CHAPTER 1

INTRODUCTION

1.1 Ecological Role of Mangrove Ecosystem

A mangrove is a woody plant that grows at the interface between land and sea in tropical and sub-tropical latitudes with harsh conditions such as high salinity, extreme tides, high temperatures and muddy, anaerobic soils (Kathiresan & Bingham, 2001). As specialized adaptations to their harsh environment, mangrove plants have exposed breathing roots, support roots and buttresses, salt-excreting leaves and viviparous water-dispersed propagules (Duke, 1992).

Mangroves or mangal, defined as a habitat or forest of mangrove plants (Duke, 1992) as described above, are unique ecological environments that host a rich diversity of terrestrial and aquatic fauna. More common on the forest floor and the water edge is the huge variety of macrofauna and infauna (Sasekumar, 1974; Sasekumar, 1996; Ashton, 2000). Mangrove creeks and estuaries support communities of phytoplankton, zooplankton and fish (Robertson & Blaber, 1992; Robertson *et al.*, 1992; Chong *et al.*, 1990; Esteves *et al.* 2000). The mangrove ecosystem may play a special role as a nursery habitat for juveniles of fish, prawns and crabs (Robertson & Duke, 1987; Chong *et al.*, 1990; Ahmad Adnan *et al.*, 2002) where their adults normally occupy offshore or other coastal habitats (e.g. coral reefs and seagrass beds).

Mangroves are commonly believed to be highly productive ecosystems (Alongi, 1997), producing organic carbon well in excess of the ecosystem requirements and contributing significantly to the global carbon cycle. Mangrove ecosystems produce large amounts of litter in the form of falling leaves, branches and other debris (Robertson & Daniel, 1989; Gong & Ong 1990, Holmer & Olsen, 2002). Decomposition and turnover of the litter, often aided by mangrove leaf eating crabs, contributes to the production of dissolved organic matter and the recycling of nutrients in the mangrove habitat and in adjacent habitats (Robertson *et al.*, 1992; Kathiresan & Bingham, 2001). While some of this organic matter simply accumulates in the sediments, large amounts could potentially be transported offshore (Alongi, 1990; Robertson *et al.*, 1991; Lee, 1995) and support offshore communities (Marshall, 1994; Robertson & Alongi, 1995; Van Tussenbroek, 1995). These studies apparently support the "outwellng" hypothesis first mooted by Odum (Odum & de la Cruz, 1963; Odum & Heald, 1975) that salt marshes and mangroves both function as sources of nutrients that are outwelled to inshore habitats thus fueling coastal food webs.

Odum's outwelling hypothesis has however been recently challenged by marine ecologists. Nixon (1980) in his treatise of published works on salt marshes cautioned hasty acceptance of such a theory, and that the evidence did not support such a theory and in fact, the salt marsh might function more as a sink (rather than a source) for nutrients. The sink versus source controversy was taken a step further, when Nixon *et al.* (1984) showed that the mangrove estuary of Sungai Sangga Besar in Perak, Malaysia, gave no evidence of nutrient outwelling. Instead, indications of the estuarine system acting as a nutrient sink were observed. Their conclusion was based on nutrient samplings along a salinity gradient from downstream to upstream, and applying the rationale of mixing diagrams. Surprising however, support for the sink hypothesis indirectly comes from biologists who studied the organic matter flow from producers to consumers using chemical tracers (stable isotopes). Haines (1977) showed that filter feeders and other consumers in tidal creeks in Georgia's *Spartina* salt marshes had δ^{13} (^{13}C:^{12}C) ratios that were more similar to plankton than to that of *Spartina* grass, indicating that carbon from the marsh were not outwelled into the tidal creeks. In a stable isotope study in the Malaysian mangroves, both Rodelli *et al.* (1984) and Newell *et al.* (1995) found that phytoplankton carbon rather than mangrove carbon were more important in offshore fish and prawn tissues, suggesting that outwelling of mangrove materials was insignificant or that these materials (detritus) were refractory. Primavera (1996) showed that the ratios of stable carbon isotopes in shrimps collected from mangrove habitats in the Philippines were much closer to the δ^{13} values of plankton and algae than they were to those of mangrove leaves. The study suggested that mangroves did not make a major contribution to coastal food webs. Rezende *et al.* (1990) estimated that oceanic carbon contributed up to 86% of the particulate organic carbon in water samples from a Brazilian mangrove system.

1.2 Nutrients

The term 'nutrient' refers to anything besides water and carbon dioxide (CO_2) that is needed by plants in the synthesis of organic matter or skeletal material (Stowe, 1987). The most universal of such materials are nitrogen and phosphorus in usable forms. Other nutrients that are equally important to growth of microorganisms and plankton, though in lesser amounts, include iron, manganese, copper, zinc, molybdenum and cobalt.

1.2.1 Nutritive Factors

a) Nitrogen Compounds

Total nitrogen (TN) comprises of dissolved inorganic nitrogen (DIN), dissolved organic nitrogen (DON) and particulate organic nitrogen (PON) tied up in plankton and bio-detritus. DIN can be further divided into dissolved nitrogen gas (N_2), ammonia (NH_3-N, lumped with ammonium, NH_4^+, in this study), nitrate (NO_3-N) and nitrite (NO_2-N). Most phytoplankton preferentially absorb NH_3-N, which is mainly from the breakdown of organic nitrogen. In oxygenated waters, NH_3-N is rapidly oxidized (or nitrified) to NO_2-N and NO_3-N whereas in anoxic waters, NH_3-N may become abundant as nitrification is low. Under anoxic conditions, NO_3-N and NO_2-N may be reduced to N_2 gas, which escapes to the atmosphere (Chuah, 1998).

b) Phosphorus Compounds

Total phosphorus (TP) comprises of dissolved phosphorus (DP) and particulate phosphorus (PP). DP can be divided into dissolved inorganic phosphorus (DIP) and dissolved organic phosphorus (DOP). DIP (such as PO_4 ions) can be absorbed readily by phytoplankton, but some phytoplankton may have enzymes that metabolize DOP (Harris, 1986). Ionic species of PO_4 is found in both organisms and the water. It is readily assimilated by phytoplankton in this form. PP consists of organic phosphorus in the plankton, bio-detritus and inorganic particulate matter.

1.2.2 Behavior of Nutrients in Estuarine Environment

Aston (1980) summarized the following factors that control the behavior of nutrients, dissolved gases and general biogeochemistry in estuaries:

i. Changes in the volume of water in an estuary due to mixing may produce temporal changes in the distribution of nutrients and dissolved gases;

ii. Vertical and horizontal variations of nutrient in the water column may be caused by water circulation and stratification in some estuaries;

iii. Topography of the estuaries may restrict circulation;

iv. Deposition and resuspension of sedimentary materials in the estuary may disturb the budget of nutrients;

v. Chemical reactions that occurred during mixing in estuaries may cause removal or addition of dissolved nutrients. In addition, the solubility of nutrients and dissolved gases will be influenced by the changes in temperature and salinity during mixing;

vi. The biological productivity, distribution of organisms and their interaction have significant influences on the occurrence and distribution of nutrients and some gases.

The distribution of nitrogen compounds (especially nitrate) in the estuarine waters is mostly governed by biological processes (Sharp *et al.*, 1982; Cochlan *et al.*, 1991; Ferrier-Pages & Rassoulzadegan, 1994). Studies by Hobbies *et al.* (1975) showed significant correlation between algal blooms and the appearance of nitrate in the middle reaches of the Pamlico River estuary in the U.S.A. Flint and Kamykowski (1984) estimated that annual benthic regeneration rates could supply 69% of the nitrogen required to support phytoplankton primary production in the South Texas coastal waters. Bulleid (1984) found evidence that the amount of ammonium released from detritus would be able to supply about 31% of the mean daily nitrogen requirement in South West Arm, Port Hacking estuary, Australia.

Numerous studies have also shown that sediments play an important role in supplying nitrogen in aquatic systems (Shalkovitz, 1973; Vanderborght & Billen, 1975; Nedwell *et al.*, 1983; Wolaver *et al.*, 1984; Simon, 1988). Suspended matters in the water column will be deposited onto the sea or river bed as sediments. The organic matter from the sediments will decompose and become dissolved in the interstitial water before being released into the water column. A study conducted at Seto Inland Sea in Japan (Yamada *et al.*, 1987) showed that the amounts of ammonium, dissolved organic nitrogen, nitrite and nitrate as percentages of the total dissolved nitrogen of the interstitial water were in the range of 47 – 99%, 10 – 50%, 0.1 – 0.6% and 0.3 – 4.1% respectively. According to Nedwell *et al.* (1983), nitrification in sediment only occurs if the sediment has an oxidized surface layer and thus will lead to the presence of high nitrate in the water column. Nedwell *et al.* (1983) also found that when a layer of planktonic detritus is deposited onto the sediment, the surface layer of the sediment becomes deoxygenated due to respiration process. Under anoxic condition, ammonium is the predominant form of inorganic nitrogen at the sediment surface, leading to high ammonium concentration in the water column.

Numerous researches have shown evidence of phosphate 'buffering' by water-sediment/suspended matter interaction within an estuary (Suratman, 1997). Pomeroy *et al.* (1965) found that the phosphate equilibrium in the water column was maintained at 24 – 28 µg/L (0.77 – 0.90 µmol/L) PO_4^{3-}-P at Doboy Sound, U.S.A. Butler and Tibbitts (1972) found that phosphate levels in Tamar estuary were maintained at 21 – 29 µg/L (0.68 – 0.94 µmol/L) PO_4^{3-}-P before and after heavy rain. This is probably attributed to the adsorption-desorption process in maintaining the buffer system. Carritt & Goodgal (1954) and Burns & Salomon (1969) found that the adsorption process is favored under low salinity and low pH conditions. Chemical composition and mineralogy were also found to affect the phosphate adsorption process on the sediment particles (Stirling & Wormald, 1977; Stone & Mudroch, 1989). In oxygen-rich waters, phosphorus entering the estuary is adsorbed on ferric oxides and hydroxides, which in turn are adsorbed onto or flocculated with suspended matter (Lopez-Hernandez & Burnham, 1978; Sundby *et al.*, 1992). However, under anoxic condition, Fe(III) is reduced to Fe(II), thus releasing the adsorbed phosphate.

Seitzinger (1991) found that there is a rapid release of phosphate under aerobic conditions when the pH of overlying water between water-sediment is high (pH value at 9.5 – 10.5). The study concluded that this is probably the result of solubilization of iron and aluminium phosphate complexes which increase at high pH. Singh *et al.* (1992) showed that there is a rapid phosphate removal by cyanobacterium at pH 9.

The biological and non-biological processes of phosphate are likely to be influenced by the concentration of suspended solids (SS) in the water column. In turbid estuaries, DIP concentration is primarily controlled by non-biological particle interactions with DIP. In highly productive estuaries, the biological process is found to be the dominant factor that controls the DIP concentrations (Suratman, 1997).

Fisher *et al.* (1988) found that DIP uptake by plankton is sufficiently rapid to completely utilize the DIP during estuarine mixing.

1.3 Photosynthetic pigments

Phytoplankton contain a mixture of light-harvesting pigments which absorb light in the wavelength range of 400 – 700 nm. Macromolecules are synthesized from light energy and CO_2, as well as a supply of various chemical nutrients, particularly nitrogen, phosphorus and silicon. Carbon is abundant and readily available in the atmosphere and matter. The supplies of light and nutrients usually determine how fast phytoplankton grow and replicate (Little, 2000).

Chlorophyll *a* is the principal photosynthetic pigment in green, brown and red algae, diatoms, cyanobacteria and higher plants. Other accessory pigments include chlorophylls *b* and *c*, the carotenoids and phycobilins (Chuah, 1998). Measurement of chlorophyll *a* concentration is usually used in the determination of phytoplankton abundance.

1.4 Brackishwater Culture in Malaysia

The fisheries sector in Malaysia, comprising fisheries and aquaculture, plays an important role in the national economy in terms of food production, employment, income and gain of foreign exchange. In 1997, the total fish production was 1,168,973 tonnes valued at RM3.68 billion (Department of Fisheries Malaysia, 1999). Of this, 91% of the total fish production was from marine fisheries while only 8.4% was from aquaculture production.

The aquaculture industry in Malaysia started in the early 1930s with the introduction of freshwater fish culture (Chong, 1998). Brackishwater culture came in later with the introduction of shrimp farming using ponds in mangrove areas and cockle culture in mudflats in the late 1930s and 1940s respectively (Tan, 1998). Then came the culture of marine finfish in floating net-cages and the culture of green mussels using floating rafts in the 1970s. In the 1980s and 1990s, the industry picked up considerably with the increasingly intensive involvement of entrepreneurs and government agencies as well as corporate sector in large-scale shrimp farming and freshwater fish culture.

The total brackishwater culture production for 1997 was estimated at about 76,311 tonnes with a market value of RM369.38 million (Department of Fisheries Malaysia, 1998). Under the National Agriculture Policy (NAP, 1991-2010), brackishwater culture has been projected to reach 400,000 tonnes by the year 2010. These figures represent 16.7% annual increase for fish production.

The brackishwater culture in Malaysia can be generally categorized into four types, namely, brackishwater shrimp pond farming, net cage fish culture, off-bottom mussel culture and on-bottom cockle culture. In a comparison of productivity and economic returns of the four major types of brackishwater aquaculture practised in Malaysia, Chong (1998) showed that fish cage culture yielded the second highest in terms of productivity (tonnage) but the highest in terms of economic value for the years 1988 - 1995. In cage culture, space could be optimally utilized for biomass production of culture animals, including for economic benefits. Total cage fish production in Malaysia amounted to 6,023 tonnes with a total surface area of 70.72 ha in 1998, compared to 413.91 tonnes with 2.48 ha in 1983 (Department of

Fisheries, 1983; 1998). The surface area of cage culture has increased tremendously, although the productivity per surface area in 1998 (85.2 tonnes/ha) was much lower than in 1983 (166.9 tonnes/ha).

1.5 Impacts of Aquaculture on Water Quality

The impact of net cage aquaculture along the Malaysian coast is yet to be known though there have been reports on increased incidence of fish disease and fish kills from low dissolved oxygen related to organic pollution, for example, at Kukup, Johor (Phillips, 1998). Fish cage farms which are often very closely clustered at sheltered mangrove waters may cause sedimentation at the cage site by obstructing river and tidal flows, and hence reducing their dispersion effects. Wolanski *et al.* (1980) demonstrated by numerical modeling that the effluent plume as discharged from shrimp ponds sited in mangrove areas did not significantly move away from the ponds during ebb flow, but moved back during the opposite flood flow. He showed that the exchange rates between pond water and seawater were low due to 'lateral trapping' by the surrounding mangrove vegetation.

It is also widely believed that fish cage aquaculture causes organic enrichment of the seabed since only a small proportion of the feed is assimilated, while a large proportion is deposited as uneaten food and faecal excretion. This leads to progressive transformation of the seabed into flocculent anoxic substrates (Gowen & Bradbury, 1987; Iwama, 1992; quoted by Karakassis *et al.*, 1998). The use of trash fish feed as practised in Malaysia and many countries in the region, is probably the main contributor to nutrient enrichment (Beveridge, 1996; Costa-Pierce, 1996). Warren-Hansen (1982) found that food wastage, organic and nutrient loading were several times higher when trash fish was used when compared with fish farms where pellet feed was used.

Oversupply of nutrients and poorly circulated water condition can lead to eutrophication. Eutrophication is defined as a process of enrichment of nutritive substances, mainly phosphorus and nitrogen, in a relatively poor aquatic environment. This phenomenon will lead to the increase in abundance and changes in species composition of both microscopic and higher forms of biological life in the system (Rosenberg, 1985). The increased organic matter in the water and sediments results in an increase of oxygen demand. If the process continues, the decay of large amount of organic matter will deplete the available oxygen in the water and result in large fish kills (Rosenberg, 1985).

Eutrophication of coastal waters could also be the cause of harmful algal blooms (HAB), commonly known as red tides. HAB may cause paralytic shellfish poisoning (PSP) through the consumption of marine fish and shellfish. In Malaysia, HAB causing PSP have been observed in Sabah waters (Wong & Ting, 1984) and in the Straits of Malacca (Ismail *et al.*, 1997). The presence of high nutrient concentrations especially near the bottom (nitrate, phosphate $\geq$ 6 μmol/L), warmer temperatures ($\geq$ 27°C) and column thermal stratification appeared to trigger episodic red tide blooms caused by dinoflagellates in Manila Bay (Velasquez *et al.*, 1997). It is also known that HAB (*Chattonela* and *Heterosigna spp.*) associated with aquaculture ponds in Thailand caused stress and non-feeding of shrimps (Lirdwitayaprasit, 1997).

Numerous studies on impact of fish cage culture on the water quality and bottom sediment have been carried out in the temperate regions (Cornel & Whoriskey, 1998; Foy & Rosell, 1991; Lehtinen *et al.*, 1998). In general, the results of temperate studies indicated that the impacts are localized and restricted to areas in the immediate vicinity of fish farms (Cornel & Whoriskey, 1998; Gowen & Bradbury, 1987). In the tropical and sub-tropical waters where fish cage culture is growing rapidly, not much is known of the impacts on the water quality. The environmental impacts of aquaculture in the tropics and sub-tropics may be very different from the temperate regions. Cultured fish are mostly fed with trash fish feed in the tropical and sub-tropical farms (e.g. Hong Kong, Thailand and Malaysia) while in most temperate farms, pellet feed is used (e.g. Canada and Mediterranean waters). Warren-Hansen (1992) reported that food wastage and organic and nutrient loadings are several times higher when trash fish is used compared with fish farms where pellet feed is used. The use of trash fish is believed to generate food wastes of smaller particle size, which may facilitate a wider dispersion and cause greater impact on a larger area (Wu *et al.*, 1994). In addition, the higher water temperature in the tropics and sub-tropics may allow a higher rate of biological processes in the water, influencing the plankton dynamics.

Malaysia is known to be one of the largest producers of cultured fish in the Southeast Asia (Rimmer & Russell, 1998). With the rapid expansion rate of fish cage farming in Malaysia, studies on the effects of fish cage farming on the environment are very important to ensure the aquaculture development is sustainable commercially and environmentally.

1.6 Objectives of Study

The main aim of this study is to investigate whether coastal cage culture activities cause any increased nutrient concentrations of surrounding waters. The hypothesis that cage culture increases nutrient concentrations in the water column, which in turn causes increased phytoplankton production was tested in this study. This hypothesis has the following basis: fish feeding → nutrient leaching from fish feed → increased phytoplankton production.

To test the above hypothesis, several investigations were carried out at the Matang mangrove estuaries with the following specific objectives:

a) To compare nutrient and chlorophyll *a* concentrations in cage and non-cage sites;

b) To determine whether phytoplankton blooms (based on chlorophyll *a* concentrations) are directly associated with increased nutrient concentrations or otherwise;

c) To test whether the nutrient and chlorophyll *a* concentrations were actually due to cage culture effects and not confounded by seasonal, tidal or diel effects;

d) To monitor and compare the rates of nutrient release from two major types of fish feed – ground trash fish feed and formulated pellet feed.