FISH AND TROPHIC CONNECTIVITY ACROSS CORAL REEF AND MANGROVE HABITATS OF NORTH EASTERN LANGKAWI ISLAND, PENINSULAR MALAYSIA

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ABSTRACT

The presence of disparate biotopes of coral reefs and mangroves in one general area is unique. These biotopes may form ecologically connected ecosystems when occurring in close proximity such as in tropical Langkawi Island, Malaysia. Connected marine biotopes can provide various ecological services to fish community such as nursery, feeding habitats and shelter. As such, this study aims to test two hypotheses regarding Langkawi's coral reefs and mangroves 1) the biotopes are ecologically connected via habitat utilization by the fish fauna and 2) the biotopes are ecologically connected via trophic energy pathways. Gill nets and fish pots were deployed to determine common overlapping fish species in both biotopes. Samples of primary producers, sediment and consumers were subjected to dual stable isotope analysis and stomach content analysis in the case of fishes. Coral community and habitat complexity as proxies for refuge cover were determined based on r-K-S adaptive strategists and coral morphology diversity respectively. The present study discovered a relatively high number of common species, 31 out of a total of 149 fish species, suggested there was movement of fishes between habitats. Despite the turbid water, the coral cover was considerably high, 47.21% with low mortality and dominated by stress-tolerators. The habitat complexity was also relatively high with 2.06 index of morphological diversity indicated a fairly good refuge area. Stomach content analysis of fish revealed benthic invertebrates and small nekton as the main food items. Stable isotope analysis showed that the $\delta^{13}C$ values of zooplankton (-21.66 ± 0.72 ‰ SE) were closer to phytoplankton (-21.64 ± 0.79 ‰ SE). The fishes even as far as the upstream mangrove had relatively enriched $\delta^{13}C$ values (-8.88 to -22.37 ‰) close to the values of coral zooxanthellae (-15.39 ± 0.33 ‰ SE) and phytoplankton, but distinctly distant from mangrove-derived source (-28.83 ± 0.38 ‰ SE). A Bayesian mixing model of stable isotopic analysis in R (SIAR) depicted coral zooxanthellae as the major carbon contributor to fish nutrition in the coral reefs (90.0%) and mangrove (63.7%). Since phytoplankton contributed 32.0% in the mangrove estuary, mangrove carbon was relatively unimportant to the food web even in the mangrove estuary itself. Under the turbid water condition, mucus productions are expected by corals. It is hypothesized that coral mucus and zooplankton are the vehicles of energy transfer from coral zooxanthellae to consumers in the mangrove habitat. The present study suggests that fish movements and outwelling of extruded mucus and zooplankton connect coral reef to mangrove.

ABSTRAK

Kewujudan habitat yang berbeza seperti terumbu karang dan bakau di satu kawasan umum adalah unik. Kedua habitat ini boleh membentuk ekosistem yang terkait secara ekologi apabila wujud berhampiran seperti yang terdapat di Pulau Langkawi, Malaysia. Habitat marin yang terkait boleh memberi pelbagai khidmat ekologi kepada komuniti ikan seperti tapak semaian, habitat makanan dan juga tempat berlindung. Justeru itu, kajian ini adalah untuk menguji dua hipotesis tentang terumbu karang dan bakau di Langkawi iaitu 1) kedua-dua biotop adalah terkait secara ekologi melalui penggunaan habitat oleh fauna ikan 2) kedua-dua biotop adalah terkait secara ekologi melalui pengaliran tenaga trofik. Pukat hanyut dan bubu dipasang untuk menentukan spesis ikan yang sama di kedua habitat. Sampel bagi pengeluar utama, sedimen dan pengguna telah dianalisis dengan menggunakan kaedah dwi isotop stabil dan kandungan perut bagi ikan. Komuniti karang dan kekompleksan habitat sebagai proksi perlindungan telah ditentukan melalui strategi adaptasi r-K-S dan kepelbagaian morfologi karang. Kajian ini mendapati bilangan spesies ikan yang sama (31 spesies) bagi kedua habitat adalah agak tinggi daripada jumlah 149 spesis ikan disampel. Ini memberikan bukti bahawa terdapat pergerakan ikan di antara kedua habitat yang dikaji. Walaupun keadaan air laut keruh, liputan karang adalah agak tinggi, 47.21% dengan kadar kematian yang rendah dan didominasi karang yang bertoleransi tinggi terhadap tekanan alam sekitar. Kekompleksan habitat juga agak tinggi dengan indeks kepelbagaian morfologi sebanyak 2.06. Ini menunjukkan bahawa ianya suatu kawasan perlindungan yang agak baik. Analisis kandungan perut ikan menunjukkan bahawa makanan utamanya adalah ikan kecil dan invertebrata bentik. Analisis isotop stabil menunjukkan bahawa nilai δ^{13}C zooplankton (-21.66 ± 0.72 ‰ SE) adalah hampir sama kepada nilai fitoplankton (-21.64 ± 0.79 ‰ SE). Ikan-ikan termasuklah yang dijumpai dalam bakau di hulu sungai mempunyai nilai $\delta^{13}C$ (-8.88 to -22.37 ‰) yang hampir sama kepada nilai zooxantela karang (-15.39 ± 0.33 ‰ SE) dan fitoplankton tetapi jauh daripada nilai sumber bakau (-28.83 ± 0.38 ‰ SE). Model campuran Bayesian analisis isotop stabil dalam R (SIAR) menggambarkan zooxantela karang sebagai penyumbang utama karbon kepada pemakanan ikan dalam habitat terumbu karang (90.0%) dan bakau (63.7%). Memandangkan fitoplankton menyumbangkan 32.0% karbon dalam bakau, karbon bakau adalah kurang penting kepada jaringan makanan dalam kawasan bakau. Dalam keadaan air yang keruh, penghasilan mukus karang adalah dijangkakan tinggi. Oleh itu, dihipotesiskan bahawa mukus karang dan zooplankton adalah pembawa bagi pertukaran tenaga kepada pengguna dalam habitat bakau. Daripada hasil kajian adalah dicadangkan bahawa pergerakan ikan dan pengaliran keluar mukus karang dan zooplankton memperkaitkan terumbu karang kepada bakau.

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TABLE OF CONTENTS

PAGE

CHAPTER ONE

CHAPTER TWO

CHAPTER THREE

CHAPTER FOUR

CHAPTER FIVE

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

A	**Alkl**	*Alepes kleinii*
	Anch	*Anodontostoma chacunda*
	Anth	*Anodontostoma thailandiae*
	Abva	*Abudefduf vaigiensis*
	Atma	*Atule mate*
C	**Chsu**	*Chelon subviridis*
	Crus	Crustaceans
	Coral	Coral reef zone
	Cope	Copepod
	Case	*Caranx sexfasciatus*
	Caig	*Caranx ignobilis*
	Capr	*Carangoides praeustus*
	Caob	*Carangoides oblongus*
	Cacu	*Caesio cunning*
D	**Detr**	Plant Detritus
	Dia	Diatoms
	DO	Dissolved oxygen
	Drpu	*Drepane punctate*
	Deru	*Dendrophyssa russelli*
E	**Eujo**	*Eubleekeria jonesi*
	Eusp	*Eubleekeria splendens*
	Echi	Echinoderms
	Elma	*Elops machnata*
	Epor	*Ephippus orbis*
	Epco	*Epinephelus coioides*
	Eper	*Epinephelus erythrurus*
	Epse	*Epinephelus sexfasciatus*
	Epbl	*Epinephelus bleekeri*
G	**Geer**	*Gerres erythrourus*
	Gefi	*Gerres filamentosus*
	Geoy	*Gerres oyena*
H	**Hiwa**	*Himantura walga*
K	**KC**	Kilim coral
	KM	Kilim mangrove
	KMC	Kilim mangrove-coral
	KMU	Kilim upstream mangrove
L	**Lesp**	*Leiognathus splendens*
	Leeq	*Leiognathus equulus*
	Leda	*Leiognathus daura*
	Lebr	*Leiognathus brevirostris*
	Lalu	*Lagocephalus lunaris*
	Lulu	*Lutjanus lutjanus*
	Luvi	*Lutjanus vitta*
	LIT	Line Intercept Transect
	Luru	*Lutjanus russelli*
	Lujo	*Lutjanus johnii*
M	**Mala**	Malacostracas
	Moch	*Monachanthus chinensis*
	Moll	Molluscs
	MPB	Microphytobenthos
	Mg	Mangrove zone
	Mg-C	Mangrove-coral zone
	MBL	Marine Biological Laboratory
	Mose	*Moolgarda seheli*
O	**ORP**	Oxidation Reduction Potential
P	**Plgi**	*Plectorhinchus gibbosus*
	Poka	*Pomadasys kaakan*
	Pase	*Paranibea semiluctuosa*
	Plat	*Platycephalidae*
	Psst	*Pseudotriacanthus strigilifer*
	PMC	Peluru Straits mangrove-coral
	Pcha	Polychaetes
	Pori	Porifera
	PDB	PeeDee Belemnite
	PCA	Principal Component Analysis
	PM	Peluru Straits mangrove
S	**Scvo**	*Scolopsis vosmeri*
	Siae	*Sillago aeolus*
	Sisi	*Sillago sihama*
	Spje	*Sphyraena jello*
	SpC	Specific Conductance
	SIA	Stable isotope analysis
	SIAR	Stable isotope analysis in R
	SC	Kisap coral
	SM	Kisap mangrove
	SMC	Kisap mangrove-coral
	Sija	*Siganus javus*
	Scco	*Scomberoides commersonnianus*
	Scly	*Scomberoides lysan*
	Scto	*Scomberoides tol*
	SMU	Kisap upstream mangrove
T	**Thha**	*Thryssa hamiltonii*
	Trbi	*Triacanthus biaculeatus*
	TDS	Total Dissolved Solids
	TC	Tg. Rhu coral
	TM	Tg. Rhu mangrove
	TMU	Tg. Rhu upstream mangrove
	Tycc	*Tylosurus crocodilus crocodilus*
U	**UNESCO**	United Nations Educational, Scientific and Cultural Organization
	Up	Upstream mangrove zone
	Upsu	*Upeneus sundaicus*
V	**Vabu**	*Valamugil buchanani*

LIST OF APPENDICES

1.0 INTRODUCTION

1.1 What is connectivity?

In the large oceanic environments throughout the world, marine habitats or biotopes such as coral reefs, mangroves and seagrass meadows are usually patchily distributed. Due to the nature of such geographically patchy distributions, each biotope is separated by seawater. The spaces or gaps between biotopes provide transportation routes, like a “blue highway” (Kelley & Ryan, 2000). Through this blue highway, items such as nutrients, organic matter, sediments, pollutants, energy, organisms and even genes can regulate between biotopes, either of the same or different types. Such regulation forms a connection between biotopes, which is termed as connectivity.

In general, connectivity can be divided into two different forms, namely, genetic connectivity and ecological connectivity (Nagelkerken, 2009a; Sale et al., 2010). While genetic connectivity mostly involves the flow of genes among populations between biotopes, ecological connectivity, which requires a more complex understanding refers to exchanges of nutrients, organic matter or abiotic materials and also movements of living organism between biotopes (Nagelkerken, 2009a; Sale et al., 2010). In the context of the present study, ecological connectivity is studied and focused on the coral reef and mangrove biotopes.

1.2 Ecological connectivity of biotopes

There are three ways that adjacent disparate biotopes such as coral reef and mangrove are ecologically connected. They can either be physically, biogeochemically or biologically connected. Physical connectivity involves sediment transfers, flow regulations and hydrodynamic processes such as waves, currents, tidal changes and water body movements (Ogden & Gladfelter, 1983; Wolanski, 2001). Biogeochemical connectivity on the other hand involve exchanges of nutrients and organic matters between biotopes. Biological connectivity is probably the most complicated, involving the study of life-cycles, nursery habitats, trophodynamics, movements and migrations of organisms (Sheaves, 2005, 2009). Although all three forms of connectivity are strongly related, this present study mainly focuses on biological connectivity, particularly on the marine ichthyofauna.

Movement of marine fauna between biotopes is the most conspicuous component of biological connectivity (Sheaves, 2009). Several studies on connectivity involving movement or migration of marine fauna have been conducted in the past. These include the juvenile and adult habitat connectivity among mobile fauna (Gillanders, Able, Brown, Eggleston, & Sheridan, 2003), connectivity between fish in seagrass beds, mangroves and coral reefs (Dorenbosch, 2006; Jaxion-Harm, Saunders, & Speight, 2012), seagrass fish assemblages adjacent to mangroves and coral reefs (Unsworth et al., 2008) and ontogenetic migration of *Lutjanus fulvus*, *L. johnii* and several other coral reef fishes between habitats (Jones, Walter, Brooks, & Serafy, 2010; Nakamura et al., 2008; Tanaka et al., 2011). Many of these studies have shown that marine fauna, in particular fish, utilised more than one habitat during their life cycle, either for nursery, shelter or for feeding. Such connectivity is crucial in ensuring the survival of fish larvae, enhancing fish biomass, structuring populations, maintaining food web dynamics and even increasing the resilience of habitats to natural disasters (Mumby & Hastings, 2008; Mumby et al., 2004; Sheaves, 2009).

1.3 Coral reefs

Coral reefs are basically a framework of calcareous structures built mostly by reef building corals known as scleractinian (hard) corals, hence the name. Coral reefs are dynamic systems and they influence the oceans’ chemical balance due to their ability to take in and temporarily bind calcium that enters sea water, which in turn each calcium atom depositing a molecule of CO_2 (Birkeland, 1997). These hard corals are living symbiotically with hundreds of thousands of dinoflagellate endosymbionts of the genus *Symbiodinium*, known as zooxanthellae. Zooxanthellae are responsible for the enhancement of calcification and the formation of the massive coral reef framework (Muller-Parker & D'Elia, 1997). In addition, the zooxanthellae are also responsible for deriving energy from sunlight through photosynthesis to satisfy the energy requirements of the hard corals (Burke, Selig, & Spalding, 2002; Sorokin, 1993). Through photosynthesis, coral reefs produce 5 - 20 g m^{-2} of organic carbon or 50 – 200 g of wet biomass rendering them one of the world's most productive ecosystems (Sorokin, 1993).

Despite this productive system, the symbiotic relationship between coral and zooxanthellae causes coral reefs to have strict requirements in terms of temperature, salinity, stable substrates and solar irradiance. Therefore, they are found mostly in the tropics, bound by the Tropic of Cancer and Tropic of Capricorn, where irradiance is consistent. Within this tropical zone, a longitudinal variation of species diversity and composition occurs, creating different biogeographic regions. Among all the regions, the one with the highest number of species is the Indo-West Pacific region (Hoeksema, 2007). A triangular delineation marks this high biodiversity hotspot, known as the Indo-Pacific Coral Triangle (Hoeksema, 2007; Veron et al., 2009). Malaysia, with an estimated reef area of 4000 km^2, is one of the countries located within this coral triangle and is acknowledged to possess the highest coral diversity in the world (Burke, Selig, & Spalding, 2002; Veron et al., 2009).

Coral reefs provide numerous ecological benefits, such as shelter and breeding grounds for various marine organisms, coastal protection, biogeochemical services, climate record (Moberg & Folke, 1999) and aesthetic, recreational benefits as well as being assets to the Malaysian tourism industry (Affendi, 2005). From an economic point of view, it has been estimated that in South East Asia, coral reefs provide an annual net value of between RM 75,000 to RM 900,000 per square kilometre which includes tourism, fisheries and coastal protection (Burke et al., 2002). On the West Coast of Peninsular Malaysia, the total annual economic value of coral reefs has been estimated to be RM 41,407 per hectare of coral reef (MPP-EAS, 1999).

1.4 Mangroves

Mangrove habitats or mangals naturally exist on the boundary between terrestrial and the saline sea environment. They are globally distributed only within the latitude of 23.5°N and 23.5°S making them almost exclusively tropical, similar to the coral reefs. Their latitudinal restriction is related to seawater temperature, which is delimited by a 20°C isotherm during winter (Hogarth, 2007). Besides being globally limited by temperature, mangroves are also subjected to local physiological constraints such as rainfall, tidal regime, wave actions and river flow (Alongi, 2009). As a key ecosystem occupying the harsh conditions between terrestrial and marine environment, mangroves are fairly robust and highly adaptable to saline and inundated conditions (Alongi, 2008).

One of the most notable adaptations of mangrove is the root architecture system such as prop roots, knee roots and pneumatophores. Not only are these root systems effective in gaseous transport in water-logged and anaerobic conditions, they are also able to exclude salt during water uptake. In addition, mangrove roots provide anchorage in unstable muddy soil, turning the soil into hard substrate while increasing the surface area for various fauna (Hogarth, 2007). Mangrove roots also host many epibionts and invertebrates such as annelid worms, arthropods, molluscs and crustaceans (Hogarth, 2007; Sasekumar & Ooi, 2005). Some of this fauna, particularly herbivorous crabs, are able to break down mangrove leaves to litter which is subsequently decomposed to detritus by microbes (Hogarth, 2007). The decomposed leaves contribute to the detritus food chain rendering mangrove to be regarded as a productive feeding ground for various marine fauna. The complex mangrove root system with substantial food provision serves as a suitable nursery ground for fish communities (Laegdsgaard & Johnson, 2001).

In addition to the nursery ground function, mangroves also function as a buffer to erosion, sedimentation, storm, waves and tsunamis. Besides providing ecological functions and coastal protection, Peninsular Malaysia's mangroves' worth of RM 3.4 billion or RM 41,407 per hectare proves that they are also economically important (MPP-EAS, 1999). Despite the fact that mangroves have such important functions and values, we are on the verge of losing them mostly due to irresponsible coastal development and aggravated by natural disasters such as storms and tsunamis. This development has caused a loss of approximately a third of the world's mangrove in five decades (Alongi, 2002). Meanwhile in Malaysia, an estimated total of 59,543 ha or 14% of mangrove reserves were lost between 1984 and 2004 (Chong, 2007a; Chong, Lee, & Lau, 2010).

1.5 Physical attributes of seawater and habitat complexity

The condition of seawater is important to determine the suitability of a habitat for living marine organisms. Changes in the seawater's physical attributes provide insights to any environmental changes that may be detrimental to the biotopes and the associated marine organisms. Environmental changes can happen due to local anthropogenic activities or natural events such as daily tidal changes or the El-Niño phenomena (Alongi, 2008; Glynn, 1997; Hoegh-Guldberg et al., 2009). On a global level, both coral reefs and mangroves are subjected to larger scale impacts by events such as rising temperature and ocean acidification (Hoegh-Guldberg et al., 2009; Veron, et al., 2009).

Coral reefs are sensitive and susceptible to environmental changes, in contrast to the robust and highly tolerant mangrove (Alongi, 2008; Kleypas, McManus, & Menez, 1999). Due to the different tolerance limits of mangroves and coral reefs, it is necessary to examine the physical attributes that distinguish the water body of both biotopes. Temperature and pH are most important attributes, because these are indicators for ocean warming and acidification respectively. Salinity is also a crucial attribute, because it can influence the species and type of organisms that resides in the habitat. Turbidity is another important attribute particularly in coral reefs because the sediment particles, plankton and even microscopic organisms within the water column scatter sunlight and thus reduce the penetration of light required by the corals for photosynthetic processes (Rogers, 1990). On the other hand, turbid water provides higher chance for fish survival because it functions well as a shelter from visual predators (Benfield & Minello, 1996).

An important element of reducing predation risk for fish besides turbid water is structural or habitat complexity. A habitat with higher complexity will attract more fishes due to the higher availability of shelter to avoid predation (Gratwicke & Speight, 2005) and the provision of food resources (Nagelkerken, 2009b; Nagelkerken et al., 2008). In addition, the physical structures of habitat can interact with various complex ecological processes, consequently influencing the assemblages of fish communities and their interaction with predators (Caley & St John, 1996). Habitat complexity has also been found to influence fish preference on habitat selection, such as larval settlement and recruitment (Nakamura, Kawasaki, & Sano, 2007). As for mangroves, fishes are shown to be attracted to the structural complexity and shade in mangrove habitats (Cocheret de la Morinière, Nagelkerken, van der Meij, & van der Velde, 2004; Nagelkerken et al., 2010; Verweij et al., 2006).

For the present study, the focus on habitat complexity is restricted to coral reefs and the scope will cover only the provision of sufficient shelter or refugia. Habitat complexity of coral reefs is referred to as the reef health condition and structural complexity. A healthy reef condition is determined through a combination of several measures - ecological strategy of corals, live coral cover, mortality index and the morphological diversity of corals, which will also be used as an index for habitat complexity in the coral reefs (Edinger & Risk, 2000).

Overall, physical attributes and habitat complexity are some of the factors influencing the utilization of both coral reefs and mangroves by marine fauna particularly fishes. The combination of both factors will ultimately provide important evidence to prove the presence of an ecological connectivity between these two biotopes. The juxtaposition of factors affecting the habitat conditions of coral reefs and mangroves can provide explicit information on how connectivity is facilitated. For instance, extreme physical attributes, unhealthy conditions and high predation risk in a habitat can cause marine fauna to avoid that habitat and influence their distribution, which consequently will disrupt ecological connectivity. Conversely, a good condition of habitat can attract more fauna, widen their spatial distribution, influence their resource partitioning and ultimately preserve a high biodiversity.

1.6 Source contribution

Coral reef and mangrove biotopes that occur in close proximity will usually form a complex ecosystem with ecological connectivity (Dorenbosch et al., 2005; Nagelkerken, 2007; Unsworth et al., 2008; Jones et al., 2010; Grol et al., 2011). In a complex ecosystem, mangroves are known to serve as nursery ground for reef fishes, providing food and shelter to their juveniles (Sheaves, 2005; Grol et al., 2011; Tanaka et al., 2011). Among the functions of nursery grounds, food provision by mangrove to reef fishes has been given the most attention (Nagelkerken et al., 2000; Laegdsgaard and Johnson, 2001; Chong, 2007; Tanaka et al., 2011). The major contributor of food sources to the fish community is often believed to be mangrove detritus, via direct or indirect trophic pathways (Nakamura et al., 2008; Sheaves, 2005). Other studies have revealed that various sources like phytoplankton and microphytobenthos (MPB) can also contribute significantly in mangrove habitats (Bouillon, Mohan, Sreenivas, & Dehairs, 2000), especially to the zooplankton and small nekton community (Chew, Chong, Tanaka, & Sasekumar, 2012). However, in other coupled biotopes, such as mangroves with seagrass beds, it appears that the mangroves' contribution to the fish food web is marginal compared to the seagrass beds (Lugendo, Nagelkerken, van der Velde, & Mgaya, 2006; Marguillier, van der Velde, Dehairs, Hemminga, & Rajagopal, 1997; Nagelkerken & van der Velde, 2004a; Nyunja et al., 2009). This has been attributed to the poor nutritional value of mangrove detritus, which is low in nitrogen, i.e. high C/N ratio (Wolcott & O'Connor, 1992). Consumers are likely to shift their food preference to more nutritious ones if available. Moreover, most fishes cannot digest the largely lignin-cellulosic component of mangrove detritus (Wolcott & O'Connor, 1992).

Compared to mangrove – seagrass bed connectivity, there is a paucity of information on the trophic contribution of tropical coral reefs to mangrove and vice-versa. Coral derived organic matter, largely in the form of mucus released into the water column, is considered relatively nutritious due to its high protein content or lower C/N ratio (Coles & Strathmann, 1973; Johannes, 1967; Wyatt, 2011). Coral mucus contains nutrient rich components of lipids, triglycerides and proteins (Benson & Muscatine, 1974; Coles & Strathmann, 1973; Ducklow & Mitchell, 1979) and consequently has been proposed as one of the energy transfer pathways from coral hosts and their zooxanthellae to the reef consumers (Benson & Muscatine, 1974; Ducklow & Mitchell, 1979; Richman, Loya, & Slobodkin, 1975). The coral mucus aggregates to form suspended flocs that are able to trap organic particles including bacteria (Naumann, Richter, el-Zibdah, & Wild, 2009; Wild, Huettel, Klueter, & Kremb, 2004), further enhancing their nutritional value (Johannes, 1967). The nutritional values are evident as mucus is consumed by various reef-associated fauna such as fishes, crabs, shrimps, zooplanktons and even benthic invertebrates (Benson & Muscatine, 1974; Johannes, 1967; Naumann, Mayr, Struck, & Wild, 2010; Richman et al., 1975). For example, in an oligotrophic subtropical reef such as Heron Island, coral mucus flocs have been hypothesized to fuel the benthic and pelagic food chains (Wild et al., 2004). Although coral mucus contribution is apparent in the food web of subtropical nutrient-poor coral reefs, its contribution in tropical coupled coral reef and mangrove biotopes is largely unknown. In such tropical coupled systems where turbidity and dissolved inorganic nutrients are usually higher, the trophic inputs from phytoplankton, MPB and mangrove detritus may be equivocal.

Fish are highly diverse in trophic groups and feeding strategies, making their community highly complex, particularly when they utilize different habitats that occur adjacent to each other. Various studies have provided evidence of trophic links between mangroves and adjacent habitats through fish movements as a result of life cycle requirements, especially relating to ontogenetic shifts (Mumby et al., 2004; Nakamura et al., 2008; Unsworth et al., 2008; Jones et al., 2010; Tanaka et al., 2011). Most of these studies however have focused on only one or a few species, while investigations at the community level with high numbers of species are unfortunately lacking. Such studies are more likely to provide comprehension of broad-scale trophic connectivity and interdependency between coral reefs and mangroves (Polis, 1994; Abrantes and Sheaves, 2009).

1.7 Stomach content and stable isotope analysis

Traditional stomach content analysis assesses the consumer's diet over a short temporal scale of up to a few hours of recently ingested food and is able to provide a diet description and determine feeding guilds (Cocheret de la Morinière et al., 2003; Drazen et al., 2008). However, stable isotope analysis (SIA) has increasingly been used in ecological studies, especially those related to the trophodynamics of various marine ecosystems including connected habitats (Chew et al., 2012; Nagelkerken & van der Velde, 2004b; Nakamura et al., 2008; Tanaka et al., 2011; Wyatt, Waite, & Humphries, 2012). SIA discriminates the heavier isotope of carbon (^{13}C) and nitrogen (^{15}N) in the metabolic pathways of the consumers' tissues. The measurements of heavy to light isotopes ratio of carbon ($^{13}C/^{12}C$) and nitrogen ($^{15}N/^{14}N$), in the unit of ‰ (parts per million), denoted as $\delta^{13}C$ and $\delta^{15}N$ respectively, are the basis of tracing the sources and trophic pathways in ecological communities (Peterson & Fry, 1987; Hobson & Wassenaar, 1999; Zanden & Rasmussen, 2001). It is generally accepted that $\delta^{15}N$ is greatly enriched at successive trophic levels thus allowing it to estimate consumer's trophic position. On the other hand $\delta^{13}C$, only marginally enriched with trophic transfer, determines the primary sources of consumers' diets (McCutchan, Lewis, & McGrath, 2003; Minagawa & Wada, 1984; Post, 2002; Vander Zanden & Rasmussen, 2001). Based on this concept, one of the most common applications of SIA is the use of the Bayesian mixing model to estimate the contribution of each primary source (Parnell, Inger, Bearhop, & Jackson, 2010).

1.8 Research problems and questions

The present study is largely influenced by early studies in Langkawi, Malaysia in 2005 that discovered some reef fishes in the adjacent mangrove estuary – this suggests a plausible ecological connectivity between coral reefs and mangroves through fish movements (Chong, Affendy, Ooi, & Chew, 2005; Chong et al., 2005). However, the study did not show the functionality of the mangroves, whether as a feeding, refugia, spawning ground or simply just another habitat.

In recent years, several studies have revealed that the existence of non-reef habitats adjacent to coral reefs can significantly influence the composition of the reef fish community (Dorenbosch et al., 2005; Grol et al., 2011; Jaxion-Harm et al., 2012; Mumby et al., 2004). Several islands in the Caribbean harbour higher densities of reef fish species when non-reef and coral reefs habitats exist in close proximity (Nagelkerken & van der Velde, 2002). Some of these fish species move and migrate to non-reef habitats during some parts of their life-cycle as they utilize these habitats for various reasons such as nursery, feeding ground or even for avoiding predators (Chittaro, Usseglio, & Sale, 2005; Nagelkerken, van der Velde, et al., 2000; Sheaves, 2005; Unsworth et al., 2008). These adjacent non-reef habitats are believed to be sources of juvenile reef fishes and hence will influence the reef fish community when they migrate into the coral reefs (Dorenbosch et al., 2005; Dorenbosch, van Riel, Nagelkerken, & van der Velde, 2004). As such, focus is given to determine and compare the distribution and diversity of fish from both adjacent biotopes in northeast Langkawi. If a similarity of fish species is detected, this will indicate that there is an exchange of fish species between coral reefs and mangroves (Chittaro et al., 2005; Laroche, Baran, & Rasoanandrasana, 1997; Lugendo, Nagelkerken, Jiddawi, Mgaya, & van der Velde, 2007), which implies that ecological connectivity exists.

A recent study in Matang Mangrove Forest, Malaysia showed evidence that mangroves function as nursery area mainly due to the easily available food resource for certain reef fishes (Tanaka et al., 2011). However, other studies in the Indo-Pacific region suggested otherwise where the function of mangroves as nursery ground is relatively minor and the connectivity was said to be less significant (Huxham, Kimani, & Augley, 2004; Laroche et al., 1997). Although there are studies that reported the presence of juvenile reef fishes in the mangroves, their function as nursery ground is still largely unclear. The mangroves could serve as refugia, spawning or feeding grounds or simply another habitat, but there is insufficient evidence to prove these functionalities. Thus, the non-reef habitat function as nursery ground is not necessarily true in all cases (Chittaro et al., 2005).

With regards to refugia, it is already generally accepted that mangroves provide refuge for fishes (Sheaves, 2005). Therefore, fishes will face higher predation risk if they swim out of the mangroves and into the coral reefs. However, if coral reefs can provide substantial refuge cover, fishes can utilise coral reefs during low tide, when mangroves are not fully inundated. The question of how much cover coral reefs can provide to the fish communities can be answered through examining the habitat complexity of the coral reef. This contributes to habitat connectivity and optimizes the fish trade-off strategy between predation risk and food availability (Grol et al., 2011). Food availability is another aspect that contributes to biotope connectivity, which gives rise to the question of the primary source of food contribution to the fish community. To answer this, both stomach content analysis and the SIA approach will be used in the present study.

Most studies in other parts of the world have shown that connectivity exists between coastal habitats and provides mutual benefits to the connected ecosystems. However, the functionality of the connected habitats varies between locations and provides different contributions to the fish community. Regardless, the important factors that determine the functionality of connected habitats as nursery or feeding area are the availability of food source and refuge space. Clearly, habitat connectivity studies are still lacking, especially in the Indo-Pacific region as compared to the extensive works done in the Caribbean region, (Dorenbosch, 2006). Therefore, there is a need for this kind of study in Malaysia where several coastal biotopes often co-occur close to each other, while the management of these biotopes is under the jurisdiction of different government agencies.

1.9 Significance of study

The co-occurrence of disparate habitats such as coral reefs which are intolerant to high total suspended solids and turbid water mangroves within one general area is quite rare in Malaysia. The present study site in the northeast of Langkawi Island, Kedah is one of the few while other sites are located in Merambong Shoal, Johor; Seri Buat Island, Pahang and Banggi Island, Sabah in East Malaysia. These unique co-occurring habitats have the potential to substantially contribute to the whole ecosystem and its associated fauna. However, with the rapid development along the coastlines in these locations, these unique co-occurring habitats are at risk of being lost. There is an alarming concern that the hinterland in Langkawi is developing rapidly along with the removal of mangrove forests (Shahbudin, Zuhairi, & Kamaruzzaman, 2012) and the increased terrestrial downstream flow to the coral reefs (Jalal et al., 2009).

Coral reefs and mangroves are among the two most productive ecosystems, rich in biodiversity and able to provide various ecological services. These two biotopes, along with seagrass beds, are estimated to be able to support the livelihood of 275 million people from 100 developed countries that are dependent on coastal resources (Wilkinson & Salvat, 2012). In the past few decades, mangroves and coral reefs have suffered severe degradation due to various human pressures and natural impacts. Approximately 35% of the world's mangroves have been lost in over two decades due to aquaculture, deforestation and freshwater diversion (Mooney et al., 2005), and on top of that mangroves continue to face an average annual loss rate of 1 to 2% (Alongi, 2008). Likewise, coral reefs have suffered loss of 19% and it is estimated that a further 35% face the risk of being impacted directly by anthropogenic pressure (Wilkinson, 2008; Wilkinson & Salvat, 2012). The risk of coral reef degradation is estimated to have increased by up to 75% if local threats are combined with rising global temperature (Burke, Reytar, Spalding, & Perry, 2011). Due to these threats and risks, an urgency in the protection and conservation of these valuable biotopes is desperately needed. Most conservation efforts have focused on single biotope independently instead of the whole entity of interconnected coupled biotopes (Nagelkerken, 2009b). An integrated protection and management of such complex interconnected biotopes is imperative in order to maintain the biodiversity and ecological services they provide (McCook et al., 2009).

In Malaysia, coral reefs and mangroves are independently managed by different government departments - the coral reefs by the Marine Parks Department while mangroves are under the jurisdiction of the Forestry Department. The different jurisdictions create difficulties for simultaneously managing both habitats. With regard to rapid development rate along the coastlines, independent management only causes delay and ineffective response in addressing mangrove forest removal and pollution or sedimentation of the coral reefs. This study will provide additional information for the promotion of integrated management for both habitats simultaneously.

As mentioned in the previous sections, studies in other parts of the world have provided some evidence that coral reefs and mangroves are somehow connected. This includes fish movements and trophic linkage connecting the physically separate habitats of coral reefs and mangroves. However, one of the concerns is that the connectedness between corals and mangroves may be severed due to the fast growing development. In addition to that, independent management can disrupt the connectivity between habitats because it does not concurrently address both habitats. Hence, there is a need to elucidate this possible connectivity between the habitats. This study could provide the scientific knowledge necessary for improving the design of management strategies and protection measures.

1.10 Hypotheses and objectives

Chong et al. (2005) discovered the presence of similar fish species in both the coastal open waters and the mangroves in Langkawi and suggested the possibility of ecological connectivity between the mangroves and its closest adjacent biotope, coral reefs. However, due to the short nature of the study, they could not determine the nature of the connectivity. Thus, to continue this earlier work, the present study tested the following two hypotheses regarding the coral reefs and mangroves of Northeast Langkawi Island:-

1) The biotopes are ecologically connected via habitat utilisation by the fish fauna
2) The biotopes are ecologically connected via trophic energy pathways.

In order to test the two hypotheses, the study had the following objectives:-

i) To determine and compare the diversity and similarity of fish communities in the coral reefs and mangroves
ii) To determine the habitat complexity of coral reef for fish fauna utilisation
iii) To trace the trophic pathway from primary sources to consumers using stable isotope analysis

2.0 METHODOLOGY

2.1 Study site and habitat zoning

The study area was located at the northeast of Langkawi Island, Malaysia (Fig. 2.1). The area forms part of the Kilim Limestone Karst Geoforest Park (henceforth mentioned as Kilim), the first geopark in Southeast Asia declared by UNESCO in 2007. The geopark has approximately 1,987 ha of mangroves and patchy fringing coral reefs around the near-shore islands of Langgun Island and Dendang Island, and the rocky promontory of Gua Cherita, which cover an approximate total area of 40 ha. The mangroves which grow on limestone karst have been classified as Thom (1984)'s Type IV mangrove (Chong et al., 2005), dominated by *Rhizophora apiculata* and *Ceriops tagal* (Sasekumar & Ooi, 2005). The coral reefs appear to thrive despite the relatively turbid water (maximum horizontal visibility of 2 m) with live hard coral cover ranging from 26 to 58% (Affendi, 2005).

Sampling stations were established at four major sites determined by the estuarine drainage systems of the Rhu, Kilim and Kisap rivers and coastal water of the Peluru Strait. Each site could be further separated into four zones of sampling (Fig. 2.2), namely, coral reef (Coral), mixed mangrove-coral (Mg-C), mangrove estuary (Mg) and mangrove creeks (Up). “Coral” denotes the zone that is strictly coral reef area only. “Mg-C” is the zone at the river mouth where mangroves and corals are in close proximity and the boundary could not be easily distinguished. “Mg” refers to the zone restricted to mangroves area only, usually within the river, but upstream from the river mouth. “Up” refers to the mangrove creek zone that is to the farthest upstream portion of the river.

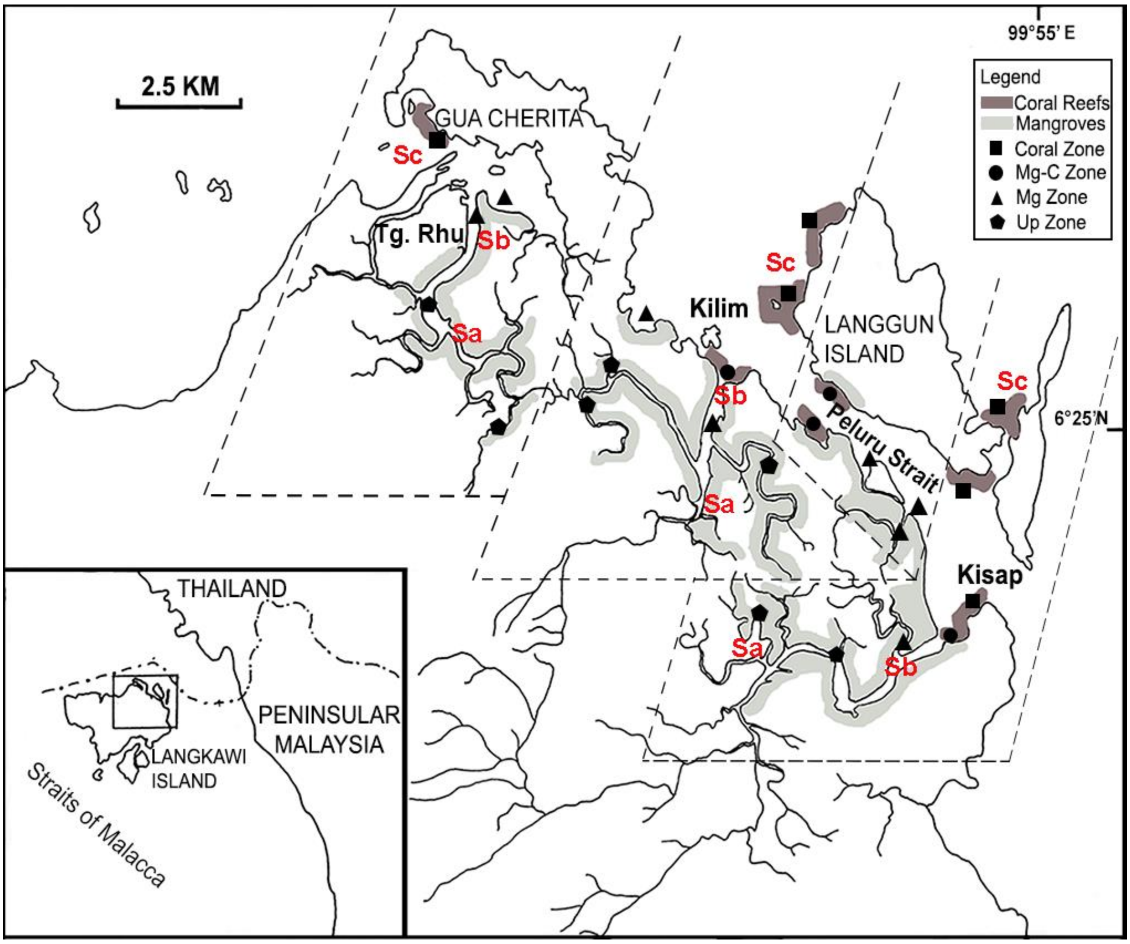

Figure 2.1: The study area, northeast Langkawi separated into four major study sites, Tg. Rhu, Kilim, Peluru Strait and Kisap. Sampling stations are shown in the legend above. Sa, Sb and Sc represent stations where seston samples were collected from mangrove creeks, mangrove estuary and nearshore waters respectively.

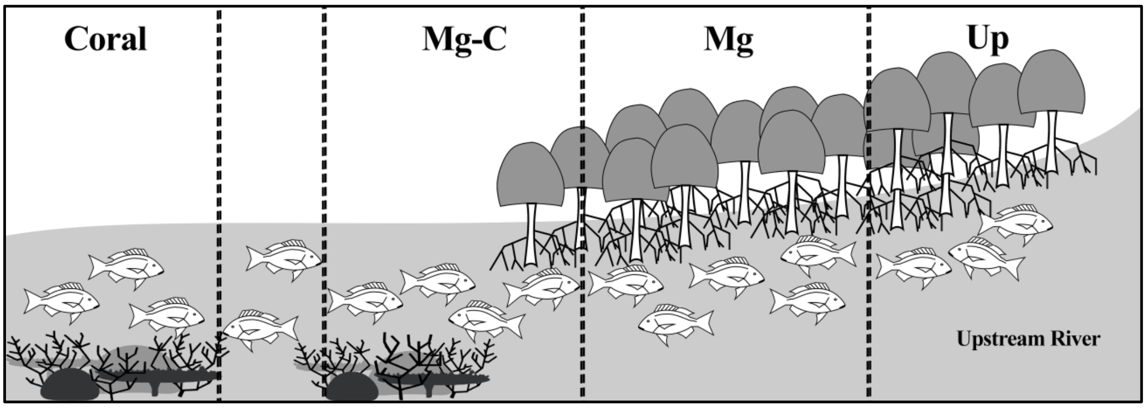

Figure 2.2: Diagrammatic representation of the four habitat zones; coral (Coral), mixed mangrove-coral (Mg-C), mangrove estuary (Mg) and creeks (Up). The coral zone is encompassed by only the coral reef biotope, while the Mg and Up zones are flanked by mangrove forests. Mg-C zone is the mixed habitat of corals that grow on the submerged limestone massive flanked by mangrove on the upper shore.

Notably, only Kilim and Kisap contain all four zones, while Tg. Rhu has three zones (Coral, Mg and Up) and Peluru Strait has only two zones (Mg-C and Mg). In Tg. Rhu, the Mg-C zone was non-existent in their geographical structure and thus could not be established. Similarly in Peluru, the Coral and Up zones could not be established. Tg. Rhu, Kilim and Kisap are the estuarine drainage systems on the main island, while the Peluru Strait is the coastal channel located between the main island and Langgun Island. Hence, a total of 13 stations in four sites were established for the present study. The nearest distances between the coral reef and the river mouth of Rhu, Kilim and Kisap are 1.6, 0.4 and 0.7 km respectively. The farthest stations of sampling in the Up zone of the Tg. Rhu, Kilim and Kisap sites were located 6.0, 5.5 and 5.0 km upstream from the river mouth, respectively. Samplings in Peluru Strait were done in the coastal inlets and bay on both sides of the channel. The zoning for each site was created to determine the range of habitats in which fish species were found. This will give an indication of the habitats that a fish species utilised in the area.

Although each site was zoned, there was still a need to categorize the zone as the coral reef or mangrove biotope, which was the aim of the present study. Thus, the coral reef biotope encompasses only the “Coral” zone while the mangrove biotope encompasses the “Up” and “Mg” zones. Due to the difficulty of distinguishing the distinct boundary of the “Mg-C” zone, this zone was not assigned to any one biotope but rather as a mix of overlapping coral reef and mangrove biotopes (Fig. 2.3). Fishes caught in this zone were difficult to determine as whether strictly coral or strictly mangrove species. The term “common fish” in the present study refers to the fish species that were found in both coral reef (“Coral”) and mangrove (“Mg” and “Up”) biotopes (Fig. 2.3).

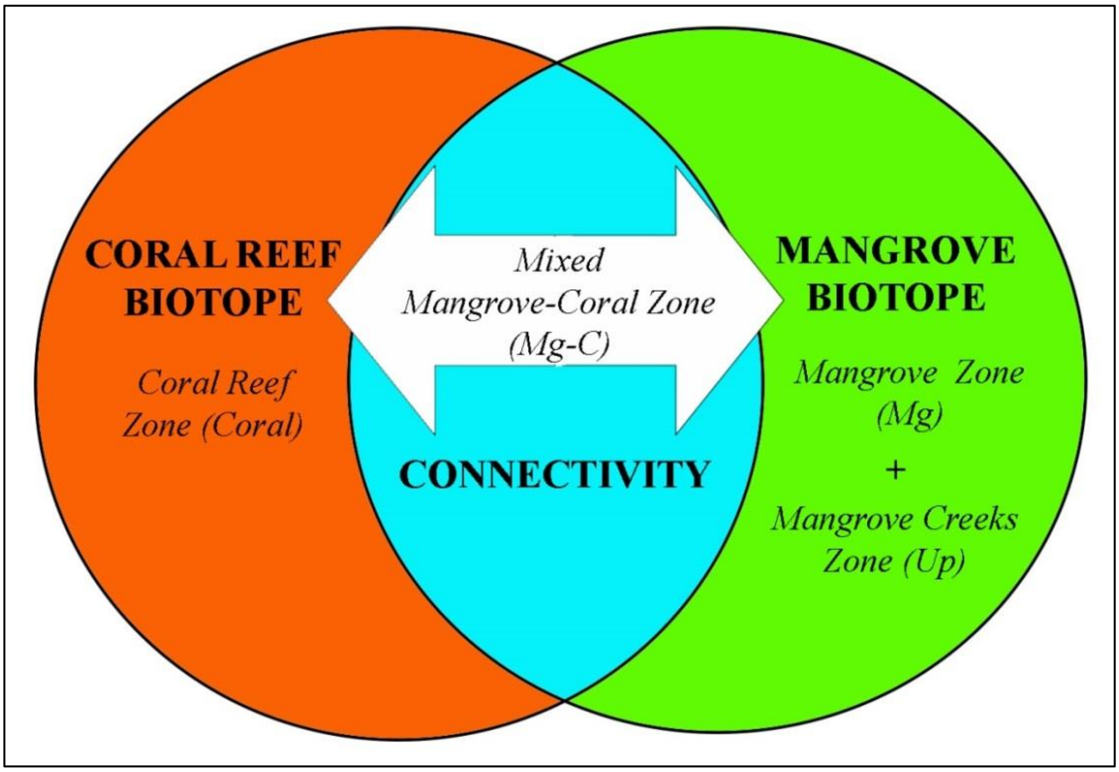

Figure 2.3: Diagrammatic illustration of the connectivity between Coral Reef Biotope and Mangrove Biotope, which encompass their respective zones. The mixed mangrove – coral zone (Mg-C) is excluded from either biotope because it is a mix of overlapping biotopes.

2.2 Fieldwork collection and sampling

2.2.1 Physical attributes of seawater

A multi-parameter probe, Hydrolab α Model DS5, was used to measure the physical properties of seawater. Measurements of temperature (°C), specific conductance, SpC (mS/cm), salinity (ppt), total dissolved solids, TDS (ppm), pH, turbidity (NTU), dissolved oxygen, DO (mg/L), oxidation reduction potential, ORP (mV) and depth (m) were taken at each sampling station. The Hydrolab probe was deployed and submerged underwater just above the bottom until all the measurement readings stabilised before they were recorded. At least three replicate measurements were taken at each station during each sampling trip.

2.2.2 Collection of fish samples

Fishes were collected eight times between October 2009 and May 2011 using bottom gill nets and fish pots (“bubu”) that were set at the fringe of both coral reefs and mangrove habitats, in the four established zones during neap tide. The gill nets used were of 1 inch and 2 inches mesh size. Both nets measured approximately 400m in length. The gill net was set to surround, before the boat moved inside it and slowly along the inner side of the net for two complete rounds before the net was retrieved. The sound produced by the outboard engine frightened and drove the fishes into the net. All fish caught were placed into separate bags according to the zones where they were caught and immediately placed in a cooler box filled with ice. All caught fish were collected at each zone, but species varied at all zones and sampling occasions.

2.2.3 Measurements and identification of fish samples

All fish samples were measured for their total length and photographs were taken for identification purposes. A fish was considered a juvenile when its total length was shorter than a third of the species’ maximum total length (Dorenbosch et al., 2005; Nagelkerken & van der Velde, 2002). For species with a maximum length of more than 90 cm, it was recorded as juvenile when its total length was less than 30 cm (Dorenbosch et al., 2005). The maximum total lengths of species were obtained from FishBase World Wide Web (Froese & Pauly, 2012). Fish were identified to species level whenever possible using several fish taxonomic guides (Fischer & Whitehead, 1974; De Bruin, Russel, & Bogusch, 1994; Kimura, Satapoomin, & Matsuura, 2009; Mohsin & Ambak, 1996). The identified fish species name was then cross-checked with FishBase World Wide Web (Froese & Pauly, 2012) to avoid synonyms. The species name from FishBase was used if any discrepancy of synonym was found.

2.2.4 Collection of corals and other samples

Approximately 2 to 5 cm of coral fragments were collected using a chisel and rubber hammer while SCUBA diving. Seston samples were collected at mangrove creeks, mangrove estuarine and nearshore waters (Fig. 2.1) using a Van-Dorn water sampler and were then pre-filtered through a 63µm mesh net in the field to remove larger particulates. The filtered seawater samples were kept in individual bottles. Zooplanktons were collected using a 163µm mesh plankton net. Fresh leaves of the dominant mangrove species, *R. apiculata* and *C. tagal* were hand collected from the branches along the fringes of the estuaries. Sediments in the coral reef were collected while SCUBA diving and an Ekman grab was used to collect estuarine sediments. Upon collection, all samples were immediately placed in a cooler box filled with ice at 4°C. The samples were then brought back to camp before immediate processing or kept in a deep freezer at -20°C.

2.2.5 Coral community structure

The coral reef areas in the sites Tg. Rhu, Kilim, Peluru and Kisap were surveyed using the line intercept transect (LIT), and corals were classified using the standard lifeform categories (English, Wilkinson, & Baker, 1997). Coral colony morphologies of r, K and S adaptive strategists (r = disturbance adapted ruderals, K= competitors, S = stress tolerators) as proposed by Edinger and Risk (2000) were used to determine the relative ecological adaptive strategy of the coral community. The lifeform categories, morphologies, codes, brief descriptions and r-K-S groupings used in the present study are presented in Table 2.1. While SCUBA diving, a total of 19 sets (Tg. Rhu = 4, Kilim = 9, Peluru = 1, Kisap = 5) of 20 m transect lines were set parallel to land at only 5m depth or less, because the visibility was near zero when depth exceeded 5m. Percentage of coral morphology categories was recorded on each transect. The coral community structure for each site was determined by plotting the proportion of live coral morphology based on their r-K-S strategist group onto the r-K-S ternary diagram. The proximity of each transect point to any corner of the ternary diagram indicates the relative ecological adaptive strategy of the coral community.

Table 2.1: List and descriptions of lifeform and morphology categories with the r-K-S groupings (from Edinger & Risk, 2000).

Lifeform Categories	Morphology Categories	Codes	Descriptions	rKS group
Scleractinian Coral: *Acropora*	*Acropora*, branching	ACB	Staghorn corals, long thin branches	r
	Acropora, digitate	ACD	Digitate, stubby, mainly *A. humilis* group	r
	Acropora, submassive	ACS	Columns, blades, very stout e.g. *A. palifera, A. cuneata*	r
	Acropora, tabular	ACT	Tables, e.g. *A. hyacinthus*	r
Scleractinian Coral: Non - *Acropora*	Branching coral	CB	Branching non-*Acropora* corals	K
	Encrusting coral	CE	Low relief corals, often small colonies	K
	Foliose coral	CF	Foliose, either horizontal or vertical, non-*Acropora*	K
	Massive coral	CM	Massive or dome-like corals of all sizes	S
	Massive – platy coral	CMP	Plate-like corals forming large colonies, e.g. *Euphyllia* spp., *Lobophyllia* spp.	S
	Submassive coral	CSM	Multilobe or “lumpy” corals, sometimes columnar or mixed massive-columnar, e.g. *Goniopora* spp., *Galaxea* spp.	S
	Tabular coral (non-*Acropora*)	CT	Tabular non-*Acropora*, especially *Montipora* spp., *Turbinaria* spp.	r
	Mushroom coral	CMR	Free living fungiid corals	K
	Millepora	CME	Fire corals	r
	Heliopora	CHL	Blue coral	r
Other Non-coral Faunas	Algae	AL	Algae of any species including macroalgae, turf algae	-
	Others	OT	Ascidians, anemones, coralliomorphs, gorgonians, giant clams etc.	-
	Coralline Algae	CA	Encrusted algae	-
	Soft coral	SC	Soft bodied coral	-
	Sponges	SP	Porifera of any type and sizes	-
Non-living Coral	Dead coral with algae	DCA	Dead coral covered with algae	-
	Recently killed coral	RKC	Recently dead coral, structure is still recognizable, no algal growth	-

Lifeform Categories	Morphology Categories	Codes	Descriptions	rKS group
Abiotic	Rock	RC	Rock of all sizes	-
	Sand	SD	Coarse sediment grain, settles to the bottom quickly if stirred	-
	Silt	SI	Fine sediment grain, forms cloud if stirred	-

2.3 Laboratory work

2.3.1 Examination of stomach contents

In the laboratory, stomach contents of 54 fish species were examined using the volumetric method according to Hyslop (1980). The dietary composition was expressed in percentage volume of food items averaged according to species. The dietary composition of fish was used to assign them into or to the closest trophic guild that would be later used to calculate the trophic fractionation correction for stable isotopic analysis (see below). Based on its diet, each fish was assigned to one out of five feeding guilds, namely, ‘Herbivores’ (species that feed largely on plant material including phytoplankton), ‘Omnivores’ (species that feed on a mixture of plant materials and animals), ‘Invertivores’ (species that feed entirely on invertebrates), ‘Carnivores’ (species that feed on mixture of fish and invertebrates) and ‘Piscivores’ (species that feed largely on fish). Fish were assigned to their feeding guild based on the results obtained from the principal component analysis of the stomach content data. For 23 other fish species with empty stomachs, they were assigned into the respective feeding guilds based on published information.

2.3.2 Sample preparation for isotopic analysis

Of the total of 97 species sampled, 77 of the most common species were used for the stable isotopic analysis. Fish tissue samples were dissected from the white muscles below the dorsal fin. The tissue samples were then washed copiously with distilled water. Corals were identified to species level using the Indo Pacific Coral Finder and Coral ID software (Kelley, 2009; Veron & Stafford-Smith, 2000) and are listed in Table 2.2. Their tissues samples were removed from their skeleton with filtered seawater by an air gun attached to a SCUBA tank. The resulting slurry was homogenized and the zooxanthellae were separated from their host tissue according to Muscatine et al. (1989). Decalcification of the algal pellets to remove possible carbonates was done according to Alamaru et al. (2009). The zooxanthellae were then filtered on pre-combusted GF/F filters before being washed with distilled water. Seston samples were also filtered but on pre-combusted GF/C filters before being rinsed several times with distilled water. Zooplankton samples were washed through 1000, 500, 250 and 125 µm Endecott sieves before being placed onto pre-combusted filter paper and thoroughly rinsed with distilled water. Mangrove leaves and sediment samples were thoroughly washed several times with distilled water.

Table 2.2: List of coral species collected for stable isotopic anaylsis.

No.	Coral Species
1.	*Acanthastrea hemprichii*
2.	*Acropora globiceps*
3.	*Barabattoia amicorum*
4.	*Favia speciosa*
5.	*Favites acuticollis*
6.	*Favites chinensis*
7.	*Favites marshae*
8.	*Goniastrea edwardsi*
9.	*Goniopora stokesi*
10.	*Porites australiensis*
11.	*Porites evermanni*
12.	*Porites lichen*
13.	*Porites lobata*
14.	*Porites lutea*

All processed samples were then dried in the oven at 60°C for 5 days, except seston and zooxanthellae samples for two days before they were cooled and kept in a dessicator. All samples were sent to the Marine Biological Laboratory (MBL), Woods Hole, USA, for dual ^{13}C and ^{15}N stable isotopic analysis. The sediment samples were acid treated to remove particulate inorganic carbonates, whose presence was possible given the limestone karst. The pulverised dried samples were combusted to N_2 and CO_2 gases by Europa ANCA-SL elemental analyser. The isotopic carbon and nitrogen ratios were determined by gas chromatograph system attached to a continuous – flow Europa 20-20 mass spectrometer. Results were expressed in standard δ notation, and the values were determined based on the following equations:

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

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

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

2.4 Data analysis

2.4.1 Physical attributes of seawater and life forms cover

The physical attributes of seawater were tested for differences according to zones with permutation ANOVA test followed by post hoc t-test whenever significant difference was detected. Likewise, the same tests were used to detect significant difference of life forms cover of coral community structure according to sites. These test analyses were done using the open access R software version 2.15.1.

2.4.2 Fish species cluster analysis

Due to the limitation of the catch from gill nets and “bubu”, the species diversity was likely to be under-estimated. Therefore, species lists from the recent literature were included in the present study to determine the distribution and range of the fish species found (Chong, 2005). The locations of sampled fish species from literature were compared with the zones in the present study. They were then placed into the nearest possible zones accordingly. Percent disagreement was used to compare the dissimilarity between sites. Complete linkage percent disagreement cluster analysis was performed using presence and absence data. A simple dendrogram was constructed to provide a measure of dissimilarity between sites and habitats. The statistical analysis was computed using Statistica 8.0 Software.

2.4.3 Habitat complexity and mortality index

The coral reef habitat complexity of each site was estimated as morphology diversity, which was determined using the Shannon – Wiener diversity index, ***mH’*** as given below:-

$$mH' = - \Sigma ((p_i) (\ln p_i)),$$

where p_i is the proportion of corals belonging to i^{th} category of morphology (Roberts & Ormond, 1987). The Shannon – Wiener diversity index was calculated for all of the morphology categories, where the index near 0 indicates low complexity. Reef condition was determined by the percentage of live coral cover over the total cover of all lifeform categories. Mortality index, ***M*** was calculated as a proportion of standing dead coral cover to the total cover of both dead and live corals, where

M = **dead coral/(live corals + dead corals)** (Gomez, Alino, Yap, & Licuanan, 1994).

The closer the index to 0 the more live coral is present in a particular site. The overall coral cover and indices for the northeast Langkawi were calculated by pooling the data of all transects over the four sites.

2.4.4 Stomach content and Stable Isotope Analysis in R (SIAR)

Principal component analysis (PCA) was performed on the fish's dietary composition from the stomach content analysis. All dietary composition data were arcsine transformed prior to computing PCA and the result was illustrated in a 2-dimensional biplot diagram. A simple food web design based on the feeding guilds (Fig. 2.4) was then constructed to determine the trophic fractionation of carbon ($\Delta^{13}C$) and nitrogen ($\Delta^{15}N$) where Δ denotes the change in isotope ratio between diet and consumer. $\Delta^{13}C$ and $\Delta^{15}N$ were calculated by adding the trophic shifts values with proportions of type of food consumed along the path from primary producers to each consumer (Reid et al. 2008). The trophic shift values between trophic levels were then averaged based on McCutchan et al. (2003)'s summarised analyses of protein content values and consumer's tissue muscles. The calculated $\Delta^{13}C$ and $\Delta^{15}N$ values were incorporated into the consumers' isotopic signatures as corrections for trophic fractionation prior to computing the Stable Isotope Analysis in R (SIAR).

The differences in $\delta^{13}C$ and $\delta^{15}N$ isotopes and C/N ratio were tested according to two factors, feeding guilds and habitat zones. Both factors were tested separately using the non-parametric Kruskal-Wallis test followed by a post hoc pairwise Mann-Whitney analysis, whenever significance was detected. All statistical analyses were done using R version 2.15.1.

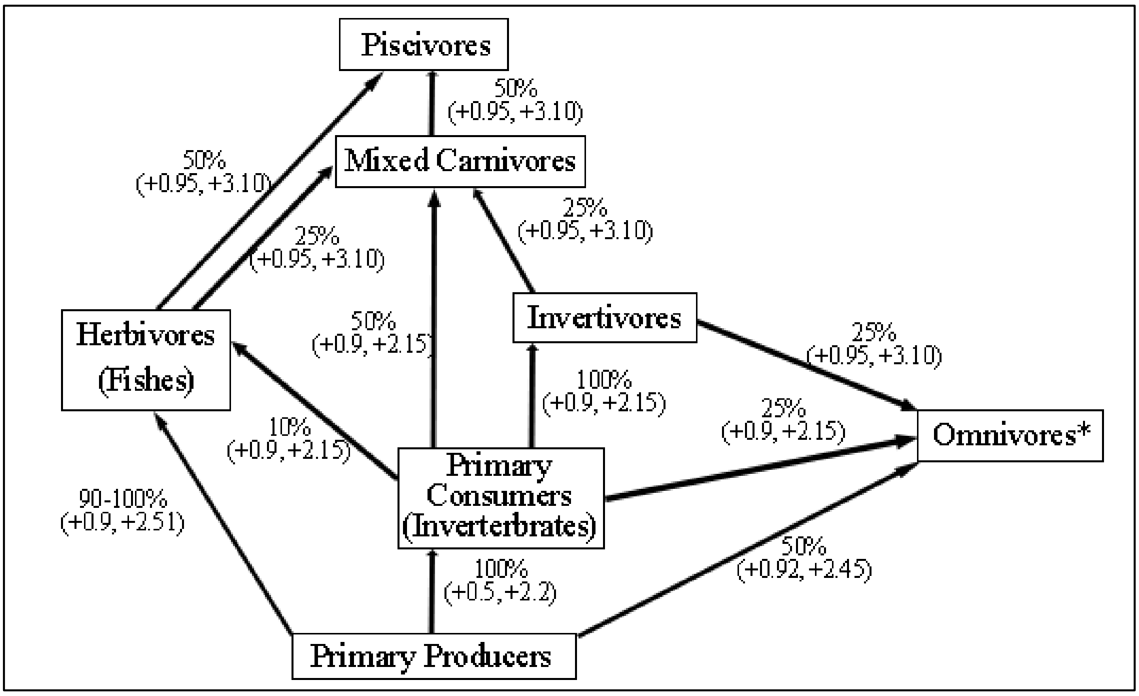

Figure 2.4: Food web design based on the feeding guilds assigned to calculate the trophic shift ($\Delta^{13}C$, $\Delta^{15}N$). Arrows points from source to consumers with percentages indicating proportions of diets consumed and trophic shift values stated in brackets (+ ^{13}C, + ^{15}N). These proportional trophic shift values were used to calculate $\Delta^{13}C$ and $\Delta^{15}N$. Primary Consumers (Invertebrates) are included in the design because they are at least one trophic level higher than the primary source.

The source contribution was determined across zones by using stable isotopic analysis. The stable isotopes analysis was computed using SIAR package in R (Parnell et al. 2010) after subtracting $\Delta^{13}C$ and $\Delta^{15}N$ values from the fish tissue isotopic values according to their designated feeding guilds. The source selection was based on the possible carbon contribution in the coupled biotopes. Zooxanthellae extracted from the scleractinian corals were considered as the major primary carbon source in the coral reef, while mangrove leaves and phytoplankton (seston) as the major carbon sources in the mangrove estuary. Benthic diatoms were another possible source of carbon in both coral reefs and mangrove estuaries, which could overlap with or become obscured by other primary sources (Bouillon et al., 2008). However, proxy $\delta^{13}C$ and $\delta\ ^{15}N$ values of the benthic diatoms from coastal mudflats adjacent to similar mangrove habitat in Matang, Malaysia (Okamura et al., 2010) were used.

3.0 RESULTS

3.1 Seawater physical attributes of biotopes

The measurements of all physical attributes in each zone are presented in Table 3.1 and Table 3.2. Salinity and pH showed a decreasing pattern from Coral zone (31.96 ± 0.16 SE ‰ and 8.05 ± 0.15 SE respectively) towards the Up zone (29.99 ± 0.46 ‰ and 7.54 ± 0.10). Temperature was highest in the Coral zone, with 30.57 °C and decreased towards the Mg-C zone, 29.74 °C and the Mg zone 29.84 °C. The lowest temperature was recorded in the Up zone at 29.27 °C, approximately just 1 °C lower than at the Coral zone. The opposite pattern was observed for TDS in which 31.30 was measured in the Coral zone and decreased to 29.29 in the Mg zone before an increment of just 0.24 in the Up zone. DO measurements recorded an inconsistent pattern from the Coral zone towards the Up zone with readings of 5.52, 4.68, 5.33 and 4.36 mg/L, respectively. Most physical parameters showed relatively consistent measurements except for Turbidity and ORP, which had high SE values. The least turbid zone was in the Up zone with just 9.71 ± 1.84 NTU, followed by Coral, 25.87 ± 7.70 NTU and Mg, 26.20 ± 5.87 NTU. The Mg-C zone measured as the most turbid zone with a reading of 54.05 ± 34.48 NTU. Despite the high SE of the ORP reading in the coral reef, the mean of ORP across all zones remained within the range of between 349.33 to 409.92 mV. In general, all physical attributes recorded higher values in the coral reef and lower values in the mangrove creeks, except for ORP.

Table 3.1: Mean and ±SE for physical attributes with measurement units in all zones within the sites of Tg. Rhu, Kilim, Peluru and Kisap. Number in parentheses denotes the number of points of measurements.

Physical Attributes	Tg. Rhu						Kilim								Peluru				Kisap					
	Coral (3)		Mg (9)		Up (3)		Coral (18)		Mg-C (10)		Mg (10)		Up (3)		Mg (13)		Mg-C (3)		Coral (4)		Mg (6)		Up (12)	
	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE
Temp (°C)	30.97	0.00	29.70	0.58	29.14	0.09	30.63	0.24	29.84	0.33	30.42	0.46	28.78	0.08	29.53	0.18	29.42	0.00	29.99	0.27	29.73	0.11	29.43	0.22
SpC (mS/cm)	48.13	0.02	48.43	0.19	48.64	0.01	47.58	1.74	47.96	0.66	49.05	0.28	46.59	0.47	48.22	0.25	49.42	0.01	47.51	0.25	37.66	1.30	45.46	0.83
Salinity (‰)	31.46	0.01	31.68	0.14	31.81	0.00	32.25	0.17	31.57	0.30	32.12	0.21	30.32	0.35	31.52	0.19	32.40	0.01	31.05	0.18	23.97	0.96	29.45	0.61
TDS (ppm)	30.81	0.01	31.00	0.12	31.12	0.01	31.52	0.14	30.96	0.24	31.51	0.16	29.79	0.28	28.79	2.14	31.63	0.00	30.67	0.16	24.14	0.94	29.06	0.55
pH	7.96	0.00	7.81	0.01	7.68	0.02	8.23	0.09	7.74	0.32	8.19	0.11	7.36	0.02	8.06	0.10	8.64	0.00	7.32	0.81	7.47	0.10	7.55	0.14
Tur (NTU)	10.00	0.20	17.10	7.82	0.13	0.07	33.79	10.14	66.19	44.60	27.20	16.55	9.07	2.51	38.42	9.91	13.60	0.67	2.13	0.72	11.72	2.27	12.26	2.21
DO (mg/L)	4.71	0.01	5.14	0.01	-	-	5.82	0.07	4.68	0.06	5.96	0.59	2.56	0.25	4.33	0.73	-	-	5.32	0.21	5.45	0.38	4.96	0.61
ORP (mV)	380.00	2.08	381.00	3.61	-	-	448.83	1.83	349.33	9.26	-	-	385.33	24.17	437.33	1.20	-	-	156.57	118.73	410.67	13.17	413.89	8.27
Depth (m)	3.77	0.50	2.18	0.48	2.37	0.03	2.05	0.51	10.24	2.35	7.56	0.57	3.00	0.42	2.63	1.36	-	-	2.42	1.38	1.83	0.42	2.44	0.80

Table 3.2: Mean and ±SE of physical attributes in all four zones of study area. (n) denotes number of points of measurements in each zones.

Physical Attributes	Coral Reef			Mangrove-Coral			Mangrove Estuary			Mangrove Creeks		
	n	Mean	± SE	n	Mean	± SE	n	Mean	± SE	n	Mean	± SE
Temperature (°C)	25	30.57	0.19	13	29.74	0.25	38	29.84	0.20	18	29.27	0.16
SpC (mS/cm)	25	47.63	1.24	13	48.30	0.53	38	46.82	0.69	18	46.18	0.62
Salinity (‰)	25	31.96	0.16	13	31.76	0.25	38	30.52	0.50	18	29.99	0.46
TDS (ppm)	25	31.30	0.13	13	31.11	0.20	38	29.29	0.84	18	29.53	0.41
pH	25	8.05	0.15	13	7.94	0.27	38	7.94	0.06	18	7.54	0.10
Turbidity (NTU)	25	25.87	7.70	13	54.05	34.48	38	26.20	5.87	18	9.71	1.84
DO (mg/L)	18	5.52	0.12	6	4.68	0.06	19	5.33	0.27	12	4.36	0.55
ORP (mV)	12	358.56	44.17	3	349.33	9.26	12	409.92	8.73	12	406.75	8.82
Depth (m)	20	2.38	0.48	8	10.24	2.35	26	3.62	0.57	18	2.52	0.53

Table 3.3: Results of permutation ANOVA and post hoc test for the physical attributes. Significant differences are detected at *p<0.05.

Attributes	*df*	*F*	*p*	Post hoc
Temperature (°C)	3, 90	6.143	0.002*	Cr > Mg-C, Mg, Up
SpC (mS/cm)	3, 90	0.746	0.594	-
Salinity (‰)	3, 90	3.981	0.005*	Cr > Mg, Up; Mg-C > Up
TDS (ppm)	3, 90	2.279	0.063	-
DO (mg/L)	3, 51	2.922	0.051	-
pH	3, 90	2.774	0.044*	Cr, Mg >Up
ORP (mV)	3, 35	1.042	0.373	-
Tur (NTU)	3, 90	1.653	0.142	-

Permutation ANOVA revealed that the differences in physical attributes among zones were all insignificant except for temperature, salinity and pH ($p < 0.05$). Post-hoc t-test detected that the Coral zone was significantly different from all the other zones with respect to temperature. In terms of salinity, significant differences were detected between Coral and Mg, Coral and Up zones as well as between mixed Mg-C and Up zones. As for pH, Coral and Mg zones were found to have significantly higher values than the Up zone (Table 3.3). Although only these three physical attributes were significantly different among zones, their mean differences were less than 2 units.

3.2 Fish species diversity and similarity

In the present study, a total of 97 species of fish from 38 families were sampled. The inclusion from a previous study from Chong et al. (2005) adds up to a total number of 147 fish species from 52 families for the whole northeast of Langkawi (see Appendix I). In Tg. Rhu, the Coral, Mg-C and Mg zones had 18, 36 and 10 species respectively. Kilim, where the main river system lies, had a total of 35, 47, 37 and 19 species in the Coral, Mg-C, Mg and Up zones respectively. Peluru Straits on the other hand, had only 16 species in the Mg-C zone and 40 species in the Mg zone. Another site of major river system, Kisap, had 22 species in its Coral zone and 29 in the mixed Mg-C zone station. The Mg station in Kisap however, had only 10 species while the Up zone had an additional 9 more species. Percent disagreement matrix and dendogram were then constructed below (Table 3.4 and Fig. 3.1). This initial analysis was done to compare the fish species composition between zones prior to further analysis.

Table 3.4: Percent Disagreement Matrix calculated using Statistica 8.0 Software. TC = Tg. Rhu coral, TMU = Tg. Rhu upstream mangrove, KMU = Kilim upstream mangrove, SMC = Kisap mangrove-coral, SMU = Kisap upstream mangrove, PMC = Peluru Straits mangrove-coral, SC = Kisap coral, KC = Kilim coral, TM = Tg. Rhu mangrove, KM = Kilim mangrove, PM = Peluru Straits mangrove, SM = Kisap mangrove, KMC = Kilim mangrove-coral.

Percent disagreement (CA.sta)													
	TC	**TM**	**TMU**	**KC**	**KMC**	**KM**	**KMU**	**PMC**	**PM**	**SC**	**SM**	**SMC**	**SMU**
TC	0.00	0.31	0.18	0.27	0.39	0.31	0.22	0.20	0.31	0.23	0.27	0.16	0.21
TM	0.31	0.00	0.27	0.35	0.41	0.35	0.28	0.33	0.39	0.31	0.29	0.27	0.28
TMU	0.18	0.27	0.00	0.28	0.32	0.27	0.13	0.15	0.26	0.20	0.22	0.14	0.16
KC	0.27	0.35	0.28	0.00	0.41	0.37	0.29	0.32	0.40	0.28	0.38	0.29	0.29
KMC	0.39	0.41	0.32	0.41	0.00	0.31	0.30	0.31	0.46	0.39	0.46	0.35	0.34
KM	0.31	0.35	0.27	0.37	0.31	0.00	0.26	0.27	0.31	0.35	0.30	0.27	0.22
KMU	0.22	0.28	0.13	0.29	0.30	0.26	0.00	0.18	0.27	0.22	0.22	0.14	0.16
PMC	0.20	0.33	0.15	0.32	0.31	0.27	0.18	0.00	0.34	0.23	0.29	0.15	0.18
PM	0.31	0.39	0.26	0.40	0.46	0.31	0.27	0.34	0.00	0.31	0.25	0.26	0.24
SC	0.23	0.31	0.20	0.28	0.39	0.35	0.22	0.23	0.31	0.00	0.29	0.20	0.24
SM	0.27	0.29	0.22	0.38	0.46	0.30	0.22	0.29	0.25	0.29	0.00	0.18	0.19
SMC	0.16	0.27	0.14	0.29	0.35	0.27	0.14	0.15	0.26	0.20	0.18	0.00	0.14
SMU	0.21	0.28	0.16	0.29	0.34	0.22	0.16	0.18	0.24	0.24	0.19	0.14	0.00

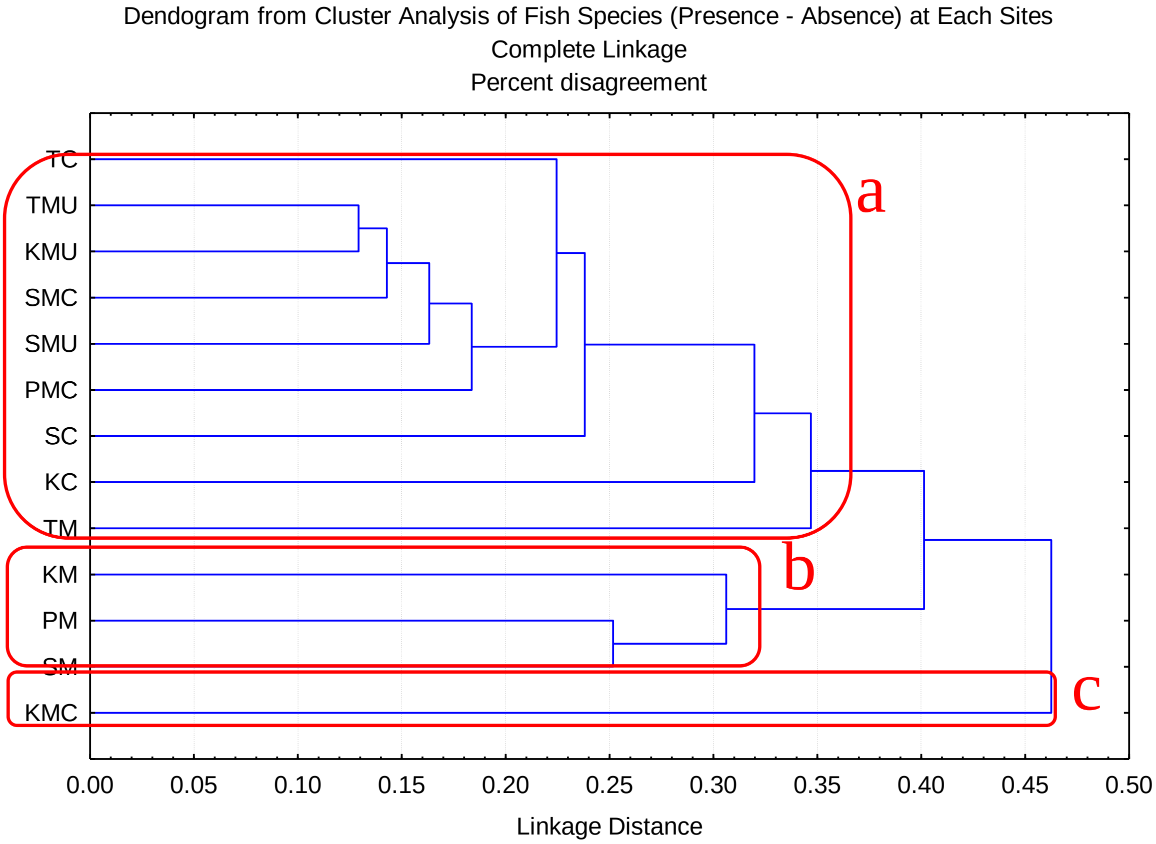

Figure 3.1: Dendogram from complete linkage cluster analysis of fish species in northeast Langkawi using presence-absence data. Three distinct clusters of (a), (b) and (c) were able to be established.

The dendogram (Fig. 3.1) illustrates that the fish species composition of the Up zones of Tg. Rhu, Kilim and Kisap (TMU, KMU, SMU), the Mg zone of Tg. Rhu (TM) and the mixed Mg-C zones of Kisap and Peluru (SMC and PMC) were closely similar to the species in the Coral zones of Tg. Rhu, Kilim and Kisap (TC, KC, SC). These nine sites were all clustered into a group denoted as (a). The dendogram depicts the Mg zones of Tg. Rhu, Kilim and Peluru (TM, KM, PM and SM) in a cluster of similar species composition given as (b). The Mg-C zone of Kilim (KMC) was the least similar to the other entire zones given as (c). The fish species composition in the mixed Mg-C zone of Kilim differed by a linkage distance of slightly less than half (D = 0.46) from the rest of the sites. The dendogram also displayed overlapping similarities, in which a conspicuous pattern is difficult to be observed. This does not refute a possible connection, however a clear conclusion could not be drawn. Thus, in order to determine if a conspicuous connection does exist, Table 3.5 and Fig. 3.2 were constructed.

Table 3.5 below displays a checklist of fish species which has been pooled into the four given zones namely Coral, Mg-C, Mg and Up, regardless of sites. The lowest number of fish species was in the Up zone with only 35 species. The fish diversity in the northeast Langkawi was highest in the Mg zone with 90 species as compared to the Coral zone, which harboured only 59 species. Since the mangrove biotope comprised both Mg and Up zones, the species that occurs in both zones were counted only once, making up the total number of 98 species present in the mangrove biotope. Finally, 60 species were found in the mixed Mg-C zone.

Table 3.5: List of fish species in northeast Langkawi, separated in to four major zones; coral (Coral), mangrove-coral (Mg-C), mangrove (Mg) and mangrove creeks (Up). "*" denotes species that were only found in literature but not in present study. 1 = present, 0 = absent

Family	**Species**	**Coral**	**Mg-C**	**Mg**	**Up**
Ambassidae	*Ambassis nalua*	0	0	1	1
Apogonidae	*Apogon hyalosoma*	0	1	0	1
Ariidae	*Arius caelatus*	0	1*	0	1*
	Arius tenuispinis	0	0	0	1*
	Arius venosus	0	1*	0	0
	Hexanematichtys sagor	0	0	1	1
	Osteogeneiosus militaris	0	0	1*	0
Batrachoididae	*Allenbatrachus grunniens*	0	1*	0	0
Belonidae	*Strongylura strongylura*	0	0	1	0
	Tylosurus crocodilus crocodilus	0	0	1	1
Caesionidae	*Caesio cunning*	1	1	1	0
Callionymidae	*Callionymus sagitta*	0	0	1*	0
Carangidae	*Alectis indicus*	0	1*	0	0
	Alepes djedaba	0	0	1	0
	Alepes kleinii	1	0	0	0
	Atule mate	1	0	0	0
	Carangoides equula	1*	0	1*	0
	Carangoides oblongus	0	0	1	0
	Carangoides praeustus	1	1	1	1
	Caranx ignobilis	0	1	1	1*
	Caranx sexfasciatus	1	1	1	0
	Scomberoides commersonnianus	1	1	1	1
	Scomberoides lysan	0	1	1	1

Family	**Species**	**Coral**	**Mg-C**	**Mg**	**Up**
	Scomberoides tol	1	0	0	0
	Trachinotus sp.	0	1	0	0
Centropomidae	*Lates calcarifer*	0	1*	0	0
Chaetodontidae	*Chaetodon octofasciatus*	1	0	0	0
	Heniochus acuminatus	0	1	0	0
Clupeidae	*Anodontostoma chacunda*	1	0	1	1
	Anodontostoma thailandiae	0	0	1	0
	Herklosichthys punctatus	0	0	1*	0
	Sardinella gibbosa	0	0	1*	0
Cynoglossidae	*Cynoglossus cynoglossus*	0	0	1	0
	Cynoglossus puncticeps	0	1*	0	0
Dasyatidae	*Dasyatis kuhlii*	0	1*	1*	1*
	Dasyatis zugei	0	1*	1*	1*
	Himantura walga	1	0	1	0
Drepanidae	*Drepane punctata*	1	1	1	0
Elopidae	*Elops machnata*	0	0	1	0
Engraulidae	*Stolephorus commersonnii*	0	0	1*	0
	Stolephorus indicus	0	0	1	0
	Thryssa hamiltonii	0	1	1	0
	Thryssa mystax	0	1*	1	0
Ephippidae	*Ephippus orbis*	1	1	1	1
Gerreidae	*Gerres erythrourus*	1	0	1	0
	Gerres filamentosus	0	1	1	1
	Gerres oyena	1	0	1	0
Gobiidae	*Acentrogobius caninus*	0	0	1	0
	Acentrogobius viridipunctatus	1*	0	0	0
	Palutrus scapulopunctatus	1*	0	1*	0
Gymnuridae	*Gymnura poecilura*	0	1*	0	0
Haemulidae	*Plectorhinchus gibbosus*	0	1	1	0
	Plectorhincus flavomaculatus	0	0	0	1*
	Pomadasys argenteus	0	1*	1*	0
	Pomadasys argyreus	0	0	1*	0
	Pomadasys hasta	0	1*	1*	0
	Pomadasys kaakan	0	1	1	1
Hemiscyllidae	*Chiloscyllium griseus*	0	1*	0	0
	Chiloscyllium indicum	0	0	1*	0
Labridae	*Halichoeres nigrescens*	1	0	0	0
	Halichoeres scalpularis	0	0	1*	0
Leiognathidae	*Eubleekeria jonesi*	0	0	1	0
	Eubleekeria splendens	0	1*	1	0
	Leiognathus brevirostris	1	1	1*	0
	Leiognathus daura	1	0	0	0
	Leiognathus equulus	1	1	1*	0
	Secutor ruconius	1	0	1	0
Lethrinidae	*Lethrinus lentjan*	1	0	0	0

Family	**Species**	**Coral**	**Mg-C**	**Mg**	**Up**
Lobotidae	*Lobotes surinamensis*	0	0	1*	0
Lutjanidae	*Lutjanus argentimaculatus*	0	1*	0	0
	Lutjanus biguttatus	1	0	0	0
	Lutjanus johnii	0	1	1*	1*
	Lutjanus lemniscatus	1	0	0	0
	Lutjanus lutjanus	1	0	0	0
	Lutjanus russelli	1	1	1	1
	Lutjanus stellatus	0	1*	0	0
	Lutjanus vitta	1	0	0	0
Megalopidae	*Megalops cyprinoides*	0	1*	0	0
Monacanthidae	*Acreichthys tomentosus*	0	0	1*	0
	Monacanthus choirocephalus	0	0	1*	0
	Monachanthus chinensis	1	1	0	1*
Mugilidae	*Chelon macrolepis*	0	0	1*	0
	Chelon subviridis	1	1*	1	1
	Ellochelon vaigiensis	1	0	1*	1
	Liza tade	0	0	1*	0
	Moolgarda perusii	1	0	1	0
	Moolgarda seheli	1	0	1	1
	Paramugil parmatus	1	0	0	0
	Valamugil buchanani	1	1	1*	1
	Valamugil cunnesius	1*	1*	1*	0
Mullidae	*Upeneus bensasi*	0	0	1*	0
	Upeneus sulphureus	0	0	1	0
	Upeneus sundaicus	1	0	0	0
	Upeneus tragula	1	0	0	0
Myliobatidae	*Aetomylaeus maculatus*	0	1*	0	0
Nemipteridae	*Nemipterus hexodon*	1	0	0	0
	Scolopsis ciliata	1	0	0	0
	Scolopsis vosmeri	1	1	0	0
Ostraciidae	*Ostracion rhinorhynchos*	0	0	0	1*
	Ostracion cubicus	0	0	0	1
Paralichthyidae	*Pseudorhombus elevatus*	0	1*	1*	0
Platycephalidae	*Cociella punctata*	0	1	0	0
	Grammoplites scaber	0	1	0	0
	Inegocia japonica	0	1	0	0
	Platycephalidae	0	0	1	0
	Platycephalus indicus	0	0	1*	0
	Suggrundus macracanthus	1	0	1*	0
Plotosidae	*Plotosus canius*	0	0	1*	1*
Polynemidae	*Eleutheronema tetradactylum*	0	1	0	0
Pomacentridae	*Abudefdef vaigiensis*	1	0	0	0
	Neoglyphidodon melas	1	0	0	0
	Stegastes obreptus	1	0	0	0
Pristigasteridae	*Ilisha filigera*	0	0	1*	0
	Ilisha melastoma	0	1	1	0

Family	Species	Coral	Mg-C	Mg	Up
Scathophagidae	*Scathophagus argus*	0	0	1*	1
Scianidae	*Dendrophyssa russelli*	0	1	1	0
	Johnius belangerii	0	1	0	0
	Johnius carutta	1*	0	0	0
	Paranibea semiluctuosa	0	0	1	0
	Pennahia anea	0	1*	0	0
	Pennahia macrocephalus	0	1*	0	1*
	Scianidae	0	1	0	0
Scombridae	*Rastrelliger kanagurta*	0	0	1*	0
Serranidae	*Cephalopholis boenak*	1	0	0	0
	Epinephelus bleekeri	1	1	0	0
	Epinephelus coioides	1	1*	1*	1
	Epinephelus erythrurus	1	0	0	0
	Epinephelus malabaricus	0	1	0	0
	Epinephelus quoyanus	1	0	0	0
	Epinephelus sexfasciatus	1	0	1*	0
Siganidae	*Siganus fuscescens*	1	0	0	0
	Siganus javus	1	1	1*	1
Sillaginidae	*Sillago aeolus*	1	0	0	0
	Sillago sihama	1	1	1	1
Sparidae	*Acanthopagrus berda*	0	0	1*	0
	Dentex angolensis	0	0	1*	0
Sphyraenidae	*Sphyraena barracuda*	0	0	1	0
	Sphyraena jello	1	1	1	0
	Sphyraena sp.	0	0	1	0
Synodontidae	*Saurida tumbil*	0	0	1*	0
Tetraodontidae	*Chelonodon patoca*	0	0	1*	0
	Lagocephalus lunaris	0	0	1	0
	Tetraodon fluviatilis	0	0	1*	0
	Tetraodon nigroviridis	0	0	1	1
Toxotidae	*Toxotes jaculatrix*	0	0	1*	1
Triacanthidae	*Pseudotriacanthus strigilifer*	1	0	1	0
	Triacanthus biaculeatus	1	1*	1	1
TOTAL		59	60	90	35

The dendogram (Fig. 3.2) suggests that fish species composition in the Up and Mg-C zones were very similar. The species in these two zones were consequently found to be similar to those in the Coral zone, allowing them to be clustered as a group (A). As depicted by the dendogram, the Mg zone had the least similar species to the other zones and was clustered as group (B). Based on both dendograms, the zones that represent coral reef and mangrove biotopes, respectively, overlapped and indicated some degree of similarity. This implies that there are common fishes in both biotopes, and which are identified and listed in Table 3.6, illustrating the connectivity between coral and mangrove biotopes.

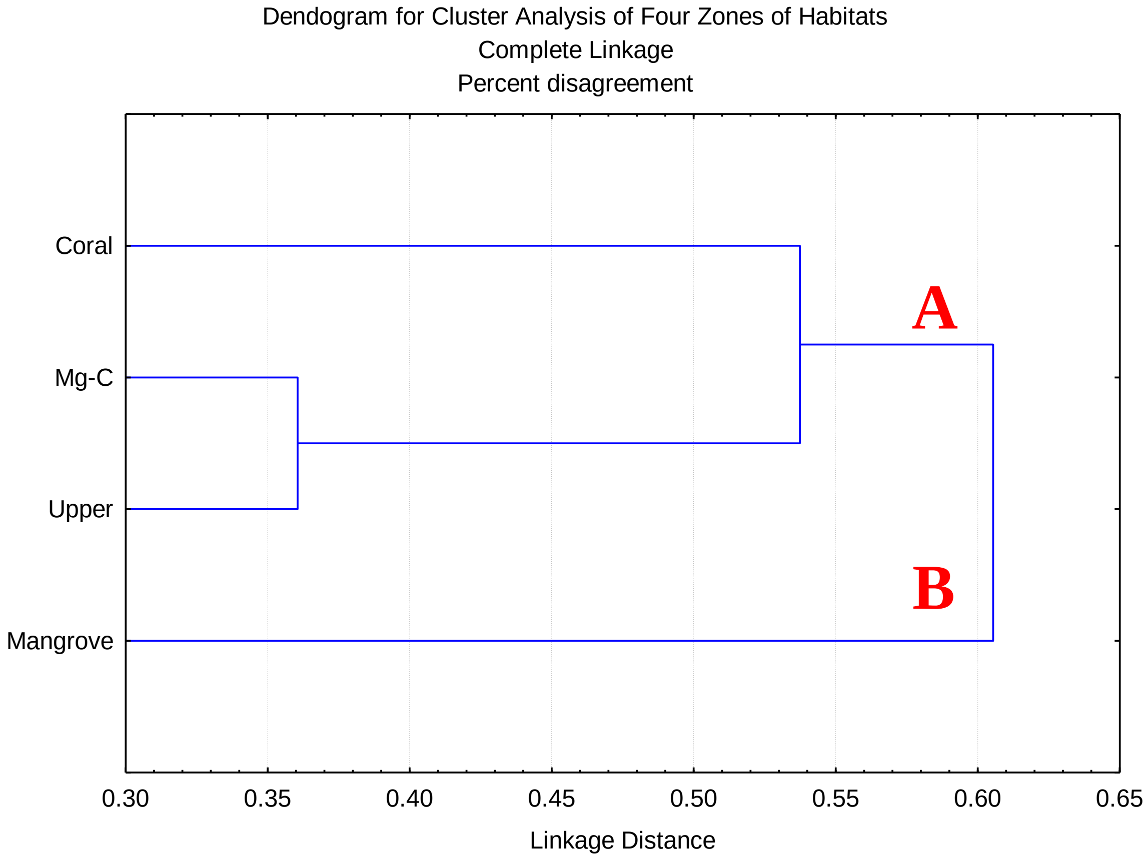

Figure 3.2: Dendogram from complete linkage percent disagreement cluster analysis of fish species in northeast Langkawi using presence-absence data.

Table 3.6: List of common species to both coral reefs and mangroves biotopes in northeast Langkawi. Fish species that are considered common are the species found in the coral reefs ("Coral") and in mangroves, which includes mangrove creeks ("Mangrove" + "Up"). Mangrove-coral zone ("Mg-C") is considered a mixed zone, where the boundary of coral and mangrove is unable to be distinguished. "0" denotes species absent; "1" denotes species present whereas "1*" denotes species that are present in previous studies (Chong et al, 2005).

Family	**Species**	**Coral**	**Mg-C**	**Mg**	**Up**
Caesionidae	*Caesio cunning*	1	1	1	0
Carangidae	*Carangoides equula*	1*	0	1*	0
Carangidae	*Carangoides praeustus*	1	1	1	1
Carangidae	*Caranx sexfasciatus*	1	1	1	0
Carangidae	*Scomberoides commersonnianus*	1	1	1	1
Clupeidae	*Anodontostoma chacunda*	1	0	1	1
Dasyatidae	*Himantura walga*	1	0	1	0
Drepanidae	*Drepane punctate*	1	1	1	0
Ephippidae	*Ephippus orbis*	1	1	1	1

Family	**Species**	**Coral**	**Mg-C**	**Mg**	**Up**
Gerreidae	*Gerres erythrourus*	1	0	1	0
Gerreidae	*Gerres oyena*	1	0	1	0
Gobiidae	*Palutrus scapulopunctatus*	1*	0	1*	0
Leiognathidae	*Leiognathus brevirostris*	1	1	1*	0
Leiognathidae	*Leiognathus equulus*	1	1	1*	0
Leiognathidae	*Secutor ruconius*	1	0	1	0
Lutjanidae	*Lutjanus russelli*	1	1	1	1
Monachantidae	*Monachanthus chinensis*	1	1	0	1*
Mugilidae	*Chelon subviridis*	1	1*	1	1
Mugilidae	*Ellochelon vaigiensis*	1	0	1*	1
Mugilidae	*Moolgarda perusii*	1	0	1	0
Mugilidae	*Moolgarda seheli*	1	0	1	1
Mugilidae	*Valamugil buchanani*	1	1	1*	1
Mugilidae	*Valamugil cunnesius*	1*	1*	1*	0
Platycephalidae	*Suggrundus macracanthus*	1	0	1*	0
Serranidae	*Epinephelus coioides*	1	1*	1*	1
Serranidae	*Epinephelus sexfasciatus*	1	0	1*	0
Siganidae	*Siganus javus*	1	1	1*	1
Sillaginidae	*Sillago sihama*	1	1	1	1
Sphyraenidae	*Sphyraena jello*	1	1	1	0
Triacanthidae	*Pseudotriacanthus strigilifer*	1	0	1	0
Triacanthidae	*Triacanthus biaculeatus*	1	1*	1	1
TOTAL		**31**	**18**	**30**	**14**

Table 3.6 lists a total of 31 common species, with 8 represented from previous studies. Thus, ten of the common fishes *Carangoides praeustus*, *Scomberoides commersonnianus*, *Ephippus orbis*, *Lutjanus russelli*, *Sillago sihama*, *Chelon subviridis*, *Valamugil buchanani*, *Epinephelus coioides*, *Siganus javus* and *Triacanthus biaculeatus* were found in all four zones with the latter five species from previous studies found in at least one zone. These 31 species signify that they were widely distributed in all zones. Fourteen species were found in the mixed Mg-C zones in the present study, none could be categorized as reef or mangrove dependent.

Table 3.7 displays the total length (TL) of the common species in all four zones, separated into juveniles and adults based on the one third of maximum length rule (Dorenbosch et al., 2005; Nagelkerken & van der Velde, 2002). Only *Caranx sexfasciatus* and *Scomberoides commersonnianus* were caught as juvenile in both biotopes as well as the mixed mangrove-coral zone. In contrast, other species were caught as adult in both of the biotopes, such as *Carangoides praestus*, *Anodontostoma chachunda*, *Himantura walga*, *Ephippus orbis*, *Gerres oyena*, *Leiognathus brevirostris*, *Chelon subviridis*, *Moolgarda perusii*, *Silago sihama*, *Sphyraena jello*, *Pseudotriacanthus strigilifer* and *Triacanthus biaculaetus*. Eight of the common species, *Caesio cunning*, *Drepane punctata*, *Gerres erythrourus*, *Lutjanus ruselli*, *Ellochelon vaigiensis*, *Moolgarda seheli*, *Epinephelus coiodes* and *Siganus javus* were caught as a mixture of juveniles and adults in either biotope. Only one species of mullet, *Valamugil buchanani* was caught as juvenile in the coral reef and as adult in the mangrove. Table 3.7 also shows that there were more species at the adult than juvenile stage in the mangrove and coral reef.

Table 3.7: Lengths (mean ± SD) of 23 common fish species in coral reefs (Coral zone only) and mangroves (Mg and Up zones) biotopes including the mixed mangrove coral zone (Mg-C). Juvenile lengths for respective species were determined with a third of maximum length rule. "*" denotes coastal water species while "^" denotes reef-associated species.

Species	Max Juvenile Length	Juvenile				Adult			
		Coral	Mg-C	Mg	Up	Coral	Mg-C	Mg	Up
*Caesio cunning**	20.00	16.03 ± 0.60	15.90	12.27 ± 0.14	0	0	0	21.80 ± 0.14	0
*Carangoides praeustus**	8.30	0	0	0	0	15.00	13.57 ± 0.90	13.58 ± 1.46	14.57 ± 1.79
Caranx sexfasciatus^	30.00	19.08 ± 1.61	18.40 ± 4.71	17.33 ± 3.59	0	0	0	0	0
Scomberoides commersonnianus^	30.00	24.80	13.50	17.75 ± 3.52	14.77 ± 1.19	0	0	0	0
Anodontostoma chacunda	7.30	0	0	0	0	15.20 ± 0.66	0	13.15 ± 1.85	12.47 ± 0.71
Himantura walga	15.00	0	0	0	0	17.40	0	17.70	0
Drepane punctata^	16.70	0	14.50	15.50	0	24.40 ± 8.63	21.18 ± 4.12	29.40 ± 7.50	0
Ephippus orbis^	8.30	0	0	0	0	16.50 ± 0.71	16.80 ± 0.42	17.50	0
Gerres erythrourus^	10.00	0	0	9.70 ± 0.28	0	20.60	0	12.75 ± 3.46	0
Gerres oyena^	10.00	0	0	0	0	15.81 ± 3.31	0	11.30 ± 0.14	0
Leiognathus brevirostris	4.50	0	0	0	0	9.50	10.95 ± 0.35	10.08 ± 1.02	0
Lutjanus russelli^	16.70	16.57 ± 0.67	15.75 ± 0.49	0	13.00	16.95 ± 0.07	17.50	17.40	0
Chelon subviridis	13.30	0	0	0	0	20.40	0	20.25 ± 4.39	18.60 ± 2.83
Ellochelon vaigiensis^	21.00	18.00 ± 2.18	0	0	0	27.03 ± 6.38	0	0	28.07 ± 2.83
Moolgarda seheli^	20.00	19.00 ± 1.41	0	19.05 ± 0.49	16.60	24.39 ± 3.89	0	26.79 ± 3.01	30.50 ± 7.09
Moolgarda perusii^	8.30	0	0	0	0	20.24 ± 1.65	0	21.08 ± 2.43	0
Valamugil buchanani	30.00	19.10 ± 0.28	17.40	0	0	0	0	0	34.55 ± 2.76
Epinephelus coioides^	30.00	20.78 ± 2.25	0	0	15.40	0	0	0	33.50 ± 4.24
Siganus javus^	17.60	16.70 ± 1.13	0	0	10.50	23.20 ± 7.35	21.00	0	0
Sillago sihama^	10.00	0	0	0	0	15.20	18.27 ± 1.52	17.15 ± 3.97	17.55 ± 4.31
Sphyraena jello^	30.00	0	0	0	0	46.50	34.90 ± 0.28	33.00 ± 2.12	0
Pseudotriacanthus strigilifer	8.30	0	0	0	0	18.00	0	14.50	0
Triacanthus biaculeatus	10.00	0	0	0	0	18.50	0	11.75 ± 0.07	15.30 ± 3.51

3.3 Coral community structure and habitat complexity

The life form cover for each site and the pooled cover of corals in northeast Langkawi are presented in Table 3.8. Although there were differences with regards to lifeform cover between sites, they were not significant (Table 3.9). The r-K-S ternary diagram indicates that corals in northeast Langkawi were composed of almost exclusively stress-tolerant strategists, which formed up to 74 % of the total coverage (Fig. 3.3). This corroborates with the high live cover of two stress tolerant corals of the massive and sub-massive morphologies, which comprised 36.18 % of the total cover (Fig. 3.4). The live cover was higher than that of non-living abiotic, with the former covering 57.60 %, whereas the latter covered 46.40 % (Fig. 3.4 and Table 3.10).

The live cover included 6.4 % of other non-coral fauna such as macroalgae (0.16 %), coralline algae (0.03 %), soft corals (2.55 %), sponges (2.13 %) and gorgonian fans, seawhips and corallimorphs (categorised as others), together covering 1.53 %. However, it was evident that the study site had a high coverage of silt (grains that are finer than sand) which amounted to 33 %. Dead corals amounted to approximately 8 %, while the mortality index, *(M)* was relatively low with a score of only 0.15. The coral morphological diversity *(mH')* was calculated to have an index value of 2.06.

Table 3.8: Percentage cover (mean ± SE) of coral life form categories in four sites – Tg. Rhu, Kilim, Peluru and Kisap. Number in parentheses denotes the number of transects. The last column represents the percentage cover of the whole of northeast Langkawi.

Lifeform Categories	CODES	SITES (%)								
		Tg Rhu (4)		Kilim (9)		Peluru (1)	Kisap (5)		NE Langkawi (19)	
		Mean	± SE	Mean	± SE		Mean	± SE	Mean	± SE
Live Scleractinian Corals	ACB	0.00	0.00	0.00	0.00	0.00	0.30	0.30	0.08	0.02
	ACS	6.13	6.13	0.00	0.00	0.00	1.10	1.10	1.58	0.36
	ACT	0.25	0.25	0.00	0.00	0.00	0.00	0.00	0.05	0.01
	CE	3.00	1.85	4.61	1.45	14.00	5.70	3.50	5.05	1.16
	CF	0.00	0.00	3.67	1.85	0.00	0.20	0.20	1.79	0.41
	CM	5.00	1.43	23.83	6.36	5.50	10.80	3.01	15.47	3.55
	CMP	0.00	0.00	0.11	0.11	0.00	1.50	1.00	0.45	0.10
	CMR	0.00	0.00	0.11	0.11	0.00	0.00	0.00	0.05	0.01
	CSM	33.13	11.12	11.89	3.55	3.00	30.20	5.73	20.71	4.75
	CT	0.13	0.13	3.94	1.58	1.50	0.00	0.00	1.97	0.45
	Total	**47.63**	**6.42**	**48.17**	**4.86**	**24.00**	**49.80**	**5.91**	**47.21**	**3.19**
Live Non-coral Fauna	AL	0.00	0.00	0.33	0.33	0.00	0.00	0.00	0.16	10.83
	CA	0.00	0.00	0.06	0.06	0.00	0.00	0.00	0.03	0.04
	OT	0.00	0.00	2.61	0.93	0.00	1.10	0.78	1.53	0.01
	SC	0.00	0.00	5.17	2.97	2.00	0.00	0.00	2.55	0.35
	SP	4.25	1.05	0.89	0.55	0.00	3.10	2.73	2.13	0.59
	Total	**4.25**	**1.05**	**9.06**	**3.44**	**2.00**	**4.20**	**3.48**	**6.39**	**1.90**
Non-living Corals	DCA	7.75	4.64	6.00	4.06	0.00	9.60	6.68	7.00	0.49
	RKC	0.00	0.00	3.06	3.06	0.00	0.00	0.00	1.45	1.47
	Total	**7.75**	**4.64**	**9.06**	**5.48**	**0.00**	**9.60**	**6.68**	**8.45**	**3.15**
Abiotic Materials	RC	5.13	5.13	1.78	1.60	0.00	3.10	1.91	2.74	1.61
	SD	0.00	0.00	2.11	1.82	0.00	3.70	2.56	1.97	0.33
	SI	35.25	7.11	29.83	5.31	74.00	29.60	8.36	33.24	1.94
	Total	**40.38**	**5.14**	**33.72**	**3.97**	**74.00**	**36.40**	**9.56**	**37.95**	**3.74**

Table 3.9: Results of permutation ANOVA for types of life forms cover in northeast Langkawi. Significant difference is detected at *p<0.05.

Life forms cover	*df*	*F*	*p*
Live scleractinian corals	3, 15	1.005	0.450
Other non-coral fauna	3, 15	0.567	0.609
Non-living corals	3, 15	0.126	0.953
Abiotic materials	3, 15	2.280	0.135

Table 3.10: Indices of morphological diversity and corals mortality and percentage cover of living/non-living corals categories by sites.

Sites	Morphological Diversity, *mH'*	Mortality Index, *M*	% Live Coral Cover	% Live Other Non-coral Fauna	% Non-living coral & Abiotic Cover
Tg. Rhu	1.67	0.14	47.63	4.25	48.13
Kilim	2.10	0.16	48.17	9.06	42.78
Peluru	0.90	0.00	24.00	2.00	74.00
Kisap	1.88	0.16	49.80	4.20	46.00
NE Langkawi	2.06	0.15	47.21	6.40	46.40

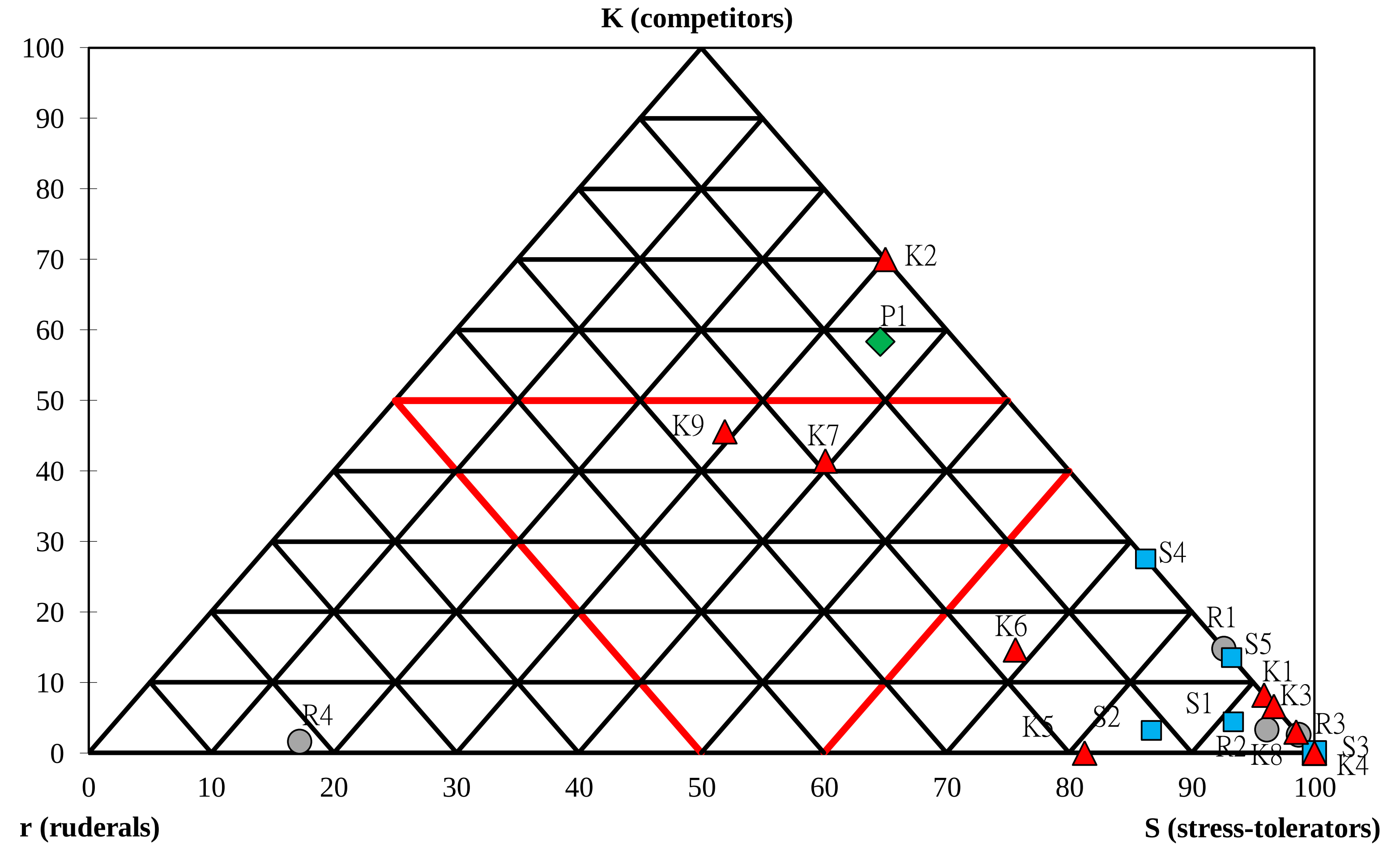

Figure 3.3: r-K-S ternary diagram of corals in the northeast Langkawi. Transects in each site are represented in respective symbols and denoted with transect numbers: Grey ○ = Tg. Rhu (R1-R4); Red △ = Kilim (K1-K9); Green ◇ = Peluru (P1); Blue □ = Kisap(S1-S5).

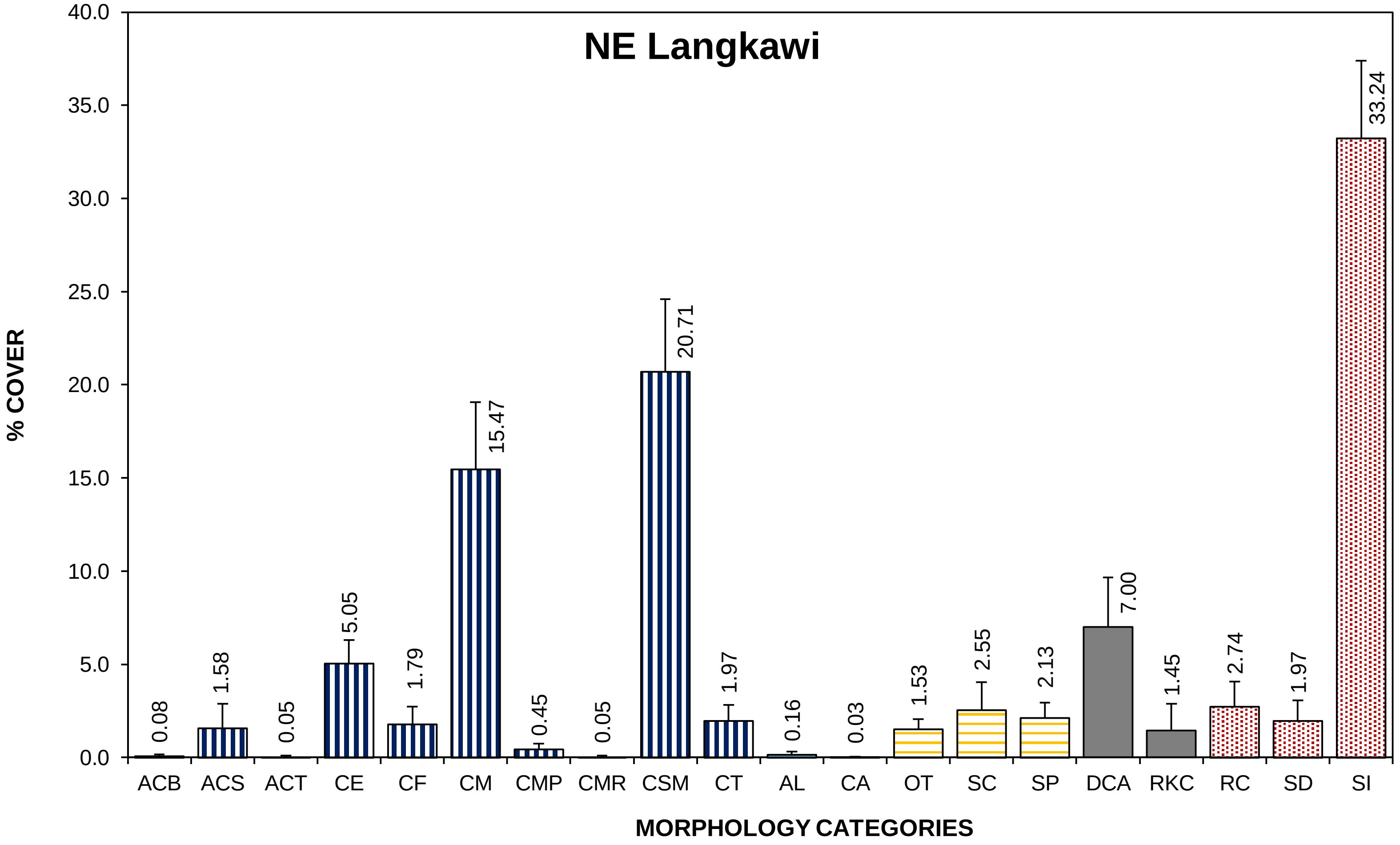

Figure 3.4: Percentage cover of various morphology categories of life forms in northeast Langkawi. The pattern fills in each bar represents the four main lifeform categories: 1) Vertical stripes = Live scleractinian coral; 2) Horizontal stripes = Other non-coral live fauna; 3) Grey = Non-living corals; 4) Dots = Abiotic. See Table 2.1 for the codes of the morphology categories.

3.4 Stomach content analysis to determine trophic guilds

The dietary composition of 54 fish species as depicted in the PCA biplot showed the six conspicuous groupings conspicuously, namely Piscivores, Mixed Carnivores, Omnivores, Herbivores, Prawn and Mixed Invertebrate feeders (Fig. 3.5a, 3.5b). The Prawn and Mixed Invertebrate feeders were subsequently combined to form one trophic guild, the Invertivores which comprised the largest number of species. Invertivores were introduced because their Δ^{15}N values were significantly lower than carnivores that feed on high-protein vertebrate animals (McCutchan et al. 2003). The first two PCA functions, with respective eigen values of 0.289 and 0.189, explained 47.8% of the total variance of the data (see Appendix II).

3.5 Stable isotopes of producers and consumers

The δ^{13}C and δ^{15}N dual stable isotope values of primary producers and fish tissues are presented in Table 3.11. The mangrove plants, *R. apiculata* and *C. tagal* had δ^{13}C mean values of -28.61 ± 0.17 ‰ (SE) and -29.05 ± 0.80 ‰, while their δ^{15}N mean values were 3.48 ± 1.35 and 3.74 ± 1.04, respectively. Seston appeared to be more enriched in δ^{13}C than mangrove detritus, with mean values of -21.64 ± 0.79. The most enriched δ^{13}C values belonged to coral zooxanthellae (Zoox) with mean value of -15.39 ± 0.33 ‰. The δ^{13}C values of reef sediment (-21.22 ± 0.31 ‰) were far from coral zooxanthellae but close to seston, whereas the values for estuarine sediment (-26.30 ± 0.29 ‰) were closer to mangrove leaves. Primary carbon sources including sediments ranked from depleted to most enriched δ^{13}C values were mangrove leaves, mangrove sediments, estuarine seston, nearshore seston, reef sediments, mangrove creek seston, benthic diatoms and coral zooxanthellae. Biplots of carbon sources and sediments are illustrated in Figure 3.6a.

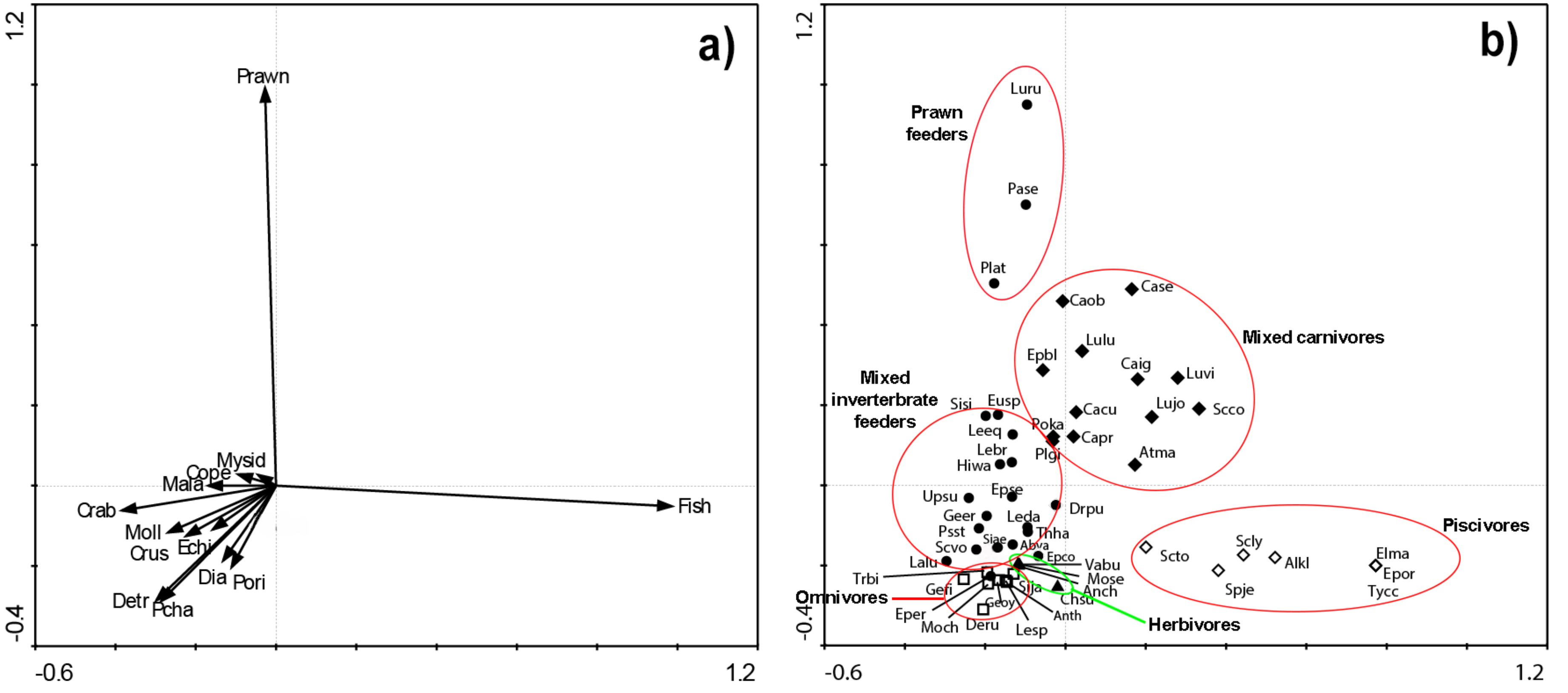

Figure 3.5: Principal component analysis (PCA) of stomach content of fishes with a) arrows denoting food consumed: Fish, Prawn, Mysid, Copepod (Cope), Malacostracas (Mala), Crab, Molluscs (Moll), Crustaceans (Crus), Echinoderms (Echi), Plant Detritus (Detr), Polychaetes (Pcha), Diatoms (Dia), Porifera (Pori) and b) fish species grouped into their respective feeding guilds: ◇= Piscivores; ◆= Carnivores; ●= Invertivores*; □= Omnivores; ▲ = Herbivores. *The feeding guild Invertivores were made up of the combined prawn and mixed invertebrate feeders. See Table 1 for species abbreviation.

Table 3.11: Mean ± SE isotope values of $\delta^{13}C$, $\delta^{15}N$ and C/N ratio of the possible primary energy sources, zooplankton and sediments. n denotes the number of samples collected for each source. *from Okamura et al. (2010).

Sources	n	$\delta^{13}C$ (‰)		$\delta^{15}N$ (‰)		C:N	
		Mean	± SE	Mean	± SE	Mean	± SE
Mangrove plants (Detritus)	6	-28.83	0.38	3.61	0.76	52.32	3.24
Rhizophora apiculata	3	-28.61	0.17	3.48	1.35	45.30	1.42
Ceriops tagal	3	-29.05	0.80	3.74	1.04	59.35	1.15
Phytoplankton (Seston)	15	-21.64	0.79	5.35	0.40	9.63	0.54
Coral zooxanthellae (Zoox)	23	-15.39	0.33	6.20	0.19	7.11	0.23
Benthic diatoms* (Diatoms)	3	-17.30	0.72	3.70	0.58	-	-
Zooplankton	11	-21.66	0.72	7.38	0.43	5.07	0.08
Sediments (Reef)	19	-21.22	0.31	5.61	0.16	9.54	0.23
Sediments (Estuary)	17	-26.30	0.29	3.70	0.13	19.06	0.89

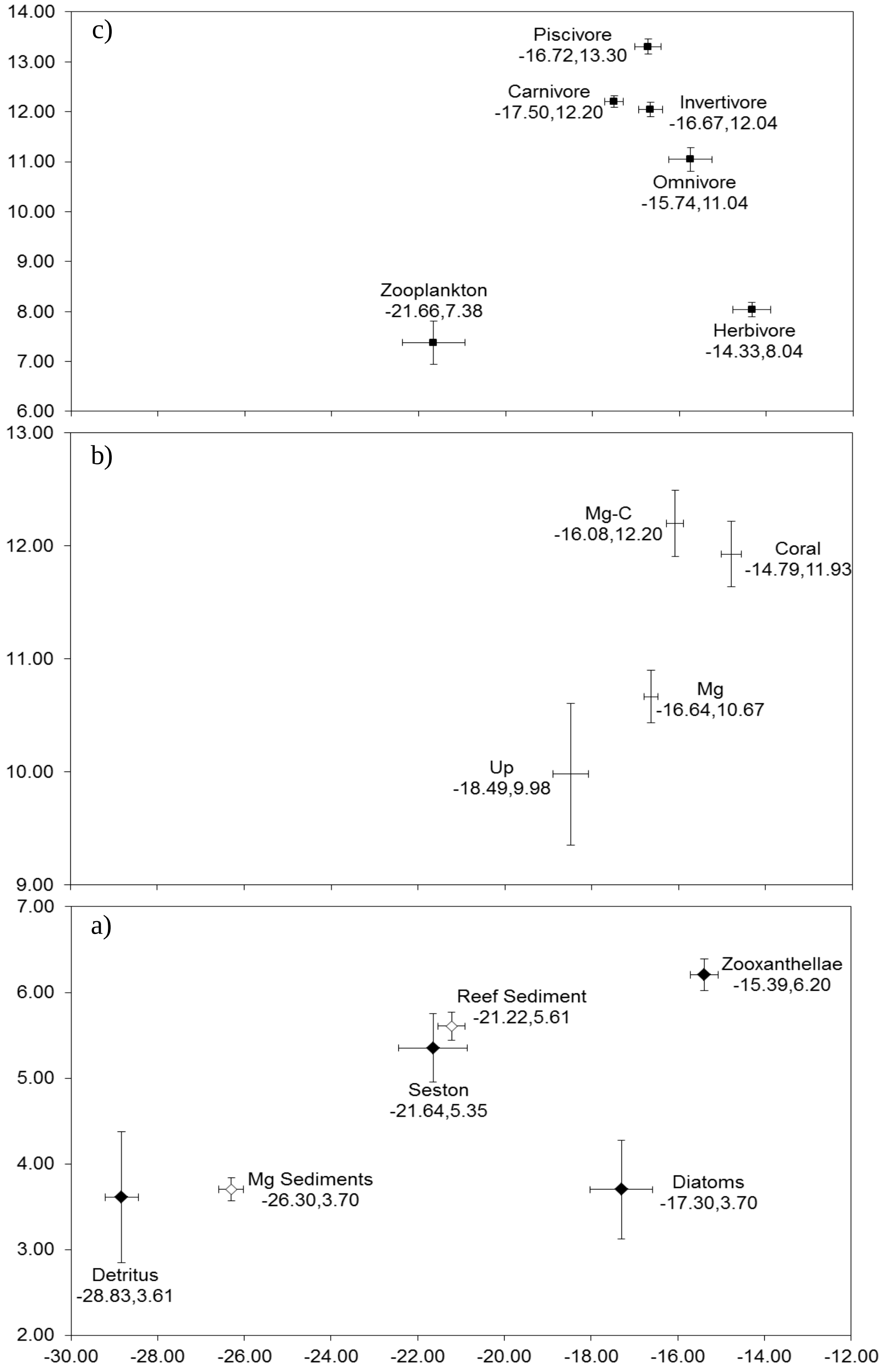

Figure 3.6: Isotopic map of $\delta^{13}C$ and $\delta^{15}N$ signatures of fish tissues (before trophic fractionation correction) by (a) primary sources include coral zooxanthellae (Zoox), benthic diatoms (Diatoms), seston or phytoplankton (Nearshore, Mangrove Estuary and Mangrove Creeks) and mangrove (Detritus), and sediments from the coral reef (Reef Sediment) and mangrove (Mangrove Sediment); (b) Habitat zones such as coral zone (Coral), mangrove-coral zone (Mg-C), mangrove estuary zone (Mg) and mangrove creek zone (Up); (c) Trophic guilds. Numerals indicate mean $\delta^{13}C$ and $\delta^{15}N$. All data are in mean ± SE.

Kruskal-Wallis analysis revealed that trophic guilds differed significantly in both their $\delta^{13}C$ (χ^2 = 52.67, df = 4, p < 0.001) and $\delta^{15}N$ (χ^2 = 173.73, df = 4, p < 0.001) values. Post hoc pairwise analysis suggested that trophic guilds significantly differed ($p<0.05$) in terms of $\delta^{13}C$ between the following pairs: piscivores – invertivores, piscivores – carnivores, piscivores – omnivores, invertivores – omnivores and herbivores – omnivores. However, in terms of $\delta^{15}N$, trophic guilds significantly differed between all pairs except carnivores – invertivores ($p<0.05$) (Table 3.12; Fig. 3.6c; see Appendix III) indicates that the trophic groupings determined by the PCA of stomach content were satisfactory. The mean values of $\delta^{13}C$, $\delta^{15}N$ and C/N ratio of the fish species, assigned to respective feeding guilds, are presented in Table 3.13. Herbivorous fishes had a large range of $\delta^{13}C$ mean values (-8.88 to -15.72 ‰), while their mean $\delta^{15}N$ values ranged from 7.18 to 8.45 ‰. The demersal grey mullets, *Moolgarda perusii, Moolgarda seheli* and *Valamugil buchanani*, were found in both reef and mangrove suggesting that these species move between these habitats.

Table 3.12: Results of Kruskal-Wallis non-parametric test and post hoc Wilcoxon Mann-Whitney test. Significant difference are at *$p<0.001$. Pairs of insignificant difference are denoted by the same letters.

Isotopic composition	Kruskal-Wallis Test*		Post hoc Wilcoxon Mann-Whitney Test
	df	χ^2	
$\delta^{13}C$	4	51.67	Herbivores^{a}, Omnivores^{a,b,c}, Invertivores^{b,c}, Carnivores^{c}, Piscivores^{c,}
$\delta^{15}N$	4	173.72	Herbivores, Omnivores, Invertivores^{a}, Carnivores^{a}, Piscivores
$\delta^{13}C$	3	33.76	Coral, Mg-C^{a}, Mg^{a}, Up
$\delta^{15}N$	3	53.66	Coral^{a}, Mg-C^{a}, Mg^{b}, Up^{b}

Another species of mullet also found in both habitats, *Ellechelon vaigiensis* was classified as omnivorous based on PCA. This is corroborated by its $\delta^{15}N$ value of 9.52 ‰, which reflects a higher trophic position than other herbivorous members of the family. Omnivorous species had mean $\delta^{13}C$ values that ranged from -11.26 to -20.28 ‰ and a mean $\delta^{15}N$ value of 11.04‰, which positioned them at a higher trophic level than herbivores. *Chaetodon octofasciatus* and *Heniochus acuminatus*, typical corallivores, were classified as omnivores in the present study since they tend to consume mixed plant and animal material. Interestingly, all three individuals of *H. acuminatus* and one *C. octofasciatus* were caught in the Mg-C zone near the river mouth, at a considerable distance of one km from the coral reef.

The trophic guild with the highest number of species was the Invertivores with a total of 32 species. Four of these species were found in both biotopes, namely *Lutjanus russelli*, *Drepane punctata*, *Himantura walga* and *Sillago sihama*. Their $\delta^{13}C$ mean values ranged from -17.61‰ to -16.79 ‰. In terms of $\delta^{15}N$ values, they had respective mean values of 12.10 ‰ 12.40 ‰, 11.84 ‰ and 11.28 ‰. In general, the invertivores had $\delta^{15}N$ mean values of 12.04 ‰, which positioned them at a higher trophic level than omnivores.

The carnivores had a mean $\delta^{13}C$ value of -17.50 ‰ and a $\delta^{15}N$ mean value of 12.20 ‰. Only three out of 18 carnivorous species were found in both reef and mangrove, namely, *Caesio cunning*, *Caranx sexfasciatus* and *Scomberoides commersonnianus*. Interestingly, *C. cunning* which is known to be reef associated was caught in the mangroves indicating that it had moved into the mangroves. The mean values of $\delta^{13}C$ for *C. cunning* was -16.58 ± 0.29 ‰ while its $\delta^{15}N$ was 13.24 ± 0.62 ‰. *Ephippus orbis*, a piscivorous species that was found in all zones, had $\delta^{13}C$ mean value of -17.44 ± 1.79 ‰ and $\delta^{15}N$ mean value of 13.81 ± 0.38 ‰. Another piscivore, *Strongylura strongylura*, a pelagic mangroves species, had enriched $\delta^{13}C$ mean value of -16.49 ± 0.36 ‰. The piscivorous barracudas, *Sphyraena barracuda*, *Sphyraena jello* and *Sphyraena* sp., found in the mangroves, had enriched $\delta^{13}C$ values that ranged from

-15.56 to -17.88 ‰. On average, fish classified as piscivores had a relatively enriched $\delta^{13}C$ value of -16.72 ± 1.49 ‰ and $\delta^{15}N$ value of 13.30 ± 0.78 ‰.

Biplots of the $\delta^{13}C$ and $\delta^{15}N$ values of the fish trophic guilds are given in Fig. 3.6c. The most enriched $\delta^{13}C$ value belonged to herbivores (-14.33 ± 0.43 ‰), whereas the most depleted were mixed carnivores (-17.50 ± 0.21 ‰). The range of these $\delta^{13}C$ values overlapped the values of benthic diatoms and coral zooxanthellae, but the values were quite far from those of seston and mangrove (Fig. 3.6a). In terms of $\delta^{15}N$ values, the piscivores (13.30 ± 0.16 ‰) were the most enriched with respect to the herbivores (8.04 ± 0.15 ‰). The trophic guilds ranked in terms of $\delta^{15}N$ enrichment are as follows: herbivores, omnivores, invertivores, carnivores and piscivores.

Table 3.13: Mean and ±SE tissues isotopes of $\delta^{13}C$, $\delta^{15}N$ (both expressed in ‰) and C/N ratio of fish species (grouped into respective feeding guilds) with number of samples collected (n) in each zone.

		n					$\delta^{13}C$		$\delta^{15}N$		C:N	
Species	Sp. Abbrv./ Refs.	Coral Reefs	Mangrove-Coral	Mangrove Estuary	Mangrove Creeks	Total	Mean	± SE	Mean	± SE	Mean	± SE
Herbivore						**65**	**-14.33**	**0.43**	**8.04**	**0.15**	**3.83**	**0.01**
Anodontostoma chacunda	Anch	0	3	7	4	14	-15.27	0.61	8.39	0.21	3.86	0.03
Chelon subviridis	Chsu	1	0	13	2	16	-15.72	0.84	8.45	0.17	3.74	0.02
Moolgarda perusii	(a)	4	0	5	0	9	-11.70	0.46	7.44	0.53	3.93	0.04
Moolgarda seheli	Mose	2	5	10	3	20	-13.90	0.84	7.98	0.11	3.82	0.01
Paramugil parmatus	(b)	1	0	0	0	1	-8.88	0.00	7.47		3.82	
Valamugil buchanani	Vabu	2	1	0	2	5	-14.80	2.38	7.18	1.37	3.83	0.04
Omnivore						**47**	**-15.74**	**0.50**	**11.04**	**0.24**	**3.81**	**0.02**
Anodontostoma thailandiae	Anth	0	0	1	0	1	-20.28	0.00	9.18		3.69	
Chaetodon octofasciatus	(d)	2	1	0	0	3	-13.03	0.41	11.90	0.11	3.79	0.03
Dendrophyssa russelli	Deru	0	0	2	0	2	-19.71	0.05	11.28	0.07	3.75	0.06
Ellochelon vaigiensis	(c)	3	2	0	3	8	-11.26	0.14	9.52	0.41	3.74	0.01
Gerres filamentosus	Gefi	0	0	6	3	9	-17.46	0.81	10.95	0.29	3.81	0.03
Gerres oyena	Geoy	4	0	2	0	6	-13.42	0.40	11.80	0.18	3.77	0.02
Heniochus acuminatus	(d)	0	3	0	0	3	-17.50	0.08	13.80	0.20	4.18	0.12
Leiognathus splendens	Lesp	0	0	4	0	4	-16.95	2.37	8.12	0.40	3.91	0.02
Monachanthus chinensis	Moch	0	4	0	0	4	-16.00	0.32	12.64	0.44	3.74	0.01
Siganus javus	Sija	2	2	0	1	5	-19.35	1.28	11.71	0.41	3.75	0.02
Triacanthus biaculeatus	Trbi	0	0	2	0	2	-16.05	0.01	11.54	0.60	3.82	0.00

Species	Sp. Abbrv./ Refs.	n					$\delta^{13}C$		$\delta^{15}N$		C:N	
		Coral Reefs	Mangrove-Coral	Mangrove Estuary	Mangrove Creeks	Total	Mean	± SE	Mean	± SE	Mean	± SE
Invertivore						**84**	**-16.67**	**0.28**	**12.04**	**0.15**	**3.78**	**0.01**
Ambassis nalua	(e)	0	0	1	1	2	-19.93	0.67	12.37	0.01	3.77	0.02
Secutor ruconius	(f)	0	1	0	0	1	-16.62		13.00		3.73	
Stolephorus indicus	(g)	0	0	1	0	1	-16.88		13.19		3.76	
Abudefduf vaigiensis	Abva	1	0	0	0	1	-18.27		11.69		3.75	
Acentrogobius caninus	(h)	0	0	1	0	1	-16.59		11.56		3.71	
Cynoglossus cynoglossus	(i)	0	0	1	0	1	-17.47		10.58		3.72	
Drepane punctate	Drpu	2	5	4	0	11	-17.61	0.79	12.40	0.27	3.80	0.03
Epinephelus coioides	Epco	2	2	0	3	7	-17.35	1.24	12.93	0.61	3.75	0.01
Epinephelus erythrurus	Eper	1	0	0	0	1	-13.17		12.15		3.78	
Epinephelus sexfasciatus	Epse	2	0	0	0	2	-15.98	0.14	13.30	0.34	3.80	0.02
Eubleekeria jonesi	Eujo	0	0	2	0	2	-15.55	0.21	10.43	0.08	3.84	0.03
Eubleekeria splendens	Eusp	0	0	1	0	1	-14.87		11.81		3.78	
Gerres erythrourus	Geer	0	0	4	0	4	-14.34	0.57	10.17	0.34	3.88	0.05
Himantura walga	Hiwa	1	0	1	0	2	-16.79	2.12	11.84	0.33	3.43	0.06
Ilisha melastoma	(g)	0	0	2	0	2	-19.30	0.73	11.94	0.28	3.78	0.01
Johnius belangerii	(j)	0	1	0	0	1	-16.37		13.59		3.75	
Lagocephalus lunaris	Lalu	0	0	1	0	1	-14.03		11.32		3.80	
Leiognathus brevirostris	Lebr	0	3	5	0	8	-15.46	0.23	11.75	0.34	3.80	0.02
Leiognathus daura	Leda	3	0	0	0	3	-16.54	0.13	13.30	0.24	3.78	0.02
Leiognathus equulus	Leeq	0	2	0	0	2	-14.97	0.21	10.52	0.17	3.84	0.03

Species	Sp. Abbrv./ Refs.	n					δ^{13}C		δ^{15}N		C:N	
		Coral Reefs	Mangrove-Coral	Mangrove Estuary	Mangrove Creeks	Total	Mean	± SE	Mean	± SE	Mean	± SE
Lutjanus russelli	Luru	3	3	1	1	8	-17.38	1.18	12.10	0.37	3.73	0.01
Paranibea semiluctuosa	Pase	0	0	1	0	1	-16.18		11.99		3.77	
Platycephalidae	Plat	0	0	1	0	1	-16.74		9.25		3.83	
Pseudotriacanthus strigilifer	Psst	0	0	1	0	1	-15.14		12.08		3.75	
Scolopsis vosmeri	Scvo	2	0	0	0	2	-16.45	0.01	13.33	0.36	4.03	0.20
Sillago aeolus	Siae	1	2	0	0	3	-13.45	0.45	12.56	0.16	3.80	0.01
Sillago sihama	Sisi	1	1	3	1	6	-17.17	1.68	11.28	0.82	3.79	0.02
Tetraodon nigroviridis	(k)	0	0	1	1	2	-22.37	0.55	9.35	0.59	3.72	0.03
Thryssa hamiltonii	Thha	0	0	2	0	2	-16.06	0.17	13.67	0.47	3.82	0.07
Thryssa mystax	(g)	0	0	1	0	1	-15.86		13.63		3.82	
Trachinotus sp.	(l)	0	1	0	0	1	-17.79		11.50		3.67	
Upeneus sundaicus	Upsu	2	0	0	0	2	-15.41	0.43	13.57	0.30	3.77	0.04
Carnivore						**101**	**-17.50**	**0.21**	**12.20**	**0.11**	**3.85**	**0.04**
Alepes djedaba	(m)	0	0	1	0	1	-18.47		11.99		3.79	
Atule mate	Atma	3	1	0	0	4	-16.04	0.19	13.13	0.23	3.81	0.06
Caesio cunning	Cacu	3	0	4	0	7	-16.58	0.11	13.24	0.24	3.79	0.03
Carangoides oblongus	Caob	0	0	1	0	1	-16.12	0.00	12.83		3.92	
Carangoides praeustus	Capr	0	0	8	4	12	-17.94	0.48	11.94	0.11	3.77	0.02
Caranx ignobilis	Caig	0	4	1	0	5	-16.09	0.43	13.53	0.23	3.75	0.01
Caranx sexfasciatus	Case	4	4	3	0	11	-17.80	0.44	11.69	0.36	3.74	0.02
Cephalopholis boenak	(n)	1	0	0	0	1	-15.09		13.28		3.78	

Species	Sp. Abbrv./ Refs.	n					δ13C		δ15N		C:N	
		Coral Reefs	Mangrove-Coral	Mangrove Estuary	Mangrove Creeks	Total	Mean	± SE	Mean	± SE	Mean	± SE
Epinephelus bleekeri	Epbl	4	3	0	0	7	-15.67	0.45	13.37	0.18	3.82	0.02
Epinephelus malabaricus	(l)	0	2	0	0	2	-20.88	1.62	10.86	0.80	3.75	0.03
Hexanematichthys sagor	(o)	0	0	1	1	2	-19.29	0.83	9.95	0.51	3.75	0.04
Lutjanus johnii	Lujo	0	3	0	0	3	-16.49	0.86	12.19	0.39	3.74	0.04
Lutjanus lutjanus	Lulu	3	0	0	0	3	-16.87	0.03	13.00	0.22	3.81	0.02
Lutjanus vitta	Luvi	3	0	0	0	3	-16.29	0.20	13.20	0.12	3.82	0.02
Nemipterus hexodon	(p)	0	3	0	0	3	-12.90	0.21	12.41	0.19	3.96	0.04
Plectorhinchus gibbosus	Plgi	0	8	0	0	8	-19.31	0.76	12.22	0.33	4.59	0.41
Pomadasys kaakan	Poka	0	2	10	1	13	-18.80	0.67	10.69	0.24	3.82	0.07
Scomberoides commersonnianus	Scco	1	0	11	3	15	-17.95	0.60	12.35	0.22	3.78	0.02
Piscivore						**25**	**-16.72**	**0.30**	**13.30**	**0.16**	**3.78**	**0.01**
Alepes kleinii	Alkl	0	1	0	0	1	-16.41		13.66		3.79	
Elops machnata	Elma	0	0	1	0	1	-13.63		11.76		3.75	
Ephippus orbis	Epor	2	3	1	2	8	-17.44	0.63	13.81	0.13	3.83	0.03
Scomberoides lysan	Scly	0	4	1	0	5	-16.32	0.08	13.13	0.12	3.80	0.03
Scomberoides tol	Scto	1	0	0	0	1	-16.29		13.10		3.84	
Sphyraena barracuda	(e)	0	0	1	0	1	-17.88		12.54		3.68	
Sphyraena jello	Spje	0	1	2	0	3	-15.92	0.97	13.27	0.99	3.74	0.01
Sphyraena sp.	(e)	0	0	1	0	1	-15.56		12.09		3.73	
Strongylura strongylura	(q)	0	0	2	0	2	-16.49	0.25	13.68	0.16	3.74	0.04

Species	Sp. Abbrv./ Refs.	n					$\delta^{13}C$		$\delta^{15}N$		C:N	
		Coral Reefs	Mangrove-Coral	Mangrove Estuary	Mangrove Creeks	Total	Mean	± SE	Mean	± SE	Mean	± SE
Tylosurus crocodilus crocodilus	Tycc	0	0	1	1	2	-18.13	0.96	13.05	0.14	3.73	0.02

***Sp. abbrv. is the abbreviation of fish species for PCA in Fig. 3.5 b), while Ref. is the references used to assign fish species into their respective feeding guild as stomach content data were not available and empty.**

References: (a) Kanou & Sano, 2004; (b) closest species to *C. subviridis*; (c) Nanjo, Kohno, & Sano, 2008; (d) Cole, Pratchett, & Jones, 2008; (e) Abrantes & Sheaves, 2009; (f) Liu, 1997; (g) Then, 2009; (h) Maugé, 1986; (i) Munroe, 2001; (j) Sasaki, 2001; (k) Shinnaka et al., 2007; (l) Smith-Vaniz, 1999; (m) Raje, 1993; (n) Beukers-Stewart & Jones, 2004; (o) Hajisamae, Chou, & Ibrahim, 2004; (p) Salini, Blaber, & Brewer, 1994; (q) Baker & Sheaves, 2005.

3.6 Fish nutrition by habitat zones

Pooled $\delta^{13}C$ values of fishes by zones show incremental mean values (enrichment) from the Up zone (-18.49 ‰) to the Coral zone offshore (-14.79 ‰), whereas the $\delta^{15}N$ value increased from Up zone (9.98 ‰) to the Mg-C zone (12.20 ‰) and declined slightly towards offshore Coral zone (11.93 ‰) (Table 3.14, see Fig. 3.6b). The change in both $\delta^{13}C$ and $\delta^{15}N$ values was, however less than 4‰. Significant differences among zones were however detected for both $\delta^{13}C$ (Kruskal-Wallis, χ^2 = 33.76, df = 3, $p < 0.001$) and $\delta^{15}N$ (χ^2 = 53.66, df = 3, $p < 0.001$) values of the sampled fishes. Post hoc pairwise analysis showed that all pairs of both C and N isotope values differed ($p<0.05$) among zones except for the following: Mg-C – Mg ($\delta^{13}C$), Coral – Mg-C and Mg – Up ($\delta^{15}N$) ($p>0.05$) (Table 3.12; see Appendix III). Their pooled $\delta^{13}C$ values were all close to those of coral zooxanthellae and benthic diatoms, except the mangrove creeks zone (Fig. 3.6).

Table 3.14: Mean ± SE isotopes of $\delta^{13}C$, $\delta^{15}N$ and C/N ratio of fish tissues pooled according to different habitat zones where they were collected; coral reefs (Coral); mixed mangroves-coral (MgC); mangrove estuary (Mangrove) and mangrove creeks (Up). n = number of samples.

Habitat Zones	n	$\delta^{13}C$ ‰		$\delta^{15}N$ ‰		C:N	
		Mean	± SE	Mean	± SE	Mean	± SE
Coral	67	-14.79	0.29	11.93	0.23	3.78	0.01
Mg-C	137	-16.08	0.29	12.20	0.20	3.90	0.05
Mangrove	81	-16.64	0.23	10.67	0.17	3.78	0.01
Up	37	-18.49	0.63	9.98	0.41	3.83	0.02

3.7 Source contribution to zooplankton and fish nutrition

SIAR results revealed that carbon contribution to zooplankton nutrition was almost equal from all four primary sources (Fig.3.7). Zooxanthellae were the highest carbon contributor in the Coral zone (median = 31.1%), followed by the Mg-C (29.8%), Mg (26.3%) and Up (13.8%) zones. The highest carbon contribution to zooplankton nutrition in the Up zone came from mangrove detritus (38.8%). Mangrove detritus also contributed to zooplankton nutrition in the Mg zone (27.9%), Mg-C zone (22.5%) and Coral zone (26.3%). Zooplankton dependence on seston was about equal for all zones; 25.2% in Coral, 25.3% in Mg-C, 25.0% in both Mg and Up zones, respectively. Benthic diatoms were the lowest carbon contributor to zooplankton nutrition; 17.4% in the Coral zone, 23.2% in the Mg-C, 21.6% in the Mg zone and 18.3% in the Up zone (see Appendix IV).

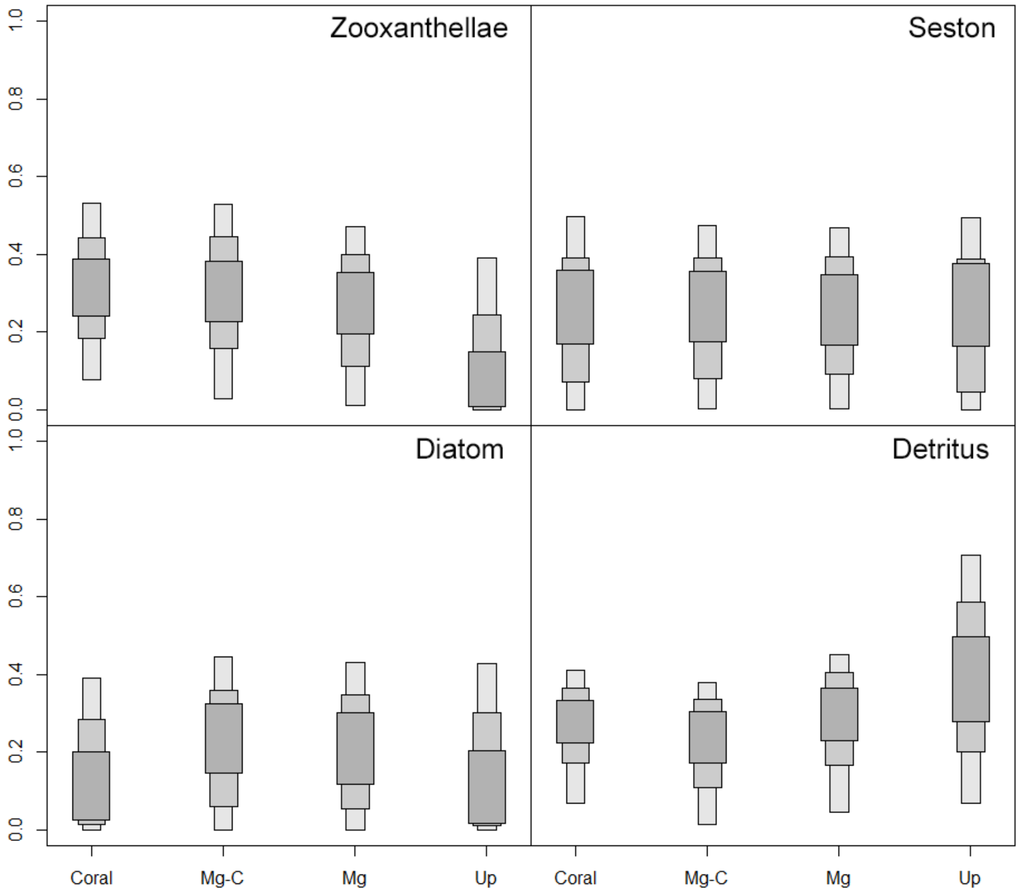

Figure 3.7: Proportional contribution of coral zooxanthellae (Zooxanthellae); phytoplankton (Seston); benthic diatoms (Diatom) and mangrove (Detritus) to zooplankton nutrition in different habitat zones of a coupled coral-mangrove ecosystem in Langkawi, Malaysia. Coral reefs (Coral); mangroves-corals (Mg-C); mangrove (Mg) and mangrove creeks (Up) as determined by Stable Isotope Analysis in R. Bars shows Bayesian confidence intervals of 50, 75 and 95%.

In contrast to zooplankton, the SIAR results indicated a relatively high source contribution of carbon from zooxanthellae to fish followed by seston in all four zones

(Fig. 3.8). Zooxanthellae contribution in the Coral zone was the highest at approximately 90.0% (median) and decreased in the landward direction through the mixed Mg-C zone (72.7%), the Mg zone (63.7%), to the Up zone (38.4%). Seston was the second major contributor to fish nutrition, with an estimated 6.0% in the Coral zone which increased to 22.6%, 32.0% and 38.4% in the Mg-C, Mg and Up zones respectively. In the Up zone, fish dependence on carbon was multi-sourced with benthic diatoms contributing 8.1% and mangrove 12.7%. Carbon signature of mangrove and benthic diatoms was very weak for fishes in the Coral, Mg-C and Mg zones, where both carbon sources contributed less than 2.9% (see Appendix V).

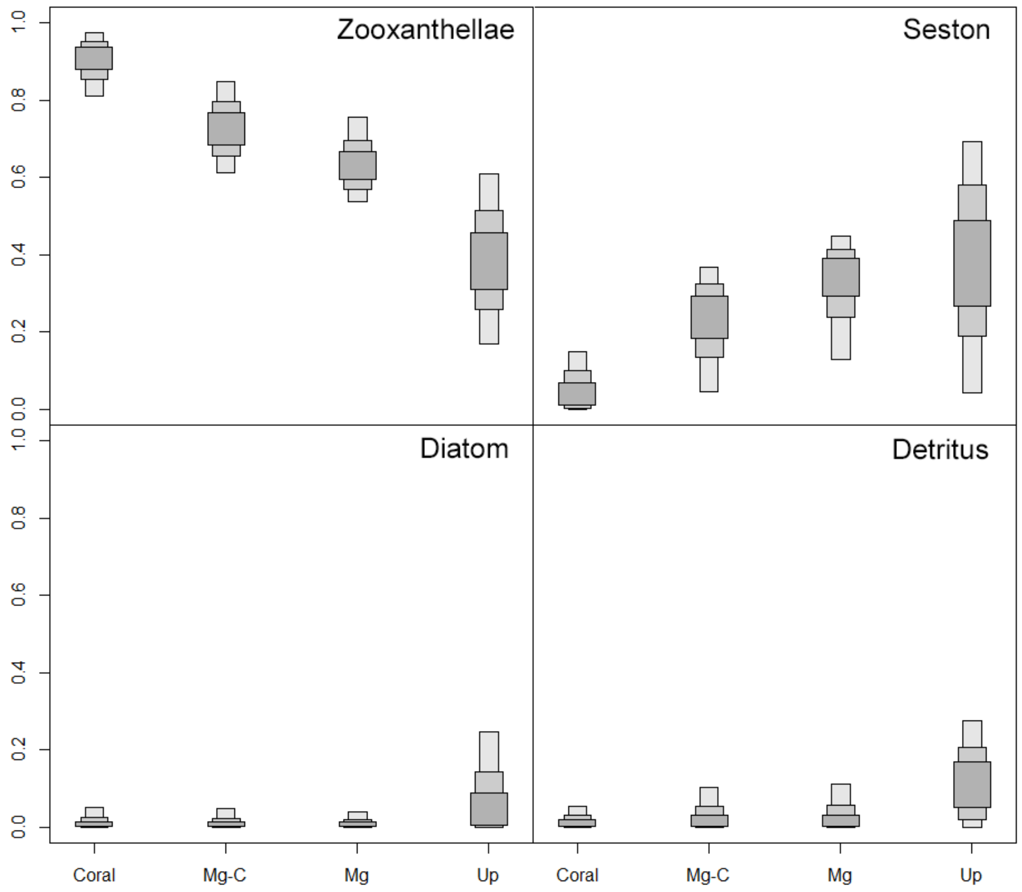

Figure 3.8: Proportional contribution of coral zooxanthellae (Zooxanthellae); phytoplankton (Seston from mangrove creeks, mangrove estuary and nearshore waters); benthic diatoms (Diatom) and mangrove (Detritus) to fish nutrition in different habitat zones of a coupled coral-mangrove ecosystem in Langkawi, Malaysia. Coral reefs (Coral); mangroves-corals (Mg-C); mangroves (Mg) and mangrove creeks (Up) as determined by Stable Isotope Analysis in R. Bars shows Bayesian confidence intervals of 50, 75 and 95%.

4.0 DISCUSSION

4.1 Source contribution to fish community

The present study suggests that fishes in Langkawi's coral-mangrove system are supported by carbon sources primarily from coral zooxanthellae and secondarily from phytoplankton. Their combined contribution amounts to 96% in both the Coral and Mg zones (Fig. 3.8), whereas mangrove and benthic diatom contribution are only marginal. Zooxanthellae contribution to fish nutrition is important in three of the zones, Coral, Mg-C and Mg, which was estimated to be more than 60% but recorded a drop in the Up zone. While zooxanthellae contribution shows a decreasing trend, phytoplankton contribution increases towards the Up zone. Mangrove detritus and diatom contribution becomes more apparent in the Up zone with reduced zooxanthellae contribution. Similarly, zooxanthellae contribution to zooplankton nutrition also follows a decreasing trend towards the Up zone (Fig. 3.7) suggesting the outer limits of its contribution from the coral reefs.

The mean $\delta^{13}C$ signature of fishes in the Up zone (-18.49 ‰) was more depleted than coral zooxanthellae (-15.39 ‰) and closer to seston (-21.64 ‰) as compared to the fishes from other zones. The mean $\delta^{13}C$ signature of bottom sediment at the Mg zone (-26.30 ‰) was distant from that of coral zooxanthellae, further indicating that the energy transport fell short at the estuary. Evidently, distance limits the influence of coral zooxanthellae which decreases towards the Up zone, i.e. farther from the reef. Nevertheless, coral zooxanthellae are still an important source of nutrition for fish communities in the Mg and Up zones due to their significant contribution of 63.7% and 38.4%, respectively (Fig. 3.8). This suggests an energy transfer pathway from zooxanthellae to consumers.

However, direct energy transfer from coral zooxanthellae to consumers is uncertain except for only one specialized group of species that directly feed on the coral polyps (Cole et al., 2008; Glynn, Stewart, & McCosker, 1972). Another possible pathway of energy transfer is via the extrusion of coral mucus (Yonge, 1972). The $\delta^{13}C$ value of coral mucus was reported to be similar and corresponds to the $\delta^{13}C$ value of coral zooxanthellae (Naumann et al., 2010). Our zooxanthellae $\delta^{13}C$ value of -15.4 ± 0.33 ‰ (see Table 12) is within the range of reported coral mucus signatures of between -15.2 ± 0.20 ‰ to -16.2 ± 0.40 ‰ (Naumann et al., 2010; Wyatt et al., 2012).

The above finding suggests that the trophic pathway from source to consumers is likely mediated by coral mucus. This pathway is possible because zooxanthellae are responsible for supplying trophic energy through translocation of the photosynthetically fixed carbon to their coral hosts (Muscatine, McCloskey, & Marian, 1981; Tremblay, Grover, Maguer, Legendre, & Ferrier-Pagès, 2012). Up to half of this assimilated carbon is eventually used to synthesize coral mucus, which is then released into the water column (Crossland, Barnes, & Borowitzka, 1980; Davies, 1984). Mucus can be slowly dislodged from the coral surface by water movements (Coles & Strathmann, 1973) and becomes suspended mucus flocs. Subsequently, the mucus flocs are then enriched by particulate organic matter (POM) and microbial communities that adhered to them (Wild et al., 2004; Naumann et al., 2009). Hence, mucus flocs with lower C/N ratio are a potential food source for zooplankton (Richman et al., 1975), invertebrates and fishes (Johannes, 1967; Benson & Muscatine, 1974; Wyatt 2011).

Phytoplankton appears to be the next preferred food by both zooplankton and fish, especially those in the Mg and Up zones. In a recent study, Chew et al. (2012) showed that phytoplankton supplies energy to zooplankton and small fishes in turbid water mangroves. The findings of Chew et al. (2012) suggest that zooplankton can assimilate carbon from phytoplankton (Fig. 3.7). The phytoplankton contribution to the fish community, however, is likely through multiple trophic levels of prey and predator known as trophic relay (Kneib, 2002). Stomach content analysis of large fish revealed that small fishes are among the highly consumed food items (Fig. 3.7), suggesting that large piscivores and carnivores consumed these small phytoplankton-dependent fishes. This is further evident from the $\delta^{13}C$ values of the predators, which were slightly closer to phytoplankton than the rest. Aside from that, their $\delta^{13}C$ values reflect that of fishes in the Mg and Up zones (Fig. 3.6) where zooxanthellae contribution decreased. This trophic pathway is feasible because predators are found deep in the mangroves (Table 3.13).

Despite this, mangrove contribution to overall nutrition of fish appeared to be marginal. For instance, zooplankton in the Up zone relies on detritus to almost 40%, but this is not highly reflected in fishes, suggesting that the mangrove detritus contribution is limited. This concurs with some insights from stable isotopic studies of late that dispute the mangrove detritus contribution to higher consumers (fishes). Bouillon et al. (2008) discussed and reviewed that contribution of mangrove detritus is uncertain and most likely to be very limited. Studies have also shown that when nutritious sources are made available, some species tend to rely on these sources rather than mangrove detritus (Nagelkerken et al., 2008). Despite being rich in carbon, the nitrogen content in mangrove leaf litter is often poor (high C/N ratio), which reduces its nutritious value. The high tannin and lignocellulose content of mangrove detritus causes indigestion and makes it less favourable food for consumers with the exception of some crab species (Wolcott & O’Connor, 1992).

Overall, stomach content analysis revealed that benthic invertebrates (prawns, polychaetes, crabs) and small fishes are the most highly consumed food items of predatory fishes (Fig. 3.5). Stomach content of the demersal and benthic species revealed a high volume of prawns and other crustaceans consumed, whereas the pelagic fish *C. cunning* (both in mangrove and coral reef) revealed the presence of prawns. This indicates that carbon was derived from benthic invertebrates, which could consume settled coral mucus, benthic diatoms and phytoplankton. The intermediate $\delta^{13}C$ signatures of predatory fishes (invertivores, carnivores and piscivores) lying between that of phytoplankton and coral zooxanthellae sources (Fig. 3.6) showed that the consumed benthic invertebrates were dependent on a mix of the aforementioned sources. This also explains the significant contributions of these sources to the fish community in the mangrove (Fig. 3.7). These observations illustrate that the energy transfer from sources to fish consumers is via trophic relay.

4.2 Physical attributes of biotopes

In the Coral zone, the turbidity is considered moderate to high, with a mean of 25.87 ± 7.70 NTU (Table 3.2) and ranging from as low as one NTU to as high as 140 NTU. This is comparable to reports from natural turbid water reefs in Palumo Shoals, Australia, where a turbidity range of 0 – 15 NTU is considered low while high turbidity ranges from 50 – 200 NTU (Anthony & Larcombe, 2000; Larcombe, Costen, & Woolfe, 2001). High turbidity attenuates the light intensity, which is necessary for endosymbiotic zooxanthellae for photosynthesis. Consequently, the physiological processes and growth of the host corals are affected (Rogers, 1990). However, various adaptive mechanisms by corals have enabled them to survive in naturally turbid and high sedimentation environments (Anthony & Larcombe, 2000). Under turbid conditions, corals are known to produce substantial amounts of mucus to waft sediments from their surface (Hubbard & Pocock, 1972; Yonge, 1972; Schuhmacher, 1977). A similar condition is observed in northeast Langkawi as the coral reefs here are exposed to moderate turbidity, yet are low in mortality (Table 3.10). Nonetheless, the turbidity measurements between coral reef and mangrove estuary are highly similar resulting in an equal predation risk in both habitats which offer fishes larger refuge area.

Turbidity has been hypothesized to reduce the predation pressure because it affects the reaction rate of predatory fishes (Benfield & Minello, 1996; Nagelkerken, 2009b). The suspended particles in turbid water scatter light and reduce the reaction rate of predators, consequently reducing predatory success (Benfield & Minello, 1996). It is one of the factors that attract fishes to brackish water habitats such as mangroves (Cyrus & Blaber, 1987). The similar turbidity recorded in the coral reefs of northeast Langkawi suggests that fishes would be equally attracted to coral reefs.

Although some of the differences in physical attributes, the zones are significant according to statistical test, their difference margins are small, less than 2 units (Table 3.2). All measurements of the attributes were carried out as point measurements which may not reflect the long term average, but are sufficient to measure the general physical attributes of the seawater because they did not fluctuate drastically, with exception of turbidity. Furthermore, measurements were carried out at many stations, resulting in large numbers of replicates, thus giving a sufficient representation for each attribute. The numbers of replicates for DO and ORP were different from the rest of the attributes because the respective probes malfunctioned during the sampling trip and did not record any readings (Table 3.1).

The measured physical attributes for coral reefs showed that the seawater condition was relatively stressful for corals. All readings of attributes for the mangroves were, however, within the tolerable range because of their robustness and high degree of ecological stability (Alongi, 2008; Giesen, Wulffraat, Zieren, & Scholten, 2006). Mangroves are well adapted to harsh environment as they are subjected to daily tidal changes in temperature, salinity and different degrees of anoxia (Alongi, 2008). Conversely, coral reefs are steno-tolerant and susceptible to even small environmental changes (Kleypas et al., 1999). The measurements of the attributes in coral reef area were found to be slightly lower than the reported measurements from Tuba Island, south of Langkawi (Jalal et al., 2009), except for temperature, which was slightly higher in the present study. The temperature readings recorded in the present study were within the range as reported by Chong et al. (2005) at the same study sites. The temperature in all zones reflect the typical tropical seawater temperature that ranges from 18 °C to 30 °C, except in the Coral zone, which was measured at the mean of 30.57 °C. This mean temperature, however, is still within the upper thermal limit of scleractinian corals of between 31°C to 32°C, hence the coral reef of Langkawi can be categorised as a marginal reef (Kleypas et al., 1999).

The reef's mean salinity, which was measured at 31.96 ± 0.16 ppt, is considered low and corroborates its categorisation as a marginal reef. Coral reefs with average seawater salinity outside the range of 34 – 36 ppt will be affected in their coral physiology (Moberg, Nyström, Kautsky, Tedengren, & Jarayabhand, 1997; Sheppard, Davy, & Pilling, 2009). The relatively low salinity of the Coral zone in Langkawi is due to freshwater inputs from nearby small rivers. However, tidal exchanges create a salinity gradient from the Coral zone to the zone nearest to freshwater source, the Up zone. Nevertheless, some corals have been reported to be able to adapt and respond physiologically to salinity changes (Moberg et al., 1997), especially in an area where there are freshwater discharges from rivers, similar to the conditions found in the present study site.

The measured pH ranged from 7 – 8, within the basic water condition of nearshore seawater. The readings corroborate with the reported pH from Tuba Island, (Jalal et al., 2009) which generally indicates no signs of detrimental water quality with regards to acidity. However, since the present site is within a limestone karst, any fall in pH could have been buffered by this. Although no measurement of water chemical attributes was done, Rau et al. (2007) reported that an increase of pH (acidity reduced) is possible from accelerated weathering of limestone through seawater reactions with bicarbonate ions.

The measurements of the physical attributes of the current study sites provide useful information of the present status of both coral and mangrove habitats. This information allows an evaluation of whether development affects the marine organisms and consequently, the connectivity between both habitats. Kilim area has been developed over the past decade, especially during the last few years, since the declaration of its Geoforest Park by UNESCO in 2007. These developments, together with the expansion of the tourism industry, have contributed to the habitat degradation, especially of the mangrove forests (Shahbudin et al., 2012). Jalal et al. (2009) reported that due to the rapid development of the tourism industry, Langkawi has been increasingly polluted during the last decade. Thus, it is imperative to conserve and protect both habitats from further destruction.

4.3 Fish species diversity and similarity

It is evident that the coral reef biotope comprising of only Coral zone is connected to the mangrove biotope, which consists of the Mg and Up zones (Fig. 2.3) via overlapping or common fish fauna (Fig. 4.1). For the present study, the zones at both ends of the study area, the Coral zone (TC, KC and SC) and the Up zone (TMU, KMU and SMU) show similar species composition indicating reef fish species are likely to move deeper into the mangrove zone and vice versa (Fig. 3.1). Although the fish species composition in the Mg zone (TM, KM, PM and SM) is slightly different from that of the Coral zone, the linkage distance of disagreement is only marginally more than half or 61% (Fig. 3.2), indicating that there is still some degree of similarity in fish species composition between the zones. The overall total of 31 common species listed (Table 3.6) constitutes approximately 21.1% of the total fish species (including species from previous studies) in northeast Langkawi. The number of common fishes is considerably high, as other studies have reported as low as only 6 and up to 43 common species between reef and non-reef habitats (Laroche et al., 1997; Nagelkerken, 2007; Thollot & Thollot, 1992). This indicates a fairly high exchange of fish species between habitats, which suggests a relatively strong connectivity (Chittaro et al., 2005).

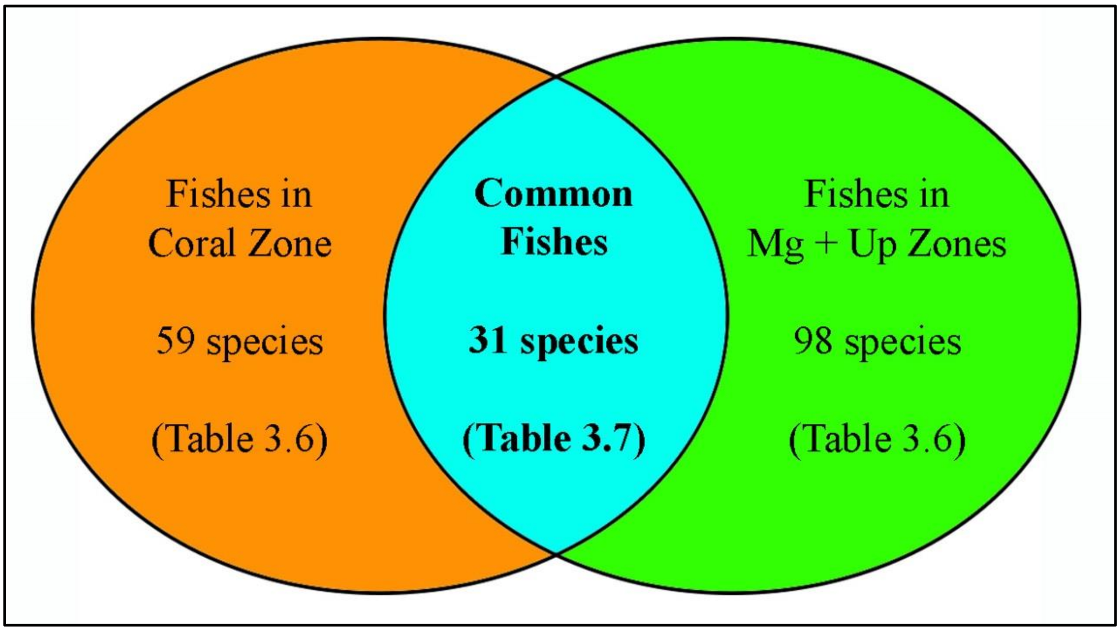

Figure 4.1: Illustration of the 31 common species (blue region) found in both coral (orange region) and mangrove (green region) biotopes. Full species names as given in the indicated table.

The relatively high turbidity levels at Langkawi's north eastern reefs and mangroves result in low visibility, rendering the visual census of fishes by diving difficult. Thus, traditional fishing methods such as gill nets and "bubu" had to be used in both coral reefs and mangroves to reduce spatial bias. The same fishing methods had similarly been applied to both biotopes to enable comparisons (Nagelkerken, 2007). Nevertheless, catches from these passive fishing gears are expected to be an underestimation (Olin, Malinen, & Ruuhijärvi, 2009). Although there were replicates, the incorporation of other species from previous studies into the present species list has resulted in a clearer picture of the fish composition in the study area. Chong et al. (2005) reported a total of 91 species from 42 families, 6 species less but 4 families more than in the present study of 97 species from 38 families. The incorporation of the previous data, however, included an additional 50 species from 14 families to the current study resulting in a total of 147 species from 52 families. This indicates that only 41 species from previous studies were caught again, whereas 56 species had not been previously found. Such a large difference is attributed to the use of different types of fishing gear as well as spatial differences in sampling. The fishing gear deployed in previous studies included gill nets, cast net and beam trawl, while only gill nets and "bubu" were deployed in the present study. Furthermore, Chong et al. (2005) carried out their sampling within a shorter period and did not sample in the coral reef. Although gill net is highly selective, it is deemed a more suitable gear and effective in catching actively mobile fishes (Olin et al. 2009), which are the key subjects connecting the biotopes. Ideally, a combination of multiple active and passive types of fishing gear should be used to ensure adequate catch of fishes (Olin et al., 2009; Rotherham, Johnson, Kesby, & Gray, 2012). Nevertheless, applying multiple fishing gear requires a higher amount of labour. Thus, the combination of previous and present results is the best way to obtain a comprehensive species list for both biotopes in northeast Langkawi.

The nursery function of mangroves in northeast Langkawi is explored by differentiating between juvenile and adult sizes for each common species listed in this study (Table 3.7). Several studies compared only the densities of juveniles in different biotopes in order to determine the significance of nursery habitat, but such generalizations should be avoided (Chittaro et al., 2005). A habitat could still potentially serve as a nursery despite having lower densities of juvenile species and vice versa. Some studies found that densities of juveniles were either equivalent or lower in the nursery than in the adult habitat (Chittaro et al., 2005; Dorenbosch et al., 2005; Nagelkerken & van der Velde, 2002). Similarly, although not in the terms of density measures, the present study has shown that the number of common species in the juvenile stage was low. Only 10 species in the mangrove biotope and 9 in the coral reef are in the juvenile stage, which constituted half the number of species in the adult stage for both of the biotopes (Fig. 4.2). This is an interesting finding because a higher number of juvenile species was expected due to the higher species richness in the mangrove biotope (Mg and Up zones) which was 98 species as compared to the coral reef biotope of 59 species (Fig. 4.1). Even this is an interesting finding because it contrasts with the findings reported elsewhere, where higher fish species richness was reported in the reefs than in the mangroves (Dorenbosch et al., 2005; Honda, Nakamura, Nakaoka, Uy, & Fortes, 2013; Jaxion-Harm et al., 2012; Nagelkerken & van der Velde, 2002).

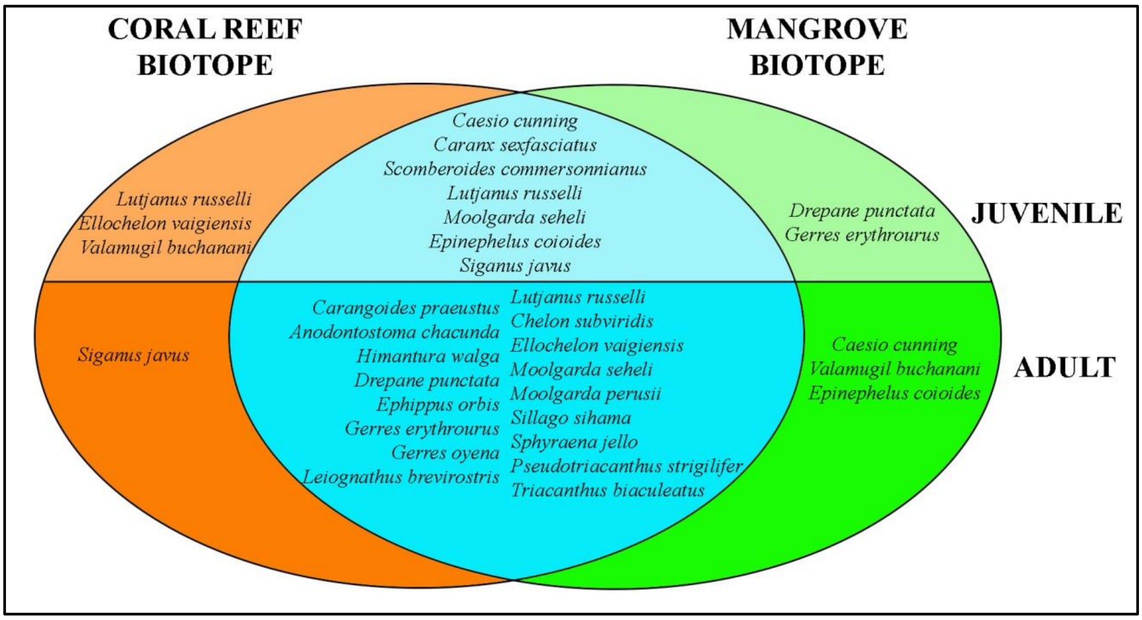

Figure 4.2: Illustration of juvenile and adult common species between coral reef and mangrove biotopes. The lighter shades of colour on the above represent species in juvenile stage while the lower darker shades of colour represent species in adult stage. The blue region represents the species that had both the juvenile and adult stages in both habitats.

The often reported nursery value of mangroves to fish may be contentious given that the measuring methods are surrounded with controversy. Standard measurements could not be agreed on among ecologists, causing difficulty in determining the value of mangroves as nursery habitat for fish from other biotopes (Nagelkerken et al., 2008). Chittaro et al. (2005) suggested that if a biotope functions as a nursery, there should be exchanges and movements of fish between nursery and adult habitats, giving a high number of overlapping common fishes. This was indeed observed in the present study for northeast Langkawi (Fig. 4.2). Nevertheless, frequent movements of species may also be due to utilisation of different biotopes only as a temporary habitat for daily feeding or sheltering (Sheaves, 2005; Unsworth et al., 2008). Consequently, the function of mangroves serving as nursery area to fishes from adjacent habitats could not be concluded, but perhaps they function either as spawning or feeding area or even as shelter.

4.4 Habitat complexity

Among the factors that attract fishes to mangroves are the root architectural complexity and the turbid condition (Cocheret de la Morinière et al., 2004; Cyrus & Blaber, 1987; Nagelkerken et al., 2010; Verweij et al., 2006). Fishes are attracted to high habitat complexity and turbid conditions of mangrove because they provide canopy cover for them to seek refuge from predators (Benfield & Minello, 1996; Cocheret de la Morinière et al., 2004; Dominici-Arosemena & Wolff, 2005; Gratwicke & Speight, 2005).

The structurally complex roots of the mangrove are known to provide important shelter to fishes (Nagelkerken et al., 2008). The pneumatophores or prop roots were reported to harbour a higher density of smaller fishes and juveniles (Cocheret de la Morinière et al., 2004; Nagelkerken et al., 2008). The mangrove roots are able to provide effective refuge because the dense root and complex network make it difficult for large predators to manoeuvre around them, hence restricting their movements. Cocheret de la Morinière et al. (2004) acknowledged that aside from mangrove roots providing shelter, the mangrove also provides above water canopy shading. The shade reduces light in the already turbid water, allowing prey fish to effectively hide from visual predators. Some fishes utilise the shade to make them invisible to predators while they maintain escape routes without being hindered by the root structures (Cocheret de la Morinière et al., 2004). Other fishes will optimize both shade and root structures to continuously stay hidden from predators.

Besides functioning as structural complexity, mangrove roots are also known to host a number of invertebrates such as shrimps, crabs, gastropods and zooplankton (Hogarth, 2007), which serve as food to some fishes. These invertebrates were observed in the stomach content of some of the sampled fishes (Fig. 3.5). As such, availability of food resources is another factor that attracts smaller fishes to mangroves (Nagelkerken, 2009b). The combined factors of structural complexity and food provision suggest that mangroves serve as a suitable feeding ground to the smaller sized fishes.

Unlike the usually clear water coral reef, the coral reef in northeast Langkawi is also subjected to higher turbidity, similar to the adjacent mangroves. Despite the turbid condition, the reefs are healthy with a live substrate cover of 53.8%. This is due to the high cover of approximately 47.21% of stress-tolerant corals (Fig. 3.3). In addition, the coral reefs habitat complexity with a *mH'* index of 2.06 is higher than that of 1.77 for habitats in Indonesia with similar stress-tolerant corals but with lower coral cover (Edinger & Risk, 2000). The turbid water condition combined with the high habitat complexity due to the rugosity of massive and submassive hard corals, offers a large refuge space for fishes (Gratwicke & Speight, 2005). Although most studies reported that reef fishes seek shelter in the mangroves (Cocheret de la Morinière et al., 2004; Laegdsgaard & Johnson, 2001), fish in northeast Langkawi have the option to utilise both coral reefs and mangroves instead of just either one. This is particularly beneficial when the mangrove forest is uncovered due to low tide and fish can move into the coral reefs. This likely encourages fish species to move between coral reefs and mangroves to avoid predators, resulting in the presence of the same species in both habitats. Consequently, this creates a connected complex ecosystem of coupled biotopes via fish movements.

There are at least six reported variables that can be used to measure habitat complexity in coral reefs namely rugosity of substratum, substratum diversity, variety of refuge holes, height of substratum structure, live cover including corals and percentage of hard substratum (Gratwicke & Speight, 2005). It is a difficult task to examine all six variables simultaneously, especially in turbid waters where visibility is low, such as in the present study site. Thus, the variable examined in the present study was substratum diversity based on the Shannon – Wiener diversity index (mH') of the coral morphology (Edinger & Risk, 2000; Roberts & Ormond, 1987), which was used to represent habitat complexity.

Three morphological types of corals, namely massive, sub-massive, and platy-massive corals make up the category of stress-tolerators, based on the r-K-S strategy (Table 2.1and Fig. 3.4). Corals of these morphologies are usually slow growing and tolerant to high sedimentation (Edinger & Risk, 2000; Rogers, 1990). The massive and sub-massive, dome-liked morphologies are more efficient in removing sediments than the flattened types because they do not easily accumulate sediments on the surface (Rogers, 1990), and thus are categorised as stress-tolerators. These features support the marginal reef categorisation in northeast Langkawi coral reefs based on physical attributes.

The tolerance of massive, submassive and platy-massive hard corals to a stressful environment contributes to higher substratum diversity and hence the habitat complexity. This is evident as they have a combined live cover of 36.6 % (Fig. 3.4), which also provides a substantial hiding area for fishes. Fishes are able to hide under the overhangs on the edges of the massive and submassive corals, whereas some can take advantage of the canopy effect of the platy-massive corals (Kerry & Bellwood, 2011).

The more structurally complex branching corals are less susceptible to sediment stress, but they are mechanically fragile to strong water hydrodynamics. The low cover of branching coral in the present study suggests that the study site is exposed to strong underwater currents, which helps to remove sedimentation on coral surfaces and thus increases the survival ability of the corals. This further suggests that sediment particles are often re-suspended due to the underwater currents as evident from the moderate level of turbidity (Larcombe & Woofle, 1999). Strong water movement also aids the removal of sediment and particle trapping mucus from the coral surface.

The moderate turbidity level conforms to the 33% cover of silt of the bottom substratum (Fig. 3.4). The higher cover of silt over sand and the increasing gradient of turbidity from the Up zone to the Coral zone suggest that sediments are transported offshore from land and mangroves. However, despite the high silt cover, coral mortality is low (mortality index, M=0.15), which connotes that the tolerant corals have thrived and adapted to the harsh environment.

In brief, the combination of structurally complex mangroves, substantial substratum diversity of live coral, and turbid waters in both biotopes makes the ecosystem in northeast Langkawi a relatively complex habitat. Fish communities can benefit from such a habitat, which provides a good refuge or shelter. Compared to habitat that exists as a single entity, a coupled complex habitat provides a larger area of shelter that will likely attract more fishes. On those accounts, connected biotopes function as shelter for the fish communities and encourage fish movements between them.

4.5 Synthesis of findings

Since $\delta^{13}C$ signatures (greater than -18 ‰) of all trophic groups in the fish community are substantially enriched with respect to mangrove and phytoplankton carbon sources, and SIAR estimated high zooxanthellae contribution (50-80%) to fish nutrition, even in the mangrove estuary (Fig. 3.8), the coral reefs of northeast Langkawi must play an important trophic role. The study area has no known seagrass beds as also corroborated by its previous survey of biodiversity (Glenda, Azhar, Chong, & Phang, 2005). The question is how could energy from zooxanthellae in the coral reefs fuel secondary production in the adjacent mangrove estuaries? Three possible scenarios of energy transfer from the coral reefs to the adjacent mangroves are deduced, which are not necessarily mutually exclusive.

These scenarios are contingent upon the following facts and suppositions:

(1) direct energy transfer from coral zooxanthellae to consumers is only evident in a specialized group of species, such as fishes from the families of Balistidae, Chaetodontidae, Scaridae and Tetraodontidae (Cole et al., 2008; Glynn et al., 1972); nevertheless in this study, none or very few of these species were present (Table 3.5).

(2) Zooxanthellae may however support the reef system via extrusion of their mucus which is of nutritional value (Wild et al., 2004; Yonge, 1972). Copious extrusions of coral mucus were observed in the study sites (Fig. 4.3). The zooxanthellae $\delta^{13}C$ value of -15.4 ± 0.33 ‰ (see Table 1) in the present study is very close to the coral mucus signature of -15.6 ± 0.21 ‰ and -15.7 ± 0.20 ‰ reported by Wyatt et al. (2012) and Naumann et al. (2010) respectively. This study postulates that the $\delta^{13}C$ signature of zooxanthellae should reflect that of the coral mucus. This is supported by the fact that zooxanthellae supply trophic energy by translocating photosynthetically fixed carbon to their coral hosts (Muscatine et al., 1981; Tremblay et al., 2012) and half of this assimilated carbon is used to synthesize coral mucus (Crossland et al., 1980; Davies,

1984; Wild et al., 2004). In addition, Meikle et al. (1988) suggested that most of the translocated carbon ends up as mucus extruded by corals. Therefore, this study hypothesizes that coral mucus mediates the energy transfer from zooxanthellae to fish in the coupled habitats of Langkawi.

(3) Suspended mucus flocs are often enriched by particulate organic matter (POM) and microbial communities that adhere to them (Naumann et al., 2009; Wild et al., 2004). Hence, mucus flocs are a potential nutritional source for zooplankton (Richman et al., 1975), invertebrates and fishes (Benson & Muscatine, 1974; Johannes, 1967; Wyatt, 2011).

Scenario 1 - In this scenario, the mucus produced by corals in the reef, sloughs off as mucus flocs, which are advected by water currents into the adjacent mangrove estuaries, where they support the resident consumers (Fig. 4.4a).

Scenario 1 is attractive based on the evidence from other studies. Under turbid water condition such as in northeast Langkawi, corals are known to produce substantial amount of mucus to waft sediments from their surface (Hubbard & Pocock, 1972; Schuhmacher, 1977; Yonge, 1972). Such mucus is slowly dislodged from the coral surface by water movements, as reported by Coles and Strathmann (1973), and also observed in the present study sites (Fig. 4.3). Mucus flocs have been recorded to be swept from reefs into adjacent lagoon waters (Coles & Strathmann, 1973; Marshall, 1965; Wild et al., 2004).

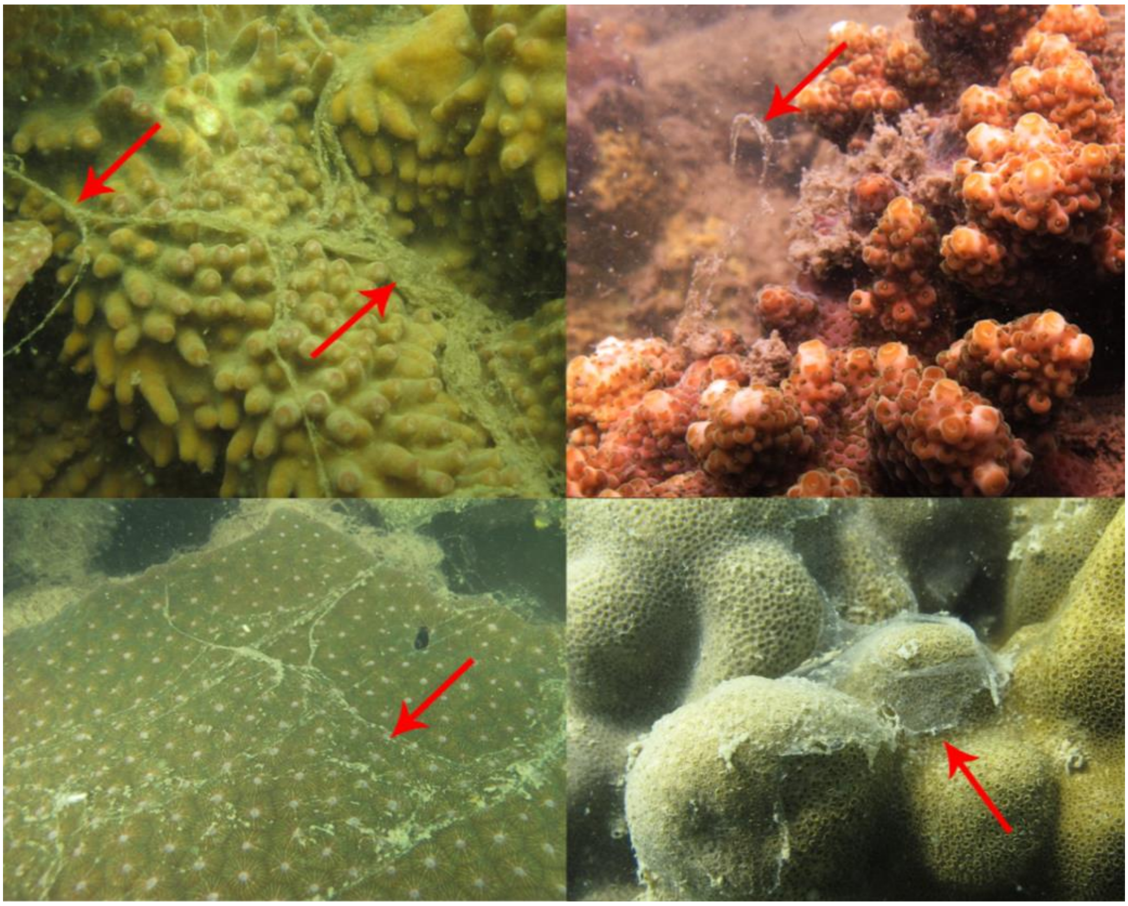

Figure 4.3: Arrows pointing to observed mucus layers being dislodged from the coral surface of 4 different species: a) *Turbinaria* sp., b) *Acropora* sp., c) *Diploastrea heliopora* and d) *Porites* sp**.**

Assuming the $\delta^{13}C$ signature of zooxanthellae as indicative of coral mucus, the outwelling of coral mucus flocs into the mangrove estuaries shows a decreasing trend with distance (i.e. from Coral to Up zone) as evident from its contribution to both zooplankton (Fig. 3.7) and fish (Fig. 3.8) nutrition. Zooplankton in the Mg and Up zones respectively utilized 30% and <15% of their total nutritional requirement from coral mucus, the rest from phytoplankton and mangrove detritus. The unutilized coral mucus flocs are less likely to have settled down on the estuary bed because the bottom sediments do not reflect mucus, but instead a mangrove signature (Table 3.11 and Fig. 3.6). Interestingly too, the coral reef sediments ($\delta^{13}C$ = -21.22 ‰) also did not reflect mucus but rather seston (-21.64 ‰) settling onto the sea bed. Thus, the outwelled mucus energy is likely utilized via the pelagic pathway instead of the benthic pathway.

Scenario 2 - In this scenario, the mucus produced in the coral reef is consumed by resident zooplankton. The reef zooplankton is then transported into the mangrove estuaries, where they serve as direct or intermediary food for higher consumers (Fig. 4.4b). Hence, Scenario 2 invokes the export of zooplankton rather than coral mucus as proposed in Scenario 1.

Reef zooplankton export to the adjacent mangrove estuaries is plausible since mucus (zooxanthellae)-fed zooplankton in the Coral zone was quite similar to that in the Mg-C zone in terms of $\delta^{13}C$ signature (Fig. 3.7). However, the exported reef zooplankton cannot be distinguished from the mangrove zooplankton; indeed, it is likely that mangrove zooplankton is similarly exported to coral reefs given the mangrove signature in “reef plankton” (Fig. 3.7). Nonetheless, since zooplankton nutrition was only 10-30% dependent on coral mucus, and estuarine fishes (Mg-C and Mg zone) had $\delta^{13}C$ signatures that indicated higher (50-80%) mucus contribution, the fishes must have gained mucus carbon from other sources. This seems unlikely via the benthic pathway as stated above. Nonetheless, the stomach content analysis revealed that benthic invertebrates (prawns, polychaetes, crabs) and small fishes, but not zooplankton, were the most consumed food of predatory fishes (Fig. 3.5). These benthic fauna and small fishes are likely supported by phytoplankton and benthic diatoms (Table 3.11). The pelagic coral mucus pathway, whether in Scenario 2 or Scenario 1, takes place via zooplankton, planktivorous fish (e.g. engraulids, ambassids, clupeids), carnivores (e.g, groupers, snappers, carangids) and piscivores (e.g. barracudas, queenfish, tenpounder). Engraulids and ambassids are small fodder fish often occurring in dense schools.

Scenario 3 - Unlike Scenario 1 and 2, which invoke the outwelling of mucus or mucus-fed zooplankton from reef to mangrove, Scenario 3 explains zooxanthellae contribution by fish movements between coral reef and mangrove estuaries (Fig. 4.4c).

Movements of fish feeding in the reef area and then into the mangrove area, and vice versa, can explain the strong $\delta^{13}C$ signature of zooxanthellae in both reef and mangrove fishes (Fig. 3.8), which cannot be fully explained in Scenario 1 and 2. Mucus or zooplankton drift alone cannot account for the much higher contribution of zooxanthellae carbon in most fishes since few species are zooplankton feeders. Scenario 3 assumes that fishes in the reef feed directly on zooxanthellae and/or coral mucus, or indirectly, that fauna that feeds on zooxanthellae or mucus. This scenario appears to be feasible given the $\delta^{13}C$ values of fish species and the evidence that such species were found in both reef and mangrove; these included 31 species or 40% of the 77 fish species listed in Table 3.13, e.g. grey mullets such as *Valamugil buchanani*, the pickhandle barracuda, *Sphyraeno jello,* the talang queenfish, *Scomberoides commersonianus*, the yellowtail fusilier *Caesio cunning*, and the bigeye trevally, *Caranx sexfasciatus*. However, some species are known to exhibit ontogenetic migration between reef and mangrove, e.g. Russell’s snapper, *Lutjanus russelli* (Sheaves, 1995), John’s snapper *L. johnii* (Tanaka et al., 2011) and the orange-spotted grouper, *Epinephelus coioides* (Sheaves, 1995).

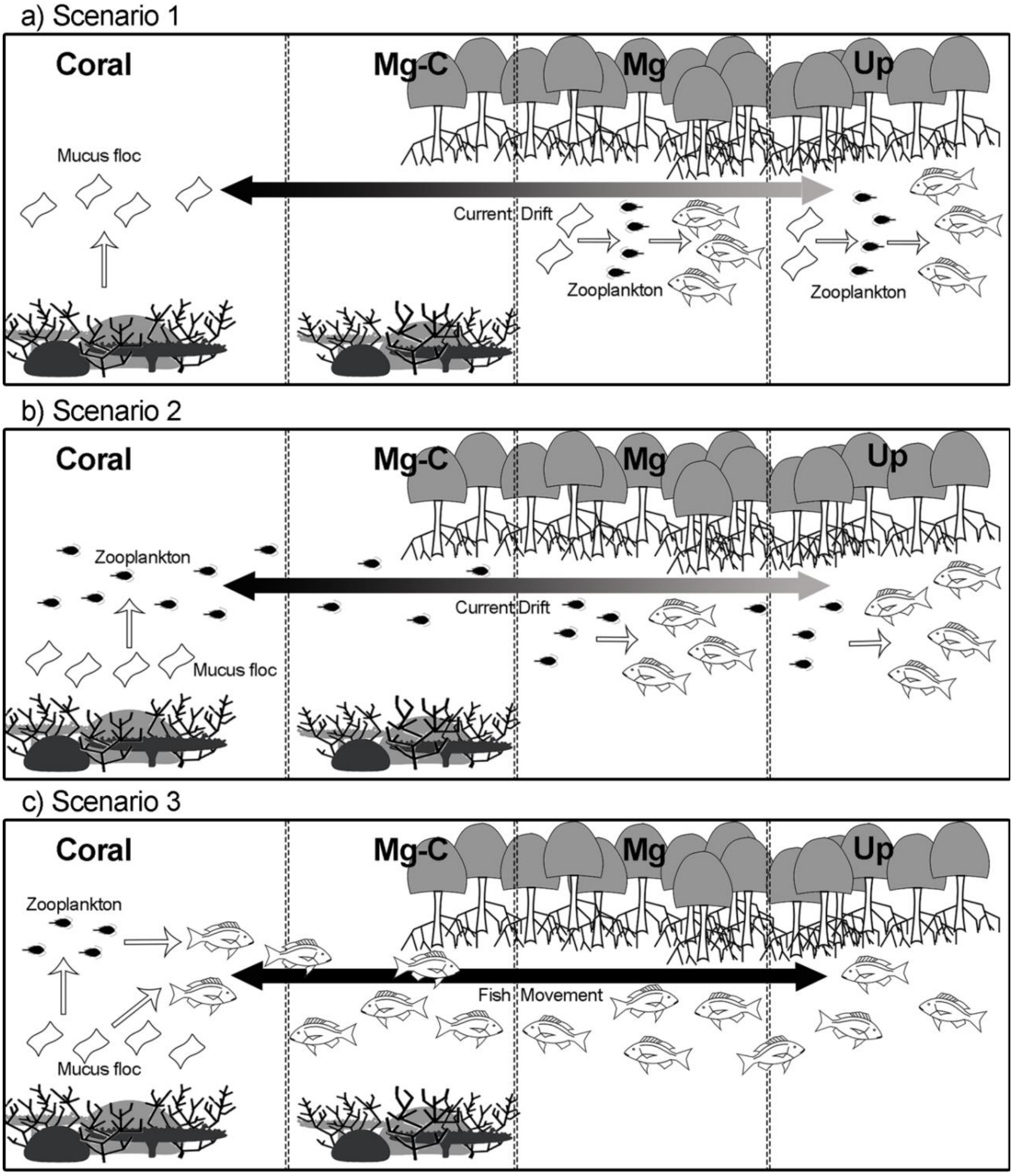

Figure 4.4: Diagrammatic representation of three possible scenarios of energy transfer from coral reef (Coral) to the adjacent mangrove (Mg + Up). (a) Scenario 1: coral mucus is outwelled into mangrove by currents and consumed by mangrove zooplankton and fishes; (b) Scenario 2: coral mucus is consumed by reef zooplankton before they are advected into mangrove and consumed by fishes. (3) Scenario 3: coral reef fishes feed on either coral mucus or/and zooplankton, migrate into mangroves and vice versa.

4.6 Limitations of present study and suggestions for future research

1) Sampling methods did not successfully sample, for each species, fish of adequate size range (small and big). This possibly indicates that the gill nets (mesh sizes are 1 inch and 2 inches) used were not able to sample all life history stages of fishes in the corals and mangroves. Hence, the nursery ground value of both corals and mangroves to fishes could not be determined.

2) The gill nets could not sample adequately the benthic and demersal fish. Some may be caught by the fish pots. Hence, this study largely missed the demersal or benthic species as well as not being able to quantify fish abundance. Therefore, the species richness for both habitats is likely underestimated even with data from previous studies. A more quantitative fishing method was not used because fishing gears such as trawl nets is unavailable on the island.

3) This study has alluded to the major contribution of coral zooxanthellae as primary producer in the study area, and that outwelled coral mucus or/and zooplankton that feed on it, fuel the adjacent mangrove waters based on stable isotope analysis. Unfortunately, the study did not sample the drifted mucus flocs to show the connectivity directly. The study was also unable to obtain the $\delta^{13}C$ signature of coral mucus. Future studies employing superior techniques and methods of study are required to test the derived hypothesis.

4) It would be more informative and beneficial if the trophic pathway from primary sources could be traced via the various trophic levels. This study did not

include the many invertebrates consumed by the fish (from stomach content analysis) in the SIA, such as prawns, crabs and polychaetes, which are likely the trophic intermediaries. This limitation was due to the lack of suitable gears as well as the limited duration of the study.

5) Although this study attempted to at least sample the copepod fauna (major zooplankton) for SIA, and to link them to their potential food of coral mucus and phytoplankton, it did not attempt to sample and sort the other zooplankton fauna due to time constraints. A more comprehensive sampling and analysis of other zooplankton would be beneficial in future studies.

5.0 CONCLUSION

The fish communities of Langkawi’s northeastern coral reefs and mangroves have a relatively high number of common (similar) species. Despite turbid waters due to the island’s rapid development, the nearshore coral reefs still display relatively high habitat complexity. These coral reefs coupled to the adjacent mainland mangroves offer a suitable refuge, feeding and habitat space for marine fishes.

One major finding is that coral zooxanthellae and phytoplankton are the two primary food sources in the coupled coastal biotopes. Based on stable isotope analysis, outwelled coral mucus and zooplankton are hypothesized to be the vehicles of transfer of source energy from coral zooxanthellae to fish consumers. However, the study has put forward three possible scenarios of habitat connectivity involving not only the transport of mucus and zooplankton, but also fish movements. Thus, the present findings support the two hypotheses of ecological connectivity set up in the study.

This study has provided important information for the management of Langkawi’s northeastern coral reefs and mangroves in general, and Kilim Geoforest Park in particular. The study suggests that a comprehensive integrated management strategy or plan should be instituted immediately in view of the fast developing tourism industry, which has given impetus to the island’s rapid development, in order to protect the health and function of the remaining mangroves and coral reef ecosystems of Langkawi island.

REFERENCES

Abrantes, K., & Sheaves, M. (2009). Food web structure in a near-pristine mangrove area of the Australian Wet Tropics. *Estuarine, Coastal and Shelf Science*, 82(4), 597–607.

Affendi, Y. A. (2005). Coral reefs of North East Pulau Langkawi. *Malaysian Journal of Science*, *24*, 145 – 158.

Alamaru, A., Loya, Y., Brokovich, E., Yam, R., & Shemesh, A. (2009). Carbon and nitrogen utilization in two species of Red Sea corals along a depth gradient: Insights from stable isotope analysis of total organic material and lipids. *Geochimica et Cosmochimica Acta, 73*(18), 5333–5342.

Alongi, D. M. (2002). Present state and future of the world's mangrove forests. *Environmental Conservation, 29,* 331 - 349

Alongi, D. M. (2008). Mangrove forests: Resilience, protection from tsunamis, and responses to global climate change. *Estuarine, Coastal and Shelf Science, 76*(1), 1–13.

Alongi, D. M. (2009). *The Energetics of Mangrove Forests*. (p. 216).

Anthony, K. R. N., & Larcombe, P. (2000). Coral reefs in turbid waters: sediment-induced stresses in corals and likely mechanisms of adaptation. In *9th International Coral Reef Symposium* (p. 6).

Baker, R., & Sheaves, M. (2005). Redefining the piscivore assemblage of shallow estuarine nursery habitats. *Marine Ecology Progress Series, 291*, 197–213.

Benfield, M. C., & Minello, T. J. (1996). Relative effects of turbidity and light intensity on reactive distance and feeding of an estuarine fish. *Environmental Biology of Fishes, 46*(2), 211–216.

Benson, A. A., & Muscatine, L. (1974). Wax in coral mucus : Energy transfer from corals to reef fishes. *Limnology and Oceanography, 19*(5), 810–814.

Beukers-Stewart, B., & Jones, G. (2004). The influence of prey abundance on the feeding ecology of two piscivorous species of coral reef fish. *Journal of Experimental Marine Biology and Ecology, 299,* 155–184.

Birkeland, C. (1997). *Life and Death of Coral Reefs* (p. 536). New York: Chapman & Hall.

Bouillon, S., Connolly, R. M., & Lee, S. Y. (2008). Organic matter exchange and cycling in mangrove ecosystems: Recent insights from stable isotope studies. *Journal of Sea Research, 59*(1-2), 44–58.

Bouillon, S., Mohan, P. C., Sreenivas, N., & Dehairs, F. (2000). Sources of suspended organic matter and selective feeding by zooplankton in an estuarine mangrove ecosystem as traced by stable isotopes. *Marine Ecology Progress Series, 208*, 79–92.

Burke, L., Reytar, K., Spalding, M., & Perry, A. (2011). *Reefs at Risk Revisited. Defenders* (Vol. 74, p. 114).

Burke, L., Selig, E., & Spalding, M. (2002). *Reefs at risk in Southeast Asia. World Fishing* (p. 72). World Resources Institute Washington, DC.

Caley, M. J., & St John, J. (1996). Refuge availability structures assemblages of tropical reef fishes. *Journal of Animal Ecology*, *65*(4), 414–428.

Chew, L. L., Chong, V. C., Tanaka, K., & Sasekumar, A. (2012). Phytoplankton fuel the energy flow from zooplankton to small nekton in turbid mangrove waters. *Marine Ecology Progress Series, 469*, 7–24.

Chittaro, P. M., Usseglio, P., & Sale, P. F. (2005). Variation in fish density, assemblage composition and relative rates of predation among mangrove, seagrass and coral reef habitats. *Environmental Biology of Fishes*, *72*(2), 175–187.

Chong, V. C. (2007a). Importance of coastal habitats in sustaining the fisheries industry. In P. E. Chee, M. N. Devakie, I. Ismail, A. L. Faazaz, N. Ahmad Adnan, D. R. Shahuntala, & A. R. Masazurah (Eds.), *Proceedings of the 4th National Fisheries Symposium* (pp. 113–137). Penang: Fisheries Research Institute.

Chong, V. C. (2007b). Mangroves-fisheries linkages - the Malaysian perspective. *Bulletin of Marine Science, 80*(3), 755–772.

Chong, V. C., Lee, P. K. Y., & Lau, C. M. (2010). Diversity, extinction risk and conservation of Malaysian fishes. *Journal of Fish Biology, 76*(9), 2009–66.

Chong, V. C., Affendy, N., Ooi, A. L., & Chew, L. L. (2005). The fishes and invertebrates of mangrove estuaries in Northeastern Langkawi Island. *Malayan Nature Journal*, *57*(2), 193–208.

Chong, V. C., Ng, Y. P., Hairi, B. J., Ooi, A. L., Chew, L. L., Amirah, M., & Affendy, N. (2005). Update of the fishes of mangrove and coastal waters of Northeastern Langkawi. *Malaysian Journal of Science, 24*, 167–184.

Cocheret de la Morinière, E., Nagelkerken, I., van der Meij, H., & van der Velde, G. (2004). What attracts juvenile coral reef fish to mangroves: habitat complexity or shade? *Marine Biology, 144*(1), 139–145.

Cocheret de la Morinière, E., Pollux, B. J. A., Nagelkerken, I., Hemminga, M. A., Huiskes, A. H. L., & van der Velde, G. (2003). Ontogenetic dietary changes of coral reef fishes in the mangrove-seagrass-reef continuum : stable isotopes and gut-content analysis. *Marine Ecology Progress Series, 246*, 279–289.

Cole, A. J., Pratchett, M. S., & Jones, G. P. (2008). Diversity and functional importance of coral-feeding fishes on tropical coral reefs. *Fish and Fisheries, 9*, 286–307.

Coles, S. L., & Strathmann, R. (1973). Observations on coral mucus “flocs” and their potential trophic significance. *Limnology and Oceanography, 18,* 673–678.

Crossland, C. J., Barnes, D. J., & Borowitzka, M. a. (1980). Diurnal lipid and mucus production in the staghorn coral *Acropora acuminata*. *Marine Biology, 60*(2-3), 81–90.

Cyrus, D., & Blaber, S. (1987). The influence of turbidity on juvenile marine fish in the estuaries of Natal, South Africa. *Continental Shelf Research, 7,* 1411–1416.

Davies, P. S. (1984). The role of zooxanthellae in the nutritional energy requirements of *Pocillopora eydouxi. Coral Reefs,* (2), 181–186.

De Bruin, G. H. P., Russel, B. C., & Bogusch, A. (1994). *The marine fisheries resources of Sri Lanka*. In *FAO Species Scientific Field Guide for Fishery Purposes*. Rome.

Dominici-Arosemena, A., & Wolff, M. (2005). Reef fish community structure in Bocas del Toro (Caribbean, Panama): Gradients in habitat complexity and exposure. *Caribbean Journal of Science, 41*(3), 613–637.

Dorenbosch, M. (2006). *Connectivity Between Fish Assemblages of Seagrass Beds, Mangroves and Coral Reefs: Evidence from the Caribbean and the western Indian Ocean*. (Doctoral dissertation, Radboud University Nijmegen, The Netherlands). Retrieved from https://repository.ubn.kun.nl/bitstream/2066/27459/1/27459.pdf

Dorenbosch, M., Grol, M. G. G., Christianen, M., Nagelkerken, I., & van der Velde, G. (2005). Indo-Pacific seagrass beds and mangroves contribute to fish density and diversity on adjacent coral reefs. *Marine Ecology Progress Series, 302*, 63–76.

Dorenbosch, M., van Riel, M. C., Nagelkerken, I., & van der Velde, G. (2004). The relationship of reef fish densities to the proximity of mangrove and seagrass nurseries. *Estuarine, Coastal and Shelf Science, 60*(1), 37–48.

Drazen, J. C., Popp, B. N., Choy, C. A., Clemente, T., De Forest, L., & Smith, K. L. J. (2008). Bypassing the abyssal benthic food web: Macrourid diet in the eastern North Pacific inferred from stomach content and stable isotopes analyses. *Limnology and Oceanography, 53*(6), 2644–2654

Ducklow, H. W., & Mitchell, R. (1979). Composition of mucus released by coral reef coelenterates. *Limnology and Oceanography, 24*(4), 706–714.

Edinger, E. N., & Risk, M. J. (2000). Reef classification by coral morphology predicts coral reef conservation value. *Biological Conservation, 92,* 1–13.

English, S., Wilkinson, C., & Baker, V. (1997). Line Intercept Transect. In *Survey Manual for Tropical Marine Resources*. Townsville.

Fishcher, W., & Whitehead, P. J. P. (Eds.). (1974). *FAO species identification sheets for fisheries purposes. Eastern Indian Ocean and Western Central Pacific, Volume 1 – 4*. Rome: FAO.

Froese, R., & Pauly, D. (2012). FishBase. *World Wide Web electronic publication*. Retrieved from www.fishbase.org

Giesen, W., Wulffraat, S., Zieren, M., & Scholten, L. (2006). *Mangrove Guidebook For Southeast Asia* (p. 186).

Gillanders, B. M., Able, K. W., Brown, J. A., Eggleston, D. B., & Sheridan, P. F. (2003). Evidence of connectivity between juvenile and adult habitats for mobile marine fauna: an important component of nurseries. *Marine Ecology Progress Series*, *247*, 281–295.

Glenda, N., Azhar, H., Chong, V. C., & Phang, S. M. (2005). The scientific, social, environmental and economic value of N.E. Langkawi: an overview of the present status. *Malaysian Journal of Science*, *24*, 219–235.

Glynn, P. W. (1997). Bioerosion and Coral-Reef Growth: A Dynamic Balance. In C. Birkeland (Ed.), *Life and Death of Coral Reefs* (pp. 68–95). Chapman & Hall.

Glynn, P. W., Stewart, R. H., & McCosker, J. E. (1972). Pacific Coral Reefs of Panama: Structure, distribution and predators. *Geologische Rundschau*, *61*(2), 483–519.

Gomez, E. D., Alino, P. M., Yap, H. T., & Licuanan, W. Y. (1994). A review of the status of Philippine reefs. *Marine Pollution Bulletin*, *29*(94), 62–68.

Gratwicke, B., & Speight, M. R. (2005). The relationship between fish species richness, abundance and habitat complexity in a range of shallow tropical marine habitats. *Journal of Fish Biology*, (66), 650–667.

Grol, M. G. G., Nagelkerken, I., Rypel, A. L., & Layman, C. A. (2011). Simple ecological trade-offs give rise to emergent cross-ecosystem distributions of a coral reef fish. *Oecologia*, *165*(1), 79–88.

Hajisamae, S., Chou, L. M., & Ibrahim, S. (2004). Feeding habits and trophic relationships of fishes utilizing an impacted coastal habitat, Singapore. *Hydrobiologia*, *520*, 61–71.

Hobson, K. A., & Wassenaar, L. I. (1999). Stable isotope ecology: an introduction. *Oecologia*, *120*(3), 312–313.

Hoegh-Guldberg, O., Hoegh-Guldberg, H., Veron, J. E. N., Green, A., Gomez, E. D., Lough, J., … Oliver, J. (2009). *The Coral Triangle and Climate Change: Ecosystems, People and Societies at Risk* (p. 276). Brisbane.

Hoeksema, B. (2007). Delineation of the Indo-Malayan centre of maximum marine biodiversity: the Coral Triangle. In W. Renema (Ed.), *Biogeography, Time, and Place: Distributions, Barriers, and Islands* (pp. 117–178). Springer.

Hogarth, P. J. (2007). *The Biology of Mangroves and Seagrasses* (p. 272). Oxford University Press.

Honda, K., Nakamura, Y., Nakaoka, M., Uy, W. H., & Fortes, M. D. (2013). Habitat use by fishes in coral reefs, seagrass beds and mangrove habitats in the Philippines. *PloS One*, *8*(8), 10.

Hubbard, J. A. E. B., & Pocock, Y. P. (1972). Sediment rejection by recent scleractinian corals: a key to palaeo-environmental reconstruction. *Geologische Rundschau*, *61*, 598–626.

Huxham, M., Kimani, E., & Augley, J. (2004). Mangrove fish: a comparison of community structure between forested and cleared habitats. *Estuarine, Coastal and Shelf Science*, *60*(4), 637–647.

Hyslop, E. J. (1980). Stomach contents analysis-a review of methods and their application. *Journal of Fish Biology*, *17*(4), 411–429.

Jalal, K. C. A., Faizul, H. N. N., Kamaruzzaman, B. Y., Shahbudin, S., Alam, M. Z., & Irwandi, J. (2009). Studies on physico-chemical characteristics and sediment environment along the coastal waters in Pulau Tuba, Langkawi, Malaysia. *Aquatic Ecosystem Health & Management*, *12*(4), 350–357.

Jaxion-Harm, J., Saunders, J., & Speight, M. R. (2012). Distribution of fish in seagrass, mangroves and coral reefs: life-stage dependent habitat use in Honduras. *Rev. Biol. Trop*, *60*(June), 683–698.

Johannes, R. E. (1967). Ecology of organic aggregates in the vicinity of a coral reef. *Limnology and Oceanography*, *12*(2), 189–195.

Jones, D. L., Walter, J. F., Brooks, E. N., & Serafy, J. E. (2010). Connectivity through ontogeny: fish population linkages among mangrove and coral reef habitats. *Marine Ecology Progress Series*, *401*, 245–258.

Kanou, K., & Sano, M. (2004). Food habits of fishes on unvegetated tidal mudflats in Tokyo Bay, central Japan. *Fisheries Science*, *70*, 978–987.

Kelley, R. A. (2009). *Indo Pacific Coral Finder*. Townsville: BYOGUIDES

Kelley, R., & Ryan, G. (2000). Crossing the Blue Highway. Australia: Australian Coral Reef Society.

Kerry, J. T., & Bellwood, D. R. (2011). The effect of coral morphology on shelter selection by coral reef fishes. *Coral Reefs*, 415–424.

Kimura, S., Satapoomin, U., & Matsuura, K. (Eds.). (2009). *Fishes of Andaman Sea, west coast of southern Thailand* (p. vi+346). Tokyo: National Museum of Nature and Science, Tokyo.

Kleypas, J. A., McManus, J. W., & Menez, L. A. B. (1999). Environmental limits to coral reef development : Where do we draw the line? *American Zoologist*, *39*, 146–159.

Kneib, R. T. (2002). Salt marsh ecoscapes and production transfers by estuarine nekton in the southeastern United States. In M. P. Weinstein & D. A. Kreeger (Eds.), *Concepts and Controversies in Tidal Marsh Ecology* (pp. 267–291). New York, Boston, Dordrecht, London, Moscow: Kluwer Academic Publishers.

Laegdsgaard, P., & Johnson, C. (2001). Why do juvenile fish utilise mangrove habitats? *Journal of Experimental Marine Biology and Ecology*, *257*(2), 229–253.

Larcombe, P., Costen, A., & Woolfe, K. J. (2001). The hydrodynamic and sedimentary setting of nearshore coral reefs, central Great Barrier Reef shelf, Australia: Paluma Shoals, a case study. *Sedimentology*, *48*(4), 811–835.

Larcombe, P., & Woofle, K. J. (1999). Increased sediment supply to the Great Barrier Reef will not increase sediment accumulation at most coral reefs. *Coral Reefs*, (18), 163–169.

Laroche, J., Baran, E., & Rasoanandrasana, N. (1997). Temporal patterns in a fish assemblage of a semiarid mangrove zone in Madagascar. *Journal of Fish Biology*, *51*(1), 3–20.

Liu, J. (1997). Morphological comparison of the feeding apparatus of three co-occurring species of ponyfishes (Leiognathidae). *Chinese Journal of Oceanology and Limnology*, *15*(3), 224–226.

Lugendo, B. R., Nagelkerken, I., Jiddawi, N., Mgaya, Y. D., & van der Velde, G. (2007). Fish community composition of a tropical nonestuarine embayment in Zanzibar, Tanzania. *Fisheries Research*, *73*, 1213–1223.

Lugendo, B. R., Nagelkerken, I., van der Velde, G., & Mgaya, Y. D. (2006). The importance of mangroves , mud and sand flats , and seagrass beds as feeding areas for juvenile fishes in Chwaka Bay , Zanzibar : gut content and stable isotope analyses. *Journal of Fish Biology*, *69*, 1639–1661.

Marguillier, S., van der Velde, G., Dehairs, F., Hemminga, M. A., & Rajagopal, S. (1997). Trophic relationships in an interlinked mangrove-seagrass ecosystem as traced by $\delta^{13}C$ and $\delta^{15}N$. *Marine Ecology Progress Series*, *151*, 115–121.

Marshall, N. (1965). Detritus over the reef and its potential contribution to adjacent waters of Eniwetok Atoll. *Ecology*, *46*(3), 343–344.

Maugé, L. A. (1986). Gobiidae. In J. Daget, J. P. Gosse, & D. F. E. Thys van denAudenaerde (Eds.), *Check-list of the freshwater fishes of Africa (CLOFFA)* (pp. 358–388). Brussels; Tervuren; Paris: ISNB; MRAC; ORSTOM. Retrieved from http://www.fishbase.org/summary/Acentrogobius-caninus.html

McCook, L. J., Almany, G. R., Berumen, M. L., Day, J. C., Green, A. L., Jones, G. P., … Thorrold, S. R. (2009). Management under uncertainty: guide-lines for incorporating connectivity into the protection of coral reefs. *Coral Reefs*, *28*(2), 353–366.

McCutchan, J. H. J., Lewis, W. M. K., & McGrath, C. C. (2003). Variation in trophic shift for stable isotope ratios of carbon, nitrogen, and sulfur. *Oikos*, *102*(2), 378–390.

Meikle, P., Richards, G. N., & Yellowlees, D. (1988). Structural investigations on the mucus from six species of coral. *Marine Biology*, *99*, 187–193.

Minagawa, M., & Wada, E. (1984). Stepwise enrichment of ^{15}N along food chains: Further evidence and the relation between δ^{15}N and animal age. *Geochimica et Cosmochimica Acta*, *48*, 1135–1140.

Moberg, F., & Folke, C. (1999). Ecological goods and services of coral reef ecosystems. *Ecological Economics*, *29*(2), 215–233.

Moberg, F., Nyström, M., Kautsky, N., Tedengren, M., & Jarayabhand, P. (1997). Effects of reduced salinity on the rates of photosynthesis and respiration in the hermatypic corals *Porites lutea* and *Pocillopora damicornis*. *Marine Ecology Progress Series*, *157*, 53–59.

Mohsin, A. K. M., & Ambak, M. A. (1996). *Marine Fishes and Fisheries of Malaysia and Neighbouring Countries*. Serdang: University Pertanian Press.

Mooney, H. A., Cropper, A., Capistrano, D., Carpenter, S. R., Chopra, K., Dasgupta, P., … Zhao, S. (2005). *Ecosystems and Human Well-Being: Wetlands and Water Synthesis : A Report of the Millennium Ecosystem Assessment*. (J. Sarukhan & A. Whyte, Eds.) (p. 68). Washington, DC.: World Resources Institute.

MPP-EAS. (1999). *Total economic valuation: coastal and marine resources in the Straits of Malacca* (p. 52). Quezon City, the Philippines.

Muller-Parker, G., & D’Elia, C. F. (1997). Interactions Between Corals and Their Symbiotic Algae. In *Life and Death of Coral Reefs* (pp. 96–113). New York: Chapman & Hall.

Mumby, P. J., Edwards, A. J., Ernesto Arias-Gonzalez, J., Lindeman, K. C., Blackwell, P. G., Gall, A., … Llewellyn, G. (2004). Mangroves enhance the biomass of coral reef fish communities in the Caribbean. *Journal of Geophysical Research*, *108*(B5), 533–536.

Mumby, P. J., & Hastings, A. (2008). The impact of ecosystem connectivity on coral reef resilience. *Journal of Applied Ecology*, *45*(3), 854–862.

Munroe, T. A. (2001). Cynoglossidae. In K. E. Carpenter & V. H. Niem (Eds.), *FAO species identification guide for fishery purposes. The living marine resources of the Western Central Pacific. Volume 6. Bony fishes part 4 (Labridae to Latimeriidae), estuarine crocodiles, sea turtles, sea snakes and marine mammals* (pp. 3381–4218). Rome: FAO.

Muscatine, L., McCloskey, L. R., & Marian, R. E. (1981). Estimating the daily contribution of carbon from zooxanthellae to coral animal respiration. *Limnology and Oceanography*, *26*(4), 601–611.

Muscatine, L., Porter, J. W., & Kaplan, I. R. (1989). Resource partitioning by reef corals as determined from stable isotope composition I. δ^{13}C of zooxanthellae and animal tissue vs depth. *Marine Biology*, *193*(100), 185 – 193.

Nagelkerken, I. (2007). Are non-estuarine mangroves connected to coral reefs through fish migration? *Bulletin of Marine Science, 80*(3), 595–607.

Nagelkerken, I. (Ed.). (2009a). *Ecological Connectivity among Tropical Coastal Ecosystems* (p. 615). Springer Science+Business Media.

Nagelkerken, I. (2009b). Evaluation of nursery function of mangroves and seagrass beds for tropical decapods and reef fishes: Patterns and underlying mechanisms. In I. Nagelkerken (Ed.), *Ecological Connectivity among Tropical Coastal Ecosystems* (pp. 357 – 399). Springer Science+Business Media.

Nagelkerken, I., Blaber, S. J. M., Bouillon, S., Green, P., Haywood, M., Kirton, L. G., … Somerfield, P. J. (2008). The habitat function of mangroves for terrestrial and marine fauna: A review. *Aquatic Botany, 89*(2), 155–185.

Nagelkerken, I., De Schryver, A. M., Verweij, M. C., Dahdouh-Guebas, F., van der Velde, G., & Koedam, N. (2010). Differences in root architecture influence attraction of fishes to mangroves: A field experiment mimicking roots of different length, orientation, and complexity. *Journal of Experimental Marine Biology and Ecology*, *396*(1), 27–34.

Nagelkerken, I., Dorenbosch, M., Verberk, W., Cocheret de la Morinière, E., & van der Velde, G. (2000). Importance of shallow-water biotopes of a Caribbean bay for juvenile coral reef fishes: patterns in biotope association, community structure and spatial distribution. *Marine Ecology Progress Series*, *202*, 175–192.

Nagelkerken, I., & van der Velde, G. (2002). Do non-estuarine mangroves harbour higher densities of juvenile fish than adjacent shallow-water and coral reef habitats in Curacao (Netherlands Antilles)? *Marine Ecology Progress Series*, *245*, 191–204.

Nagelkerken, I., & van der Velde, G. (2004a). Are Caribbean mangroves important feeding grounds for juvenile reef fish from adjacent seagrass beds? *Marine Ecology Progress Series*, *274*, 143–151.

Nagelkerken, I., & van der Velde, G. (2004b). Relative importance of interlinked mangroves and seagrass beds as feeding habitats for juvenile reef fish on a Caribbean island. *Marine Ecology Progress Series*, *274*, 153–159.

Nagelkerken, I., van der Velde, G., Gorissen, M. W., Meijer, G. J., Van't Hof, T., & den Hartog, C. (2000). Importance of mangroves, seagrass beds and the shallow coral reef as a nursery for important coral reef fishes, using a visual census technique. *Estuarine, Coastal and Shelf Science*, *51*(1), 31–44.

Nakamura, Y., Horinouchi, M., Shibuno, T., Tanaka, Y., Miyajima, T., Koike, I., … Sano, M. (2008). Evidence of ontogenetic migration from mangroves to coral reefs by black-tail snapper *Lutjanus fulvus*: stable isotope approach. *Marine Ecology Progress Series*, *355*(2001), 257–266.

Nakamura, Y., Kawasaki, H., & Sano, M. (2007). Experimental analysis of recruitment patterns of coral reef fishes in seagrass beds: Effects of substrate type, shape, and rigidity. *Estuarine, Coastal and Shelf Science*, *71*(3-4), 559–568.

Nanjo, K., Kohno, H., & Sano, M. (2008). Food habits of fishes in the mangrove estuary of Urauchi River, Iriomote Island, southern Japan. *Fisheries Science*, *74*, 1024–1033.

Naumann, M. S., Mayr, C., Struck, U., & Wild, C. (2010). Coral mucus stable isotope composition and labeling: experimental evidence for mucus uptake by epizoic acoelomorph worms. *Marine Biology*, *157*(11), 2521–2531.

Naumann, M. S., Richter, C., el-Zibdah, M., & Wild, C. (2009). Coral mucus as an efficient trap for picoplanktonic cyanobacteria–implications for pelagic–benthic coupling in the reef ecosystem. *Marine Ecology Progress Series*, *385*, 65–76.

Nyunja, J., Ntiba, M., Onyari, J., Mavuti, K., Soetaert, K., & Bouillon, S. (2009). Carbon sources supporting a diverse fish community in a tropical coastal ecosystem (Gazi Bay, Kenya). *Estuarine, Coastal and Shelf Science*, *83*(3), 333–341.

Ogden, J. C., & Gladfelter, E. H. (1983). *Coral reefs, seagrass beds and mangroves: Their interaction in the coastal zones of the Caribbean* (p. 133). St. Croix.

Okamura, K., Tanaka, K., Siow, R., Man, A., Kodama, M., & Ichikawa, T. (2010). Spring tide hypoxia with relation to chemical properties of the sediments in the Matang Mangrove Estuary, Malaysia. *Japan Agricultural Research Quarterly: JARQ*, *44*(3), 325–333.

Olin, M., Malinen, T., & Ruuhijärvi, J. (2009). Gillnet catch in estimating the density and structure of fish community—Comparison of gillnet and trawl samples in a eutrophic lake. *Fisheries Research*, *96*(1), 88–94.

Parnell, A. C., Inger, R., Bearhop, S., & Jackson, A. L. (2010). Source partitioning using stable isotopes: coping with too much variation. *PloS One*, *5*(3), 5.

Peterson, B. J., & Fry, B. (1987). Stable isotopes in ecosystem studies. *Annual Review of Ecology and Systematics*, *18*(1), 293–320.

Polis, G. A. (1994). Food webs, trophic cascades and community structure. *Australian Journal of Ecology*, *19*, 121–136.

Post, D. M. (2002). Using stable isotopes to estimate trophic position: models, methods, and assumptions. *Ecology*, *83*(3), 703–718.

Raje, S. G. (1993). Some aspects of biology of *Alepes djedaba* (Forsskal) from Veraval, Gujarat. *Indian Journal of Fisheries*, *40*(3), 189 – 192.

Rau, G. H., Knauss, K. G., Langer, W. H., & Caldeira, K. (2007). Reducing energy-related CO_2 emissions using accelerated weathering of limestone. *Energy*, *32*(8), 1471–1477.

Reid, D. D. J., Quinn, G. P. G., Lake, P. S. P., & Reich, P. (2008). Terrestrial detritus supports the food webs in lowland intermittent streams of south-eastern Australia: a stable isotope study. *Freshwater Biology*, *53*(10), 2036–2050.

Richman, S., Loya, Y., & Slobodkin, L. B. (1975). The rate of mucus production by corals and its assimilation by the coral reef copepod *Acartia negligens*. *Limnology and Oceanography*, *20*(November), 918–923.

Roberts, C. M., & Ormond, R. F. G. (1987). Habitat complexity and coral reef fish diversity and abundance on Red Sea fringing reefs. *Marine Ecology Progress Series*, *41*(1972), 1–8.

Rogers, C. S. (1990). Responses of coral reefs and reef organisms to sedimentation. *Marine Ecology Progress Series*, *62*, 185–202.

Rotherham, D., Johnson, D. D., Kesby, C. L., & Gray, C. A. (2012). Sampling estuarine fish and invertebrates with a beam trawl provides a different picture of populations and assemblages than multi-mesh gillnets. *Fisheries Research*, *123-124*, 49–55.

Sale, P. F., Van Lavieren, H., Ablan Lagman, M. C., Atema, J., Butler, M., Fauvelot, C., … Stewart, H. L. (2010). Preserving Reef Connectivity: A Handbook for Marine Protected Area Managers. (L. Benedetti, Ed.) *Management* (p. 79). Connectivity Working Group, Coral Reef Targeted Research & Capacity Building for Management Program, UNU-INWEH.

Salini, J. P., Blaber, S. J. M., & Brewer, D. T. (1994). Diets of Trawled Predatory Fish of the Gulf of Carpentaria, Australia, with Particular Reference to Predation on Prawns. *Australian Journal of Marine and Freshwater Research*, *45*, 397–411.

Sasaki, K. (2001). Sciaenidae. In K. E. Carpenter & V. H. Niem (Eds.), *FAO species identification guide for fishery purposes. The living marine resources of the Western Central Pacific. Volume 5. Bony fishes part 3 (Menidae to Pomacentridae)* (pp. 2791–3380). Rome: FAO.

Sasekumar, A., & Ooi, A. L. (2005). Fauna of Langkawi Mangrove Forests. *Malaysian Journal of Science*, *24*, 123–132.

Schuhmacher, H. (1977). Ability in fungiid corals to overcome sedimentation. In *Proceedings of the 3rd International Coral Reef Symposium*. Miami, Florida.

Shahbudin, S., Zuhairi, A., & Kamaruzzaman, B. Y. (2012). Impact of coastal development on mangrove cover in Kilim river, Langkawi Island, Malaysia. *Journal of Forestry Research*, *23*(2), 185–190.

Sheaves, M. (1995). Large lutjanid and serranid fishes in tropical estuaries: Are they adults or juveniles? *Marine Ecology Progress Series*, *129*, 31–41.

Sheaves, M. (2005). Nature and consequences of biological connectivity in mangrove systems. *Marine Ecology Progress Series*, *302*, 293–305.

Sheaves, M. (2009). Consequences of ecological connectivity: the coastal ecosystem mosaic. *Marine Ecology Progress Series*, *391*, 107–115.

Sheppard, C. R. C., Davy, S. K., & Pilling, G. M. (2009). *The Biology of Coral Reefs* (p. 339). Oxford University Press.

Shinnaka, T., Sano, M., Ikejima, K., Tongnunui, P., Horinouchi, M., & Kurokura, H. (2007). Effects of mangrove deforestation on fish assemblage at Pak Phanang Bay, southern Thailand. *Fisheries Science*, *73*(4), 862–870.

Smith-Vaniz, W. F. (1999). Carangidae. In K. E. Carpenter & V. H. Niem (Eds.), *FAO species identification guide for fishery purposes. The living marine resources of the Western Central Pacific. Volume 4. Bony fishes part 2 (Mugilidae to Carangidae)* (pp. 2069–2790). Rome: FAO.

Sorokin, Y. I. (1993). *Coral reef ecology* (p. 465). Berlin: Springer-Verlag.

Tanaka, K., Hanamura, Y., Chong, V. C., Watanabe, S., Man, A., Mohd Kassim, F., … Ichikawa, T. (2011). Stable isotope analysis reveals ontogenetic migration and the importance of a large mangrove estuary as a feeding ground for juvenile John's snapper *Lutjanus johnii*. *Fisheries Science*, *77*(5), 809–816.

Then, A. Y. H. (2009). *The structure and trophodynamics of the fish community in estuaries of Matang Mangrove Forest Reserve, Peninsular Malaysia*. (Unpublished Master's Thesis) University of Malaya, Kuala Lumpur.

Thollot, & Thollot, P. (1992). Importance of mangroves for Pacific reef fish species, myth or reality. In *Proceedings of the 7th International Coral Reef Symposium* (Vol. 2, pp. 934–941).

Thom, B. G. (1984). Coastal landforms and geomorphic processes. In S. C. Snedaker & J. G. Snedaker (Eds.), *The Mangrove Ecosystem: Research Methods* (pp. 3–17). Paris: UNESCO.

Tremblay, P., Grover, R., Maguer, J. F., Legendre, L., & Ferrier-Pagès, C. (2012). Autotrophic carbon budget in coral tissue: a new ^{13}C-based model of photosynthate translocation. *Journal of Experimental Biology*, (215), 1384–1393.

Unsworth, R. K. F., De León, P. S., Garrard, S. L., Jompa, J., Smith, D. J., & Bell, J. J. (2008). High connectivity of Indo-Pacific seagrass fish assemblages with mangrove and coral reef habitats. *Marine Ecology Progress Series*, *353*, 213–224.

Vander Zanden, M., & Rasmussen, J. (2001). Variation in δ^{15}N and δ^{13}C trophic fractionation: Implications for aquatic food web studies. *Limnology and Oceanography*, *46*(8), 2061–2066.

Veron, J. E. N., Devantier, L. M., Turak, E., Green, A. L., Kininmonth, S., Stafford-Smith, M. G., & Peterson, N. (2009). Delineating the Coral Triangle. *Galaxea, Journal of Coral Reef Studies*, *11*, 91–100.

Veron, J. E. N., Hoegh-Guldberg, O., Lenton, T. M., Lough, J. M., Obura, D. O., Pearce-Kelly, P., … Rogers, a D. (2009). The coral reef crisis: The critical importance of 350 ppm CO_2. *Marine Pollution Bulletin*, *58*(10), 1428–36.

Veron, J. E. N., & Stafford-Smith, M. G. (2000). Coral ID. Townsville: Australian Institute of Marine Science.

Verweij, M. C., Nagelkerken, I., de Graaff, D., Peeters, M., Bakker, E. J., & van der Velde, G. (2006). Structure, food and shade attract juvenile coral reef fish to mangrove and seagrass habitats: a field experiment. *Marine Ecology Progress Series*, *306*, 257–268.

Wild, C., Huettel, M., Klueter, A., & Kremb, S. (2004). Coral mucus functions as an energy carrier and particle trap in the reef ecosystem. *Nature*, *428*(March), 66–70.

Wilkinson, C. R. (2008). *Status of Coral Reefs of the World: 2008* (p. 304). Townsville: Global Coral Reef Monitoring Network Reef and Rainforest Research Centre.

Wilkinson, C. R., & Salvat, B. (2012). Coastal resource degradation in the tropics: Does the tragedy of the commons apply for coral reefs, mangrove forests and seagrass beds. *Marine Pollution Bulletin*, *64*(6), 1096–1105.

Wolanski, E. (Ed.). (2001). *Oceanographic Processes of Coral Reefs : Physical and Biological Links in the Great Barrier Reef* (p. 348). CRC Press.

Wolcott, D. L., & O'Connor, N. J. (1992). Herbivory in crabs: adaptations and ecological considerations. *American Zoologist*, *32*(3), 370–381.

Wyatt, A. S. J. (2011). *Oceanographic ecology of coral reefs: the role of oceanographic processes in reef-level biogeochemistry and trophic ecology*. (Doctoral dissertation, The University of Western Australia). Retrieved from https://repository.uwa.edu.au/R/-?func=dbin-jump-full&object_id=30834&local_base=GEN01-INS01

Wyatt, A. S. J., Waite, A. M., & Humphries, S. (2012). Stable isotope analysis reveals community-level variation in fish trophodynamics across a fringing coral reef. *Coral Reefs*, *31*(4), 1029–1044.

Yonge, C. M. (1972). Aspects of productivity in coral reefs. In C. Mukundan & C. S. Gopindha Pillai (Eds.), *Proceedings of the First International Symposium on Corals and Coral Reefs, Marine Biological Association of India* (pp. 1–12). Mandapam Camp, India.

APPENDIX I

List of fish species caught at 4 sites in northeast Langkawi (Fig. 2.1). “0” denotes absent and “1” denotes present. “1*” denotes species present from literature (Chong, 2005).

Family	Species	Tg. Rhu			Kilim				Peluru		Kisap			
		Coral	Mg	Up	Coral	Mg-C	Mg	Up	Mg-C	Mg	Coral	Mg-C	Mg	Up
Ambassidae	*Ambassis nalua*	0	0	0	0	0	0	1	0	0	0	0	1	0
Apogonidae	*Apogon hyalosoma*	0	0	1	0	1	0	1	0	0	0	0	0	0
Ariidae	*Arius caelatus*	0	0	0	0	1*	0	0	0	0	0	0	0	1*
Ariidae	*Arius tenuispinis*	0	0	0	0	0	0	0	0	0	0	0	0	1*
Ariidae	*Arius venosus*	0	0	0	0	0	0	0	1*	0	0	0	0	0
Ariidae	*Hexanematichtys sagor*	0	0	0	0	0	0	0	0	0	0	0	1	1
Ariidae	*Osteogeneiosus militaris*	0	0	0	0	0	0	0	0	1*	0	0	0	0
Batrachoididae	*Allenbatrachus grunniens*	0	0	0	0	0	0	0	0	0	0	1*	0	0
Belonidae	*Strongylura strongylura*	0	0	0	0	0	0	0	0	1	0	0	1	0
Belonidae	*Tylosurus crocodilus crocodilus*	0	0	0	0	0	1*	0	0	1*	0	0	1	1
Caesionidae	*Caesio cunning*	1	0	0	1	1	1	0	0	0	0	0	0	0
Callionymidae	*Callionymus sagitta*	0	1*	0	0	0	0	0	0	0	0	0	0	0
Carangidae	*Alectis indicus*	0	0	0	0	0	0	0	1*	0	0	0	0	0
Carangidae	*Alepes djedaba*	0	0	0	0	0	1	0	0	1*	0	0	0	0
Carangidae	*Alepes kleinii*	0	0	0	0	0	0	0	0	0	1	0	0	0
Carangidae	*Atule mate*	0	0	0	1	0	0	0	0	0	1	0	0	0
Carangidae	*Carangoides equula*	0	1*	0	0	0	0	0	0	0	1*	0	0	0
Carangidae	*Carangoides oblongus*	0	0	0	0	0	1	0	0	0	0	0	0	0
Carangidae	*Carangoides praeustus*	1	1*	0	0	1	1	1	0	1	0	1*	1	1
Carangidae	*Caranx ignobilis*	0	0	0	0	1	1	1	1	0	0	0	0	0
Carangidae	*Caranx sexfasciatus*	0	1	0	1	1	1	0	0	0	0	0	0	0
Carangidae	*Scomberoides commersonnianus*	0	1	0	1	1	1	1	0	1	0	0	1	1

Family	Species	Tg. Rhu			Kilim				Peluru		Kisap			
		Coral	Mg	Up	Coral	Mg-C	Mg	Up	Mg-C	Mg	Coral	Mg-C	Mg	Up
Carangidae	*Scomberoides lysan*	0	0	0	0	0	1	0	1	0	0	0	0	1
Carangidae	*Scomberoides tol*	0	0	0	1	0	0	0	0	0	0	0	0	0
Carangidae	*Trachinotus* sp.	0	0	0	0	1	0	0	0	0	0	0	0	0
Centropomidae	*Lates calcarifer*	0	0	0	0	1*	0	0	0	0	0	0	0	0
Chaetodontidae	*Chaetodon octofasciatus*	1	0	0	1	0	0	0	0	0	1	0	0	0
Chaetodontidae	*Heniochus acuminatus*	0	0	0	0	1	0	0	0	0	0	0	0	0
Clupeidae	*Anodonstomata chacunda*	0	1	0	0	0	1	0	0	1	1	0	1	1
Clupeidae	*Anodontostoma thailandiae*	0	0	0	0	0	0	0	0	0	0	0	1	0
Clupeidae	*Herklosichthys punctatus*	0	1*	0	0	0	0	0	0	0	0	0	0	0
Clupeidae	*Sardinella gibbosa*	0	0	0	0	0	1*	0	0	0	0	0	0	0
Cynoglossidae	*Cynoglossus cynoglossus*	0	0	0	0	0	0	0	0	0	0	0	1	0
Cynoglossidae	*Cynoglossus puncticeps*	0	0	0	0	1*	0	0	0	0	0	0	0	0
Dasyatidae	*Dasyatis kuhlii*	0	1*	0	0	1*	0	0	0	0	0	0	0	1*
Dasyatidae	*Dasyatis zugei*	0	1*	0	0	0	0	1*	0	0	0	1*	1*	0
Dasyatidae	*Himantura walga*	0	1*	0	1	0	1	0	0	0	0	0	0	0
Drepanidae	*Drepane punctata*	0	1*	0	1	1	1	0	0	0	0	0	0	0
Elopidae	*Elops machnata*	0	0	0	0	0	0	0	0	1	0	0	0	0
Engraulidae	*Stolephorus commersonnii*	0	0	0	0	0	0	0	0	0	0	0	1*	0
Engraulidae	*Stolephorus indicus*	0	1	0	0	0	1	0	0	0	0	0	0	0
Engraulidae	*Thryssa hamiltonii*	0	0	0	0	1	1	0	0	0	0	0	0	0
Engraulidae	*Thryssa mystax*	0	0	0	0	1*	1	0	0	0	0	0	0	0
Ephippidae	*Ephippus orbis*	0	0	0	1	1	1	0	1	0	0	0	0	1
Gerreidae	*Gerres erythrourus*	1	1	0	0	0	1*	0	0	1	0	0	1*	0
Gerreidae	*Gerres filamentosus*	0	1	1	0	1	1	1	0	1	0	0	1*	1
Gerreidae	*Gerres oyena*	1	0	0	1	0	0	0	0	1	0	0	0	0
Gobiidae	*Acentrogobius caninus*	0	0	0	0	0	0	0	0	0	0	0	1	0

Family	Species	Tg. Rhu			Kilim				Peluru		Kisap			
		Coral	Mg	Up	Coral	Mg-C	Mg	Up	Mg-C	Mg	Coral	Mg-C	Mg	Up
Gobiidae	*Acentrogobius viridipunctatus*	0	0	0	0	0	0	0	0	0	1*	0	0	0
Gobiidae	*Palutrus scapulopunctatus*	0	1*	0	0	0	0	0	0	0	1*	0	0	0
Gymnuridae	*Gymnura poecilura*	0	0	0	0	1*	0	0	0	0	0	0	0	0
Haemulidae	*Plectorhinchus gibbosus*	0	0	0	0	1	1	0	1	0	0	0	0	0
Haemulidae	*Plectorhincus flavomaculatus*	0	0	1*	0	0	0	0	0	0	0	0	0	0
Haemulidae	*Pomadasys argenteus*	0	0	0	0	1*	0	0	0	1*	0	0	0	0
Haemulidae	*Pomadasys argyreus*	0	0	0	0	0	0	0	0	1*	0	0	0	0
Haemulidae	*Pomadasys hasta*	0	0	0	0	1*	1*	0	0	0	0	0	0	0
Haemulidae	*Pomadasys kaakan*	0	0	0	0	1	1	1	0	1	0	1*	0	1
Hemiscyllidae	*Chiloscyllium griseus*	0	0	0	0	1*	0	0	1*	0	0	0	0	0
Hemiscyllidae	*Chiloscyllium indicum*	0	0	0	0	0	0	0	0	1*	0	0	0	0
Labridae	*Halichoeres nigrescens*	0	0	0	1	0	0	0	0	0	0	0	0	0
Labridae	*Halichoeres scalpularis*	0	1*	0	0	0	0	0	0	0	0	0	0	0
Leiognathidae	*Eubleekeria jonesi*	0	0	0	0	0	0	0	0	1	0	0	0	0
Leiognathidae	*Eubleekeria splendens*	0	1	0	0	0	0	0	0	1	0	1*	1*	0
Leiognathidae	*Leiognathus brevirostris*	0	0	0	0	0	1*	0	1	1	1	0	1*	0
Leiognathidae	*Leiognathus daura*	0	0	0	1	0	0	0	0	0	0	0	0	0
Leiognathidae	*Leiognathus equulus*	0	1*	0	0	1	0	0	0	0	1	0	0	0
Leiognathidae	*Secutor ruconius*	0	0	0	0	0	0	0	0	1*	1	0	0	0
Lethrinidae	*Lethrinus lentjan*	1	0	0	0	0	0	0	0	0	0	0	0	0
Lobotidae	*Lobotes surinamensis*	0	0	0	0	0	0	0	0	1*	0	0	0	0
Lutjanidae	*Lutjanus argentimaculatus*	0	0	0	0	1*	0	0	0	0	0	0	0	0
Lutjanidae	*Lutjanus biguttatus*	1	0	0	0	0	0	0	0	0	0	0	0	0
Lutjanidae	*Lutjanus johnii*	0	1*	1*	0	1	0	1*	1	1*	0	0	0	0
Lutjanidae	*Lutjanus lemniscatus*	0	0	0	1	0	0	0	0	0	0	0	0	0
Lutjanidae	*Lutjanus lutjanus*	0	0	0	1	0	0	0	0	0	0	0	0	0

Family	Species	Tg. Rhu			Kilim				Peluru		Kisap			
		Coral	Mg	Up	Coral	Mg-C	Mg	Up	Mg-C	Mg	Coral	Mg-C	Mg	Up
Lutjanidae	*Lutjanus russelli*	1	0	1	0	1	1	0	1	0	0	0	0	0
Lutjanidae	*Lutjanus stellatus*	0	0	0	0	1*	0	0	0	0	0	0	0	0
Lutjanidae	*Lutjanus vitta*	1	0	0	1	0	0	0	0	0	0	0	0	0
Megalopidae	*Megalops cyprinoides*	0	0	0	0	1*	0	0	0	0	0	0	0	0
Monacanthidae	*Acreichthys tomentosus*	0	1*	0	0	0	0	0	0	0	0	0	0	0
Monacanthidae	*Monacanthus choirocephalus*	0	1*	0	0	0	0	0	0	0	0	0	0	0
Monachantidae	*Monachanthus chinensis*	1	0	0	0	1	0	1*	1*	0	1	0	0	0
Mugilidae	*Chelon macrolepis*	0	0	0	0	0	0	0	0	1*	0	0	1*	0
Mugilidae	*Chelon subviridis*	0	0	0	1	0	1	1	0	1	0	1*	1	1
Mugilidae	*Ellochelon vaigiensis*	1	1*	0	1	0	0	0	0	1*	1	0	0	1
Mugilidae	*Liza tade*	0	0	0	0	0	0	0	0	1*	0	0	1*	0
Mugilidae	*Moolgarda perusii*	1	1	0	1	0	0	0	0	0	0	0	1	0
Mugilidae	*Moolgarda seheli*	0	0	1	1	0	1	1	0	1	1	0	1	1
Mugilidae	*Paramugil parmatus*	0	0	0	1	0	0	0	0	0	0	0	0	0
Mugilidae	*Valamugil buchanani*	0	1*	1	1	1	0	0	0	0	0	0	0	0
Mugillidae	*Valamugil cunnesius*	0	0	0	0	0	0	0	0	1*	1*	1*	1*	0
Mullidae	*Upeneus bensasi*	0	1*	0	0	0	0	0	0	0	0	0	0	0
Mullidae	*Upeneus sulphureus*	0	1	0	0	0	0	0	0	0	0	0	0	0
Mullidae	*Upeneus sundaicus*	0	0	0	1	0	0	0	0	0	0	0	0	0
Mullidae	*Upeneus tragula*	0	0	0	1	0	0	0	0	0	0	0	0	0
Myliobatidae	*Aetomylaeus maculatus*	0	0	0	0	0	0	0	1*	0	0	1*	0	0
Nemipteridae	*Nemipterus hexodon*	0	0	0	0	0	0	0	0	0	1	0	0	0
Nemipteridae	*Scolopsis ciliata*	1	0	0	0	0	0	0	0	0	0	0	0	0
Nemipteridae	*Scolopsis vosmeri*	0	0	0	1	1	0	0	0	0	0	0	0	0
Ostraciidae	*Ostracion rhinorhynchos*	0	0	0	0	0	0	1*	0	0	0	0	0	0
Ostraciidae	*Ostracion cubicus*	0	0	0	0	0	0	1	0	0	0	0	0	0

Family	Species	Tg. Rhu			Kilim				Peluru		Kisap			
		Coral	Mg	Up	Coral	Mg-C	Mg	Up	Mg-C	Mg	Coral	Mg-C	Mg	Up
Paralichthyidae	*Pseudorhombus elevatus*	0	0	0	0	1*	1*	0	0	1*	0	0	0	0
Platycephalidae	*Cociella punctata*	0	0	0	0	1	0	0	0	0	0	0	0	0
Platycephalidae	*Grammoplites scaber*	0	0	0	0	1	0	0	0	0	0	0	0	0
Platycephalidae	*Inegocia japonica*	0	0	0	0	1	0	0	0	0	0	0	0	0
Platycephalidae	Platycephalidae	0	0	0	0	0	0	0	0	1	0	0	0	0
Platycephalidae	*Platycephalus indicus*	0	1*	0	0	0	0	0	0	0	0	0	1*	0
Platycephalidae	*Suggrundus macracanthus*	0	1*	0	1	0	0	0	0	0	0	0	0	0
Plotosidae	*Plotosus canius*	0	0	1*	0	0	0	0	0	1*	0	0	0	0
Polynemidae	*Eleutheronema tetradactylum*	0	0	0	0	1	0	0	0	0	0	0	0	0
Pomacentridae	*Abudefdef vaigiensis*	0	0	0	1	0	0	0	0	0	0	0	0	0
Pomacentridae	*Neoglyphidodon melas*	1	0	0	0	0	0	0	0	0	0	0	0	0
Pomacentridae	*Stegastes obreptus*	1	0	0	1	0	0	0	0	0	0	0	0	0
Pristigasteridae	*Ilisha filigera*	0	0	0	0	0	1*	0	0	0	0	0	0	0
Pristigasteridae	*Ilisha melastoma*	0	0	0	0	1	1	0	0	0	0	0	0	0
Scathophagidae	*Scatophagus argus*	0	0	1*	0	0	1	1	0	1*	0	0	0	0
Scianidae	*Dendrophyssa russelli*	0	0	0	0	1	1*	0	0	0	0	0	1	0
Scianidae	*Johnius belangerii*	0	0	0	0	1	0	0	1*	0	0	1*	0	0
Scianidae	*Johnius carutta*	0	0	0	0	0	0	0	0	0	1*	0	0	0
Scianidae	*Paranibea semiluctuosa*	0	0	0	0	0	0	0	0	1	0	0	0	0
Scianidae	*Pennahia anea*	0	0	0	0	1*	0	0	0	0	0	0	0	0
Scianidae	*Pennahia macrocephalus*	0	0	0	0	0	0	0	1*	0	0	0	0	1*
Scianidae	Scianidae	0	0	0	0	0	0	0	1	0	0	0	0	0
Scombridae	*Rastrelliger kanagurta*	0	1*	0	0	0	1*	0	0	0	0	0	0	0
Serranidae	*Cephalopholis boenak*	0	0	0	1	0	0	0	0	0	0	0	0	0
Serranidae	*Epinephelus bleekeri*	0	0	0	1	1	0	0	0	0	1	0	0	0
Serranidae	*Epinephelus coioides*	0	0	0	1	1*	0	1	0	1*	1	0	0	0

Family	Species	Tg. Rhu			Kilim				Peluru		Kisap			
		Coral	Mg	Up	Coral	Mg-C	Mg	Up	Mg-C	Mg	Coral	Mg-C	Mg	Up
Serranidae	*Epinephelus erythrurus*	0	0	0	1	0	0	0	0	0	0	0	0	0
Serranidae	*Epinephelus malabaricus*	0	0	0	0	1	0	0	0	0	0	0	0	0
Serranidae	*Epinephelus quoyanus*	1	0	0	0	0	0	0	0	0	0	0	0	0
Serranidae	*Epinephelus sexfasciatus*	0	0	0	1	0	0	0	0	1*	0	0	0	0
Siganidae	*Siganus fuscescens*	0	0	0	0	0	0	0	0	0	1	0	0	0
Siganidae	*Siganus javus*	0	1*	0	1	1	0	1	0	0	1	0	0	0
Sillaginidae	*Sillago aeolus*	0	0	0	1	0	0	0	0	0	1	0	0	0
Sillaginidae	*Sillago sihama*	0	1	0	1	1	1*	1	1	1	0	0	0	1
Sparidae	*Acanthopagrus berda*	0	1*	0	0	0	0	0	0	0	0	0	0	0
Sparidae	*Dentex angolensis*	0	1*	0	0	0	0	0	0	0	0	0	0	0
Sphyraenidae	*Sphyraena barracuda*	0	1*	0	0	0	0	0	0	0	0	0	1	0
Sphyraenidae	*Sphyraena jello*	0	0	0	0	1	1	0	0	1	1	0	0	0
Sphyraenidae	*Sphyraena* sp.	0	0	0	0	0	1	0	0	0	0	0	0	0
Synodontidae	*Saurida tumbil*	0	0	0	0	0	0	0	0	1*	0	0	0	0
Tetraodontidae	*Chelonodon patoca*	0	1*	0	0	0	0	0	0	0	0	0	0	0
Tetraodontidae	*Lagocephalus lunaris*	0	0	0	0	0	1	0	0	0	0	0	0	0
Tetraodontidae	*Tetraodon fluviatilis*	0	1*	0	0	0	0	0	0	0	0	0	1*	0
Tetraodontidae	*Tetraodon nigroviridis*	0	0	0	0	0	0	1	0	0	0	0	1	0
Toxotidae	*Toxotes jaculatrix*	0	0	1	0	0	0	0	0	1*	0	0	1*	1
Triacanthidae	*Pseudotriacanthus strigilifer*	1	0	0	0	0	0	0	0	1	0	0	0	0
Triacanthidae	*Triacanthus biaculeatus*	1	0	0	0	0	1	0	0	1	0	1*	1*	1
TOTAL		18	36	10	35	47	37	19	16	40	22	29	10	19

APPENDIX II

Details of PCA on dietary composition of fish species computed in Canoco software.

No samples omitted

Number of samples	63
Number of species	14
Number of occurrences	260

No transformation of species data
No species-weights specified
No sample-weights specified
Centering/standardization by species = 1
Centering/standardization by samples = 0

No. of active samples: 63
No. of passive samples: 0
No. of active species: 14

Total sum of squares in species data = 148901.
Total standard deviation in species data TAU = 12.9932

**** Summary ****

Axes	1	2	3	4	Total variance
Eigenvalues :	0.289	0.189	0.125	0.09	1
Cumulative percentage variance of species data :	28.9	47.8	60.3	69.3	

Sum of all eigenvalues 1.000

APPENDIX III

Results of the non-parametric Kruskal-Wallis analysis on stable isotope signatures.

a) Results of the non-parametric Kruskal-Wallis analysis of $\delta^{13}C$ between feeding guilds, Kruskal-Wallis chi-squared, $\chi^2 = 51.6659$, df = 4, p-value = 1.62^{e-10}

Pairwise comparisons using Wilcoxon rank sum test

	Carnivore	Herbivore	Invertivore	Omnivore
Herbivore	3.70^{E-09}*	-	-	-
Invertivore	2.80^{E-03}*	3.10^{E-06}*	-	-
Omnivore	0.0081*	0.1468	0.4398	-
Piscivore	0.4019	1.20^{E-03}*	0.4398	0.4398

*denotes pairs of significant different

b) Results of the non-parametric Kruskal-Wallis analysis of $\delta^{15}N$ between feeding guilds, Kruskal-Wallis chi-squared, $\chi^2 = 173.7278$, df = 4, p-value < 2.2^{e-16}

Pairwise comparisons using Wilcoxon rank sum test

	Carnivore	Herbivore	Invertivore	Omnivore
Herbivore	$< 2^{e-16}$*	-	-	-
Invertivore	0.47	$< 2^{e-16}$*	-	-
Omnivore	0.00*	0.00*	0.00*	-
Piscivore	0.00*	0.00*	0.00*	0.00*

*denotes pairs of significant different

c) Result of the non-parametric Kruskal-Wallis analysis of $\delta^{13}C$ between habitat zones, Kruskal-Wallis chi-squared, $\chi^2 = 33.7551$, df = 3, p-value = 2.232^{e-07}

Pairwise comparisons using Wilcoxon rank sum test

	Coral	Mangrove	Mg-C
Mangrove	0.00028*	-	-
Mg-C	0.00555*	0.29527	-
Up	3.20^{E-06}*	0.00555*	0.00078*

*denotes pairs of significant different

d) Results of the non-parametric Kruskal-Wallis analysis of $\delta^{15}N$ between habitat zones, Kruskal-Wallis chi-squared, $\chi^2 = 53.6565$, df = 3, p-value = 1.328^{e-11}

Pairwise comparisons using Wilcoxon rank sum test

	Coral	Mangrove	Mg-C
Mangrove	5.90^{E-06}*	-	-
Mg-C	0.41	4.10^{E-08}*	-
Up	5.10^{E-05}*	0.28	5.30^{E-06}*

*denotes pairs of significant different

APPENDIX IV

Results of 95%, 75% and 50% probability and mean values of proportional source contribution to zooplankton in each habitat zone as determined by SIAR.

Zone	Sources			
	Zooxanthellae	Seston	Diatom	Detritus
Coral	Probability values 95 % lower = 0.077 upper = 0.53 75 % lower = 0.18 upper = 0.44 50 % lower = 0.24 upper = 0.39 Median = 0.3105572	Probability values 95 % lower = 0 upper = 0.5 75 % lower = 0.07 upper = 0.39 50 % lower = 0.17 upper = 0.36 Median = 0.252145	Probability values 95 % lower = 0 upper = 0.39 75 % lower = 0.015 upper = 0.28 50 % lower = 0.026 upper = 0.2 Median = 0.1740509	Probability values 95 % lower = 0.068 upper = 0.41 75 % lower = 0.17 upper = 0.36 50 % lower = 0.22 upper = 0.33 Median = 0.2630106
Mg-C	Probability values 95 % lower = 0.028 upper = 0.53 75 % lower = 0.16 upper = 0.44 50 % lower = 0.22 upper = 0.38 Median = 0.298267	Probability values 95 % lower = 0.0025 upper = 0.47 75 % lower = 0.08 upper = 0.39 50 % lower = 0.17 upper = 0.36 Median = 0.2531832	Probability values 95 % lower = 0.00029 upper = 0.45 75 % lower = 0.059 upper = 0.36 50 % lower = 0.15 upper = 0.33 Median = 0.2315868	Probability values 95 % lower = 0.014 upper = 0.38 75 % lower = 0.11 upper = 0.34 50 % lower = 0.17 upper = 0.3 Median = 0.2251256
Mg	Probability values 95 % lower = 0.011 upper = 0.47 75 % lower = 0.11 upper = 0.4 50 % lower = 0.19 upper = 0.35 Median = 0.2633558	Probability values 95 % lower = 0.0021 upper = 0.47 75 % lower = 0.091 upper = 0.39 50 % lower = 0.17 upper = 0.35 Median = 0.2503956	Probability values 95 % lower = 0.00047 upper = 0.43 75 % lower = 0.053 upper = 0.35 50 % lower = 0.12 upper = 0.3 Median = 0.2159093	Probability values 95 % lower = 0.045 upper = 0.45 75 % lower = 0.17 upper = 0.4 50 % lower = 0.23 upper = 0.36 Median = 0.2786814
Up	Probability values 95 % lower = 0 upper = 0.39 75 % lower = 0 upper = 0.24 50 % lower = 0.0072 upper = 0.15 Median = 0.1377116	Probability values 95 % lower = 0 upper = 0.49 75 % lower = 0.044 upper = 0.39 50 % lower = 0.16 upper = 0.38 Median = 0.2499242	Probability values 95 % lower = 0 upper = 0.43 75 % lower = 0.01 upper = 0.3 50 % lower = 0.017 upper = 0.2 Median = 0.1825484	Probability values 95 % lower = 0.068 upper = 0.71 75 % lower = 0.2 upper = 0.59 50 % lower = 0.28 upper = 0.5 Median = 0.388314

APPENDIX V

Results of 95%, 75% and 50% probability and mean values of proportional source contribution to fish in each habitat zone as determined by SIAR.

Zone	Sources			
	Zooxanthellae	Seston	Diatom	Detritus
Coral	Probability values	Probability values	Probability values	Probability values
	95 % lower = 0.81 upper = 0.97	95 % lower = 0 upper = 0.15	95 % lower = 0 upper = 0.052	95 % lower = 0 upper = 0.053
	75 % lower = 0.85 upper = 0.95	75 % lower = 0.0033 upper = 0.099	75 % lower = 0 upper = 0.025	75 % lower = 0 upper = 0.03
	50 % lower = 0.88 upper = 0.94	50 % lower = 0.011 upper = 0.069	50 % lower = 0.00097 upper = 0.015	50 % lower = 0.0017 upper = 0.019
	Median = 0.9002351	Median = 0.05904525	Median = 0.01317405	Median = 0.01671809
Mg-C	Probability values	Probability values	Probability values	Probability values
	95 % lower = 0.61 upper = 0.85	95 % lower = 0.046 upper = 0.37	95 % lower = 0 upper = 0.047	95 % lower = 0 upper = 0.1
	75 % lower = 0.66 upper = 0.8	75 % lower = 0.13 upper = 0.32	75 % lower = 0 upper = 0.023	75 % lower = 0 upper = 0.054
	50 % lower = 0.68 upper = 0.77	50 % lower = 0.18 upper = 0.29	50 % lower = 0.0011 upper = 0.014	50 % lower = 0.0015 upper = 0.031
	Median = 0.7265861	Median = 0.2260533	Median = 0.01206371	Median = 0.02887637
Mg	Probability values	Probability values	Probability values	Probability values
	95 % lower = 0.54 upper = 0.76	95 % lower = 0.13 upper = 0.45	95 % lower = 0 upper = 0.041	95 % lower = 0 upper = 0.11
	75 % lower = 0.57 upper = 0.7	75 % lower = 0.24 upper = 0.41	75 % lower = 0 upper = 0.02	75 % lower = 0 upper = 0.056
	50 % lower = 0.59 upper = 0.67	50 % lower = 0.29 upper = 0.39	50 % lower = 0.0009 upper = 0.012	50 % lower = 0.0014 upper = 0.031
	Median = 0.6373761	Median = 0.3199941	Median = 0.0111313	Median = 0.02838711
Up	Probability values	Probability values	Probability values	Probability values
	95 % lower = 0.17 upper = 0.61	95 % lower = 0.043 upper = 0.69	95 % lower = 0 upper = 0.25	95 % lower = 0 upper = 0.27
	75 % lower = 0.26 upper = 0.52	75 % lower = 0.19 upper = 0.58	75 % lower = 0 upper = 0.14	75 % lower = 0.02 upper = 0.21
	50 % lower = 0.31 upper = 0.46	50 % lower = 0.27 upper = 0.49	50 % lower = 0.0058 upper = 0.089	50 % lower = 0.051 upper = 0.17
	Median = 0.3844547	Median = 0.3837586	Median = 0.08053116	Median = 0.127193

APPENDIX VI

Dietary composition of fish species used for computing PCA in Canoco software.

Species	Code	n	Alga	Diatom	Detritus	Polychaeta	Fish	Copepoda	Crustacean	Malacostraca	Mysid	Crab	Prawn	Echinodermata	Mollusca	Porifera	Sum
Abudefdef vaigiensis	Abva	1	0.00	0.00	0.00	3.89	0.00	89.49	0.00	1.95	0.00	0.78	0.00	0.00	0.00	0.00	
Alepes kleinii	Alkl	1	0.00	0.00	0.00	0.00	80.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Anodontostoma chacunda	Anch	8	0.00	13.39	14.04	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.68	
Anodontostoma thailandiae	Anth	1	0.00	9.86	51.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.76	
Atule mate	Atma	4	0.00	4.40	16.57	0.00	26.21	0.00	0.00	0.00	0.00	0.00	13.89	0.00	0.00	0.00	
Caesio cunning	Cacu	4	0.00	0.00	0.00	0.00	5.32	5.56	0.57	0.00	0.00	0.23	21.10	0.00	0.00	0.00	
Carangoides oblongus	Caob	1	0.00	0.00	0.00	0.00	2.50	0.00	0.00	0.00	0.00	0.00	58.84	0.00	0.84	0.00	
Carangoides praeustus	Capr	1	0.00	0.00	0.00	0.00	3.45	0.00	0.00	0.00	0.00	0.00	13.79	0.00	0.00	0.00	
Caranx ignobilis	Caig	4	0.00	0.03	0.00	0.00	25.13	0.00	0.61	0.00	0.00	0.00	35.50	24.39	0.00	0.00	
Caranx sexfasciatus	Case	5	0.00	0.00	0.00	0.00	20.94	0.00	0.00	3.33	0.00	0.00	64.44	0.00	0.00	0.00	
Chaetodon octofasciatus	Choc	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Chelon subviridis	Chsu	3	0.00	12.20	24.48	0.32	9.10	0.00	4.61	0.00	0.00	7.66	0.00	0.00	0.00	1.95	
Dendrophyssa russelli	Deru	1	0.00	0.00	3.23	80.65	0.00	0.00	16.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Drepane punctata	Drpu	8	0.00	0.07	9.51	14.79	6.07	0.00	2.44	2.57	0.00	0.00	7.70	3.13	0.51	0.00	
Elops machnata	Elma	1	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Ephippus orbis	Epor	1	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Epinephelus bleekeri	Epbl	6	0.00	0.03	8.26	0.00	4.37	0.00	0.00	0.00	1.25	16.64	40.67	0.00	0.00	0.00	
Epinephelus coiodes	Epco	2	0.00	0.00	0.16	0.00	0.87	0.00	30.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Epinephelus erythrurus	Eper	1	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Epinephelus quoyanus	Epqu	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	50.00	0.00	0.00	0.00	0.00	
Epinephelus sexfasciatus	Epse	1	0.00	1.38	0.00	0.00	0.00	0.00	45.58	0.00	0.00	0.00	4.86	0.00	0.00	0.00	
Eubleekeria splendens	Eusp	2	0.00	8.86	29.11	0.00	0.00	0.94	0.00	0.00	0.00	0.00	30.95	0.00	25.62	0.00	
Gerres erythrourus	Geer	2	0.00	0.00	0.00	25.00	0.00	0.00	0.00	0.00	0.00	5.00	5.00	0.00	42.86	0.00	
Gerres filamentosus	Gefi	7	0.00	0.00	2.48	40.54	0.00	0.00	7.37	2.45	0.00	14.43	0.54	1.10	20.56	0.00	
Gerres oyena	Geoy	6	0.17	0.00	8.42	19.77	0.00	0.00	0.79	20.90	0.00	0.00	0.00	0.00	5.61	0.00	
Heniochus acuminatus	Heac	1	0.00	0.00	0.00	11.11	1.85	0.00	1.85	0.00	0.00	0.00	0.00	18.52	0.00	1.85	
Himantura walga	Hiwa	2	0.00	0.00	3.16	20.00	0.00	0.00	0.00	0.00	0.00	0.00	15.79	0.00	25.00	0.00	

Inegocia japonica	Inja	2	0.00	0.00	0.00	0.00	50.00	0.00	0.00	0.00	0.00	0.00	31.25	0.00	0.00	0.00	
Lagocephalus lunaris	Lalu	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	99.00	0.00	0.00	1.00	0.00	
Leiognathus brevirostris	Lebr	3	0.00	8.73	16.65	0.00	0.00	4.75	0.00	0.19	0.00	0.00	13.17	0.00	1.90	0.33	
Leiognathus equulus	Leeq	1	0.00	0.00	35.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	21.43	0.00	0.00	0.00	
Leiognathus splendens	Lesp	3	0.00	0.00	13.18	26.65	0.00	1.72	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Leoignathus daura	Leda	3	0.00	0.00	2.79	0.67	1.00	0.14	0.14	1.05	0.00	4.73	1.39	0.81	3.76	0.00	
Lethrinus lentjan	Lele	2	0.00	0.00	0.00	0.00	0.00	0.00	25.00	0.00	0.00	50.00	0.00	0.00	0.00	0.00	
Lutjanus johnii	Lujo	4	0.00	0.00	0.35	0.00	43.75	0.00	1.41	2.08	2.82	17.31	26.16	0.00	4.01	0.00	
Lutjanus lemniscatus	Lule	3	0.00	0.00	0.00	0.00	96.00	0.00	0.00	0.00	0.00	0.00	4.00	0.00	0.00	0.00	
Lutjanus lutjanus	Lulu	2	0.00	0.00	0.00	0.00	11.01	7.58	0.43	7.58	0.00	7.58	43.10	0.00	0.00	0.00	
Lutjanus russelli	Luru	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	
Lutjanus vitta	Luvi	4	0.00	0.00	0.00	0.00	39.41	0.00	0.20	0.00	0.00	0.00	34.48	0.00	0.00	0.00	
Monachanthus chinensis	Moch	4	0.00	0.03	30.71	0.35	0.00	0.00	8.01	0.12	0.00	4.00	0.00	10.16	1.27	0.03	
Moolgarda seheli	Mose	4	0.00	7.53	17.52	0.00	0.00	0.00	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.52	
Paranibea semiluctuosa	Pase	1	0.00	0.00	0.00	0.00	0.00	4.35	0.00	0.00	8.70	0.00	86.96	0.00	0.00	0.00	
Platycephalidae	Plat	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	33.33	66.67	0.00	0.00	0.00	
Plectorhincus gibossus	Plgi	10	0.00	0.14	0.38	3.62	11.38	0.77	1.69	0.00	0.00	38.98	20.61	0.00	1.17	0.05	
Pomadasys kaakan	Poka	10	0.00	0.04	2.36	4.00	8.11	0.11	3.40	0.11	0.00	17.08	21.86	0.00	0.00	0.01	
Pseudotriacanthus strigilifer	Psst	2	0.00	0.00	7.89	0.00	0.00	0.00	0.56	8.95	0.00	22.37	2.45	41.65	4.70	0.00	
Scolopsis ciliata	Scci	5	0.00	0.00	24.10	26.10	0.00	0.00	0.80	2.01	0.00	6.02	0.80	4.02	0.00	0.00	
Scolopsis vosmeri	Scvo	3	0.00	0.00	4.12	0.73	0.00	0.00	0.00	0.13	0.00	48.33	0.36	3.30	0.73	0.00	
Scomberoides commersonnianus	Scco	8	0.00	0.00	0.13	0.00	48.84	0.00	0.00	0.00	0.00	0.00	25.00	0.00	0.00	0.00	
Scomberoides lysan	Scly	3	0.00	0.00	0.00	0.00	67.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Scomberoides tol	Scto	2	0.00	0.00	0.00	0.00	24.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Siganus fuscescens	Sifu	4	79.68	0.00	0.00	0.00	0.00	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Siganus javus	Sija	5	6.74	1.61	13.44	0.05	0.00	0.97	0.00	0.11	0.00	0.00	0.00	0.21	0.30	44.08	
Sillago aeolus	Siae	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	35.29	0.00	0.00	0.00	0.00	
Sillago sihama	Sisi	5	0.00	0.00	1.39	1.39	0.00	0.00	10.63	10.91	0.00	20.00	26.11	0.00	0.00	0.00	
Sphyraena jello	Spje	3	0.00	0.55	6.36	0.00	62.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.44	0.00	
Thryssa hamiltonii	Thha	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	
Toxotes jaculatrix	Toja	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	26.98	25.40	0.00	0.00	0.00	
Triacanthus biaculeatus	Trbi	2	0.00	0.00	6.00	1.50	0.00	0.00	0.00	0.00	0.00	8.51	0.00	0.00	47.46	0.00	

Tylosurus crocodilus crocodilus	Tycc	2	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Upeneus sundaicus	Upsu	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	50.00	5.56	11.11	33.33	0.00	
Upeneus tragula	Uptr	5	0.00	0.00	0.00	0.00	0.00	0.00	25.93	0.00	0.00	0.00	74.07	0.00	0.00	0.00	
Valamugil buchanani	Vabu	5	0.00	26.01	11.32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.91	
Sum			**86.592**	**94.860**	**365.119**	**281.199**	**948.730**	**116.771**	**288.274**	**64.431**	**112.763**	**584.266**	**943.894**	**118.393**	**225.078**	**55.170**	**4285.539**
Mean			**1.374**	**1.506**	**5.796**	**4.463**	**15.059**	**1.854**	**4.576**	**1.023**	**1.790**	**9.274**	**14.982**	**1.879**	**3.573**	**0.876**	
VOL%			**2.021**	**2.213**	**8.520**	**6.562**	**22.138**	**2.725**	**6.727**	**1.503**	**2.631**	**13.633**	**22.025**	**2.763**	**5.252**	**1.287**	**100.000**
FO			**3**	**17**	**30**	**20**	**27**	**12**	**24**	**16**	**4**	**24**	**34**	**11**	**19**	**12**	**253**
FO%			**1.186**	**6.719**	**11.858**	**7.905**	**10.672**	**4.743**	**9.486**	**6.324**	**1.581**	**9.486**	**13.439**	**4.348**	**7.510**	**4.743**	

APPENDIX VII

Fish stable isotope signatures for carbon, $\delta^{13}C$ and nitrogen, $\delta^{15}N$ with trophic fractionation correction for carbon, $\Delta^{13}C$ and nitrogen, $\Delta^{15}N$ used in computing SIAR.

Habitat	**Species**	**Feeding guilds**	**$\delta^{13}C$**	**$\Delta^{13}C$**	**$\delta^{15}N$**	**$\Delta^{15}N$**	**C:N**
Coral	*Chelon subviridis*	Herbivore	-12.01	-12.96	9.34	6.65	3.76
Coral	*Moolgarda perusii*	Herbivore	-10.44	-11.39	10.90	8.21	4.08
Coral	*Moolgarda perusii*	Herbivore	-10.49	-11.44	7.23	4.54	3.78
Coral	*Moolgarda perusii*	Herbivore	-10.59	-11.54	7.29	4.60	3.86
Coral	*Moolgarda perusii*	Herbivore	-14.18	-15.13	9.16	6.47	3.96
Coral	*Moolgarda seheli*	Herbivore	-12.69	-13.64	7.17	4.48	3.85
Coral	*Moolgarda seheli*	Herbivore	-9.97	-10.92	8.07	5.38	3.79
Coral	*Paramugil parmatus*	Herbivore	-8.88	-9.83	7.47	4.78	3.82
Coral	*Valamugil buchanani*	Herbivore	-9.67	-10.62	8.06	5.37	3.80
Coral	*Valamugil buchanani*	Herbivore	-10.40	-11.35	8.99	6.30	3.78
Coral	*Chaetodon octofasciatus*	Omnivore	-13.52	-14.92	11.94	7.76	3.76
Coral	*Chaetodon octofasciatus*	Omnivore	-13.36	-14.76	11.70	7.52	3.84
Coral	*Ellochelon vaigiensis*	Omnivore	-11.40	-12.80	9.88	5.71	3.68
Coral	*Ellochelon vaigiensis*	Omnivore	-11.01	-12.41	9.69	5.52	3.71
Coral	*Ellochelon vaigiensis*	Omnivore	-11.24	-12.64	9.16	4.98	3.77
Coral	*Gerres oyena*	Omnivore	-12.07	-13.47	12.05	7.87	3.76
Coral	*Gerres oyena*	Omnivore	-14.34	-15.74	12.54	8.37	3.72
Coral	*Gerres oyena*	Omnivore	-14.64	-16.04	11.74	7.56	3.73
Coral	*Gerres oyena*	Omnivore	-13.61	-15.01	11.68	7.50	3.83
Coral	*Siganus javus*	Omnivore	-16.62	-18.02	12.70	8.52	3.82
Coral	*Siganus javus*	Omnivore	-21.10	-22.50	10.99	6.82	3.73
Coral	*Abudefduf vaigiensis*	Invertivore	-18.27	-19.67	11.69	7.34	3.75
Coral	*Drepane punctata*	Invertivore	-15.72	-17.12	13.45	9.10	3.77
Coral	*Drepane punctata*	Invertivore	-15.79	-17.19	13.19	8.84	3.81
Coral	*Epinephelus coioides*	Invertivore	-13.68	-15.08	11.82	7.47	3.77
Coral	*Epinephelus coioides*	Invertivore	-15.87	-17.27	14.08	9.73	3.75
Coral	*Epinephelus erythrurus*	Invertivore	-13.17	-14.57	12.15	7.80	3.78
Coral	*Epinephelus sexfasciatus*	Invertivore	-15.83	-17.23	13.64	9.29	3.78
Coral	*Epinephelus sexfasciatus*	Invertivore	-16.12	-17.52	12.96	8.61	3.82
Coral	*Himantura walga*	Invertivore	-14.67	-16.07	12.16	7.81	3.38
Coral	*Leiognathus daura*	Invertivore	-16.77	-18.17	13.09	8.74	3.81
Coral	*Leiognathus daura*	Invertivore	-16.54	-17.94	13.04	8.69	3.73
Coral	*Leiognathus daura*	Invertivore	-16.31	-17.71	13.78	9.43	3.80
Coral	*Lutjanus russelli*	Invertivore	-12.93	-14.33	11.70	7.35	3.69
Coral	*Lutjanus russelli*	Invertivore	-16.02	-17.42	11.66	7.31	3.72
Coral	*Lutjanus russelli*	Invertivore	-15.30	-16.70	12.44	8.09	3.72
Coral	*Scolopsis vosmeri*	Invertivore	-16.44	-17.84	13.69	9.34	4.23
Coral	*Scolopsis vosmeri*	Invertivore	-16.47	-17.87	12.97	8.62	3.83
Coral	*Sillago aeolus*	Invertivore	-13.87	-15.27	12.30	7.95	3.77
Coral	*Sillago sihama*	Invertivore	-13.68	-15.08	12.86	8.51	3.72
Coral	*Upeneus sundaicus*	Invertivore	-14.98	-16.38	13.27	8.92	3.73

Habitat	Species	Feeding guilds	δ^{13}C	Δ^{13}C	δ^{15}N	Δ^{15}N	C:N
Coral	*Upeneus sundaicus*	Invertivore	-15.83	-17.23	13.87	9.52	3.81
Coral	*Atule mate*	Carnivore	-15.87	-17.63	12.96	7.48	3.74
Coral	*Atule mate*	Carnivore	-15.81	-17.57	13.09	7.61	3.81
Coral	*Atule mate*	Carnivore	-15.86	-17.62	12.69	7.21	3.70
Coral	*Caesio cunning*	Carnivore	-16.31	-18.07	12.60	7.11	3.82
Coral	*Caesio cunning*	Carnivore	-16.57	-18.33	12.92	7.44	3.72
Coral	*Caesio cunning*	Carnivore	-17.08	-18.84	12.59	7.11	3.71
Coral	*Caranx sexfasciatus*	Carnivore	-17.60	-19.36	12.34	6.86	3.68
Coral	*Caranx sexfasciatus*	Carnivore	-16.06	-17.82	11.91	6.42	3.69
Coral	*Caranx sexfasciatus*	Carnivore	-15.88	-17.64	12.00	6.52	3.70
Coral	*Caranx sexfasciatus*	Carnivore	-16.78	-18.54	9.08	3.60	3.70
Coral	*Cephalopholis boenak*	Carnivore	-15.09	-16.85	13.28	7.79	3.78
Coral	*Epinephelus bleekeri*	Carnivore	-13.00	-14.76	12.84	7.35	3.81
Coral	*Epinephelus bleekeri*	Carnivore	-16.06	-17.82	13.24	7.75	3.77
Coral	*Epinephelus bleekeri*	Carnivore	-16.07	-17.83	13.41	7.92	3.81
Coral	*Epinephelus bleekeri*	Carnivore	-16.37	-18.13	12.89	7.41	3.78
Coral	*Lutjanus lutjanus*	Carnivore	-16.93	-18.69	12.56	7.08	3.80
Coral	*Lutjanus lutjanus*	Carnivore	-16.85	-18.61	13.26	7.78	3.84
Coral	*Lutjanus lutjanus*	Carnivore	-16.83	-18.59	13.17	7.69	3.78
Coral	*Lutjanus vitta*	Carnivore	-15.90	-17.66	13.05	7.57	3.82
Coral	*Lutjanus vitta*	Carnivore	-16.37	-18.13	13.10	7.61	3.79
Coral	*Lutjanus vitta*	Carnivore	-16.59	-18.35	13.44	7.95	3.86
Coral	*Scomberoides commersonnianus*	Carnivore	-16.05	-17.81	14.01	8.53	3.81
Coral	*Ephippus orbis*	Piscivore	-15.94	-18.25	14.20	7.01	3.85
Coral	*Ephippus orbis*	Piscivore	-16.04	-18.35	13.88	6.69	3.75
Coral	*Scomberoides tol*	Piscivore	-16.29	-18.60	13.10	5.91	3.84
MgC	*Anodontostoma chacunda*	Herbivore	-13.30	-14.25	8.83	6.14	3.92
MgC	*Anodontostoma chacunda*	Herbivore	-13.69	-14.64	9.13	6.44	3.84
MgC	*Anodontostoma chacunda*	Herbivore	-13.23	-14.18	9.06	6.37	3.86
MgC	*Moolgarda seheli*	Herbivore	-9.42	-10.37	8.23	5.54	3.80
MgC	*Moolgarda seheli*	Herbivore	-12.25	-13.20	7.74	5.05	3.83
MgC	*Moolgarda seheli*	Herbivore	-11.32	-12.27	8.83	6.14	3.77
MgC	*Moolgarda seheli*	Herbivore	-10.52	-11.47	7.22	4.53	3.78
MgC	*Moolgarda seheli*	Herbivore	-10.10	-11.05	7.32	4.63	3.80
MgC	*Valamugil buchanani*	Herbivore	-13.12	-14.07	7.99	5.30	3.74
MgC	*Chaetodon octofasciatus*	Omnivore	-12.21	-13.61	12.07	7.90	3.76
MgC	*Ellochelon vaigiensis*	Omnivore	-11.18	-12.58	10.70	6.53	3.74
MgC	*Ellochelon vaigiensis*	Omnivore	-11.57	-12.97	10.86	6.68	3.74
MgC	*Heniochus acuminatus*	Omnivore	-17.44	-18.84	13.44	9.27	4.02
MgC	*Heniochus acuminatus*	Omnivore	-17.65	-19.05	14.13	9.96	4.41
MgC	*Heniochus acuminatus*	Omnivore	-17.40	-18.80	13.81	9.64	4.11
MgC	*Monachanthus chinensis*	Omnivore	-16.47	-17.87	11.59	7.42	3.74
MgC	*Monachanthus chinensis*	Omnivore	-15.18	-16.58	13.72	9.54	3.72

Habitat	**Species**	**Feeding guilds**	**δ^{13}C**	**Δ^{13}C**	**δ^{15}N**	**Δ^{15}N**	**C:N**
MgC	*Monachanthus chinensis*	Omnivore	-15.81	-17.21	12.42	8.25	3.75
MgC	*Monachanthus chinensis*	Omnivore	-16.55	-17.95	12.83	8.65	3.75
MgC	*Siganus javus*	Omnivore	-17.96	-19.36	12.69	8.51	3.72
MgC	*Siganus javus*	Omnivore	-17.58	-18.98	11.40	7.22	3.77
MgC	*Drepane punctata*	Invertivore	-16.16	-17.56	13.32	8.97	3.76
MgC	*Drepane punctata*	Invertivore	-17.53	-18.93	12.62	8.27	3.78
MgC	*Drepane punctata*	Invertivore	-16.70	-18.10	13.38	9.03	3.81
MgC	*Drepane punctata*	Invertivore	-15.39	-16.79	12.84	8.49	3.73
MgC	*Drepane punctata*	Invertivore	-16.04	-17.44	11.55	7.20	3.74
MgC	*Epinephelus coioides*	Invertivore	-15.61	-17.01	14.39	10.04	3.75
MgC	*Epinephelus coioides*	Invertivore	-15.97	-17.37	14.04	9.69	3.76
MgC	*Johnius belangerii*	Invertivore	-16.37	-17.77	13.59	9.24	3.75
MgC	*Leiognathus brevirostris*	Invertivore	-16.17	-17.57	13.16	8.81	3.79
MgC	*Leiognathus brevirostris*	Invertivore	-15.52	-16.92	12.32	7.97	3.78
MgC	*Leiognathus brevirostris*	Invertivore	-15.19	-16.59	12.49	8.14	3.78
MgC	*Leiognathus equulus*	Invertivore	-14.76	-16.16	10.34	5.99	3.81
MgC	*Leiognathus equulus*	Invertivore	-15.18	-16.58	10.69	6.34	3.87
MgC	*Lutjanus russelli*	Invertivore	-16.58	-17.98	13.02	8.67	3.75
MgC	*Lutjanus russelli*	Invertivore	-16.81	-18.21	13.74	9.39	3.73
MgC	*Lutjanus russelli*	Invertivore	-19.32	-20.72	11.98	7.63	3.72
MgC	*Secutor ruconius*	Invertivore	-16.62	-18.02	13.00	8.65	3.73
MgC	*Sillago aeolus*	Invertivore	-13.92	-15.32	12.86	8.51	3.79
MgC	*Sillago aeolus*	Invertivore	-12.55	-13.95	12.52	8.17	3.82
MgC	*Sillago sihama*	Invertivore	-15.88	-17.28	13.89	9.54	3.81
MgC	Trachinotus sp.	Invertivore	-17.79	-19.19	11.50	7.15	3.67
MgC	*Atule mate*	Carnivore	-16.61	-18.37	13.79	8.30	3.99
MgC	*Caranx ignobilis*	Carnivore	-16.53	-18.29	13.34	7.86	3.73
MgC	*Caranx ignobilis*	Carnivore	-17.16	-18.92	13.54	8.06	3.74
MgC	*Caranx ignobilis*	Carnivore	-15.51	-17.27	12.78	7.29	3.75
MgC	*Caranx ignobilis*	Carnivore	-14.72	-16.48	13.89	8.40	3.80
MgC	*Caranx sexfasciatus*	Carnivore	-20.17	-21.93	12.18	6.69	3.87
MgC	*Caranx sexfasciatus*	Carnivore	-16.35	-18.11	14.09	8.60	3.79
MgC	*Caranx sexfasciatus*	Carnivore	-19.35	-21.11	11.69	6.20	3.73
MgC	*Caranx sexfasciatus*	Carnivore	-17.46	-19.22	10.99	5.51	3.68
MgC	*Epinephelus bleekeri*	Carnivore	-16.16	-17.92	13.27	7.78	3.78
MgC	*Epinephelus bleekeri*	Carnivore	-16.03	-17.79	13.81	8.32	3.88
MgC	*Epinephelus bleekeri*	Carnivore	-16.01	-17.77	14.14	8.66	3.91
MgC	*Epinephelus malabaricus*	Carnivore	-19.26	-21.02	11.66	6.17	3.78
MgC	*Epinephelus malabaricus*	Carnivore	-22.51	-24.27	10.06	4.57	3.73
MgC	*Lutjanus johnii*	Carnivore	-17.41	-19.17	12.69	7.21	3.80
MgC	*Lutjanus johnii*	Carnivore	-14.77	-16.53	11.42	5.94	3.77
MgC	*Lutjanus johnii*	Carnivore	-17.30	-19.06	12.46	6.98	3.66
MgC	*Nemipterus hexodon*	Carnivore	-12.49	-14.25	12.16	6.68	3.93
MgC	*Nemipterus hexodon*	Carnivore	-13.01	-14.77	12.77	7.29	4.04

Habitat	**Species**	**Feeding guilds**	**δ^{13}C**	**Δ^{13}C**	**δ^{15}N**	**Δ^{15}N**	**C:N**
MgC	*Nemipterus hexodon*	Carnivore	-13.20	-14.96	12.29	6.81	3.91
MgC	*Plectorhinchus gibbosus*	Carnivore	-19.87	-21.63	12.13	6.64	4.04
MgC	*Plectorhinchus gibbosus*	Carnivore	-19.99	-21.75	13.12	7.64	7.23
MgC	*Plectorhinchus gibbosus*	Carnivore	-20.43	-22.19	11.64	6.15	3.92
MgC	*Plectorhinchus gibbosus*	Carnivore	-19.43	-21.19	11.12	5.63	3.81
MgC	*Plectorhinchus gibbosus*	Carnivore	-17.92	-19.68	12.92	7.44	5.28
MgC	*Plectorhinchus gibbosus*	Carnivore	-22.90	-24.66	11.23	5.75	4.10
MgC	*Plectorhinchus gibbosus*	Carnivore	-18.47	-20.23	11.96	6.47	4.04
MgC	*Plectorhinchus gibbosus*	Carnivore	-15.49	-17.25	13.69	8.20	4.31
MgC	*Pomadasys kaakan*	Carnivore	-20.23	-21.99	10.74	5.26	4.67
MgC	*Pomadasys kaakan*	Carnivore	-18.02	-19.78	12.05	6.56	3.84
MgC	*Alepes kleinii*	Piscivore	-16.41	-18.72	13.66	6.47	3.79
MgC	*Ephippus orbis*	Piscivore	-17.50	-19.81	13.92	6.73	3.82
MgC	*Ephippus orbis*	Piscivore	-16.52	-18.83	13.88	6.69	4.03
MgC	*Ephippus orbis*	Piscivore	-16.01	-18.32	14.07	6.89	3.79
MgC	*Scomberoides lysan*	Piscivore	-16.19	-18.50	13.37	6.18	3.79
MgC	*Scomberoides lysan*	Piscivore	-16.53	-18.84	13.27	6.08	3.82
MgC	*Scomberoides lysan*	Piscivore	-16.35	-18.66	13.16	5.97	3.83
MgC	*Scomberoides lysan*	Piscivore	-16.45	-18.76	13.18	5.99	3.86
MgC	*Sphyraena jello*	Piscivore	-15.59	-17.90	14.92	7.73	3.74
Mangrove	*Anodontostoma chacunda*	Herbivore	-13.17	-14.12	8.69	6.00	3.79
Mangrove	*Anodontostoma chacunda*	Herbivore	-13.21	-14.16	8.28	5.59	3.81
Mangrove	*Anodontostoma chacunda*	Herbivore	-14.43	-15.38	9.41	6.72	3.81
Mangrove	*Anodontostoma chacunda*	Herbivore	-20.92	-21.87	9.18	6.49	3.87
Mangrove	*Anodontostoma chacunda*	Herbivore	-15.07	-16.02	8.19	5.50	3.71
Mangrove	*Anodontostoma chacunda*	Herbivore	-17.96	-18.91	8.66	5.97	3.72
Mangrove	*Anodontostoma chacunda*	Herbivore	-14.67	-15.62	8.70	6.01	3.76
Mangrove	*Chelon subviridis*	Herbivore	-22.68	-23.63	9.64	6.95	3.79
Mangrove	*Chelon subviridis*	Herbivore	-20.30	-21.25	8.70	6.01	3.64
Mangrove	*Chelon subviridis*	Herbivore	-13.36	-14.31	8.20	5.51	3.65
Mangrove	*Chelon subviridis*	Herbivore	-14.59	-15.54	8.50	5.81	3.69
Mangrove	*Chelon subviridis*	Herbivore	-15.24	-16.19	9.14	6.45	3.74
Mangrove	*Chelon subviridis*	Herbivore	-14.07	-15.02	8.28	5.59	3.72
Mangrove	*Chelon subviridis*	Herbivore	-16.62	-17.57	8.43	5.74	3.75
Mangrove	*Chelon subviridis*	Herbivore	-16.57	-17.52	8.58	5.89	3.71
Mangrove	*Chelon subviridis*	Herbivore	-13.35	-14.30	8.41	5.72	3.66
Mangrove	*Chelon subviridis*	Herbivore	-13.37	-14.32	8.06	5.37	3.64
Mangrove	*Chelon subviridis*	Herbivore	-16.86	-17.81	8.33	5.64	3.72
Mangrove	*Chelon subviridis*	Herbivore	-14.79	-15.74	7.04	4.35	3.96
Mangrove	*Chelon subviridis*	Herbivore	-13.67	-14.62	7.26	4.57	3.76
Mangrove	*Moolgarda perusii*	Herbivore	-11.50	-12.45	5.84	3.15	4.07

Habitat	**Species**	**Feeding guilds**	**$\delta^{13}C$**	**$\Delta^{13}C$**	**$\delta^{15}N$**	**$\Delta^{15}N$**	**C:N**
Mangrove	*Moolgarda perusii*	Herbivore	-11.71	-12.66	6.43	3.74	3.97
Mangrove	*Moolgarda perusii*	Herbivore	-11.36	-12.31	6.64	3.95	3.80
Mangrove	*Moolgarda perusii*	Herbivore	-11.23	-12.18	7.19	4.50	3.82
Mangrove	*Moolgarda perusii*	Herbivore	-13.77	-14.72	6.31	3.62	4.03
Mangrove	*Moolgarda seheli*	Herbivore	-12.15	-13.10	8.69	6.00	3.81
Mangrove	*Moolgarda seheli*	Herbivore	-11.79	-12.74	8.44	5.75	3.80
Mangrove	*Moolgarda seheli*	Herbivore	-12.01	-12.96	7.56	4.87	3.88
Mangrove	*Moolgarda seheli*	Herbivore	-12.17	-13.12	7.51	4.82	3.84
Mangrove	*Moolgarda seheli*	Herbivore	-14.31	-15.26	8.29	5.60	3.82
Mangrove	*Moolgarda seheli*	Herbivore	-21.57	-22.52	8.70	6.01	3.80
Mangrove	*Moolgarda seheli*	Herbivore	-20.39	-21.34	8.04	5.35	3.81
Mangrove	*Moolgarda seheli*	Herbivore	-19.94	-20.89	8.31	5.62	3.79
Mangrove	*Moolgarda seheli*	Herbivore	-19.54	-20.49	8.39	5.70	3.85
Mangrove	*Moolgarda seheli*	Herbivore	-16.61	-17.56	7.90	5.21	3.72
Mangrove	*Anodontostoma thailandiae*	Omnivore	-20.28	-21.68	9.18	5.01	3.69
Mangrove	*Dendrophyssa russelli*	Omnivore	-19.77	-21.17	11.35	7.18	3.69
Mangrove	*Dendrophyssa russelli*	Omnivore	-19.66	-21.06	11.21	7.04	3.81
Mangrove	*Gerres filamentosus*	Omnivore	-15.82	-17.22	10.26	6.08	3.87
Mangrove	*Gerres filamentosus*	Omnivore	-14.01	-15.41	10.24	6.07	3.73
Mangrove	*Gerres filamentosus*	Omnivore	-17.52	-18.92	11.28	7.10	3.73
Mangrove	*Gerres filamentosus*	Omnivore	-18.80	-20.20	12.57	8.39	3.77
Mangrove	*Gerres filamentosus*	Omnivore	-15.33	-16.73	11.04	6.87	3.81
Mangrove	*Gerres filamentosus*	Omnivore	-16.56	-17.96	10.66	6.48	3.72
Mangrove	*Gerres oyena*	Omnivore	-12.59	-13.99	11.26	7.08	3.77
Mangrove	*Gerres oyena*	Omnivore	-13.27	-14.67	11.55	7.38	3.84
Mangrove	*Leiognathus splendens*	Omnivore	-13.28	-14.68	7.39	3.22	3.97
Mangrove	*Leiognathus splendens*	Omnivore	-21.56	-22.96	9.05	4.87	3.89
Mangrove	*Leiognathus splendens*	Omnivore	-12.44	-13.84	7.53	3.35	3.90
Mangrove	*Leiognathus splendens*	Omnivore	-20.50	-21.90	8.49	4.32	3.87
Mangrove	*Triacanthus biaculeatus*	Omnivore	-16.06	-17.46	12.14	7.96	3.81
Mangrove	*Triacanthus biaculeatus*	Omnivore	-16.04	-17.44	10.95	6.77	3.82
Mangrove	*Acentrogobius caninus*	Invertivore	-16.59	-17.99	11.56	7.21	3.71
Mangrove	*Ambassis nalua*	Invertivore	-20.60	-22.00	12.38	8.03	3.75
Mangrove	*Cynoglossus cynoglossus*	Invertivore	-17.47	-18.87	10.58	6.23	3.72
Mangrove	*Drepane punctata*	Invertivore	-16.23	-17.63	11.88	7.53	3.76
Mangrove	*Drepane punctata*	Invertivore	-22.81	-24.21	11.02	6.67	4.02
Mangrove	*Drepane punctata*	Invertivore	-22.01	-23.41	11.73	7.38	3.90
Mangrove	*Drepane punctata*	Invertivore	-19.39	-20.79	11.45	7.10	3.73
Mangrove	*Eubleekeria jonesi*	Invertivore	-15.34	-16.74	10.50	6.15	3.88
Mangrove	*Eubleekeria jonesi*	Invertivore	-15.76	-17.16	10.35	6.00	3.81
Mangrove	*Eubleekeria splendens*	Invertivore	-14.87	-16.27	11.81	7.46	3.78
Mangrove	*Gerres erythrourus*	Invertivore	-14.99	-16.39	9.43	5.08	4.01
Mangrove	*Gerres erythrourus*	Invertivore	-14.65	-16.05	11.07	6.72	3.87
Mangrove	*Gerres erythrourus*	Invertivore	-12.66	-14.06	10.13	5.78	3.76

Habitat	Species	Feeding guilds	$\delta^{13}C$	$\Delta^{13}C$	$\delta^{15}N$	$\Delta^{15}N$	C:N
Mangrove	*Gerres erythrourus*	Invertivore	-15.06	-16.46	10.04	5.69	3.87
Mangrove	*Himantura walga*	Invertivore	-18.92	-20.32	11.51	7.16	3.49
Mangrove	*Ilisha melastoma*	Invertivore	-18.57	-19.97	12.22	7.87	3.79
Mangrove	*Ilisha melastoma*	Invertivore	-20.03	-21.43	11.66	7.31	3.76
Mangrove	*Lagocephalus lunaris*	Invertivore	-14.03	-15.43	11.32	6.97	3.80
Mangrove	*Leiognathus brevirostris*	Invertivore	-14.17	-15.57	12.43	8.08	3.75
Mangrove	*Leiognathus brevirostris*	Invertivore	-16.13	-17.53	10.83	6.48	3.74
Mangrove	*Leiognathus brevirostris*	Invertivore	-15.61	-17.01	10.59	6.24	3.81
Mangrove	*Leiognathus brevirostris*	Invertivore	-15.21	-16.61	11.31	6.96	3.86
Mangrove	*Leiognathus brevirostris*	Invertivore	-15.69	-17.09	10.89	6.54	3.88
Mangrove	*Lutjanus russelli*	Invertivore	-17.83	-19.23	12.02	7.67	3.79
Mangrove	*Paranibea semiluctuosa*	Invertivore	-16.18	-17.58	11.99	7.64	3.77
Mangrove	Platycephalidae	Invertivore	-16.74	-18.14	9.25	4.90	3.83
Mangrove	*Pseudotriacanthus strigilifer*	Invertivore	-15.14	-16.54	12.08	7.73	3.75
Mangrove	*Sillago sihama*	Invertivore	-14.95	-16.35	11.20	6.85	3.89
Mangrove	*Sillago sihama*	Invertivore	-16.53	-17.93	10.78	6.43	3.76
Mangrove	*Sillago sihama*	Invertivore	-16.74	-18.14	10.84	6.49	3.80
Mangrove	*Stolephorus indicus*	Invertivore	-16.88	-18.28	13.19	8.84	3.76
Mangrove	*Tetraodon nigroviridis*	Invertivore	-21.82	-23.22	9.95	5.60	3.69
Mangrove	*Thryssa hamiltonii*	Invertivore	-15.89	-17.29	13.20	8.85	3.75
Mangrove	*Thryssa hamiltonii*	Invertivore	-16.23	-17.63	14.14	9.79	3.89
Mangrove	*Thryssa mystax*	Invertivore	-15.86	-17.26	13.63	9.28	3.82
Mangrove	*Alepes djedaba*	Carnivore	-18.47	-20.23	11.99	6.50	3.79
Mangrove	*Caesio cunning*	Carnivore	-16.43	-18.19	14.09	8.60	3.88
Mangrove	*Caesio cunning*	Carnivore	-16.50	-18.26	13.20	7.71	3.76
Mangrove	*Caesio cunning*	Carnivore	-16.27	-18.03	14.07	8.58	3.87
Mangrove	*Caesio cunning*	Carnivore	-16.86	-18.62	13.20	7.72	3.76
Mangrove	*Carangoides oblongus*	Carnivore	-16.12	-17.88	12.83	7.34	3.92
Mangrove	*Carangoides praeustus*	Carnivore	-14.41	-16.17	11.23	5.74	3.77
Mangrove	*Carangoides praeustus*	Carnivore	-19.23	-20.99	11.90	6.41	3.67
Mangrove	*Carangoides praeustus*	Carnivore	-19.05	-20.81	12.25	6.77	3.78
Mangrove	*Carangoides praeustus*	Carnivore	-16.47	-18.23	11.16	5.67	3.77
Mangrove	*Carangoides praeustus*	Carnivore	-16.31	-18.07	12.42	6.93	3.81
Mangrove	*Carangoides praeustus*	Carnivore	-17.79	-19.55	11.99	6.50	3.76
Mangrove	*Carangoides praeustus*	Carnivore	-17.08	-18.84	12.34	6.85	3.71
Mangrove	*Carangoides praeustus*	Carnivore	-18.14	-19.90	12.02	6.53	3.68
Mangrove	*Caranx ignobilis*	Carnivore	-16.53	-18.29	14.08	8.59	3.72
Mangrove	*Caranx sexfasciatus*	Carnivore	-19.14	-20.90	11.19	5.70	3.80
Mangrove	*Caranx sexfasciatus*	Carnivore	-18.82	-20.58	11.49	6.01	3.77
Mangrove	*Caranx sexfasciatus*	Carnivore	-18.21	-19.97	11.62	6.13	3.70
Mangrove	*Hexanematichthys sagor*	Carnivore	-20.11	-21.87	9.44	3.96	3.72
Mangrove	*Pomadasys kaakan*	Carnivore	-20.64	-22.40	9.96	4.47	3.75
Mangrove	*Pomadasys kaakan*	Carnivore	-22.50	-24.26	9.33	3.84	3.76
Mangrove	*Pomadasys kaakan*	Carnivore	-20.67	-22.43	10.27	4.79	3.80

Habitat	Species	Feeding guilds	δ^{13}C	Δ^{13}C	δ^{15}N	Δ^{15}N	C:N
Mangrove	*Pomadasys kaakan*	Carnivore	-19.68	-21.44	9.99	4.51	3.73
Mangrove	*Pomadasys kaakan*	Carnivore	-18.23	-19.99	10.61	5.13	3.76
Mangrove	*Pomadasys kaakan*	Carnivore	-16.97	-18.73	11.53	6.04	3.72
Mangrove	*Pomadasys kaakan*	Carnivore	-14.89	-16.65	10.76	5.27	3.78
Mangrove	*Pomadasys kaakan*	Carnivore	-15.87	-17.63	10.23	4.74	3.73
Mangrove	*Pomadasys kaakan*	Carnivore	-16.59	-18.35	12.27	6.78	3.75
Mangrove	*Pomadasys kaakan*	Carnivore	-17.81	-19.57	11.13	5.65	3.70
Mangrove	*Scomberoides commersonnianus*	Carnivore	-15.41	-17.17	10.82	5.34	3.82
Mangrove	*Scomberoides commersonnianus*	Carnivore	-21.16	-22.92	12.70	7.21	3.83
Mangrove	*Scomberoides commersonnianus*	Carnivore	-15.18	-16.94	12.89	7.40	3.80
Mangrove	*Scomberoides commersonnianus*	Carnivore	-15.40	-17.16	11.77	6.29	3.67
Mangrove	*Scomberoides commersonnianus*	Carnivore	-17.61	-19.37	13.05	7.56	3.81
Mangrove	*Scomberoides commersonnianus*	Carnivore	-16.20	-17.96	13.77	8.29	3.73
Mangrove	*Scomberoides commersonnianus*	Carnivore	-18.89	-20.65	12.21	6.73	3.77
Mangrove	*Scomberoides commersonnianus*	Carnivore	-18.97	-20.73	11.89	6.41	3.74
Mangrove	*Scomberoides commersonnianus*	Carnivore	-18.60	-20.36	12.12	6.64	3.69
Mangrove	*Scomberoides commersonnianus*	Carnivore	-22.40	-24.16	12.03	6.54	3.71
Mangrove	*Scomberoides commersonnianus*	Carnivore	-15.12	-16.88	12.10	6.62	3.79
Mangrove	*Elops machnata*	Piscivore	-13.63	-15.94	11.76	4.57	3.75
Mangrove	*Ephippus orbis*	Piscivore	-17.13	-19.44	14.03	6.85	3.79
Mangrove	*Scomberoides lysan*	Piscivore	-16.07	-18.38	12.70	5.51	3.70
Mangrove	*Sphyraena barracuda*	Piscivore	-17.88	-20.19	12.54	5.36	3.68
Mangrove	*Sphyraena jello*	Piscivore	-14.43	-16.74	11.49	4.30	3.73
Mangrove	*Sphyraena jello*	Piscivore	-17.74	-20.05	13.41	6.22	3.76
Mangrove	*Sphyraena sp.*	Piscivore	-15.56	-17.87	12.09	4.90	3.73
Mangrove	*Strongylura strongylura*	Piscivore	-16.74	-19.05	13.52	6.33	3.69
Mangrove	*Strongylura strongylura*	Piscivore	-16.24	-18.55	13.84	6.65	3.78
Mangrove	*Tylosurus crocodilus crocodilus*	Piscivore	-17.17	-19.48	13.19	6.00	3.71
Up	*Anodontostoma chacunda*	Herbivore	-16.70	-17.65	7.57	4.88	3.93
Up	*Anodontostoma chacunda*	Herbivore	-14.71	-15.66	6.91	4.22	4.01
Up	*Anodontostoma chacunda*	Herbivore	-17.88	-18.83	7.05	4.36	3.85
Up	*Anodontostoma chacunda*	Herbivore	-14.82	-15.77	7.83	5.14	4.17
Up	*Chelon subviridis*	Herbivore	-22.30	-23.25	8.36	5.67	3.71
Up	*Chelon subviridis*	Herbivore	-11.81	-12.76	8.96	6.27	3.85
Up	*Moolgarda seheli*	Herbivore	-13.05	-14.00	8.03	5.34	3.93
Up	*Moolgarda seheli*	Herbivore	-15.14	-16.09	7.53	4.84	3.93
Up	*Moolgarda seheli*	Herbivore	-13.10	-14.05	7.60	4.91	3.87

Habitat	**Species**	**Feeding guilds**	**δ^{13}C**	**Δ^{13}C**	**δ^{15}N**	**Δ^{15}N**	**C:N**
Up	*Valamugil buchanani*	Herbivore	-19.42	-20.37	9.06	6.37	3.95
Up	*Valamugil buchanani*	Herbivore	-21.40	-22.35	1.78	-0.91	3.88
Up	*Ellochelon vaigiensis*	Omnivore	-11.66	-13.06	9.14	4.96	3.77
Up	*Ellochelon vaigiensis*	Omnivore	-11.53	-12.93	9.67	5.49	3.76
Up	*Ellochelon vaigiensis*	Omnivore	-10.47	-11.87	7.10	2.92	3.73
Up	*Gerres filamentosus*	Omnivore	-18.94	-20.34	10.48	6.31	3.97
Up	*Gerres filamentosus*	Omnivore	-18.01	-19.41	10.06	5.89	3.87
Up	*Gerres filamentosus*	Omnivore	-22.20	-23.60	11.98	7.80	3.80
Up	*Siganus javus*	Omnivore	-23.49	-24.89	10.77	6.59	3.71
Up	*Ambassis nalua*	Invertivore	-19.26	-20.66	12.36	8.01	3.78
Up	*Epinephelus coioides*	Invertivore	-21.49	-22.89	10.74	6.39	3.71
Up	*Epinephelus coioides*	Invertivore	-16.41	-17.81	14.28	9.93	3.82
Up	*Epinephelus coioides*	Invertivore	-22.40	-23.80	11.14	6.79	3.71
Up	*Lutjanus russelli*	Invertivore	-24.24	-25.64	10.24	5.89	3.71
Up	*Sillago sihama*	Invertivore	-25.24	-26.64	8.09	3.74	3.75
Up	*Tetraodon nigroviridis*	Invertivore	-22.91	-24.31	8.76	4.41	3.75
Up	*Carangoides praeustus*	Carnivore	-17.97	-19.73	11.95	6.46	3.77
Up	*Carangoides praeustus*	Carnivore	-19.79	-21.55	12.20	6.72	3.84
Up	*Carangoides praeustus*	Carnivore	-19.03	-20.79	11.87	6.38	3.83
Up	*Carangoides praeustus*	Carnivore	-19.99	-21.75	12.00	6.51	3.83
Up	*Hexanematichthys sagor*	Carnivore	-18.46	-20.22	10.46	4.97	3.79
Up	*Pomadasys kaakan*	Carnivore	-22.37	-24.13	10.06	4.58	3.71
Up	*Scomberoides commersonnianus*	Carnivore	-20.14	-21.90	11.67	6.18	3.83
Up	*Scomberoides commersonnianus*	Carnivore	-19.45	-21.21	11.67	6.19	3.84
Up	*Scomberoides commersonnianus*	Carnivore	-18.74	-20.50	12.58	7.09	3.88
Up	*Ephippus orbis*	Piscivore	-20.26	-22.57	13.46	6.27	3.85
Up	*Ephippus orbis*	Piscivore	-20.12	-22.43	13.05	5.86	3.73
Up	*Tylosurus crocodilus crocodilus*	Piscivore	-19.09	-21.40	12.92	5.73	3.75

APPENDIX VIII

Commands for computing SIAR Package in R

```
consumer<-
      read.table(file="C:/Users/user/Documents/Studies/Msc/Data/SI/con
      sumer.txt",header=TRUE)

sources<-
      read.table(file="C:/Users/user/Documents/Studies/Msc/Data/SI/sou
      rce.txt",header=TRUE)

tef<-
      read.table(file="C:/Users/user/Documents/Studies/Msc/Data/SI/TEF
      .txt",header=TRUE)

library (siar)

model1<-
      siarmcmcdirichletv4(consumer,sources,tef,concdep=0,100000,10000)

siarplotdata(model1)

siarmatrixplot(model1)

siarhistograms(model1)

siarproportionbygroupplot(model1)

siarproportionbysourceplot(model1, prn=TRUE,grp=1,probs=c(5,25,75,95))

siarproportionbysourceplot(model1,scl=0.7,xspc=0.2,prn=T,xlabels=c("Co
      ral","Mg-C","Mg","Up"))

out<-model1$output

fix(out)

median(out[,1])
```

APPENDIX IX

Commands for computing Permutational ANOVA and t-test in R

Permutational ANOVA

```
summary  (aov(Temperature~Habitat, data=para) )

iter <- 1000

perm_test <- numeric(iter)

for(i in 1:iter) {
      perm_index <- sample(1:94)
      perm_data <- data.frame(para[,1],para[perm_index,2])
      names(perm_data) <- c("Habitat", "Temperature")
      fit <- aov(Temperature~Habitat, data=perm_data)
      perm_test[i] <- (summary(fit))[[1]]$F[1]
}

pval <- sum(perm_test >= 1.349)/iter

pval
```

Permutational t-test

```
iter <- 9999

meanD <- numeric(iter+1)

meanD[1] <- mean(up)-mean(mg)

for(i in 2:length(meanD)){
      index <- sample(1:56, size=38, replace=F)
      mgperm <- mgup[index]
      upperm <- mgup[-index]
      meanD[i] <- mean(upperm)-mean(mgperm)
      }

mean(abs(meanD)>=abs(meanD[1]))
```

APPENDIX X

Summary of permutation ANOVA test computed in R

(Temperature ~ Habitat)

```
              df    Sum Sq    Mean Sq    F value    Pr(>F)
 Habitat      3     18.82     6.273      6.143      0.000756***
 Residuals    90    91.9      1.021
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

(SpC ~ Habitat)

```
              df    Sum Sq            Mean Sq    F value    Pr(>F)
 Habitat      3     43.8              14.59      0.746      0.527
 Residuals    90    1760.1   19.56    19.56
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

(Salinity ~ Habitat)

```
              df    Sum Sq    Mean Sq    F value    Pr(>F)
 Habitat      3     57.6      19.213     3.981      0.0103 *
 Residuals    90    434.4     4.826
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

(TDS ~ Habitat)

```
              df    Sum Sq    Mean Sq    F value    Pr(>F)
 Habitat      3     79.7      26.58      2.279      0.0849 .
 Residuals    90    1050      11.67
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

(DO ~ Habitat)

```
              df    Sum Sq    Mean Sq    F value    Pr(>F)
 Habitat      3     11.8      3.934      2.922      0.0427 *
 Residuals    51    68.66     1.346
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

(pH ~ Habitat)

```
              Df    Sum Sq    Mean Sq    F value    Pr(>F)
 Habitat      3     2.99      0.9971     2.774      0.0459 *
 Residuals    90    32.35     0.3594
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

(ORP ~ Habitat)

```
              df    Sum Sq    Mean Sq    F value    Pr(>F)
 Habitat      3     24861     8287       1.042      0.386
 Residuals    35    278418    7955
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

(Turbidity ~ Habitat)

```
              df    Sum Sq    Mean Sq    F value    Pr(>F)
 Habitat      3     14951     4984       1.658      0.182
 Residuals    90    270555    3006
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```