting more offshore (Bouillon et al., 2000; Miller et al., 2008; Abrantes et al., 2015). Stable isotope analysis also supports the view of ontogenetic shift in the grey mullet‘s diet, from more microalgae in small juveniles to more mangrove detritus in adults (Chong, 1977).

Another detritivorous iliophage, *S. argus* is equally dependent on mangrove detritus at the juvenile and adult stage, but prefers a diet of microalgae at the larval stage (Wongchinawit & Paphavasit, 2009). Interestingly, *S. argus* in our study had a $\delta^{13}C$ value of -18.0 ± 1.2 ‰ which is higher than the same species in mangrove habitats, e.g. -25.2 ‰ in Matang (Then, 2008) and -24.2 ‰ in southwest Thailand (Zagars et al., 2013). This suggests that the mudflat‘s iliotrophic layer is poorer in mangrove detritus compared to the mangrove habitat, or contains more refractory mangrove carbon, or the detritus comes from a non-mangrove origin.

In conclusion, both fish and invertebrate consumers in the Klang Strait mudflat have enriched $\delta^{13}C$ values, indicating that the mudflat productivity is primarily fueled by autochthonous production due to microphytobenthos and phytoplankton and, to a very limited extent, allochthonous production via phytodetritus. Pelagic–benthic coupling processes including strong tidal mixing in shallow turbid waters likely sustain microphytobenthos (and phytoplankton) production that significantly enters the food web. Iliophages fish have depleted $\delta^{13}C$ value indicating more contribution from mangrove detritus as opposed to benthic and decapod feeders that have higher $\delta^{13}C$ value. Fishes of the mixed macrobenthos guild generally occupies the lower trophic level while carnivorous fishes of SH and ST are at higher trophic levels. The maximum of five trophic levels is high considering the transitory, extreme, and highly dynamic environment of the mudflat.

CHAPTER 8: GENERAL DISCUSSION AND CONCLUSION

8.1 Mudflat fish community

A total of 116 species of fish species has been identified to ingress into the Klang Strait mudflat during high tide (Table 8.1). Of these, 21 species of fish were considered to be characteristic or very common in the mudflat (> 70 % of relative occurrence over time). These species belonged to the ariids, cynoglossids, engraulids and sciaenids, commonly found in the coastal area of west Peninsular Malaysia (Then, 2008; Chong et al., 1990; Chong et al., 2012b). Although the two study sites (Bagan Pasir and Bagan Sungai Buloh mudflat) have their own exclusive species, more than half (74 species) of the total fish species can be found in both sites. These species can be considered as common mudflat species. There were 26 species of fish found exclusively in Sungai Buloh mudflat while Bagan Pasir mudflat had 16 exclusive fish species. However, these species had less than 10 % of relative occurrence, and can be considered as occasional visitors to the mudflat. Compared to the Matang mudflats (located 180 km north of current study site), about 66 % of Matang fish species overlapped with that of Klang (Chong et al., 2012b). Sampling gears used in the Matang study included the otter trawl, beam trawl and gill nets. This study by Chong et al. (2012b) had a higher number of fish species when compared to the previous study by Chong et al. (1990), but lower compared to the current study. However, differences could be attributed to the differences in sampling periods and different types of fishing gear. Nevertheless, the major mudflat fish species in both areas were quite similar, namely, ambassids, ariids, cynoglossids, engraulids, clupeids, mugillids and sciaenids.

Table 8.1 Checklist of fish species recorded in the Klang Strait mudflat (Bagan Pasir, BP and Bagan Sungai Buloh, SB), compared to the Matang coastal mudflat (records from Chong et al., 2012b) and Klang coastal mangroves (records from Chong et al., (1990) and Sasekumar & Chong, (1991)). Value indicates percentage frequency of occurrence from monthly and diel samplings. Commercial status of each species is based on commercial fish landings (Department of Fisheries Malaysia, 2016). * indicates low commercial value but consumed; ** indicates commercially exploited.

Family	**Species name**	**Klang Strait**			**Matang**	**Commercial importance**
		BP mudflat	**SB mudflat**	**Mangrove**	**Mudflat**	
Ambassidae	*Ambassis commersoni*			X		
	Ambassis gymnocephalus	80.8	60.0	X	X	
	Ambassis kopsii			X		
Anguillidae	*Anguilla nebulosa*			X		*
Aplocheilidae	*Aplocheilus panchax*			X		
Apogonidae	*Apogon hyalosoma*			X		
Ariidae	*Arius arius*	3.8	4.0			*
	Arius maculatus	73.1	52.0	X	X	*
	Arius microcephalus	3.8				*
	Arius oetik		8.0		X	*
	Arius venosus	11.5		X	X	*
	Batrachocephalus mino			X		*
	Cryptarius truncatus	30.8	16.0	X	X	*
	Hexanematichthys sagor	73.1	100	X	X	*
	Ketengus typus			X	X	*
	Nemapteryx caelata	30.8	44.0	X	X	*
	Nemapteryx nenga	6.3	6.3			*
	Osteogeneiosus militaris	11.5	8.0	X	X	*
	Plicofollis argyropleuron	76.9	76.0	X		*
Atherinidae	*Atherinomorus lacunosus*			X		
Bagridae	*Mystus gulio*			X		*
Batrachoididae	*Allenbatrachus grunniens*		4.0	X		*
Belonidae	*Ablennes hians*			X		*
	Strongylura leiura			X		*

Table 8.1, continued

	Strongylura strongylura	88.5	60.0	X	X	*
	Tylosurus crocodilus		8.0	X		*
Carangidae	*Alepes djejaba*				X	**
	Carangoides malabaricus	11.5		X		**
	Caranx ignobilis			X		**
	Caranx melampygus			X		**
	Megalaspis cordyla			X		**
	Parastromateus niger			X		**
	Scomberoides commersonnianus		4.0	X	X	**
	Scomberoides tala		6.3			**
	Scomberoides tol		8.0			**
	Trachinothus blochii	6.3	6.3			**
Chirocentridae	*Chirocentrus dorab*			X		**
	Chirocentrus nudus		4.0			**
Cichlidae	*Oreochromis mossambicus*	15.4	32.0	X		*
Clupeidae	*Anodontostoma chacunda*	7.7	44.0	X	X	*
	Escualosa thoracata	26.9	16.0	X	X	*
	Hilsa kelee	3.8				**
	Opisthopterus tardoore	23.1	76.0			*
	Sardinella melanura			X		*
	Tenualosa toli			X		**
Cynoglossidae	*Cynoglossus arel*		6.3			**
	Cynoglossus bilineatus	80.8	76.0	X	X	**
	Cynoglossus cynoglossus	88.5	88.0			**
	Cynoglossus lingua	84.6	68.0	X	X	**
	Cynoglossus puncticeps	50.0	48.0	X	X	**
Dasyatidae	*Brevitrygon imbricata*			X		*
	Brevitrygon walga	30.8	32.0		X	*
	Dasyatis bennetti	19.2	32.0			*
	Dasyatis zugei	15.4	40.0	X		*

Table 8.1, continued

	Himantura pastinacoides		8.0			*
	Himantura uarnak	15.4	28.0	X		*
	Neotrygon kuhlii		4.0			*
	Taeniura lymma	3.8				*
Drepaneidae	*Drepane longimana*	3.8	12.0	X		**
	Drepane punctata	34.6	56.0	X		**
Eleotridae	*Butis butis*			X	X	
	Butis koilomatodon	3.8		X	X	
Elopidae	*Elops machnata*			X		**
Engraulidae	*Coilia dussumieri*	19.2	36.0			*
	Setipinna taty	34.6	88.0	X		*
	Stolephorus baganensis	57.7	36.0	X	X	**
	Stolephorus indicus			X	X	**
	Stolephorus tri	3.8	16.0	X		**
	Thryssa hamiltonii		36.0	X	X	*
	Thryssa kammalensis	92.3	92.0	X	X	*
	Thryssa mystax		4.0	X		*
	Thryssa setirostris			X		*
Ephippidae	*Platax teira*	3.8	4.0			**
Gerreidae	*Gerres erythrourus*	3.8		X	X	*
	Gerres filamentosus			X	X	*
Gobiidae	*Acentrogobius caninus*			X	X	
	Aulopareia unicolor				X	
	Boleophthalmus boddarti		4.0	X	X	
	Glossogobius giuris			X	X	*
	Odontamblyopus rubicundus	3.8	8.0			*
	Ophiocara porocephala			X		
	Oxuderces dentatus				X	
	Oxyurichthys uronema				X	
	Periophthalmodon schlosseri			X		*
	Pseudapocryptes elongatus			X	X	*

Table 8.1, continued

	Pseudotrypauchen multiradiatus				X	
	Stigmatogobius sadanundio			X		
	Taenioides nigrimarginatus	7.7	8.0		X	
	Trypauchen vagina	3.8	4.0	X		
	Trypauchenichthys sumatrensis				X	
Gymnuridae	*Gymnura poecilura*			X		*
Haemulidae	*Plectorhinchus gibbosus*	6.3				*
	Pomadasys argenteus			X		**
	Pomadasys kaakan	15.4	24.0	X	X	**
	Pomadasys maculatus			X		*
Hemiramphidae	*Hemiramphus far*	73.1	24.0			*
	Zenarchopterus buffonis			X		*
	Zenarchopterus caudovittatus			X		*
	Zenarchopterus dispar				X	
Hemiscylliidae	*Chiloscyllium griseum*				X	
	Chiloscyllium hasselti	25.0				
	Chiloscyllium indicum	3.8		X		
	Chiloscyllium plagiosum	3.8	4.0		X	
Kurtidae	*Kurtus indicus*	7.7	20.0			
Latidae	*Lates calcarifer*	7.7	8.0	X	X	**
Leiognathidae	*Eubleekeria splendens*			X	X	*
	Leiognathus bindus			X		*
	Leiognathus brevirostris	3.8	64.0		X	*
	Leiognathus daura			X		*
	Leiognathus fasciatus			X		*
	Leiognathus lineolatus			X		*
	Secutor insidiator	3.8	12.0			*
	Secutor ruconius	7.7	12.0		X	*
Lobotidae	*Lobotes surinamensis*	19.2	12.0			**
Lutjanidae	*Lutjanus johnii*			X	X	**

Table 8.1, continued

	Lutjanus sanguineus			X		**
Monodactylidae	*Monodactylus argenteus*			X		*
Mugilidae	*Ellochelon vaigiensis*	11.5	4.0			**
	Paramugil parmatus	3.8				**
	Planiliza melinopterus	50.0	76.0	X	X	*
	Planiliza subviridis	100.0	100.0	X	X	**
Mullidae	*Upeneus sulphureus*	7.7	28.0	X	X	*
Muraenesocidae	*Congresox talabonoides*		18.8			**
	Gymnothorax thyrsoideus			X		
	Uropterygius concolor			X		
Myliobatidae	*Aetomylaeus nichofii*			X		**
Ophichthidae	*Neenchelys buitendijki*				X	
Paralichthyidae	*Pseudorhombus arsius*			X		**
	Pseudorhombus javanicus			X		**
Platycephalidae	*Grammoplites scaber*			X		*
	Platycephalus indicus		16.0	X	X	*
	Sorsogona tuberculata			X		*
Plotosidae	*Plotosus canius*	92.3	80.0	X	X	**
	Plotosus lineatus	6.3				**
Polynemidae	*Eleutheronema tetradactylum*	88.5	96.0	X	X	**
	Leptomelanosoma indicum	26.9	4.0			**
	Polydactylus plebeius			X		**
	Polydactylus sextarius		6.3			**
	Polynemus indicus				X	**
	Polynemus paradiseus	6.3	6.3			**
Pristigasteridae	*Ilisha elongata*		12.0			*
	Ilisha filigera			X		*
	Ilisha macrogaster		6.3			*
	Ilisha megaloptera			X		*
	Ilisha melastoma	11.5	44.0	X		*

Table 8.1, continued

Scatophagidae	*Scatophagus argus*	46.2	64.0	X	X	*
Sciaenidae	*Aspericorvina jubata*	26.9	40.0	X	X	*
	Dendrophysa russelii	7.7	56.0	X	X	*
	Johnius amblycephalus			X		*
	Johnius belangerii	34.6	56.0	X	X	**
	Johnius borneensis	15.4	28.0	X	X	**
	Johnius carouna	96.2	92.0	X	X	**
	Johnius carutta		4.0	X		*
	Johnius coitor			X		*
	Johnius weberi			X	X	*
	Nibea soldado	61.5	48.0	X	X	**
	Otolithes ruber	76.9	96.0	X		**
	Otolithoides biauritus	11.5	28.0			**
	Panna microdon	80.8	80.0	X	X	**
	Pennahia anea	7.7	16.0	X	X	**
	Pennahia macrocephalus				X	*
	Protonibea diacanthus	3.8				**
Scombridae	*Rastrelliger brachysoma*	3.8				**
	Scomberomorus commerson		4.0			**
Serranidae	*Epinephelus longispinis*			X		**
	Epinephelus sp.		4.0			**
Siganidae	*Siganus canaliculatus*	3.8	12.0	X	X	**
	Siganus javus			X		**
	Siganus vermiculatus	3.8		X		*
Sillaginidae	*Sillago chondropus*			X		**
	Sillago sihama	30.8	12.0	X		**
Soleidae	*Synaptura commersonnii*	11.5	4.0			**
	Zebrias zebra				X	*
Sphyraenidae	*Sphyraena barracuda*			X		**
	Sphyraena jello			X		**

Table 8.1, continued

	Sphyraena putnamae		4.0			**
Stromateidae	*Pampus argenteus*	7.7	72.0	X	X	**
	Pampus chinensis	7.7	44.0	X	X	**
Syngnathidae	*Doryichthys boaja*		4.0			
Synodontidae	*Harpadon nehereus*	7.7	20.0	X	X	**
	Saurida tumbil			X		**
Terapontidae	*Terapon jarbua*	7.7		X	X	*
	Terapon theraps	26.9	12.0	X	X	*
Tetraodontidae	*Arothron leopardus*			X		
	Chelonodon patoca			X	X	
	Dichotomyctere fluviatilis	42.3	40.0	X	X	
	Dichotomyctere nigroviridis			X	X	
	Lagocephalus lunaris		44.0	X	X	
	Takifugu oblongus	42.3	88.0	X		
Tetrarogidae	*Vespicula trachinoides*				X	
Toxotidae	*Toxotes chatareus*			X		*
	Toxotes jaculatrix			X		*
	Toxotes microlepis	11.5	36.0			*
Triacanthidae	*Triacanthus biaculeatus*				X	*
Triacanthidae	*Triacanthus nieuhofii*		16.0			*
	Tripodichthys blochii			X		*
Trichiuridae	*Lepturacanthus savala*		4.0	X		**
	Trichiurus lepturus	34.6	48.0	X		**
Total number of species		90	100	135	77	162

Based on the studies of Chong et al. (1990) and Sasekumar and Chong (1991), who used the beam trawl, bag net and gill net as sampling gears, a total of 135 species of fish in the Selangor mangrove are recognized. The Sagor catfish, bald glassy and greenback mullet were among the most important fish species in terms of abundance and biomass. Compared to the current mudflat study, 67 species were common to both habitats (Table 8.1). These species may swim into the mudflat from the mangrove-lined estuaries or vice versa, or are transient species making use of the mudflat as corridor to other habitats. There were 48 species of fish that were found in the mudflat but not in the mangrove area. These species are likely those that enter into the mudflat from the subtidal coastal area. Among them are the Tardoore *Opisthopterus tardoore*, halfbeak *Hemiramphus far* and tonguesole *Cynoglossus cynoglossus* which are common species in mudflat area. Other species such as the mackerel (*Rastrelliger brachysoma* and *Scomberomorus commerson*), queenfish (*Scomberoides tala* and *Scomberoides tol*) and threadfin (*Polydactylus sextarius* and *Polynemus paradiseus*) were occasional visitors from offshore waters.

8.2 The food web of Klang Strait mudflat

The mudflat food web is fueled by energy from two important basal sources, that is the microphytobenthos at the mud bottom and phytoplankton in the water column. A very minor and third basal source is of terrestrial origin, mangrove detritus. These basal sources support fishes and marine organisms up to five trophic levels (Figure 8.1). Organisms at second trophic level are mainly primary consumers such as copepods that derived their carbon mainly from phytoplankton and microphytobenthos, which in turn are fed by larger organisms such as prawns, anomurans, crabs, and fishes such as the ambassids and clupeids that formed the CO guild, and carangids and engraulids that formed the SZ guild. Other organisms reside on trophic level two are the bivalves, polychaetes and other smaller decapods such as *Acetes* shrimps and blind pea crab *Xenophthalmus pinnotheroides*. These organisms formed the main food for the fishes of MX, PO, SH and SD guilds, particularly the ariids, cynoglossids, drepanids, sillaginids, haemulids, sciaenids and polynemids. The shrimps and prawns were also the bulk for the overall diets of Klang mudflat fishes. Fishes from the ST guild such as the belonids and polynemids, at the highest trophic level of between four and five, feed primarily on other fishes such as ambassids, engraulids, mugillids and sciaenids. Another branch of the food web is the IL guild, comprising of the mugillids that feed primarily on microphytobenthos and phytoplankton, and a scatophagid that feeds mainly on plant detritus.

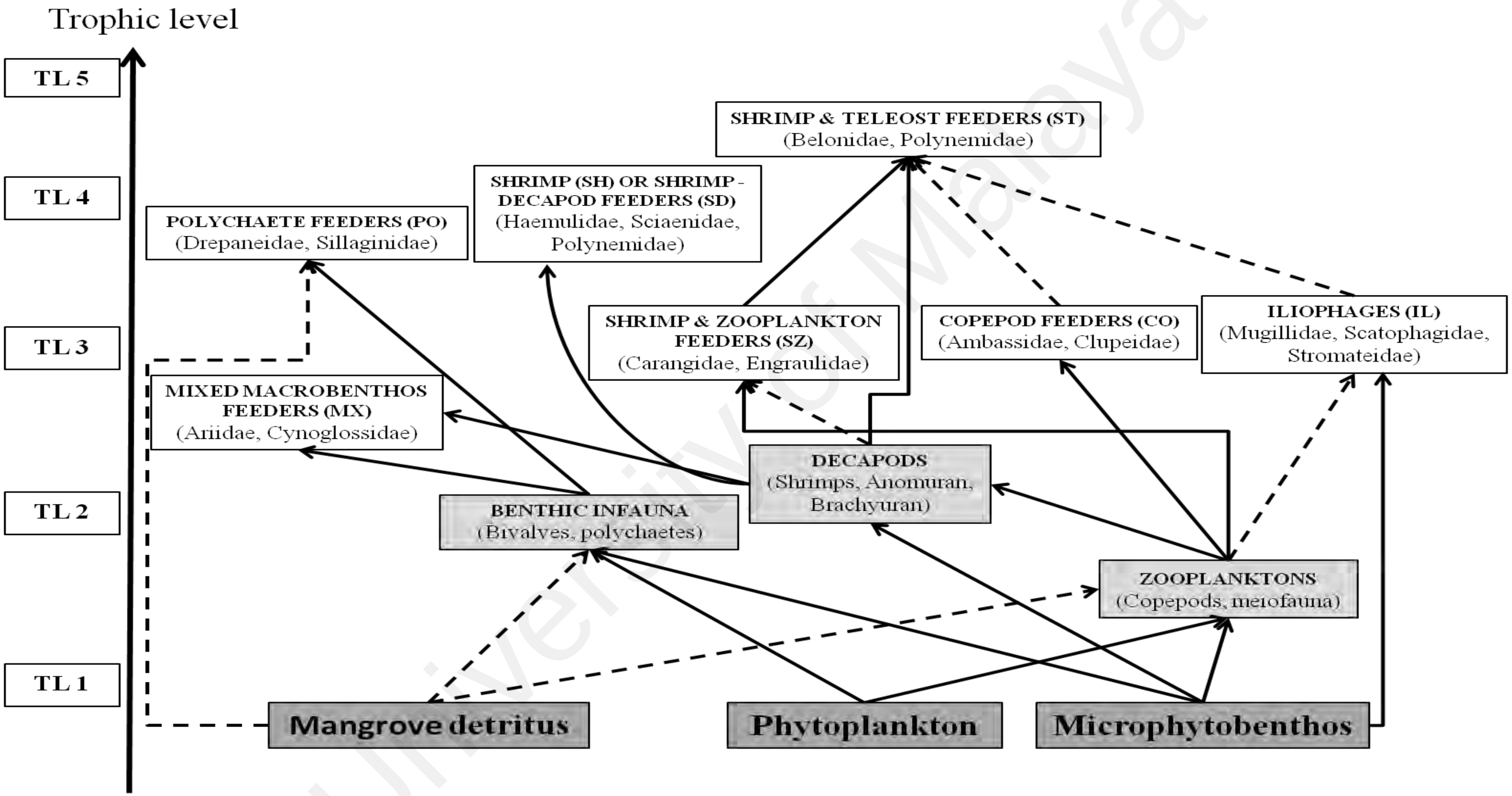

Figure 8.1 Constructed Klang mudflat food web depicting the main trophic pathways from primary producers (dark grey) to consumers of the tropical mudflat ecosystem (light grey = invertebrates; white = fish). TL = trophic level (1 - 5, first to fifth level). Representative examples are given in parentheses. Pathways to large animals (e.g. reptiles, birds, mammals) are excluded. Solid and dotted lines represent primary and secondary food resources respectively.

Comparison between the Klang mudflat (present study) and Matang mudflat (Chong et al., 2012b) shows that the shrimp and mixed macrobenthos feeders are the two largest guilds. Such similarity supports the observations made by other workers that although the fish species composition differs between estuarine habitats, their trophic structures generally remain similar whether in the tropical or temperate region (Elliott et al., 2002; Barletta & Blaber, 2007). In an extensive review of the global estuarine fishes, Elliott et al. (2007) provided seven broad categories of estuarine fishes, based on the feeding mode functional guild, which include detritivore, herbivore, omnivore, zooplanktivore, zoobenthivore, piscivore, and miscellaneous/opportunist. Except the herbivore and omnivore categories, the dietary trophic guilds of IL, CO+SZ, SH+SD+PO, ST and MX of the present study correspond to the other groups in the classification of Elliott et al. (2007), respectively. However, their herbivore group (subcategory phytoplankton) falls in our IL group. Although the global estuarine fish guilds appear to cover most functional groups, it appears that specific estuarine habitats and food resources can modify them. For instance, the global herbivore (subcategory macrophyte) and omnivore categories are not present in the Klang mudflat since macroalgae and seagrasses are either absent or insignificant. Instead, our IL group contains predominantly herbivorous fishes that not only consume fresh microalgae but also detritus, micro- and meiofauna found on the surface sediments of the mudflat. A comparison of food web with other mudflats in the temperate region showed a rather similar observation. For example, the fish assemblage in unvegetated mudflat at Tokyo Bay, Japan comprised of six feeding guilds namely the small benthic and epiphytic crustacean, zooplankton, detritus, mollusk, polychaete and fish feeders (Kanou et al. 2004). In the Mamanguape river estuary, Brazil, 17 dominant fish species formed the five primary feeding guilds that are the detritivore, zooplanktivore, zoobenthivore-epifaune, zoobenthivore-infaune and piscivore (Canpos et al. 2015).

Mangrove carbon (mangrove detritus) appears refractory to assimilation in most fishes, as suggested by previous workers (e.g. Rodelli et al., 1984; Newell et al., 1995; Bouillon et al., 2008). However, Hayase et al. (1999) and Chong et al. (2001) who studied in the Matang Mangrove Forest Reserve showed that fish and shrimps assimilated their carbon mainly from mangrove or terrestrial sources. In particular, study by Tanaka et al. (2011) showed shift in carbon assimilation with growth of John‘s snapper *Lutjanus johnii* from coastal food web during young to inner mangrove area as they grow. Diet of John‘s snapper consisted of mainly penaeids, *Acetes* shrimps and mysids that were generally have depleted $\delta^{13}C$ values in the inner mangrove area. Study by Chong et al. (2001) on the banana prawn *F. merguensis* recorded $\delta^{13}C$ values that ranged from -25.7 ‰ (mangrove) to -19.9 (offshore waters), with an assimilation of as high as 84 % of their carbon needs from mangrove. In the present study, the $\delta^{13}C$ values of banana prawn in the coastal mudflat ranged from -17.8 to -18.6 ‰ and assimilate carbon mainly from phytoplankton (61.2 %). Kammal anchovies caught in the Matang Mangrove Forest Reserve waters also had a wide range of $\delta^{13}C$ values (-23.9 to -16.3 ‰), where offshore individuals had more enriched $\delta^{13}C$ values than estuaries individuals (Then, 2008). Both ontogenetic dietary shift from copepods to shrimps and habitat shift towards more offshore areas were reflected in these studies. Similarly, the Kammal anchovy in the present study also demonstrated a rather similar pattern where shrimps and copepods constituted an important diet in the mudflat but the diet shifted towards more shrimps (57.5 %IRI vs 38.6 %IRI) with a much enriched mean $\delta^{13}C$ values (-16.3 ± 0.2 ‰) farther offshore.

8.3 Trophic effects due to eutrophication

In the present study (Chapter 7), the mean $\delta^{13}C$ value for senescent mangrove leaves (-28.5 ± 2.4 ‰) is close to that of Rodelli et al. (1984) (-27.1 ± 1.2 ‰) and Newell et al. (1995) (-28.3 ± 0.4 ‰) based on collections in 1979 and 1989 respectively from the same study area (Figure 8.2). Our mean $\delta^{13}C$ value for water-column microalgae (-19.78 ± 0.9 ‰) is however slightly enriched relative to -20.9 ‰ obtained by Rodelli et al. (1984). Our δ13C value for MPB (-16.6 ‰) is also more enriched compared to -19.6 ‰ for MPB extracted from the stomachs of *Boleophthalmus boddarti*, an iliophagous mudskipper living on the Klang mudflat (Newell et al. 1995). This is interesting because, except mangrove and phytoplankton, the current $\delta^{13}C$ signatures of MPB, fishes and prawns are all more enriched by 0.9 - 2.8 ‰ relative to signatures of the same species 30 years ago (Figure 8.3). We surmise that this shift in isotopic signature of consumers may be from CO_2 limitation as a result of eutrophication and high primary production (Voβ and Struck 1997; Oczkowski et al. 2014) occurring in Klang Strait waters and sediments (Lee & Bong, 2008; Chew et al., 2015, Teoh et al., 2016).

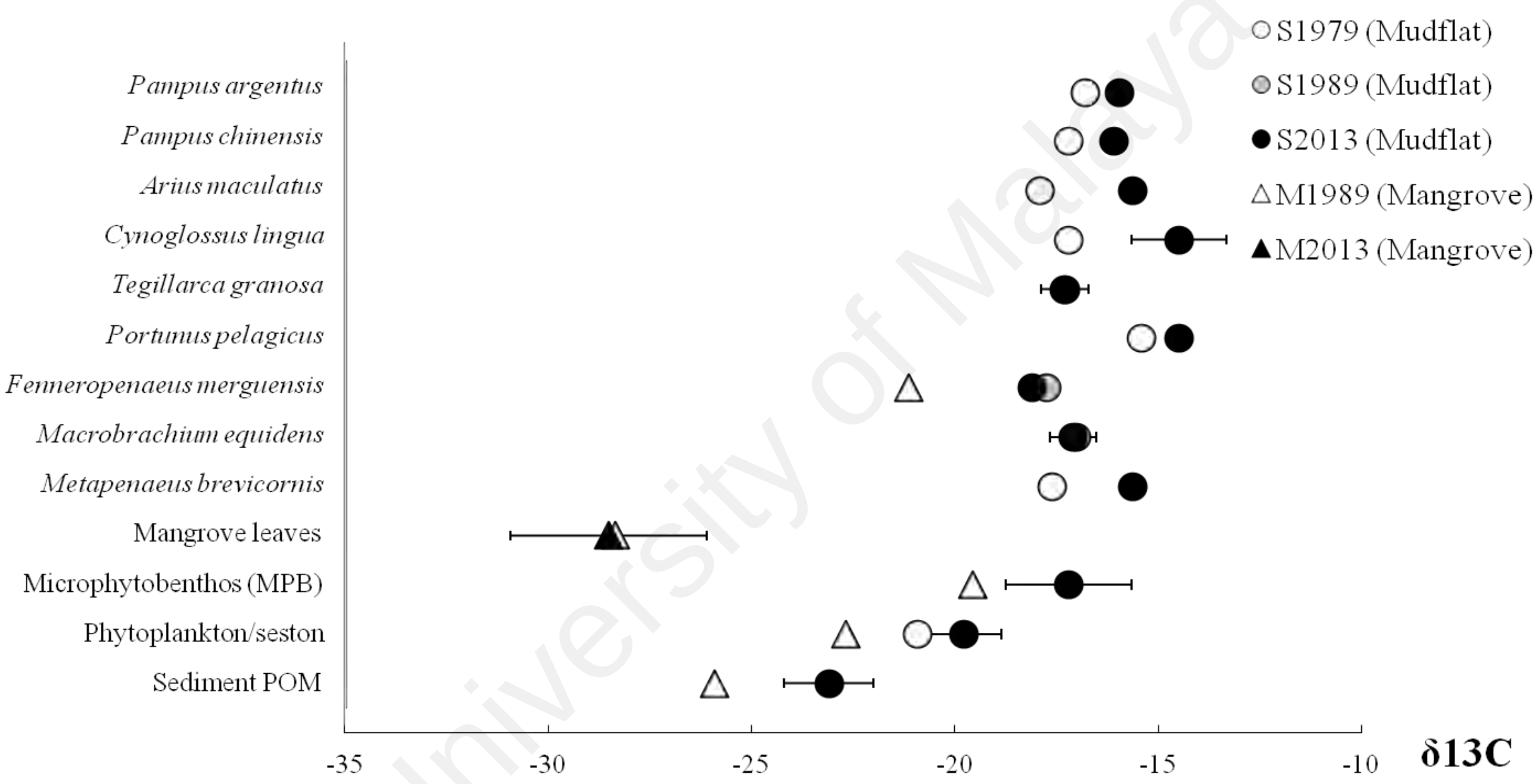

Figure 8.2 Comparison of stable isotopic carbon ratios ($\delta^{13}C$) values of various organisms and basal sources between current (S2013, solid circle; M2013, solid triangle) and previous studies by Rodelli et al. (1984) (S1979, empty circle) and Newell et al. (1995) (M1989, empty triangle; S1989, grey circle) at the Klang Strait mudflats.

8.4 The economic value of mudflat fish to coastal fisheries

The importance of coastal mudflats to the socio-economy has been addressed in terms of supporting the coastal fisheries (see Figure 2.3). The coastal ichthyofauna that utilize the Klang Strait mudflat are mainly the juvenile of fish species of which at least 87 % are commercially exploited on maturity (Table 8.1). The total annual landings of all commercially exploited mudflat fish species in Selangor state is 400,000 metric tons with an economic value of USD 50 million (Department of Fisheries Malaysia, 2016). Fodder fish such as engraulids and ambassids, although do not fetch high economic relevance, are integral to the food web as intermediate prey food for other economically important fish species.

The present study also shows that the mudflat prawns and shrimps (largely penaeids and sergestids) are a major food source for the majority of the fish species in Klang Strait mudflat. In fact, prawns and shrimps provide a surplus production of 42,000 metric tonnes for fisheries with a high economic value of USD 86 million (Department of Fisheries Malaysia, 2016). In addition, the mudflat‘s high productivity enables the successful culture of blood cockles in the coastal mudflat with a production that reached 41,404 metric tonnes in 2010 (Department of Fisheries Malaysia, 2010). Thus the high fisheries yield that is attributed to the mudflat underlines its importance as a rich feeding ground, nursery, and habitat for coastal fishes, shrimps and molluscs.

8.5 Ecological role and conservation of tropical mudflats

The functioning role of intertidal mudflat as an important feeding ground has been well attested by several previous studies (Elliott & Dewailly, 1995; França et al., 2008; Lim et al., 2018). The ingression and usage of the Klang mudflat by its fish community is illustrated in Figure 8.3. The high productivity of the mudflat is fueled by autochthonous carbon or energy provided by both microphytobenthos and phytoplankton and sustained by close coupling of pelagic-benthic processes in the shallow turbid waters. Despite the input of allochthonous carbon source from mangrove detritus, its contribution to fish nutrition appears limited. However, the high organic matter, bacteria and other microorganisms, decomposition and other heterotrophic processes likely drives a prominent microbial loop that benefits mainly the zooplankton and filter feeders. Mudflat macrofauna such as shrimps, molluscs and polychaetes make use of the mudflat‘s food resources and are in turn fed by fishes (and birds) that forage in the mudflat. In this study, prawns and shrimps have been identified as the most important prey items to the majority of the fish species in the Klang Strait mudflat (Section 6.4). The mudflat fish on their return to the subtidal and offshore waters are fed by their larger predators including mammals.

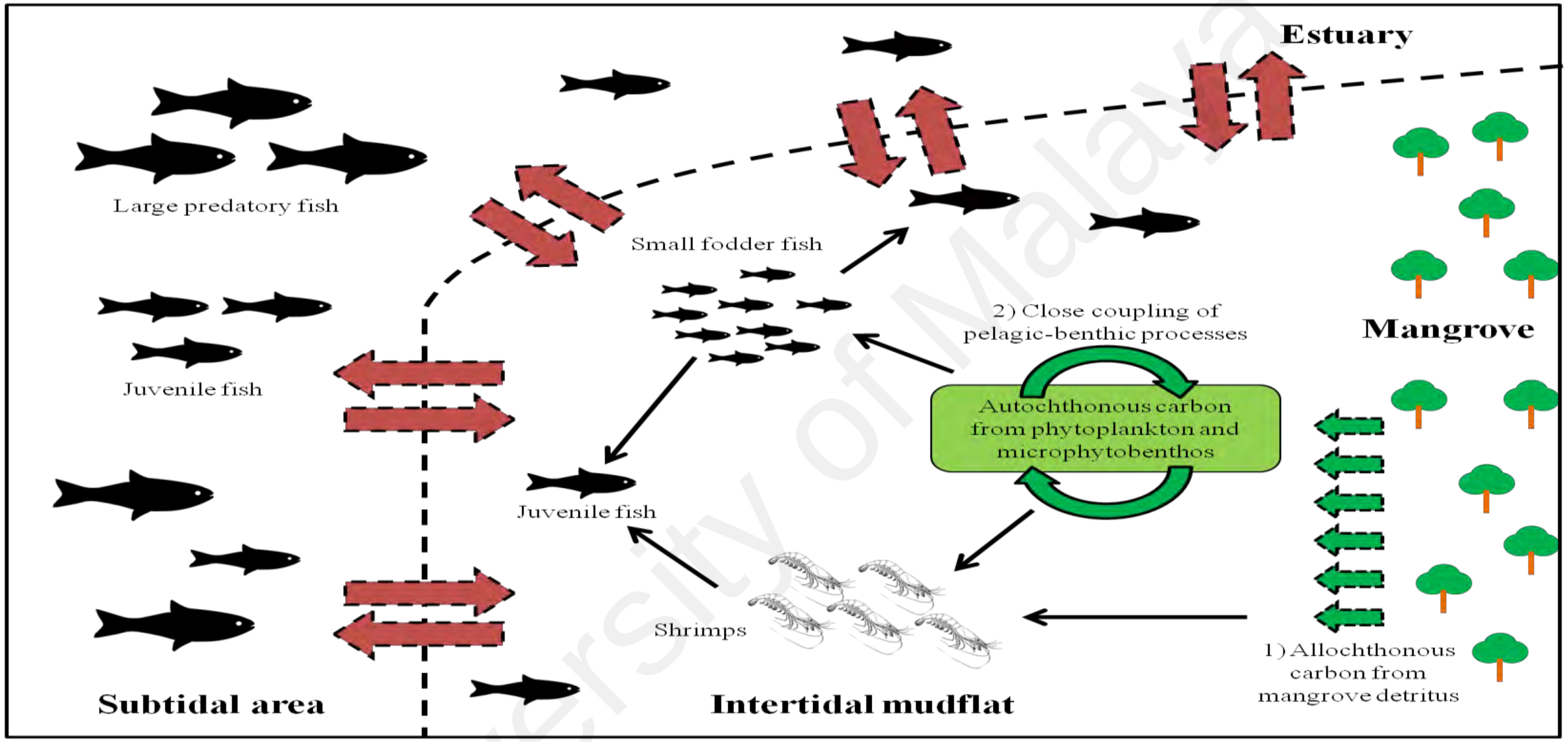

Figure 8.3 Conceptual model of fish community ingression into Klang Strait mudflat. Red arrows indicate fish movements into the intertidal mudflat area during high tide (and out during low tide). Green arrows indicate the movement of carbon: 1) from allochthonous sources such as mangroves, 2) autochthonous carbon sources from phytoplankton and microphytobenthos despite high turbidity; this is due to close coupling of pelagic-benthic processes that maintain high primary production in shallow water. Trophic energy from these basal food sources is channeled to primary and secondary consumers (e.g. zooplankton, benthic infauna and shrimps), and to other higher consumers such as fodder and juvenile fish that enter the mudflat during high tide. Piscivory is likely much reduced in the mudflat where large predatory fishes are kept out due to shallow and turbid waters. Nevertheless, the mudflat‘s trophic energy is turned out or exported to offshore waters via fish (and shrimps and others) migration where they are predated or fished by humans. In-situ predation of fish (mainly gobiids) and invertebrates by shore birds and mammals (e.g. otters, monkeys) including humans represents another energy outflow from the mudflats during low tide.

Based on circumstantial evidence, the present study also supports the refugial role of the coastal mudflat. The piscivorous fishes in the mudflat only constituted 7.8 % of the fish community in terms of species and 3.5 % in terms of abundance. In addition, several species in the mixed macrobenthos guild fed on other fish, and prey fish contributed to a very small proportion of their diet (< 5 %IRI). Predation by larger fishes is often hindered by their large body size in shallow water (Ryer et al., 2010), or reduced due to high turbidity and wave turbulence (Abrahams & Kattenfield, 1997). Large piscivorous fish in the Klang mudflat that usually prey on anchovies included the Indian threadfin, *Leptomelanosoma indicum,* and the Spanish mackerel, *Scomberomorus commerson* (see more in section 6.1.3, 6.1.4). These predatory fish were found to be larger in size in the subtidal compared to the intertidal area. In particular, over 80 % of the fourfinger threadfin *E. tetradactylum* in the intertidal area were found to be less than 20.0 cm in length, whereas in the subtidal area, 64 % of them were found to be of larger sizes (> 20 cm). This species is known to achieve first sexual maturity at a length of 20 cm (Pember et al., 2005), and to make use of mangrove estuaries as its nursery area prior to sexual maturity (Blaber et al., 1995; Martin, 2005).

The mangrove forest has previously been reported as the major nursery habitat for juvenile fishes and invertebrates (Chong et al., 1990). This has been attributed to the naturally complex structure of the mangrove forest due to their aerial roots and pneumatophores as well as fallen branches (Robertson & Blaber, 1992; Blaber, 2000). However, Tse et al. (2008) who conducted a comparative study between mudflat and mangrove habitat found that despite being structurally less complex than mangrove, the mudflat offers similar species diversity, composition and feeding opportunity as the mangroves. The ample feeding opportunity provided by the mudflat appears to outweigh the predation risks. The present study on the Klang coastal mudflat supports these findings.

In summary, this study has shown that the Klang Strait mudflat despite its low aesthetic value provides beneficial refugia and feeding ground for a large number of fish species and shrimps that are integral to the coastal fishery. Coastal management development and planning will need to take cognizance of this. The reclamation or removal of the intertidal mudflat for development purposes will not only destroy a crucial feeding ground and habitat for fishes and shrimps, but also impact the adjacent estuaries and mangrove ecosystem given the connectivity between these habitats (Healy & Hickey, 2002; Gao & Zhao, 2006; Chong et al., 2012a).

8.6 Limitations of study

a) The present study is very much field-based relying on a traditional fishing gear, the barrier or enclosure trap (locally called *belat*), that can effectively be used in shallow waters and on soft bottom for fish samplings. However, unlike the trawl, the enclosure trap has never been used in scientific surveys and its limitations including the fish escapement or retention factor have never been assessed before. In most trawl surveys, a fish retention factor of 0.5 is used (per Sparre & Venema, 1998). In this study, since fish escapement is unknown, it was not factored into the calculation of fish density and biomass. Hence, in all likelihood the derived fish density and biomass are underestimated.

b) Very small fish (young juvenile and postlarvae) as well as shrimps (sergestids and mysids) were not sampled by the barrier net (mesh size 1.5”). Also, the burrowing species such as gobies and mudskippers were severely undersampled.

c) The enclosure trap cannot operate effectively in deeper waters (> 2 m) and thus, the subtidal edge of the mudflat had to be sampled using gill nets in the present study.

Unfortunately, gill nets only give relative abundance or CPUE data that cannot be compared to the catch data obtained from the enclosure trap.

d) In the trophic study based on stomach content analysis, the ingested food examined were not always recently ingested because the captured fish could have ingested and digested its food from 0-5 hour before (on ingression). This is a limitation due to the long deployment of the barrier net during ebb tide. It may explain the high presence of empty to quarter-filled stomachs (about 50 %), and lack of full stomachs (13 %). Hence, the stomach content fullness index could not be gainfully used to indicate recent food ingestion.

8.7 Future studies

a) Only two sampling sites of the Klang Strait mudflat had been selected for this study due to funding, effort and time restrictions. Although the two sites showed high similarity (64 %) in mudflat species, there were differences in species utilizing the mudflats as well as fish standing stocks. Another site at the Jeram mudflat in Klang Strait which supports unique polychaete reef growths shows characteristic fish species such as triacanthids (Eeo et al., 2017). Yet, another comparison of the fish community of Klang mudflat with that recorded in the Matang mudflat (Chong et al., 2012b) attests to differences in diversity and standing stocks. This shows that the mudflat despite its homogenous appearance may differ in its nursery ground value which may be due to bottom or substrate differences since water parameters were consistent among sites. Further studies on other mudflat sites and their substrates will be interesting to shed more light on the effects of edaphic factors and other physical structures.

b) Given that the mudflat fish are essentially fishes that ingress into the mudflat during high tide, these fish (and other vagile species) must return to the subtidal water during ebb tide. It is hypothesized that a narrow coastal strip beyond the mudflat edge serves as a retreat zone just like the many creeks and waterways in the mangrove hold the mangrove fish during ebb tide. It is unfortunate that this subtidal water aspect was not examined in detail in the present work due to sampling constraints arising from the lack of a suitable comparable gear (as used in the intertidal mudflat) and opposition to trawling by the local community. Future work on the subtidal retreat zone to prove this hypothesis would be interesting and to substantiate whether increased predation during high tide drives the mudflat fishes into shallow waters.

c) The present study has shed light on the importance of the mudflat habitat as a nursery and refugia ground for small and juvenile fish. Future works on the mudflat plankton would be useful to determine whether fish larvae make use of the shallow waters in the mudflat as accumulation or retention areas before they penetrate the estuaries via upstream advection processes (Levin, 1986). On the other hand, is the presence of fish or invertebrate larvae in the mudflat the result of larval outwelling from the adjacent mangroves and estuaries? (see Ooi & Chong, 2011). Such larval studies may further show the interconnectivity between mudflat, estuaries and mangroves, as a result of ontogeny and migration. Moreover, assessing and defining the carrying capacity of mudflat can also helps on developing predictive models of mudflat recruitment to show the consequences of mudflat loss.

d) Although the refugial role of mudflat has been accepted based on circumstantial evidence of the absence of many predaceous fishes as well as prey fish in examined stomachs, this role should be substantiated through investigations that provide direct evidence. For example, microcosm experiments could be set up to examine the role of water depth, turbidity and mud substrates in relation to predation and fish behavior.

e) The present study also examined the standing stocks and biomass of prawns and shrimps in the mudflat area to understand how the many fish species share seemingly similar food resources. Further studies could be conducted to determine the abundance of other key prey species identified in the present study, such as *Acetes* shrimps which are known to exhibit high standing stocks exploited by a known and regular fishery. Since both penaeid and sergestid shrimps are important prey food for mudflat fishes and hypothesized to be the reason why these fishes cohabitate by sharing a common food resource in abundance (Section 6.5), it would be interesting to conduct further studies to verify this. For example, selected mudflat sites where such prey food is nil or low could be examined for their fish diversity and abundance.

f) Through the use of stable C and N isotopes of producers and consumers, the present study has shown the importance of autochthonous sources of energy via phytoplankton and microphytobenthic production in the mudflat. The contribution of allochthonous sources such as mangrove detritus, despite the close proximity of mangrove forests, is surprising minimal. Further studies could be conducted to investigate whether this is due to a lack of outwelled mangrove litter into the mudflat area due to hydrological and/or topographical reasons, or really a matter of mangrove detritus being refractory to assimilation by fishes. Since mangrove detritus has been reported to be assimilated by a number of estuarine organisms, including bivalves, gastropods and certain crustaceans like crabs (Hayase et al., 1999; Niiyama et al., 2012; Bui & Lee, 2014; Yurimoto et al., 2014), which are very abundant in both mangrove and mudflat, it is possible that the energy is channeled through other pathways. For instance, is there a flow from these animals to shore birds which are known to feed on molluscs and crabs?

g) Seascape connectivity between mudflat and adjacent mangrove habitat was only briefly discussed in this study. Compared to studies on the adjacent Klang mangrove (Chong et al., 1990; Sasekumar & Chong, 1991), the present study showed that 67 of the fish species overlapped with the mangrove fish community. However, records from these mangrove studies were of two decades old. Changes in mangrove fish community throughout this period as a result of dwindling mangrove forest and anthropogenic influences were not properly documented and reflected. Therefore any differences in comparison to the current study will be biased. Future studies should consider concurrent studies of both habitats such as community structure, migration and habitat use between the mudflat and adjacent mangrove. A better understanding of connectivity between these habitats is crucial to conservation prioritization (Weeks, 2017).

h) With the ever increasing human activities occur at nearshore, estuarine and upstream area, intertidal mudflats have a high potential for being impacted by land claims, organic enrichments, industrial and domestic effluents discharge. Therefore studies on how coastal and upsteam landscape uses and changes can affect the integrity and wellbeings of mudflats down streams and subsequently the animals that rely on the mudflats are crucial. For instance, de Boer and Prins (2002a) investigation in an exploited and unexploited control area at Inhaca Island mudflat showed a shifted community structure towards lower diversity, lower evenness and higher dominance. Modelling and predictive models can be established to estimate the repercussions of mudflat loss due to these human activities. Cozzoli et al. (2014) introduced a mixed modeling approach that integrate numerical hydrodynamic models and species distribution model as a viable way to investigate the response of fauna towards anthropogenic modification of their habitats. Future studies can incorporate the mixed modeling approach with data from current study to provide a more meaningful data to environmental managers.

8.8 Conclusion

This study is the first ecological study on the fish community structure and food web of a Malaysian intertidal mudflat. It has achieved all three objectives that were set out to be addressed, including testing two proposed hypotheses: mudflat fishes are likely to coexist by sharing similar food resources in abundance, and mudflat fish community is supported by autochthonous rather than allochthonous (mangrove) carbon inputs, which were supported. The study has shown that the intertidal mudflat during high tide is important as a feeding and refugial ground to 116 fish species, particularly fish at the young or juvenile stage. The mudflat is regularly visited by abundant fishes belonging to the families of ariids, engraulids, clupeids, mugillids and sciaenids. Occasional visitors to the mudflats include fishes from the families of carangids, scombrids and lobotids. Seasonal variability in fish diversity and abundance is modulated by the monsoons and rainfall, while daily variability can be attributed to the diel light condition and fish behavior.

The trophic structure of the fish community comprises five trophic levels that are occupied by eight feeding guilds. Four of these guilds comprise of cohabiting species that largely share a common but large prey resource, namely, prawns and shrimps. Other feeding guilds consist of specialists with little niche overlapped and generalists that feed on a wide range of prey items. Despite turbid waters, the mudflat food web is mainly fueled by phytoplankton and microphytobenthos as a result of close pelagic-benthic coupling attributed to strong tidal mixing in shallow water. The findings of this study thus show that tropical coastal mudflats are not wastelands; that, they are critical feeding and nursery areas for marine fishes. Most of these fishes are commercially exploited or support a subsistence fishery for the local community. Rational development planning and conservation of intertidal mudflats should therefore be part of any coastal zone management initiative. Meanwhile, the fisheries department should take cognizance of the vast fisheries contribution of coastal mudflats and treat them as an essential fish habitat for fisheries management.

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LIST OF PUBLICATIONS AND PAPERS PRESENTED

List of publications

1) **Lee, S. L.,** Chong, V. C., Loh, K. H. & Yurimoto, T. (2013). Are intertidal mudflat communities (fish and shrimp) affected by cockle culture? *Malaysian Journal of Science (SCS Sp Issue)*, 131-140.

2) **Lee, S. L.,** Chong, V. C., & Yurimoto, T. (2016). Ichthyofauna on a tropical mudflat: implications of spatial and temporal variability in assemblage, structure and abundance. *Estuaries and Coasts, 39*, 1543-1560.

3) **Lee, S. L.,** Chong, V. C., & Then, A, Y. T. (2019). Fish trophodynamics in tropical mudflats: a dietary and isotopic perspective. *Estuaries and Coasts, 42*, 868-889.