CHAPTER 1

GENERAL INTRODUCTION

1.1 Zooplankton of mangrove estuaries

The mangrove forest is one of the major ecosystems of the biosphere. Approximately 60%-75% of the tropical coasts are covered by mangrove forests (Por, 1984). The Ramsar Convention classified mangroves as both intertidal vegetated sediments on sheltered coasts in the marine ecosystem and intertidal forested wetlands in the estuarine ecosystem (Davies and Claridge, 1993).

The mangrove environment is very dynamic. Its ecology in general may be considered as the result of a combination of climatic, hydrological, geophysical, geomorphic and biological factors (Varadachari and Kesava Das, 1984). Mangrove ecosystems by nature include the aquatic element. This may be merely the temporary intrusion of seawater along open coasts at high tide, or it may be waters of tidal creeks or estuaries surrounded by mangroves (Grindley, 1984). In situation where there is a prolonged association between the water body and the mangrove ecosystem, there can be opportunities for significant interactions between the mangroves and the plankton of the estuary. Tropical estuaries and lagoons are among the most productive and zooplankton-rich ecosystems in the world (Robertson and Blaber, 1992). Zooplankton abundance within mangrove waterways / channels is higher than adjacent coastal waters (Robertson et al. 1988, Robertson and Blaber, 1992).

Zooplankton are planktonic animals that drift passively with the water currents. They are volumetrically abundant with sizes ranging from several microns to 2 cm. Most zooplankton consume phytoplankton or detritus and serve as an essential link in aquatic food chains by converting plant matter to animal matter, while others are primary carnivores. Some species obtain nutrition by the direct uptake of dissolved organic nutrients. Zooplankton basically gather food via filter feeding or raptorial feeding. Raptorial feeders seize and eat individual cells by removing a few selected prey (Kennish, 1989).

Holozooplankton are permanently planktonic animals (e.g. copepods, cladocerans and rotifers). While the holozooplankton forms important trophic links, the meroplankton comprised of larvae produced by commercially important fish, shrimp and crab species. In spite of their importance, relatively little work has been done on mangrove zooplankton as compared to studies on shrimp and fish communities in mangroves (Robertson and Blaber, 1992).

Both biological and physico-chemical conditions in estuaries control zooplankton species composition, abundance and distribution. These microfauna must adapt to varying stresses associated with biological (e.g. scarcity of food, competition, and predation) and physical-chemical factors (e.g. temperature, salinity, mass movements of water, and dissolved oxygen levels) (Kennish, 1990).

Mangrove estuaries and creeks usually show significant salinity fluctuations during wet and dry seasons. Larger fresh water input during wet seasons brings about changing conditions in estuaries. Uniformly high temperatures and large amounts of organic debris derived from mangroves or marginal forests upstream are also characteristic features of estuaries (Grindley, 1984). The fluctuations in salinity occurring during rainy seasons may cause periodic mass mortalities of marine organisms. Such physico-chemical fluctuations are particularly significant to the zooplankton since a wide variety of holoplanktonic and meroplanktonic organisms appear in mangrove estuaries. As in the open sea, the zooplankton tends to be more diverse than the phytoplankton in estuaries.

In mangrove estuaries as a result of the fluctuating freshwater input, there may be major changes in the salinity zones with the seasons. The degree of freshwater flushing and the seasonal variation in salinities in other mangrove systems such as coastal lagoons, are the main factors controlling the species composition of mangrove zooplankton communities (Grindley, 1984).

The holoplankton is dominated by small copepod species although most of the taxonomic groups present in neritic waters may be found in estuaries, particularly if salinities are high. Large rhizostomid jellyfish are seasonally abundant. Planktonic foraminifera, hydroid medusae, euphausids, salps and larvaceans are however rarely encountered in mangrove estuaries. Mysids and amphipods may be abundant but as these spend much of their time on the bottom it is sometimes considered as tychoplankton rather than true plankton. Meroplanktonic forms including invertebrate larvae are seasonally abundant, particularly the larvae of barnacles, polychaete worms and decapod crustaceans. Pelagic eggs, larvae and juveniles of several species of fish appear in many samples.

In almost all the estuaries, the greatest species diversity occurs among neritic forms near the mouth. Various marine species penetrate to different degrees into the lower reaches. The upper reaches are often dominated by estuarine species. The zooplankton of estuaries may thus be divided into four components on the basis of salinity tolerance: (1) a stenohaline marine component penetrating only into the river mouth (e.g. *Corycaeus* spp.) (2) a euryhaline marine component penetrating further up the estuary (e.g. *Paracalanus* spp.) (3) a true estuarine component comprising species confined to estuaries (e.g. *Pseudodiaptomus* spp. and (4) a freshwater component comprising species normally found in fresh water (e.g. *Diaptomus* spp.) (Grindley, 1984).

Many studies have been done on the abundance and species composition of zooplankton in the brackish waters of tropical estuaries (e.g. Madhupratap and Haridas, 1975; Woodridge, 1977; Youngbluth, 1980; Grindley, 1981; Shanmugam et al., 1986; Robertson et al., 1988: In Oka, 2000). The composition and distribution of zooplankton in the Matang waters was studied by Oka, (2000) where the density of zooplankton ranged from 4,473 to 212,381 ind. m^{-3}. Copepoda were consistently the most abundant component of zooplankton. Table 1.1 shows the range of density / biomass of zooplankton in different types of mangrove habitat (e.g. estuary, bay and lagoon).

Zooplankton sampling in the mangroves is known to be difficult owing to shallow depths, high turbidity, high sediment load and periodic fluctuation of the different physical and chemical parameters which influence zooplankton distribution and abundance (Goswami, 1984).

Table 1.1 Zooplankton community standing stocks (densities and dry mass) and dominant taxa (> 80% of total numbers) in tropical mangrove waterways. A = converted from wet weight, assuming dry weight = 0.019 wet weight (Omori, 1969); B = only adult copepods (Robertson and Blaber, 1992).

Location	Habitat	Salinity Range (‰)	Net Mesh Size (μm)	Density (no. m^{-3})	Biomass (mg m^{-3})	Dominant Taxa
Africa						
Ivory Coast[1,2]	Coastal Lagoon	0-30	64	Up to $2.5x10^{5}$	Up to 48.2	*Acartia clausi*, *Pseudodiaptomus hessei*, *Oithona brevicornis*, *Paracalanus* sp., rotifers, *Penilia* sp., *Evadine* sp.
Americas						
Venezuela[3]	Coastal Lagoon	6-35	70	$9.01\text{-}28x10^{5}$	2.3-55.7	*Oithona hebes*, *Brachionus plicatilis*, *Favella panamensis*.
Brazil[4]	Estuary	3-24	50	$6x10^{2}\text{-}1.5x10^{5}$		*Oithona* sp., *Pseudodiaptonus acutus*
Brazil[5]	Estuary	14-32	50	$6x10^{4}\text{-}2.2x10^{5}$		*Pseudodiaptonus acutus* *Euterpina acutifrons* *Acartia lilljeborgii*, *Oithona orals*, *Paracalanus* sp.
Puerto Rico[6]	Embayment	30-37	202	$1.3x10^{2}\text{-}4.2x10^{3}$		*Acartia tonsa*, *Pseudodiaptomus cokeri*
Asia						
India[7,8]	Estuary	5-20	75	$1.0x10^{3}\text{-}4.9x10^{4}$	$40\text{-}176^{A}$	-
India[9]	Estuary	3-33	119	$1.2x10^{2}\text{-}7.4x10^{4}$		*Oithona* spp.
Thailand[10]	Estuary	NA	100	$2.0x10^{4}\text{-}1.7x10^{5}$		*Oithona brevicornis*, *Acartia* spp., *Corycaeus* spp. *Microsetella norvegica*
Singapore[11]	Estuary	14.5-29.4	>10	$3.7X10^{3}\text{-}1.1X10^{5B}$	<1-623	*Acartia* spp.
Australia, New Guinea						
New Guinea[12]	Estuary	0-25.4	105	$1.5x10^{2}\text{-}1.7x10^{4}$	<1-623	*Oithona aurensis*, *Parvocalanus crassirostris*, *Oithona simplex*, *Oncea media*, *Oithona attenuata*, Bivalve larvae
Australia[13]	Estuary	7-38	105	$2.0x10^{2}\text{-}6.1x10^{4}$		*Parvocalanus crassirostris*, *Oithona simplex*, *Paracalanus spp.* *Oithona australis*, *Euterpina acutifrons*.
Australia[14]	Estuary	0-35	290	-	-	*Gladioferens pectinatus*, *Calamoccia trifida*, *Boeckella fluvialis*, *Sulcanus conflitus*, *Pseudodiaptomus colefaxi*, *Oithona brevicornis*.

Sources: 1. Arfi *et al.*, 1987., 2. Caumette *et al.*, 1983; 3. Zoppi de Roa, 1974; 4. Teixeira *et al.*, 1969; 5. Tundisi *et al.*, 1973; 6. Youngbluth, 1980; 7. Bhunia and Choudury, 1982; 8. Sakar *et al.*, 1984; 9. Shanmugan *et al.*, 1986; 10. Marumo *et al.*, 1985; 11. Chua, 1973; 12. Robertson *et al.*, 1990; 13. Robertson *et al.*,1990; 13. Robertson *et al.*, 1988; 14. Kennedy, 1978.

1.2 Zooplankton dynamics

Biotic and abiotic factors

Effects of light

A number of biotic and abiotic factors affect zooplankton dynamics and community structure. Light is a major factor regulating diel vertical migration of zooplankton (Forward, 1988). Light acts as cue which triggers faunal migration where changes in illumination at sunrise elicits vertical movements of the organisms (Sterns & Forward, 1984; Forward, 1986; Stearns, 1986). Vertical migration seems to be a response to the following light cues: (1) a change in depth of a particular light intensity, (2) a change in underwater spectra, (3) a change in the polarized light pattern, (4) an absolute amount of change in light intensity, and (5) a relative rate of intensity change (Sterns & Forward, 1984; Swift & Forward, 1988; Forward, 1985). The cue for initiating vertical movements is the rate and direction of change in light intensity from the ambient level (adaptation intensity) which itself can change over a day (Forward et al., 1984). Fermin & Seronay (1997) showed that the presence of light not only attract sufficient quantities of zooplankton that satisfies the food requirement of fish fry but also enables the fish to locate and efficiently prey on their planktonic food.

Effects of temperature

Temperature influences zooplankton physiology and ecology (Heinle, 1969, 1981). Lower temperatures, for example, favor zooplankton with higher fecundity (McLaren, 1974). The vertical migration of zooplankton populations into deeper, colder areas of a thermally stratified system confers an advantage to the organisms with regards to fecundity. Seasonal variation in species composition and abundance of zooplankton are well documented in temperate waters with regards to temperature variations (Jeffries & Johnson, 1973).

Effects of salinity

Tolerance to salinity limits zooplankton distribution within an estuary. Zooplankton fauna are responsive to salinity levels encountered along the longitudinal axis of an estuarine system. They respond to salinity changes in the vertical plane as well (Stickney, 1984). The salinity tolerances of holoplankton and meroplankton differ among species and may vary among ontogenic stages within a single species (Lippson et al., 1981). The patterns of species succession and dominance from the upper reaches to the mouth of an estuary, therefore are contingent upon salinity concentrations. Salinity extremes often arrests growth and increase mortality of susceptible forms. However, species experiencing widely fluctuating salinities can survive these conditions by active osmoregulation or by tolerating low internal osmolality (Miller, 1983)

Water circulation

Hydrographic conditions in an estuary such as riverine discharges, tidal currents and waves, strongly affect zooplankton position. Tidal exchange is the single most important factor controlling zooplankton distribution (Grindley, 1981). The currents in estuaries displace zooplankton populations, especially in small systems or those characterized by strong inflow which may translocate larvae to coastal oceanic waters, thereby reducing standing crops in the main body of the estuary (McLucsky, 1981). The vertical migration behavior of many zooplankton species interacts with the two-way estuarine flow to enable the populations to maintain their location in the estuary. However, circulation patterns typically exacerbate spatial heterogeneity in zooplankton communities.

Zooplankton feeding

Zooplankton have an essential role in estuarine food chains as an intermediate link between primary producers (i.e. phytoplankton) and secondary consumers. The grazing on zooplankton or phytoplankton provides energy for higher-trophic-level organisms. However, many zooplankters are omnivorous which complicates the structure of estuarine food webs. Observations on copepods indicate that they feed by means of a passive filtration process of small particles or by active capture of large particles. In the active capture of prey, copepods initially detect a food particle by chemo- or mechanoreception, and subsequently, seize it. Feeding appears to be much more sophisticated among copepods where some species display selective feeding behavior (Harris, 1982).

The rate of ingestion of zooplankton increases with increasing prey density up to a limit after which the ingestion rate becomes constant. This relationship can be described by using a number of models, such as the Ivlev equation and Michaelis-Menten equation. A feeding threshold of zooplankton also exists below which phytoplankton are no longer exploited. Feeding thresholds preclude the elimination of phytoplankton populations via grazing pressure. While zooplankton ingest large amounts of food, only a portion is assimilated, with the remainder being egested. Assimilation efficiencies for zooplankton measured by several different methods often exceed 50% and may equal 99% in some cases (Heinle, 1981).

1.3 Aquaculture

Aquaculture is now an increasingly valuable contributor to global food supply, providing a growing and diverse range of high quality products for export or for local consumption in many countries. It can be more than just a potential means for reducing the need to import fisheries product. It increases number of jobs, enhances sport and commercial fishing, and is a reliable source of protein for the future. Aquaculture contributes 19% of the world's fish production. It is growing at an extraordinary rate of 8.8% per year since 1986 as compared to 0.7% for capture fisheries production (Williams and Bimbao, 1998). The rapid expansion in marine fish farming during the last 20 years has led to a growing concern about environmental impacts due to waste discharge from the farms (Gowen and Bradbury, 1987; Frid and Merar, 1989; Aure and Stigebrandt, 1990).

1.31 Aquaculture in Malaysia

Aquaculture in Malaysia is a young and fast growing industry and contributes significantly towards fish production in the country since its beginning in the 1930's. The Malaysian Government has recognized the close link between mangroves and coastal fisheries, and thus certain coastal mangrove areas have been designated for the purpose of maintaining suitable nursery and breeding grounds for crustaceans, molluscs and fishes (Bakar, 1984). There are few types of brackish water aquaculture in Malaysia: cage net culture, pond culture, mussel culture and cockle culture. Fish cage aquaculture in Malaysia is considered a relatively young industry having begun in the early 1980's, but now a fast growing industry contributing significantly to the aquaculture sector. 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 (Annual Fisheries Statistics, 1983 & 1998). Within Southeast Asia, Malaysia is one of the largest producers of cultured fish, especially the giant seabass (Rimmer and Russell, 1998).

Aquaculture 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 land and water. The projected figures of production for brackish water culture is 400,000 tonnes covering 20,000 ha. In incremental terms, these figures represent 16.7% and 11.1% annual growth for fish production and new area utilised, respectively. Presently, brackishwater culture covers 7,500 ha (Chong, 1998). This is due to the insatiable, local as well as world market demand for fish and shrimp against a backdrop of stagnating yields from capture fisheries (Chong, 1998).

The rapidly growing aquaculture industry in the Asia Pacific region has led to great concern of its perceived impacts on the environment. The environmental effects arising from aquaculture activities include damage of habitat especially coastal habitats, nutrient enrichment around fish ponds cages, disease transmission, applications of therapeutic chemicals and antibiotics which are harmful to natural populations, loss of biodiversity, salination of inland water, coastal erosion, social disruption and land-use conflicts (Chong, 1998). The main impact of cage culture systems is nutrient enrichment resulting in eutrophication and depressed DO levels. The use of trash fish feed as practiced in Malaysia and many countries in the region, is probably the main contributor to nutrient enrichment (Beveridge & Costa-Pierce, 1996).

1.4 Importance and scope of study

World aquaculture production has increased at an average annual rate of 9.6% between 1980 and 1990 which is five times the global population growth rate (Csavas, 1994). Between 1987 and 1997, global production of farmed fish and shellfish more than doubled in weight and value, as did its contribution to world fish supplies (FAO, 1999). In ASEAN, the marine aquaculture production rose from 592,000 tonnes in 1992 to 715,000 tonnes in 1996 (FAO, 1999).

The rapid increase of aquaculture has led to a greater concern about its impact on the environment. Production practices and their impacts on marine ecosystems vary widely. Farmed fisheries are said to supplement stocks of natural ocean fisheries but this is not true for all types of aquaculture. Some types of aquaculture may reduce wild stocks through collection of wild seedstock, habitat modification, disease and other environmental impacts such as the generation of large amounts of waste (Naylor et al., 2000).

Studies in temperate regions indicate that marine fish aquaculture exerts a localized environmental impact, usually in the immediate vicinity of fish farms (Phillips &

Beveridge, 1986; Anon, 1987; Gowen & Bradbury, 1987; Molver et al., 1988). The impact is greater on the benthic sediments than in the water column (Songsangjinda et al., 1993; Wu et al., 1994). Organic enrichment of the seabed is the most widely encountered impact of caged cultured fisheries (Gowen and Bradbury, 1987; Iwama, 1991, cited in Karakassis et al. 2000). This is because a small proportion of the carbon supplied to the fish via the feed is retrieved through the harvest whereas a considerable amount reaches the seabed, either as wasted food pellets or as faecal excretions.

When a culture site is used for a long period of time, sediment quality deteriorates. Songsangjinda et al. (1993) reported that the value of organic nitrogen, total nitrogen, total phosphorus, ignition loss and total sulphide are significantly higher in cage areas where groupers and seabass were cultured for more than 3 years as compared to areas where they had been cultured in less than 3 years. The deteriorating condition of the sediment quality in a culture site in relation to the 'age' of the fish farm may adversely affect fish production. Leong and Wong (1990) who examined disease outbreaks at fish farms reported a greater frequency of disease outbreak in older fish farms. The major impact is therefore on the sea bottom, where anoxic sediments create a high oxygen demand, production of toxic gas and a decrease in benthic diversity within a 1 km radius of the farm (Wu et al., 1994; Wu, 1995). In the Matang Mangrove Forest reserve in Sungai Sangga Besar (SSB) where floating fish cage culture is present, there are significantly higher macrobenthos abundance in non-cage sites than sites inside the cage area (Natin, 2001). Fish cage areas apparently attract scavenging nassarid gastropods while non-cage areas are dominated by the blood cockle, *Anadara granosa*.

In the Asia Pacific region, cultured marine fish are fed with trash fish. Many intensive and semi-intensive aquaculture systems use 2-5 times more fish protein, in the form of fish meal, to feed the farmed species than is supplied by the farmed product. In contrast, extensive and traditional systems use little or no fish meal, although nutrient-rich materials are often added to the water to stimulate growth of algae and other organisms on which the fish feed.

A proportion of fish meal remains uneaten because quantities and quality are often inappropriate and also because aquaculture systems and their management tend to confound optimization of ingestion (Beveridge et al., 1991) Studies indicate that the proportion of uneaten food varies from around 1% to as much as 30%. This also confirms that the system, type of feed and management are important determinants of wastage (Beveridge et al., 1991).

Fish feed introduces large amount of organic and inorganic nutrients into the fish farm. High protein (nitrogen) content is one characteristic of trash fish (Qian et al., 2001) The present study therefore looked at one of the possible impacts of cage fish culture on the natural zooplankton community, through nutrient and food enrichment of the water column. The hypothesized scenario of the chain of events that could follow from trash fish feeding as well as from cultured fish excretion is as follows: (1) released dissolved nutrients (e.g. C, NH_4 , PO_4) → increased phytoplankton production → increased zooplankton production; and (2) suspension of fine trash feed or fish fecal particles → increased abundance of detritivorous, omnivorous or / and coprophagous zooplankton. Both chains of events could eventually lead to increased zooplankton density /biomass and particularly because of (2), the DO levels are depressed from the increase in zooplankton and bacterial respiration. Another chain of event is as follows: the released of particulate organic nutrients → consumption and degradation by bacteria → release of dissolved inorganic nutrients to the water. Again this leads to increased bacteria respiration (depressed oxygen) and eutrophication. The high bacterial content in aquaculture waters may significantly deteriorate water quality by lowering the DO and pH levels (Qian et al., 2001). In Matang, aquaculture operators often encountered mass fish kills in the early morning due to low dissolved oxygen. The above hypothesis was tested in the present study by comparing zooplankton abundance in cage and non-cage areas. The results of the study will be of great value to aquaculture management and habitat rehabilitation.

1.5 Aims of study

A research programme was initiated in University of Malaya to investigate the effects of cage culture on water quality, phytoplankton, zooplankton and macrobenthos in the mangrove environment. This was due to the lack of such studies on the environmental effects of fish cage culture in mangrove waters. Cage culture impacts on these parameters have been separately reported (e.g. Alongi et al., 2001; Natin, 2001).

The present study only examines the effects caused by floating fish cage culture on the natural zooplankton community of the Matang Mangrove Forest Reserve. It also identifies the physical and chemical factors that influence the abundance and distribution of zooplankton.

The main objective of the present study is to compare the biomass, density and composition of zooplankton within and outside fish cage culture areas to determine if there are any differences.

Another objective of the study is to understand these differences (if any) by examining and comparing the physico-chemical environment of the cage and non-cage areas.

To achieve the above objectives, this study carried out the following investigations:

1) sampling and quantification of zooplankton within and outside fish cage culture areas
2) measurement of water parameters including chlorophyll-*a* concentration within and outside fish cage culture areas, and
3) sampling of zooplankton within and outside fish cage culture areas for 12 hours to determine, if any, diel and tidal effects on zooplankton biomass and density.