CHAPTER FOUR

GENERAL DISCUSSION

4.1 WATER PARAMETERS BETWEEN CAGE AND NON-CAGE SITES

The water parameters did not vary much between the cage and non-cage areas in SSB, over the 4 months of study. The mean pH, temperature and conductivity were quite similar oscillating within a narrow range. In SSB, water pH values of the inside, middle and away stations were almost similar; however, water pH in SSB was generally lower than in SSK (non-aquaculture river) (Figure 6). This could be due to aquacultural activity since salinity between the two rivers was not significantly different (Figure 9) and depressed pH values could not just be due to freshwater input from upstream. This is also due to increased bacterial activity where seawater as a buffer and tidal circulation could mask this effect.

The water parameters (mainly for pH, temperature, conductivity and salinity) observed over 12 hours, fluctuated only slightly during ebb and flood tides for both rivers (SSB and SSK). However, the mean dissolved oxygen, showed wide fluctuations during the daytime at ebb tide in SSK. The general trend for all stations here was an increase in pH, temperature, dissolved oxygen and salinity during the day before a decline in the late evening. This trend follows the flood-ebb cycle. As the river floods, water from the sea rushes in increasing the pH before falling again as the tide receded. The same goes for temperature as sea water from the open sea warms up under the afternoon sun. This warmer offshore sea water flows into the river (during flood tide) thereby increasing the water temperature in the estuary. The drop in salinity was seen in SSB as the tide ebbed, indicating the higher fresh water input into the larger of the two Sangga rivers.

The level of DO was low in the early morning and increased as the day progressed. Alongi *et. al* (2001) noted a similar trend while sampling in the fish cages (see Figures 78 and 79). The oxygen levels tend to drop in the evening to the early hours of the morning and peaking in the late afternoon. This indicates photosynthesis from phytoplankton playing an important role in increasing DO levels.

The water parameters (mainly pH, temperature, conductivity and salinity) of SSB recorded during the 1-day "grid" sampling differed only slightly amongst the grid stations. The mean dissolved oxygen was lower inside the cage area as compared to outside the cage area (Figure 26). Water pH increased towards the middle of the river from the bank, the latter being due to more shallow water close to the mud bottom where forest litter abound.

4.2 BOTTOM AND SEDIMENT CHARACTERISTICS IN CAGE AND NON-CAGE SITES

Sediment parameters (mainly pH, temperature and organic matter) as observed in both SSB and SSK over 4 months did not vary much except for mean redox potential where values were higher during December (Figure 30). Comparatively lower redox potential in SSB showed more anoxic conditions of the sediment as compared to SSK. Anoxic conditions usually relate to organic pollution and insufficient dissolved oxygen to decompose organic matter.

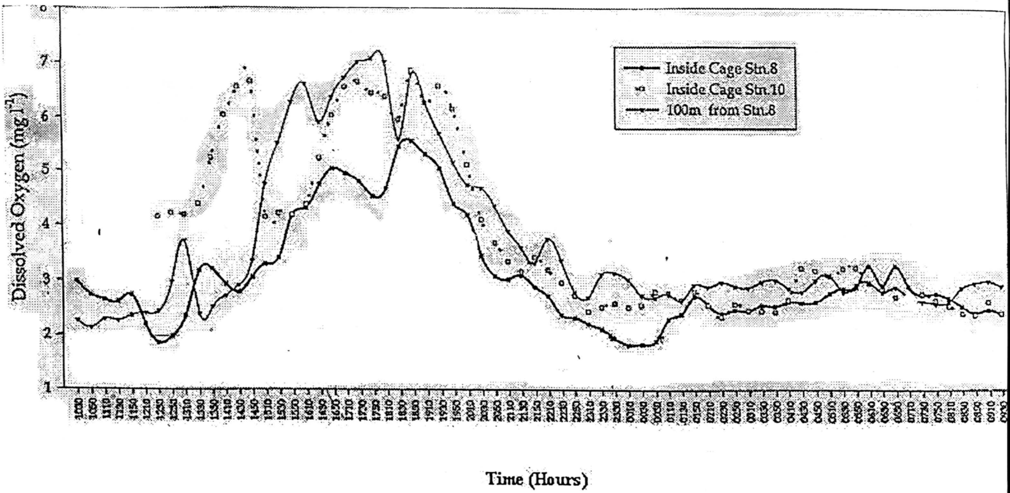

Figure 78: Dissolved Oxygen in Cage Farm Stations 8 and 10 (taken from Alongi *et al.*, 2001, in press) Stations 8 and 10 are Respectively in Transects 3 and 4 of Present Study

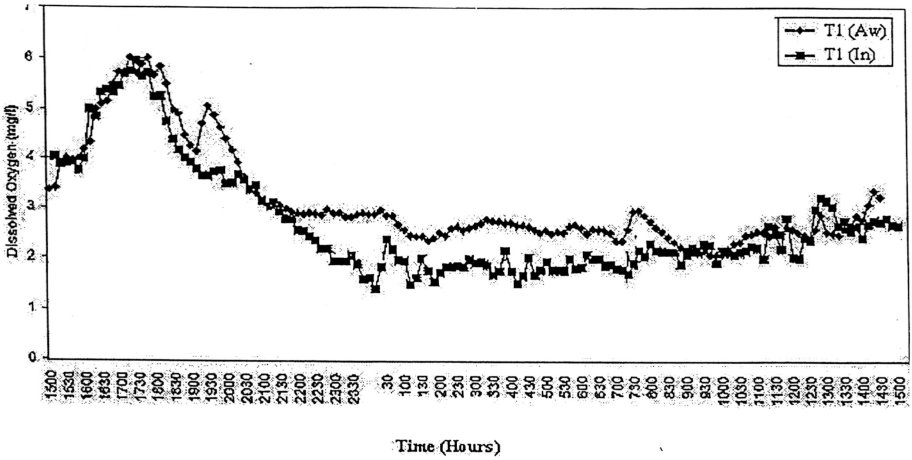

Figure79: Dissolved Oxygen Recorded by Hydrolab Cast in Cage Farm on Transect 1 (Alongi, pers.comm.)

When examined over 12 hours, all sediment parameters fluctuated only slightly during ebb and flood tides in both rivers (SSB and SSK). The mean sediment redox potential showed wide fluctuations among grid stations over the cage farm in SSB (Figure 41). This shows that areas of high organic matter (contributing to anoxic or low redox condition of the sediment) are rather patchy under the cage farm area. The bottom sediment pH apparently followed the trend of the water pH, i.e. increasing at flood tide.

The bottom sediment type in SSB ranged from mainly silt to very fine sand. Over the 4 months of study, clayey and silty sediments were mainly found, which was also reported by Muhammad Ali *et al.* (1999b).

The sediment mapping study indicates a 'plume' of fine sediments comprising silt and clay from the mangrove fringe, through the cage farm in SSB (Transect 2) to the middle of the river, with decreasing contribution of these sediments in that order. The 'sand' component however decreased in the opposite direction and was especially prominent outside the cage area particularly on its upstream side (see Figure 51). This observation strongly suggests that the cage farm obstructs the downstream river flow so that heavier river-borne sediments settle first on its upstream side.

Sediment pH and temperature varied within a narrow range amongst the grid stations in and around the cage farm. Sediment redox potential however were lower at the middle of the river, indicating more anoxic conditions in deeper waters. Organic matter was also slightly higher in the middle of the river. Accumulating organic matter and low dissolved oxygen possibly gave rise to the anoxic conditions seen at the middle of the river. Previous trawl surveys had indicated a large accumulation of mangrove plant litter in the deeper part of the river (Chong *et al.*, 1994). Total organic matter of bottom sediment in the Matang water channels was found to range from 4.6% to 27.2%, with a mean closer to 12% (Muhammad Ali *et al.*, 1999a).

4.3 Impact of Cage Aquaculture on Macrobenthos Diversity and Abundance

Generally the water channels in the Matang mangrove forest showed relatively low density and diversity of macrobenthic animals. A total of 2,181 macrobenthos animals belonging to 53 species were recorded in the present study. The macrobenthos species of SSB and SSK falls into nine taxa; Bivalvia (9 species), Gastropoda (14), Polychaeta (13), Nemertea (1), Echinoidea, Pisces (2), Decapoda (8), Isopoda (2) and Amphipoda (2) (see Table 4).

The total of 44 families found in Sungai Sangga Besar (SSB, aquaculture river) and Sungai Sangga Kecil (SSK, non-aquaculture river) was slightly higher than the 41 families reported by Muhammad Ali *et al.* (1999a). Othman and Arshad (1993) recorded 53 families from the Matang mangroves, where polychaetes (28 families or 52.9 %) were the dominant group, followed by molluscs, crustaceans and echinoderms. The previous studies also concluded that macrobenthos abundance within the mangrove channels were low.

It was found that in SSB, differences in macrobenthos abundance is influenced more by position along the river (transect) rather than by time (4 months only) or whether it is a cage or non-cage site (along the same transect) (see 3.4). The difference in macrobenthos abundance even between adjacent transects could be quite different. These results indicate that macrobenthos abundance may vary quite greatly along the river length. This contention is further substantiated by the results obtained from the second ANOVA, this time with time removed (see 3.4.1.1b). Significant differences in macrobenthos abundance were observed amongst transects 1, 2, 3 and 4. Interestingly, the second ANOVA gave significantly different results this time between cage and non-cage stations, i.e. away stations has significantly higher macrobenthos abundance than inside stations, and this is only discerned when the macrobenthos abundance was high, as for instance at transects 3 and 4, which were located closer to the river mouth. It is clear from the second analysis that there was cage culture effect, but its detection depends on the animal abundance; comparative cage and non-cage sites which are closer to the river mouth and having higher animal abundance are more likely to show any difference, if any. This point of generally higher animal diversity and abundance towards the river mouth, attributable to increased bottom dissolved oxygen, will be further discussed below.

Proximity to the river mouth is known to be positively correlated to macrobenthos abundance and diversity (Othman and Arshad, 1993). The same trend as observed in SSB in the present study was also observed in SSK. However, macrobenthos in SSK were generally and comparatively more diverse and abundant for all transects, and this implies a 'less disturbed' habitat.

Macrobenthos abundance in SSB was dominated by the bivalve, *Anadara granosa* and nassarid gastropods. This could be attributed to cockle culture, which is quite well developed in the estuary and fish cage culture that apparently attracts nassarids to the cage area. Bivalve and gastropod abundance were however comparatively low in SSK, while other macrobenthos taxa were much higher in SSK. This may indicate changes in the structure of the macrobenthos community in SSB by the aquaculture activity (both cockle and cage culture), but which were not observed in SSK.

Although RDA ordination results showed that the abundance of nassarids and *Assiminea* sp. corresponded to larger particle size (more sandy substrates) [see Fig. 70], these results are in part due to the fact that the monthly samples (in the RDA) were taken from the outer region of the fish farm (i.e. towards the middle part of the river) which contained comparatively coarser sediments. This is clearly seen from the sediment contour map (see Figure 51). However, the spatial analysis of animal distribution from the grid sampling clearly indicated no nassarids sampled off the upstream side of the farm (see Table 6) even though coarser sediments were predominantly found here. This happened because the grid samples were not used in the RDA since recordings of certain water parameters were not in due to equipment failure.

Spatial analysis also indicates that the nassarids were indeed found more under the cage farm at its outer region, in the vicinities of B4 and C3 (Figure 51), where sandy substrates still predominated (50-60%). Other sites under the cage farm but with less sand have less nassarids. Therefore, the RDA ordination results are valid, and it is postulated that another important co-factor (not considered in RDA) which could explain the abundance of nassarids under the outer cage area is the presence of left over feed material (trash fish) on the river bottom. Nassarid gastropods are known to be scavengers (Arnold and Birtles, 1989).

Blood cockles, *A. granosa*, on the other hand, prefer more clayey silt substrates as indicate by RDA ordination (Figure 69). Spatial analysis however indicates that this type of substrates is equally important both inside and outside the cage area (Figures 49 and 50), hence eliminating substrate preference as a reason for variable distribution of cockles in the SSB estuary. Thus, the major question here is why blood cockles and other bivalves were not or hardly ever found below the floating cages? There are several possible answers, but not necessarily mutually exclusive ones. The first is that since cockle culture is essentially an artificial-seeding operation therefore one would not expect seeding inside the cage area. This is true to a certain extent since large areas on the opposite side of the cage farms (all cage farms are located on the right bank of SSB) are cockle-seeded. But this does not explain the abundance of cockles found on the cage farm side, particularly in between the farms, as for instance along the 'A' transect in the grid sampling (see Table 6; Figure 51). If artificial seeding is the cause, it cannot explain why other 'wild' bivalve species (e.g. *Plecyora trigona, Tellina* spp.) were hardly found under the cages. The second answer could be preference of bivalves for certain sediment and water chemistry. RDA ordination indicates that these animals may prefer higher sediment pH and comparatively lower water pH and salinity than other animals (Figure 69), as would be encountered in most estuaries. However, these conditions were also encountered in the cage areas. A third answer could be the smothering of bivalves under the continuous rain of sedimentation in cage areas (due to reduction in water movement) along with long period of depressed oxygen levels especially during the night. Bivalves are more vulnerable than gastropods since they are largely sedentary. *A. granosa* was found away from the cages (in non-aquaculture area), where is has a higher resilience for low DO than most other bivalves. Alongi *et al.* (2001) recorded low levels of oxygen (< 2 mg/l) inside SSB fish cage (Station 8, 2 km downstream of transect 1 in present study) at a depth of 1-2 m between 11.30 pm-1.00 am (1.5 hr), during spring tide, using a continuous data logger (Figure 78). However, inside the fish cage on transect 1, continuous data logging of DO indicated low levels (<2 mg/l) over a much longer period from 11.00 pm – 7.00 am (7 hr) (Figure 79). Interestingly, Figure 79 also showed that during the critical night period, oxygen levels on the same transect but away from the cage hovered between 2.2 – 3.0 mg/l.

It has been stated earlier and also from the above discussion that aquaculture activity at the estuary of SSB has to a certain extent change the bottom macrobenthic community structure. However, the available evidence suggests a general vulnerability of Matang's subtidal macrobenthos community; even without aquaculture, it is stressed by periodically low dissolved oxygen (DO) levels. Apart from the findings of Alongi *et al.* (2001), Chong *et al.* (1999) recorded very low bottom DO levels (1.0-1.5 mg/l) during the night at the lower reaches of Sungai Selinsing river (non-cage area, 4.5 km upstream), which they attributed to resuspended bottom sediments and organic matter caused by strong spring tidal currents. DO levels at both banks however rarely fall below 2 mg/l (2 m depth), even during spring tide and night. They also recorded mean DO at 1-m depth that increased in the offshore direction, from 2.11 mg/l (18.5 km upstream) to 4.68 mg/l (river mouth), while the vertical drop in DO (to 4-8 m depth) varied between 33-76% and 4-13% at the vicinity of these stations respectively.

In a cross-river sampling of the same transect and river, Muhammed Ali *et al.* (1999a) showed clearly the dramatic drop in macrobenthos diversity and abundance from both sides of the river towards its middle region, concomitant with low DO. Therefore, oxygen stress could explain why the subtidal macrobenthos community in the Matang mangroves is generally low in diversity and abundance, although diversity and abundance gradually increase towards the river mouth. Nevertheless, cage aquaculture operations through the addition of nutrients and organic matter, and cockle harvesting through the disturbance of bottom sediments may exacerbate this stress (see Alongi *et al.*, 2001; Figure 79). This contention can be further substantiated by comparing the subtidal macrobenthic communities of SSB and SSK.

The subtidal macrobenthos of SSK probably reflects that of an undisturbed or less disturbed mangrove channel by aquaculture activity. This is exemplified by its significantly higher macrobenthos abundance (see sections 3.4.1.1c and 3.4.2.1). RDA ordination shows clearly a community dominated by polychaetes (Figure 69) and which is quite distinct from that present in SSB (see Figure 69). Physically, SSK is distinguished from SSB by its deeper water of higher pH and DO, while its sediment generally has higher (more positive) redox values. (see Figure 69). This conditions apparently are more conducive for polychaetes. Polychaete abundance was found to be much higher in SSK than in SSB. Polychaete distribution was also different between the two rivers. In SSB, polychaete abundance was slightly higher in the middle of the river, while in SSK it is much more near the river banks (see Figures 55 and 56). In SSK, the overall polychaete abundance at the middle and sides of the river was about 3 and 28 times higher than in SSB, respectively. Only 5 species of polychaetes were recorded from SSB, most of them outside the cage areas, whereas there were 11 species from SSK.

Besides polychaetes, other animals such as crustaceans, particularly the crab, *Xenophthalmus pinnotheroides* and the isopod, *Sphaeroma terebrans*, were more frequently encountered in SSK than in SSB (see Appendix 11). Amphipod abundance was also higher at the banks in SSK but there were no benthic amphipods sampled in SSB. Interestingly, amphipods were collected in high numbers fouling the net surface of cage nets (Madin, pers. comm.). The amphipod aggregation on the cage net surface may have an effect on its abundance elsewhere, while those in SSK were more widely distributed attaching itself to the roots and detritus by the banks. However, it is possible that these amphipods were of different species, and that cage amphipods represented unique populations.

Bivalves and gastropods were noticeably much lower in abundance in SSK than in SSB. Blood cockles were not sampled in SSK and it is obvious that cockle rearing in SSB has significantly altered the community structure there. Cage culture in SSB also gives similar impact by attracting large numbers of scavenging nassarid gastropods.

Since routine monthly samplings of macrobenthos were always taken during the day, one important question that needs to be addressed is whether the seemingly poor diversity and abundance of macrobenthos in SSB as observed in cage areas is attributed to diel variability (day/night) or/and tidal phase (flood/ebb). This question was addressed in section 3.4.2. The results indicated that basically macrobenthos abundance in both SSB and SSK were not significantly affected by either diel or tidal phase differences (main effects). However, there are significant interaction effects. For instance, during the day while abundance in SSK was greater than in SSB, there were essentially no significant differences between tidal phase, or between inside cage (or right bank) and away stations (left bank) for both rivers. Similarly, during night, there were also no significant differences between tidal phase or between inside and away stations in SSB. These results further substantiated the earlier findings that differences between inside stations and away stations are significant only with higher animal abundance, as were observed on transects closer to the mouth of SSB.

In contrast, during night in SSK, there were significant difference in abundance between left and right banks during ebb and flood tides: during ebb, the left bank was higher in abundance, while during flood, the right bank was higher in abundance. The reason why the abundance at the right bank was lower than the left bank (see Figure 76, left diagram) could be due to stronger ebb current since the station was located on the bend of the river (see Figure 1). However, on the flood the opposite was true and this cannot be readily explained.

In SSK, the changes in abundance was noted in amphipods, increasing in abundance on both banks during night between 7.30 pm to 10.30 pm at the right bank station and between 5.00 pm to 11.00 pm on the left bank station. The abundance of amphipods, could be due to higher activity at low light intensity as in the evening and night time.