CHAPTER ONE

INTRODUCTION

1.1 MANGROVE ECOSYSTEM AND PRODUCTIVITY

The term mangrove is used to describe halophytic trees and shrubs that grow in the intertidal zone, typically along sheltered coastlines in tropical or subtropical areas. Another use of the term mangrove or mangal refers to the mangrove ecosystem itself. There are many environmental factors that can affect the diversity, distribution and productivity of the plant and animal communities in the mangal. Factors such as topography, climate, tidal range and substratum characteristics are important factors that influence the mangrove community.

Mangrove ecosystems are among the most productive natural ecosystems in the world (Gong *et al.*, 1992; Ong, 1993; Sukardjo, 1995). Mangrove primary productivity ranges from 400-1400 gC/m^2/yr (see Chong 1996). Odum and Heald (1975) first provided evidence based on the Floridean system in the United States that mangrove net primary productivity supported important detrital marine food webs. More recent studies shows that in tropical Indo-Pacific waters, the classical detrital food chain of Odum and Heald (1975), may be modified as follows: mangrove leaf litter → sesarmid crabs → detritus → saprophytes → detritus consumers → lower carnivorous → higher carnivorous, since mangrove crabs are abundant and play an important role in removing the litter fall (Robertson, 1986; Robertson & Daniel, 1989). A detritus-based food web is more established within the mangrove creeks, inlets and channels, and in the immediate inshore waters (Odum and Heald, 1975; Ong and Sasekumar, 1984; Robertson *et al.*, 1992, Chong *et al.*, 2001). However, the functioning of the mangrove ecosystem is still incompletely known.

The interaction between mangrove ecosystem and fish resources explained by Odum & Heald (1972), is as follows: the organic matter produced by mangroves, particularly in the form of fallen leaves, is transformed into detritus particles by bacteria, microalgae, protozoans and permeated fungi, which are eventually transported into the surrounding waters by tidal flushing (outwelling). The detrital particles, including various organisms found on them are utilized as food by large consumer organisms such as fish, shrimps and crabs. However, this outwelling concept has been challenged by various workers based on parallel studies in temperate salt marshes which indicate that such coastal habitats may function more as carbon sinks (e.g. Nixon, 1984) and more recently, by stable isotope studies tracing the flow of carbon, nitrogen and sulphur from primary producers to consumers (e.g. Rodelli *et al.*, 1984; Chong *et al.*, 2001).

That mangroves function more as a sink than as a source of carbon or detrital materials may have further support from numerical modeling and field observations. A large proportion of the mangrove litter is retained physically in the mangroves as a result of their extensive and aerial root systems. Due to hydrodynamics, mangroves 'laterally trap' leaf litter, nutrients and water borne contaminants within a narrow coastal layer (Wolanski and Ridd, 1986; Wolanski *et al.*, 1990). Leaf litter is also retained through grazing and burying by sesarmid crabs (Leh and Sasekumar, 1985; Robertson and Daniel, 1989). Mangrove trees are the main suppliers of organic matter in tropical brackish water ecosystems, where the productivity of these ecosystems depends largely on litter fall (Ochiai *et al.*, 1997). The Matang mangroves in Taiping, Perak produced an average of 18 t organic matter ha^{-1} yr^{-1} (Ong, 1993).

Besides mangrove detritus, plankton and benthic microflora (chiefly diatoms) are other available primary energy sources within the mangrove ecosystem. Plankton productivity appears to be generally lower in estuarine mangroves compared to more open waters of mangrove-fringed lagoons and bays (Chong, 1996). There is little data on benthic primary production in mangrove substrates. Standing stocks of microalgae in tropical sediments are generally low, attributable to low light intensity under the dense mangrove canopy (Alongi, 1989) and to the inhibition of benthic diatom growth by DOC (probably soluble phenolic compounds) in the sediment pore water (Cooksey and Cooksey, 1978). In more open areas such as in mudflats, benthic standing stocks are expected to be high. In the Klang mangroves of Selangor, diatoms constituted a large part of the microphytobenthos with numbers ranging from 1.4×10^3 to 4.4×10^3 cells per mm^3 in the top 0.2 cm of the substrate (Sarpedonti and Sasekumar, 1996).

Dual stable C and N ratio analyses of primary producers and prawns have clarified the important role of mangrove detritus as the primary food source for juvenile prawns inhabiting the upper estuaries of the Matang mangrove swamp in Malaysia. The contribution of mangrove carbon to prawn tissues, as high as 84%, decreased in the offshore direction, as the contribution by phytoplankton became progressively more important. Prawns located 2 km outside the mangrove swamp still exhibited a dependency of 15-25 % on mangrove carbon, but farther offshore (7-10 km) in shallow waters, the prawn's food was basically phytoplankton, with some contribution from benthic microalgae (Chong *et al.*, 2001).

Chong *et al.* (2001) and Newell *et al.* (1995) indicated that offshore prawns may be consuming substantial amounts of benthic microalgae. Rodelli *et al.* (1984) found that juvenile prawns in Klang mangrove creeks (Malaysia) assimilated on average 65 %

mangrove carbon, but this dependency gradually decreased offshore. Microscopic examination has shown that variable amounts of identifiable mangrove detritus, in addition to animal and benthic algal remains, were present in the guts of mangrove animal species, including prawns, collected from both tidal creeks and offshore (Chong and Sasekumar, 1981; Leh and Sasekumar, 1984; Sasekumar and Chong, 1987).

These studies and others (e.g. Wells, 1990, Robertson and Duke, 1990; Chong *et al.*, 1990) therefore support the important role of mangroves as a habitat, feeding and nursery ground for marine fish, prawns and other organisms (see below). Chong *et al.* (1997) indicated that about half of the fish and nearly all the prawn species caught commercially depend on mangroves during their young stages. The life-cycles of various fishes, prawns, crabs, molluscs, etc. are strongly coupled to the mangrove habitat for a part of their life-history.

Mangrove ecosystems have significant ecological, environmental and socio-economic value which includes their stabilising effect on marginal beaches, maintenance of coastal water quality, reduction in the severity of coastal storm, wave and flood damage, and production of timber and other forest products. Unfortunately, mangrove forests are fast disappearing at alarming rates due to various human impacts, such as reclamation for aquaculture, farming, residential and industrial development. Malaysia lost 12% of its mangrove forests between 1980 and 1990, equivalent to an annual loss of 1.3% (Spalding *et al.*, 1997). It is important to understand the significance of the biodiversity of mangrove ecosystems to their functioning and sustainability and the importance of different habitat factors (tree species, diversity, salinity, tidal regimes) for sustaining diversity.

1.2 MANGROVE MACROBENTHOS

The benthos refers to those organisms, both plant and animal, attached to, living on, in or near the seabed. Benthic fauna have been broadly differentiated into populations residing on the seafloor or on a firm substrate (epifauna) and populations living in the sediment (infauna) (Kennish, 1990). The benthic fauna of estuaries may be grouped according to size: macrofauna (those retained by sieves of 0.5 – 2 mm), meiofauna (those retained by sieves of 0.04 – 0.1 mm) and microfauna (smaller than 0.1 mm) (Perkins, 1974). For the purpose of this study, only benthic macrofauna were sampled.

As mangroves are found at the land-water interface, they form a heterogeneous ecosystem and support a high diversity of wildlife, both micro- and macroscopic, terrestrial and aquatic (marine and freshwater), temporary and residential. The dominant macrofauna in terms of numbers and species are the molluscs and crustaceans. They are found as encrusting epifauna (firmly attaching themselves to solid substrata, like tree trunks and roots), substratum epifauna (living on the surface of the mud), substratum infauna (animals living within the sediment for part or most of their lives) and wood-boring infauna (Berry, 1963, 1972; Macnae, 1968; Hutchings and Saenger, 1987).

The mangrove benthic community, consisting of molluscs, crabs and other invertebrates, plays a role in the decomposition process of mangrove debris and litter, by initially fragmenting them. As the primary consumers of the mangrove products, including detritus, they act as a pathway through which energy and materials are transferred to a higher trophic level. The benthos components support predators or carnivorous fish and crabs including commercially important species. Macrobenthos, being a component of the food chain in the mangrove ecosystem, is important in sustaining the mangroves' role as a feeding ground. Macrobenthos are a source of food for marine fish which ingress into the shore at high tide (Sasekumar and Chong, 1986).

The Crustacea, Mollusca and Polychaeta are well represented in estuarine benthic communities (Kennish, 1990). The dominant molluscs are the gastropods of the families Cerithidae, Ellobiidae, Littorinidae and Neritidae (Macnae, 1968). They predominate on the trunks, prop roots and lower branches of trees and move vertically in synchrony with the tides (Berry, 1972). Bivalves include encrusting oysters and mussels, mud-burrowing *Geloina*, *Sinonovacula* and the wood-boring shipworms of the Teredinidae family. Gastropod molluscs are an important component of mangal fauna (Macnae, 1968) and can therefore be used as indicators of faunal diversity to compare locations (Walthew, 1995).

Many species of crustaceans occur in mangrove habitats. Brachyura (true crabs) are the most abundant group of soil macrofauna within mangroves both in terms of numbers and biomass (Jones, 1984). The mangrove crab fauna is dominated by the two families Ocypodidae and Grapsidae, and each family by one genus, *Uca* and *Sesarma* respectively (Jones, 1984). The mangrove crab fauna of Singapore and Malaysia comprised 53 % grapsids and 30 % ocypodids (Tan and Ng, 1994). Other crustaceans commonly associated with mangroves include a few predatory swimming crabs of the family Portunidae, hermit crabs, the burrowing mud lobster *Thalassina*, amphipods, isopods and barnacles.

Molluscs as well as crustaceans are important animals in mangrove areas, playing important ecological roles including serving as major food items for fish and birds. Marine fishes are also known to move into the mangrove forest at high tide to predate on mangrove macrobenthos (Sasekumar *et al.*, 1984). Studies on the diet of sciaenid fish (Yap, 1995) and eel catfish (Leh and Sasekumar, 1993) indicate marine prawns and macrobenthos are important sources of food.

1.2.1 Distribution of Mangrove Macrobenthos

The Indo-West Pacific region, as well as having high mangrove vegetation diversity, also tends to have high species richness of animals (Ricklefs and Latham, 1993). Macrofaunal zonation patterns raise questions of which factors determine community structure. Both molluscs and crustaceans are essentially marine in origin and face problems of water and salt balance, desiccation, oxygen availability, biomass and temperature limitations in the mangroves (Jones, 1984).

The distribution, abundance and zonation of the macrofauna in mangrove forests has been described in relation to physical and chemical factors (Berry, 1963, 1972; Macnae, 1968; Sasekumar, 1974; Frith *et al.*, 1976; Wells, 1983, 1984; Plaziat, 1984; Macintosh, 1984; Shokita, 1985; Kumar, 1995). Studies also indicate distinct vegetation zonation perpendicular to the shoreline and also zonation horizontally along the estuarine coast. In such studies macrofaunal zonation patterns have been attributed to frequency of tidal inundation, salinity, moisture level, sediment particle size, organic content, food sources, predation and competition.

Physical and chemical factors in the estuarine environment clearly influence the functional morphology and behavior of the benthos (Levinton, 1982). Levels of dissolved oxygen, organic matter, sediment load and sediment particle size played an important role in influencing the abundance and diversity of macrobenthos (Muhammad Ali *et al.*, 2000).

Distribution of macroinvertebrates in the world varies highly among species, with some macroinvertebrates being widely spread whereas others are more restricted to specific areas. Species composition and abundance in estuaries markedly vary temporally. Diversity is a useful parameter for assessing the stability of macrobenthic communities (Kennish, 1990). Marine invertebrates form an important linkage between the primary detritus at the base of the food web and consumers in higher trophic levels.

Studies on the structure of macrobenthic communities show that the abundance, biomass and diversity of macrobenthic communities decrease with depth and shallow water. Sedimentary characteristics such as grain size play an important role (Karakassis and Eleftheriou, 1997; Cyr, 1998) and affect chemical exchanges within the water column (Cyr, 1998).

The spatial distribution and abundance of benthic macroinvertebrates within estuarine habitats have also been related to other physical factors, notably waves and currents (Karakassis and Eleftheriou, 1997). Biological factors and chemical factors also influence the distribution of the benthic macrofauna (Kennish, 1990; Karakassis and Eleftheriou, 1997). Kennish (1990) indicated that the concentration of organic matter in sediments are known to influence benthic community structure and composition.

Distribution of benthic macroinvertebrates throughout an estuary is also a function of larval dispersal and recruitment. The distribution of other sediment related variables, such as pollutants and sediment particle size is likely to be heterogenous. Physical environmental factors, such as water depth, currents and sediment types, are believed to determine large scale patterns of distributions (Gray, 1974; Warwick and Uncles, 1980; Barry and Dayton, 1991).

The species composition of benthic communities depends greatly on the sediment type (Carriker, 1967; Holland, 1985; Kennish, 1990). The availability of organic matter and oxygen below the sediment-water interface has profound effects on the vertical distribution of macrobenthic species (Dauer *et al.*, 1987, In: Kennish, 1990). According to Day (1981) [cited by Kennish, 1990] it is not the average but the extreme conditions of environmental factors which limit the abundance and distribution of the benthic macrofauna in estuaries.

Both physical and biological disturbances play important role as determinants of species abundance, distribution and diversity in estuarine benthic communities. The succession pattern of a benthic community hinges on the frequency and nature of disturbances (Johnson, 1972; cited by Kennish, 1990). The occurrence of species also depends on biological adaptations.

There is good background research on the Malaysian mangroves, although there is a lack of quantitative data on the flora and fauna. Much of the early data available on macro-invertebrates in Malaysia are non-quantitative (Berry, 1963; Macnae, 1968; Berry, 1972; Sasekumar, 1974). More recent studies have provided quantitative data and related distribution of molluscs and crustaceans to environmental factors (Sasekumar, 1974; Frith *et al.*, 1976; Wells, 1983, 1984; Plaziat, 1984; Shokita, 1985; Sagathevan, 1992; Kumar, 1995; Jiang and Li, 1995; Yu *et al.*, 1997; Ashton *et al.*, 1999). There are few investigations on the macrobenthos occurring in mangrove estuaries in Malaysia or elsewhere, much less the number of in-depth studies on the macrobenthos inhabiting mangrove channels. In contrast, the macrobenthos living in the mangrove forest floor have been studied extensively (Sasekumar, 1974; Frith *et al.*, 1976). Large populations of marine fishes reside in mangrove estuaries (Chong *et al.*, 1990; Sasekumar *et al.*, 1994) and it is believed they consumed macrobenthos found in these habitats. Little is however known about the ecological roles of invertebrates in the mangrove ecosystem (Wells, 1990).

In the Selangor mangroves in Malaysia Berry (1972) recorded 32 gastropods and 34 crustaceans, and Sasekumar (1974) recorded 25 gastropods and 46 crustacean species (14 grapsids and 15 ocypodids). Frith *et al.*, (1976) recorded 27 mollusc species and 36 crustacean species from mangrove forests in Thailand and Yu *et al.*, (1997) recorded 37 mollusc species and 27 crustacean species in mangroves in China. Kumar (1995) recorded lower diversity (3.03) and richness (4.50) in India, even when polychaetes, molluscs and crustaceans were included. Kumar (1995) also showed macrobenthos (molluscs, crustaceans and polychaetes) had maximum diversity and density at the mouth of the estuary and decreased upstream. Jiang and Li (1995) showed that the species and abundance distribution of molluscs increased with salinity and recorded 44 species at high salinity (23.8) and 16 species at low salinity (10.9) in China.

Tan and Ng (1994) recorded 192 bracyuran crabs, 51 grapsid species and 36 ocypodid species, from mangroves in Malaysia and Singapore. The subgenus *Littoraria* has a worldwide distribution but shows maximum diversity in the central Indo-Pacific (21 species out of 36 total) with up to 10 species found together in a single mangrove swamp in Singapore (Reid, 1986). Sasekumar (1974) recorded 87 common species of invertebrates, more than 40 of which were crustaceans where brachyuran fauna constituted the largest population.

In the Matang Mangrove Forest Research, macrobenthos studies have been done by Sarpedonti and Sasekumar, 1997; Ashton *et al.*, 1999; Kosuge, 1999, 2000; Muhammad Ali *et al.*, 1999a, 1999b, 2000; Kawamura *et al.*, 2000; Omari *et al.*, 2000; Shamsuddin and Azman, 2000.

1.3 ANIMAL DISTRIBUTION AND ABUNDANCE

Animal distribution is determined by a complex series of responses to the physical and biological characteristics of their environment (Odum and Heald, 1972). Many species move from one habitat to another during various phases of their life histories. The principal movements of the ichthyofauna appear to be primarily in response to changes in physical and chemical factors, and biological factors including interspecific competition and predation which are of secondary importance.

Animals are associated with characteristic habitats or microhabitats whose presence or absence may specifically influence marine species composition and abundance (Odum and Heald, 1972). The ecology of populations and communities determines which factors or processes limit or generate changes to population size. Sediment characteristics are the prime factors structuring benthic assemblages (Schlacher *et al.*, 1998). High spatial heterogeneity in community structure is a key feature of the biota at the soft-sediment area. In benthic communities, it is likely that community structure is determined by a combination of biological accommodation and physical control (Boesch, 1974; Menge and Sutherland, 1976; Day, 1977).

1.3.1 Effects of Water Parameters

Many environmental factors influence the diversity and productivity of mangrove ecosystems. Water parameters are important when they interact and thus determine the suitability of habitat to marine life (Hynes, 1970). All mangrove studies should include measurements of environmental parameters that characterise the conditions at the site and at the time of data collection (English *et al.*, 1994). A study on the physico-chemical environment of the Matang area had been done by Chong *et al.* (1999).

Boto and Bunt (1981) emphasized that there is a positive correlation between pH and dissolved oxygen. Extremes in pH can make the water body inhospitable to life. Low pH is especially harmful to immature fish (Lobban and Harrison, 1994). Acidic water also speeds up the leaching of heavy metals harmful to fish. The alkalinity of seawater is higher and more stable compared to fresh water (Lobban and Harrison, 1994). Sasekumar *et al.*, (1994) indicated that the pH of the Matang channels showed lower values of 6.8 to 7.5. Chong *et al.* (1999) recorded that pH values in Sungai Sangga Besar (SSB) increased gradually from upperstream towards downstream ranging from 7.24 to 8.84 at the depth of 1 metre.

The densities of benthic community decrease concomitantly with temperature (Brandimarte and Shimizu, 1996). In tropical environments, seasonal temperature changes are little but offshore temperature decreases with water depth. Temperature plays an important role in the distribution of organisms in the mud flats. The major groups of macrobenthos including fish and prawn exhibit population fluctuations both at the species level and at the community level, in response to seasonal changes in temperature (Choudhury *et al.*, 1984). Sasekumar *et al.* (1994) indicated that in the

Matang channels, surface temperature averaged 30.0^{0}C while the bottom waters were only slightly lower. Chong *et al.* (1999) recorded that the mean water temperature in SSB at the depth of 1-metre increased from 29.63^{0}C to 30.76^{0}C in the offshore direction.

In estuarine waters the concentration of dissolved oxygen is a function of temperature salinity and pressure (Wetzel, 1983; Tyson and Pearson, 1991). The fundamental processes that control dissolved oxygen in an estuary is the neap-spring tidal cycling (Nelson *et al.*, 1994). The oxygen concentration is often an important factor regulating benthic community structure (Fraser, 1997). Chong *et al.* (1999) indicated that the mean dissolved oxygen at the depth of 1- metre in SSB increased from 2.33 mg/l to 5.24 mg/l in the offshore direction, but decreased in the vertical direction.

Salinity plays an important role in the distribution of marine invertebrates. Organisms in mangrove habitats acquire a certain degree of euryhalinity that insured them against fluctuating environmental conditions. Salinity regimes are related to the seasonal rainfall patterns. During the wetter months, salinity values decrease. Studies done by Chong *et al.* (1999) showed that in SSB, the mean salinity measured at the depth of 1-metre increased from 21.77 ppt to 26.59 ppt in the offshore direction. There were seasonal changes in the salinity profiles in the Matang system where salinities were distinctively lower during the wet season (May and Nov) than during the dry season (Feb and Aug) (see Chong *et al.*, 1999).

Turbidity is the condition resulting from suspended solids in the water, including silt, clay, industrial wastes, sewage and plankton. Highly turbid water during high tide indicated that turbidity is caused by tidal action. In shallow estuaries there is a stronger interaction between the water column and the bottom (Day *et al.*, 1989). Suspended particles absorb heat thus raising water temperature, which in turn lowers dissolved oxygen levels. Water depth is considered as one of the limiting factors known to influence fish population size (Thresher, 1983). Sasekumar *et al.* (1994) indicated that the Matang channels and the inshore waters were generally turbid.

1.3.2 Effects of Bottom Sediment Characteristics

Great variations in faunal densities and species richness in tropical waters have been attributed to the great variety of habitats and environmental conditions. Topographical heterogeneity refers to the variety of physical or structural features found in the habitat. The characteristics of the community such as diversity and richness are also modified by topographical heterogeneity (MacArthur and MacArthur, 1961; Menge *et al.*, 1985).

1.3.2.1 Sediment Parameters

Soil characteristics are one of the most important environmental factors directly affecting mangrove productivity and structure. These methods concentrate on major physical and chemical properties of the soils, such as pH (hydrogen ion concentration), Eh (Redox potential), salinity and particle size.

pH

Oxidation and reduction processes also affect the pH. Seawater has a pH greater than 8. However, the reduction processes caused by excess water tend to stabilise the pH of anaerobic soils to values near pH 7. If plants are actively growing in the sediment the production of organic acids and carbon dioxide may cause root zone pH to be even lower. The carbon dioxide arising from the decomposition of organic matter and from animal respiration also lowers soil pH values.

The acidity of the soil influences the chemical transformation of most nutrients and their availability to plants. Most mangrove soils are well buffered, having a pH in the range of 6 to 7, but some have a pH as low as 5. Measurement of the acidity or alkalinity of soils using pH must be done with fresh samples to avoid oxidation of iron pyrites to sulphuric acid, thus giving a much lower value of pH than normally occurs *in situ* (English, 1994).

Redox Potential (Eh)

Since mangrove soils are typically waterlogged, and hence anaerobic, microbial decomposition takes place through a series of oxygen-reduction (redox) processes. The redox potential (Eh) is a quantitative measure of reducing power which provides a diagnostic index of the degree of anaerobiosis or anoxia (Patrick and Delaune, 1977). Totally anoxic sediments have Eh below –200 mV, while typical oxygenated soils have potentials of above +300 mV. As the soil becomes progressively more anoxic and reducing, nitrate is converted to nitrogen (+200 to +300 mV), ferric iron (Fe^{3+}) is converted to ferrous (Fe^{2+}) (+100 to +200 mV) and sulphate is reduced to sulphide and carbon dioxide to methane (-200 to –100 mV) (Boto, 1984).

The measurement of Eh has been used as a rapid means of assessing the potential impact of additional organic input to marine sediment (Pearson and Stanley, 1979). Reliable measurements of Eh require great care to minimize exposure to the soil sample to air (English, 1994). The presence of organic carbon increases the rate of reactions, because microbes use it as an energy source. Mangrove soil is often anoxic and thus has low or negative Eh (Patrick and Delaune, 1977).

When a soil is flooded the rate of oxygen diffusion is greatly reduced. When oxygen is limited it is soon depleted by the aerobic respiration of soil bacteria and hence anaerobic microbial decomposition takes place through a series of oxidation-reduction (redox) processes. These processes contribute to the Eh of the soil. Eh is a parameter which is easy to measure and indicates whether a soil is oxidised or reduced.

Sediment Texture and Characteristics

Particle-size analysis is often used in soil science to evaluate soil texture. Sediment texture is based on different combinations of silt, clay and sand that make up the particle-size distribution of a soil sample (Folk, 1974). The most important environmental variables considered to control the distribution and abundance of benthic animals in estuaries are several interrelated static sediment variables, such as grain type, size and organic content, which in turn are determined by the hydrodynamic features of the estuary (Brandimarte and Shimizu, 1996).

All soils and sediments are composed of particles with a wide range of sizes. These are generally divided into three major groups; gravel (greater than 2 millimetres), sand (0.062-2 millimetres) and mud (silt and clay) (<0.062 mm or 62 μm). The mud fraction is further divided into coarse silt (62-15.6 um), fine silt (15.6-3.9 um) and clay (less than 3.9 um). The species composition and growth of mangroves is directly affected by the physical composition of mangrove soils. The proportions of clay, silt and sand, together with the grain size, dictate the permeability (or hydraulic conductivity) of the soil to water, which influences soil salinity and water content. Nutrient status is also affected by the physical composition of the soil, with clay soils generally higher in nutrients than sandy soils (English, 1994).

The associated changes in flow-rate, depth and temperature are important both directly and indirectly in their effects on the structure and composition of the sediments. However, hydrodynamics do not only affect benthic animals through their effects on static variables, but also influence the stability of the sediment and the nature of the food supply available to these animals (Warwick and Uncles, 1980).

Organic Matter

Densities of benthic communities decreased due to the decrease of organic matter input from terrestrial ecosystems (Brandimarte and Shimizu, 1996). The organic matter is useful as an energy source for benthic organisms of the detrital food chain (Efford and Hall, 1975; Petr, 1971; Terek, 1980). Most freshly deposited organic matter are either utilized by benthic organisms or resuspended and exported during the tidal phase (Kelley *et al.*, 1990). Dauwe *et al.* (1998) suggested that the highest benthic diversity was however found in sediment with intermediate quantity of organic matter.

1.4 AQUACULTURE

The aquaculture industry is fast becoming the main sector meeting the increasing demand for fish. It is highly probable that aquaculture will be an important industry playing a major role in fish and food production in the next century. Global farm production of finfish and shellfish has more than doubled in the past decade (FAO, 1999). Although farmed fisheries stocks are used to supplement natural ocean fisheries, some types of aquaculture reduce wild stocks through the collection of wild seedstock, and are the cause of habitat modification, fish disease and other environmental impacts such as generation of large amounts of waste (Naylor *et al.*, 2000). Recently, efforts have been made to minimize environmental impacts and to utilize less damaging methods of culturing commercially viable species within the coastal zone (Costa-Pierce, 1996; Midlen and Redding, 1998).

1.4.1 Aquaculture Development

In Malaysia, the last two decades saw a rapid transition from small-scale aquaculture farms to large commercial or multinational enterprises. Aquaculture therefore is expected to become more important as a major contributor to fish production in the near future. Under the National Agriculture Policy or NAP (1991-2010), aquaculture production has been projected to reach 600,000 tonnes by the year 2010 through the utilisation of some 35,000 ha of surface area of land and water. The projected figures only for brackishwater culture are 400,000 tonnes produced on a surface area of 20,000 ha. In incremental terms, these figures represent 16.7% and 11.1% annual growth for fish production and new area utilised, respectively (Chong, 1998). Present areas used for brackishwater culture are in the region of 7,500 ha.

The fisheries sector in Malaysia plays an important role in providing fish as a source of food and protein. Contributing about 1.57% to the National Gross Domestic Product (GDP), it provides direct employment to more than 79,000 fishermen and 20,000 fish culturists (Annual Fisheries Statistics, 1997). In 1997, the total production from the fisheries sector amounted to 1,280,907 tonnes valued at RM 4.35 billion. The aquaculture sector recorded a production of 107, 984 tonnes, 10% of the total fish production (Annual Fisheries Statistics, 1997).

Total brackishwater production for 1997 was estimated at about 76,311 tonnes with a market value of RM306.22 million (Annual Fisheries Statistics, 1997). Brackishwater culture constitutes 70 % of the entire aquaculture industry which also includes freshwater aquaculture. The productions for cockle and mussel for 1997 was estimated at about 58,400 tonnes and 1,779 tonnes, respectively (Annual Fisheries Statistics, 1997).

In Malaysia, shrimp ponds dominate the coastal aquaculture scene; in 1995, fish cages constituted only 72 ha as compared to ≈ 2620 ha of shrimp ponds (Chong, 1998). However, the rate of increase in fish cage farming is nearly six times faster than the growth of shrimp pond cultivation, and cage culture is at least as productive as pond culture ($\approx 3\ t\ ha^{-1}\ yr^{-1}$) (Chong, 1998).

Development plans for further aquaculture expansion are embodied in the New Agricultural Policy or NAP (1991-2010) and the role of aquaculture for the future has been well emphasised in the Seventh Malaysian Plan (1996-2000) and the Second Industrial Master Plan (1996-2005) (Ismail, 1997). To achieve the goals of the NAP, the Fisheries Department has formulated an action plan with respect to aquaculture development – the Aquaculture Development Action Plan (ADAP) which identifies the major thrust areas for expansion, namely cage culture, shrimp farming in former agricultural land and in new methods such as, recirculating tank and raceway culture. Suitable areas for aquaculture development are identified, zoned or demarcated as

'Aquaculture Development Areas' (ADA) to be presented to state authorities for land alienation. An Aquaculture Operation Plan is formulated for the implementation of ADAP, which includes among others one important area, an integrated water and effluent management plan.

1.4.2 IMPACTS OF CAGE CULTURE

The rapid growth of brackish water pond culture in Malaysia was first experienced in the late 1970s, stretching into the early 1990s. The species cultured in brackish water ponds are mainly the penaeid prawns (mainly *Penaeus monodon*), with fish (*Lates calcarifer*, *Epinephelus* sp. and red tilapia) of lesser importance (Choo, 1996).

Both cage and pen cultures are types of enclosure culture and involve holding fish captive within an enclosed space whilst maintaining a free exchange of water. The two methods, are however distinct from one another; a cage is totally enclosed on all sides, or all sides but the top, by mesh or netting, whereas a pen is an enclosure whose bottom is formed by the lake or sea bottom (Beveridge, 1984).

Like most other types of aquaculture, cage culture began in Southeast Asia, although it is thought to be of comparative recent origin (Ling, 1977). Cages have several advantages because they use existing water bodies, require comparatively low capital outlay and use simple technology. They can be used not only primarily as a method for producing high quality protein cheaply, but also, as is happening in Malaysia and Singapore, to clean up eutrophicated waters through the culture and harvesting of planktivorous species.

Cage and pen culture, like other methods of rearing fish, may be classified as extensive, semi-intensive, or intensive on the basis of feeding and stocking density. Extensive culture relies solely on naturally available foods such as plankton, detritus, benthos and no supplementary feeding is given. Semi-intensive culture involves the addition of low protein (<10%) feed stuffs, usually compounded from locally available plants or agricultural by-products to supplement the intake of natural food, whereas in intensive culture operations, fish rely almost exclusively on an external supply of high protein (>20%) food, usually based on fish meal (Beveridge, 1984).

Small rivers enriched with some organic material will have larger benthic populations and carry more detritus and insect life in the drift, than in polluted streams. Heavily polluted sites, however, are not suitable due to low dissolved oxygen levels which can retard growth and cause fish kills (Beveridge, 1984). In fast flowing rivers, however, intensive or semi-intensive fish culture is not advisable due to excessive loss of feed. Extensive and semi-intensive methods are only suitable for fish which are planktivorous, or which feed on benthos, detritus or drift, and are not suitable for fish with high protein requirements or which do not have the anatomical, physiological or behavioural adaptations to deal with these types of food (Beveridge, 1984).

The introduction of cage or pen culture to a water body has an impact on the environment which can lead to conflict, since inland waters are often, and increasingly so, under pressure from other uses and for a wide variety of purposes. The establishment of cage and pen farming operations in a lake, reservoir or river can also have an impact outside the immediate vicinity of the site, by its demands for construction materials (Cariaso, 1983).

Cage and pen structures can have a considerable impact on local currents and this has a number of implications. Sediment transportation in an aquatic system, although influenced by a number of factors, is principally determined by current flow (Smith, 1975; Gibbs, 1977). A sudden increase in the rate of sedimentation in an area would disrupt benthic communities (Brinkhurst, 1974) and accelerate filling in (ageing) of the water body, which could interfere with navigation. Siltation in the vicinity of cages and pens has been reported from Egypt, India, Malaysia, Singapore, Sri Lanka and Thailand (IDRC-SEAFDEC, 1979). Siltation problems caused by enclosures are most likely to occur in rivers and in areas of lakes, where large rivers flows in. Of more importance, however, are the effects of reduced current on the fish culture operation.

Environmental impact is common to all methods of enclosure culture. An enclosure is more of an open fish rearing system than land based ponds, raceways or tanks, and there is a far greater degree of interaction between the caged or penned fish and the outside environment than it occurs in other systems.

In earth and concrete ponds, the fish are fully exposed to the vagaries of climate (sunlight, temperature etc.), and there is also a degree of interaction between the cultured fish and other organisms. However, microscopic and macroscopic organisms such as viruses, bacteria and fungi, and phytoplankton, zooplankton and insects can be carried unimpeded into the ponds in inflowing water. Birds and other invertebrates also have relatively free access to ponds and raceways unless elaborate trapping or other preventive methods are used (Meyer, 1981; Martin, 1982).

Fish cage aquaculture is well developed in freshwater and coastal temperate and boreal regions, so the impact of cage farming in these areas is fairly well understood (Gowen and Bradbury, 1987; Aure and Stigebrandt, 1990). Most environmental impact studies in coastal waters have focused on benthic organic enrichment and subsequent eutrophication of the plankton communities. Most data from freshwater cage farming systems indicates that eutrophication is readily apparent, especially in small lakes where currents are slow and dilution of waste is limited (Beveridge, 1996; Costa-Pierce, 1996).

In coastal waters, the degree of impact appears to be closely dependent upon coastal hydrology and geomorphology. In coastal ecosystems where water circulation and tidal flushing is vigorous, many studies have either failed to detect any influence or have detected only transitory impacts on coastal water quality and food chains (Aure and Stigebrandt, 1990; Weston, 1991). The effects of cage farming are more apparent in semi-enclosed estuaries or fjords where water exchange and tides are limited (Wallin and Hakanson, 1991).

In the tropics where growth of fish cage aquaculture is fastest (DeSilva, 1998), the impacts of fish farming on coastal water quality and food webs, especially on plankton abundance and production, is poorly understood (Nunes and Parsons, 1998). Most data on aquaculture impacts in tropical coastal waters concerns shrimp ponds rather than net cage farming, reflecting the dominance of pond culture (Phillips, 1998).

1.4.3 Potential Impacts of Cage Culture in Malaysia

Malaysia is one of the largest producers of cultured fish, especially seabass, in southeast Asia (Rimmer and Russell, 1998). The impact of the development of cage aquaculture along the Malaysian coast is unknown. Ambitious targets have been set for growth in the industry in Malaysia, making it imperative that future site selection be based on an adequate understanding of the environmental impacts, if any, of existing cages.

In Malaysia, fish cage aquaculture contributes to aquaculture's economy and also as major source of food. There are several environmental issues to be addressed, which are concerned with site selection and the way the aquaculture is managed. However, the environmental effects such as nutrient enrichment, habitat damage, disease transmission, harmful algal blooms, abuse of chemical or antibiotic use, biodiversity loss, fisheries stocks, land subsidence, salination of inland water, waterway use, coastal erosion, geomorphology and hydrology etc. will limit its total production (Chong, 1998).

Daily water exchange allows the release of organic matter (from animal wastes and feeds), phosphate, nitrates, nitrites, ammonia and BOD from culture ponds into the surrounding waters. The degree of nutrient enrichment of the environment depends on the species being cultured, type of feed, frequency of feeding and hydrodynamics of the water system utilised (Chong, 1998). Nutrient enrichment of coastal waters by organic wastes is also contributed by fish cage culture that uses ground trash fish.

Shrimp farmers practice a daily pond water exchange of 30-50%, normally in the second month of culture. These exchanges also allow the release of organic matter (from animal wastes and feeds), phosphate, nitrates, nitrites, ammonia and BOD from culture ponds into the surrounding waters. The degree of nutrient enrichment of the environment depends on the species being cultured, the type of feed, the frequency of feeding and the hydrodynamics of the water system utilised. Nutrient enrichment of coastal waters by organic wastes is also contributed by fish cage culture that uses exclusively ground trash fish (the preferred feed for the cultured carnivorous fishes).

Dry pelleted commercial feeds are more costly but uncommon, although mash forms are available. It does appear that existing conditions prohibit the regular use of formulated fish feed which are considered less polluting to the environment. Feeding protocols could have significant impact in terms of polluting the surrounding water (Phillips, 1994). Decreasing the feeding frequency with fish age for sea bass has been suggested by Boonyaratpalin (1994). Wu *et al.* (1994) found that food losses from fish cages ranged from 1-15 %, but with trash fish it could be as high as 40 %. Phosphorus loss is much higher with trash fish compared to dry feed (Warren-Hansen, 1982). Protein digestion by cultured animals is the cause of nitrogenous outputs.

Fish or shrimp culture dependent on imported fry brings with it the transmission of imported disease-causing organisms. Under intense cage fish culture, diseases outbreaks occurred during stocking and grow-out phases. Mangrove snappers although of lower economic value were the preferred choice over the more susceptible sea bass. Disease outbreaks could have serious environmental impact if there is transmission of (often exotic) disease patogens from cultured populations to feral populations. Any such transmission could damage existing fisheries with dire socio-economic consequences. However, susceptibility of feral populations to such diseases is not known or poorly studied.

Disease outbreaks in culture systems are followed by applications of therapeutic chemicals and antibiotics, such as chlorine, formalin, acetic acid, sulphamonomethoxine, oxytetracycline, ampicillin, nitrofurazone, methylene blue, copper salts, etc. Probiotics which are concoctions of bacteria, enzymes and buffers, are recent introduction to shrimp farming technology with claims of disease prevenion, biodegradation of organic wastes and increasing production. Some of these chemicals may biodegrade eventually or become oxidised to become less harmful, but others are more persistent. Their entry into the surrounding waters may be harmful to natural populations, or induce natural resistance of harmful microbes to the applied antibiotics.

The severity of effluent discharge to the surrounding waters is dependent on the hydrographical regime, which involved the topography, tides and water currents. Poor exchange rates between 'pond' water and sea water due to "lateral trapping" by the surrounding mangrove vegetation (Wolanski *et. al.*, 1980). This phenomenon will have significant adverse environmental impact due to the expected poor dispersion of pond effluents and contamination of water intakes of adjacent prawn farms.

Altered flushing patterns of an estuary or river are caused by construction of coastal ponds on former mangrove lands. The effect of this (by removing mangroves) is sedimentation at the entrance of the river. Mangrove-fringes rivers or creeks are kept deep by ebb tide flow which is stronger than flood flow. This is attributed to the increased tidal prism within the vegetated portion at the riverbanks (Wolanski *et al.*, 1980). Suspended net cages especially in large clusters physically cause heavy sedimentation at the cage by obstructing river flow. Together with sedimentataion of unused feeds, the effect is a shallowing of the river system and a modification of the bottom substrate profile. Fishermen using the Sungai (River) Sangga Besar in Matang, Perak, as a waterway to offshore waters, had complained that thriving net cage culture at its river mouth caused the shallowing of many parts of the river (Chong, 1998).

1.5 AIMS OF STUDY

In view of the lack of studies on the environmental effects of fish cages, particularly in mangrove waters which are increasingly being utilized for this purpose, a research programme was initiated in the University of Malaya to investigate the effects of cage culture on water quality, phytoplankton, zooplankton and macrobenthos in the mangrove environment.

The main objective of the present study is to investigate the impact of floating cage culture operations in the Sungai (River) Sangga Besar (Matang Mangrove Forest Reserve, Perak, Malaysia) on subtidal macrobenthos diversity and abundance.

In order to achieve the objective, the following investigations and analyses were carried out:

a) Monthly characterization of the water quality and bottom sediment directly under fish cages and away from cage areas (control site) within the river,

b) Monthly estimation and comparison of the diversity and abundance of macrobenthos directly under fish cages and away from cage areas (control site) within the river,

c) Comparison of the species abundance and environmental data obtained from Sungai Sangga Besar (impacted river) with that obtained from another nearby river, Sungai Sangga Kecil (control river), where there is no aquaculture,

d) Univariate and multivariate procedures for the analysis of species abundance and environmental data.

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