CHAPTER 4

DISCUSSION

4.1 Significance of Aquaculture-induced Nutrient Concentrations

Generally, the nutrient concentrations at the estuary of Sg. Sangga Besar (SSB, high-density fish cage culture) were higher than at Sg. Jaha (SJ, low-density fish cage culture) and Sg. Sangga Kecil (SSK, without fish cage culture). The most obvious impact of nutrient loading on water quality in the present study is the higher NH_3-N and PO_4^{3-} concentrations in the aquaculture estuaries as compared to the cage-free estuary.

Comparison among the stations at SSB and SJ indicated that the NH_3-N concentrations inside the cages were consistently higher than outside cages (as discussed in Section 3.3a). The 12-hour study showed that the mean NH_3-N concentrations inside fish cages at SSB were significantly higher than outside the fish cages, which in turn were significantly higher than at the cage-free estuary (SSK) (see Figure 3.4.2). On the other hand, there were no significant differences in the background NH_3-N concentrations among the three estuaries, i.e. in cage-free sites (see Section 3.2a). The NH_3-N at the farm sites mainly originates from the trash fish feed, fish excretion and decomposition of nitrogenous feed compound. The results suggest that the higher NH_3-N concentrations were localized inside the farm area, and that its impact outside the farm area would have been greatly diluted by both riverine discharge and tidal flushings. Wu *et al.* (1994) in a study at four fish culture sites in Hong Kong observed that ammonia levels were significantly higher inside three out of the four fish culture zones, and decreased to background levels at the control stations, clearly demonstrating the source of ammonium pollution.

The recorded phosphate levels present an interesting but contrasting picture. The background $P0_4^{3-}$ level in SSB was significantly higher than that in both SSK and SJ (Section 3.2d). However, within the estuary itself, there were no real differences between the farm sites and those outside them (Fig. 3.3.10). These results suggest that it is unlikely that upstream sources contribute to the discrepancy in $P0_4^{3-}$ levels between SSB and SSK, which are interconnected with the same upstream sources, and that the difference in background levels between SSB and SSK must be due to the presence of the cage farms in SSB. This contention is further supported by the higher background levels in SSB as compared to SJ which had only very few farms. Interestingly, within the farm itself, the mean $P0_4^{3-}$ level of SJ (0.76 μmol/L) was comparable to that of SSB (0.57 μmol/L), if not significantly higher. Water column mixing must have dispersed and diluted any nutrient patch or plume from the farms to the background levels as observed in the surrounding waters; such plumes were obviously more abundant in SSB than SJ. The $P0_4^{3-}$ release from the farms appeared intermittent, as when released (from feeds) during fish feeding in the morning and evening. In contrast, NH_3-N release appeared continuous, from the cultured fish and associated cage organisms as well. This could explain why differences between cage and non-cage sites within the same estuary were not so obvious for $P0_4^{3-}$ as compared to NH_3-N. Nevertheless, the input of PO_4^{3-} by fish cages appears large in comparison to other sources like mangroves and phytoplankton. Alongi *et al.* (2002) estimated that the input of trash fish feed contributes a moderate proportion of N (32-36%) and a higher percentage of P (83-99%) to the Matang mangrove estuaries than do phytoplankton and mangroves.

Multivariate analysis using the Principal Component Analysis (PCA) further substantiated the above observations that most of the samples with high PO_4^{3-} and NH_3-N concentrations were from the fish cages in SSB, and some from the cages in SJ (Table 3.6.3). This further supports the contention that both ammonia and phosphate nutrients in SJ and SSB were mainly inputs from the fish farms, while the higher PO_4^{3-} levels at SSB probably also reflect its estuarine water characteristic as influenced by upstream activities (mainly industrial and agricultural development), which were not present in SJ. The linear arrangement of many fish cages along one side of the river bank of SSB can impede tidal flushing, reducing the water flow velocity. Madin & Chong (2002) who measured tidal velocities within the farm area at SSB and SJ indicated a significant drop (50-80%) in current velocities. Iwama (1991) reported that the current velocity in a single fish cage could be reduced by 65%. The reduction in water movement at the cage areas in SSB may trap nutrients within the farm area, leading to higher nutrient concentrations. An NH_3-N plume around the cage farms in SSB (Figure 3.6.3) was detected in the present study, which further confirms the persistence of NH_3 around the farm sites.

From the present study, the nitrate and nitrite concentrations at SSB recorded were 2.14-18.93 μmol/L and 0.43-8.79 μmol/L respectively, with salinity ranging from 16 to 26 ppt. Nixon *et al.* (1984) in a previous study at SSB before the introduction of fish cage culture indicated that the NO_2 + NO_3 concentrations decreased with increasing water salinity, and the presence of NO_2 + NO_3 was not detectable at salinity above 18 ppt. The present study shows that nitrate and nitrite levels in SSB have increased significantly since the 1980s. The NO_3-N and NO_2-N levels were consistently higher in SSB, followed by SSK and then SJ. SSB is slightly polluted, possibly due to contribution from the main river, Sg. Sepetang, which receives runoff from the textile industry, leather tanning, food industry, edible oil industry, rubber mills, mangrove plantations and pig farms upstream (Chong *et al.*, 1999). SSK, also a distributary of Sg. Sepetang, probably receives nutrient input from the same sources as well. Studies by Wu *et al.* (1994) at mariculture sites in the Hong Kong waters related the higher levels of nitrate and nitrite in the fish cage zones to mariculture activities and contribution from the nearby river which was polluted by upstream human activities.

Warren-Hansen (1982) reported that food wastage and organic and nutrient loadings were several times higher when trash fish was used instead of pellet feed. Trash fish feed also generated food wastes of smaller particle size, facilitating a wider dispersion and greater impact over a much larger area. According to Qian *et al.* (2001), the use of minced trash fish gave release rates of orthophosphate and ammonia that were respectively 6-12 times and 4-88 times higher than those of the cultivated fish.

The nutrient leaching study showed significant increase in NH_3-N concentrations in the fish cages (when feed was given) as compared to the non-cage sites (control). Nevertheless, there was no significant difference between the cage waters given the two different types of fish feed. There was also no significant difference in the initial nutrient concentrations immediately after feeding, though the concentrations of NH_3-N, NO_3-N and PO_4^{3-} in the pellet-fed cages dropped to the background level faster than the trash fish-fed cages. It is possible the scale of feeding in SJ (low-density cage culture) was not large enough to cause significant pollution impact.

4.2 Seasonal, Tidal and Diel Effects

Seasonal effect was observed only from the NO_2-N concentrations where it was significantly higher in the wet season than in the dry season, while the other nutrient parameters did not show any significant difference. Tidal effect was observed mainly during the wet season, but not the dry season. In the wet season, the mean NH_3-N, NO_3-N, NO_2-N and PO_4^{3-} concentrations in SSB were significantly higher during the flood tide than the ebb tide. This can be explained by the increased rainfall and runoff from the SSB catchment area, increasing the flow volume of the river and diluting the nutrient levels especially during ebb tide when higher volume of freshwater flowed downstream. SJ, with a smaller catchment area, also showed similar seasonal effect for the NH_3-N and NO_2-N concentrations. On the other hand, Shamsudin and Ambak (1983) found that the wet monsoon increased the ammonium nitrogen, nitrate nitrogen, and DO concentrations of the aquaculture-free Sg. Ibai estuary in Terengganu, situated on the East Coast of Peninsular Malaysia. The land use on the upstream of Sg. Ibai was predominantly agriculture, hence, excessive rainfall might have increased leaching of nutrients from agriculture land to the receiving watercourse.

In the present study, assessment of the sampling results was based on wet and dry seasons, due to the fact that significant difference in the salinity of estuarine waters was noted. Significantly higher salinity ($p<<0.05$) was recorded in the dry season as compared to the wet season. On the other hand, it is possible that the nutrient concentrations during the wet and dry seasons were also influenced by the spring/neap tides. Sampling conducted during the wet season (May 2000) coincided with the neap tide while during the dry season (August 2000), towards the tail-end of spring tide. Nevertheless, the average tidal amplitudes for the wet and dry seasons were 1.3 m and 1.7 m respectively and the scale of difference is considered to be fairly small.

Significantly higher nitrite during the wet season (neap tide) than the dry season (spring tide) was found in the present study. Tanaka and Choo (2000) also found that nitrite was dominant in the neap tide at SSB and they attributed this to predominance of nitrification inside the estuary during neap tides. On the other hand, they noted higher concentrations of ammonium and phosphate during the spring tide, while the present study did not show similar trend. It is assumed that the seasonal effect may be more dominant in the present study.

Only the surface water quality was assessed in the present study. Tanaka and Choo (2000) found little or no stratification of NH_4-N, NO_3-N, NO_2-N, PO_4-P, salinity and turbidity with respect to both the spring and neap tides at stations near to the present study area, indicating that the estuarine water of SSB was rather well-mixed.

In the present study, the nutrient concentrations during flood tide were generally higher than during ebb tide. The 12-hour study supports the contention that the mean NH_3-N and NO_2-N concentrations during the flood tide were significantly higher than during the ebb tide, irrespective of wet or dry season. One possible explanation is that nutrients from upstream and within the estuaries are not completely flushed out to the open sea during ebb tide. Even the exchanged estuarine water is likely to remain in the nearshore coastal water given the shallow water and extensive tidal flats. Wolanski *et al.* (1990) demonstrated that tidal hydrodynamics in mangroves are such that lateral trapping of a coastal boundary layer occurs, allowing very little mixing with offshore water. Frictional effects dominate, such that both ebb and flood tidal flows are fan-like, implying that the return coefficient (fraction of the water that leaves the estuary at ebb tide returns at the following flood tide) is large (Wolanski & Imberger, 1987; Wolanski *et al.*, 1992). Therefore, flush-out nutrients during ebb tide are moved back to the estuarine system during flood tide.

Flood tide is associated with increased pH values and salinity of the estuarine water and vice versa. The pH value has important influence in the nutrient equilibrium between the water-sediment phases (Nedwell *et al.*, 1999). Changes in the ionic strength of the water can influence solute exchange. For example, NH_4^+ ions can be desorped from sediment particles into the water column by Na^+ in seawater during flood tide. Gardner *et al.* (1991) argued that mobilization of NH_4^+ from intertidal sediments by Na^+ in tidal water increases export of NH_4^+ (into water column) and thereby diminishes benthic ammonium concentrations and nitrification in intertidal sediments. Caetano *et al.* (1997) reported a pulsed release of NH_4^+ into the water column upon tidal inundation of intertidal sediments.

The ANOVA showed no significant effects in the nutrient concentrations with respect to the diel cycle in the present study (see Table 3.7.1). Harrison *et al.* (1997) also found no apparent diel cycle in nutrient concentrations at two mangrove tidal creeks of the Indus River Delta in Pakistan.

4.3 Chlorophyll *a* in Relation to Nutrients and the Physical Environment

The present study indicated that the chlorophyll *a* levels fluctuated closely following the diel cycle (see Table 3.4.1e). The 12-hour study showed that the chlorophyll *a* concentrations inside fish cages increased steadily from the morning and peaked in the evening (6.00 pm). The dramatic increase in chlorophyll *a* concentrations in a short duration of time (4 to 6 hours) may be attributed to the vertical migration of phytoplankton in the water body. Coupled with photosynthesis which was to a certain extent light-limited in the morning, increased photosynthetic activity took place with abundant sunlight in the afternoon, and further enhanced with available nutrients in the water column inside the cages. During this period, the nutrient concentrations, especially PO_4^{3-}, declined to their lowest levels due to uptake by the phytoplankton. Increased pH values were also noted. In a concurrent investigation with this study, a 24-hour monitoring of the dissolved oxygen (DO) levels by the Hydrolab Cast inside [station E2-2 (IN) of the present study] and away [station E4-0 (OUT) of the present study] from the cage by Alongi (pers. comm.) showed that the DO levels at SSB increased from early morning, peaked in the late afternoon and gradually dropped again from the evening to the early morning. This indicates the important role of phytoplankton photosynthesis in increasing the DO levels in the water column. Chlorophyll *a* levels were the highest during peak illumination and declined steadily towards the night. Photosynthesis declined with decreasing light illumination while phytoplankton continued to be consumed by zooplankton (Ooi, 2002), further reducing the phytoplankton biomass and hence, the chlorophyll *a* concentrations, during nighttime.

The 24-hour DO levels (Figure 4.3.1) also showed that the DO levels dropped drastically during nighttime, to as low as 1.5 mg/L inside the fish cage, while the minimum DO level outside the cage was 2.5 mg/L. The extreme low DO inside the cage may be attributed to uptake of oxygen for respiration (fish and plankton) and decomposition of waste materials. This may have also led to fish kills, which have occurred occasionally in the fish farms. The fish farmers have installed and activated mechanical aerators at the fish farms during nighttime to counter this problem.

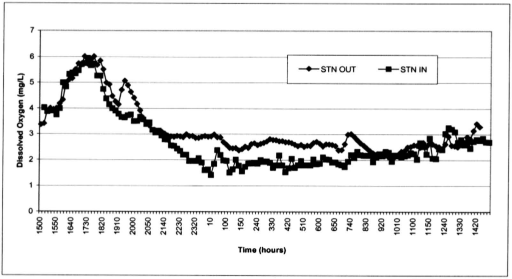

Figure 4.3.1 – Dissolved oxygen (DO) recorded by Hydrolab Cast (Alongi, pers. comm.).

In SSB, chlorophyll *a* concentrations inside the fish cage rose dramatically in the late afternoon, indicating increased photosynthetic activity. However, the chlorophyll *a* levels in SSK (non-aquaculture estuary) did not show a similar trend. It is possible that the chlorophyll *a* bloom in SSK was limited by available nutrients. Results from the grid sampling showed that the concentrations of chlorophyll *a* inside the cages were not always higher than outside cages. This suggests the patchy distribution of the phytoplankton. In another concurrent investigation with this study, Natin (2001) found more scavenging macrobenthos such as gastropods (Nassaridae and *Assiminea* sp.) on the riverbed in the fish farm as compared to the riverbed outside the cages. Uneaten feed and undigested food materials from the cultured fish dropped to the riverbed and were taken up by the scavengers. Therefore, nutrient leaching from the sources was probably of short duration, hence limiting the available nutrients for phytoplankton consumption.

Gowen *et al.* (1983) explained that the inconsistency between nutrient enrichment and lack of significant chlorophyll *a* increase may be attributed to limited utilization of the excretory wastes due to rapid flushing time so that phytoplankton are not present long enough to capitalize on the high production of nutrients. Mesocosm experiments in the Eastern Mediterranean by Pitta (1996) have shown that there was a time delay of 3 to 8 days (depending on the season) between nutrient enrichment and the peak of the phytoplankton biomass.

In the present study, the chlorophyll *a* concentrations were found to be significantly higher during the dry season as compared to the wet season. Qasim and Wafar (1990), quoted by Trott & Alongi (1999), found that phytoplankton biomass and productivity were the highest in pre- and post-monsoon periods; the lowest standing crop and activity occurred during the monsoon when scouring and runoff from land enhanced turbidity causing severe light limitation. The reason for significantly higher chlorophyll *a* concentrations in SJ (lower nutrient) than SSB (higher nutrient); i.e., an inverse trend for the nutrient concentrations, is not known. However, turbidity may be an important factor. In the same estuary, Alongi *et al.* (2002) recorded higher total suspended solids (TSS) in SSB (77 mg/L) than in SJ (40 mg/L) in April 2000. SSB has a heavy traffic of fishing boats. Chong *et al.*

(1999) recorded high turbidity of 39 – 67 NTU (Nephelometric Turbidity Unit) in SSB over a 15-month study. Boat traffic coupled with cockle harvesting at the river mouth churned up the bottom sediment and increased turbidity, hence reducing sunlight penetration into the water column and impeded phytoplankton photosynthesis.

4.4 Comparison of Water Quality

The range and mean water quality results of SSB, SJ and SSK for August 2000 were tabulated in Table 4.4.1. In general, comparison among the Matang estuaries and other water bodies with similar characteristics (cage culture or mangrove/salt marsh waters) showed variations and similarities. The nutrient and chlorophyll *a* levels recorded by Alongi *et al.* (2002) in April 2000 are comparable to the present study. Interestingly, Nixon *et al.* (1984) recorded significantly higher levels of ammonium (1.5 – 24.7 μmol/L) and phosphate (1.9 – 17.9 μmol/L) in SSB in the early 1980s when fish cage culture was not present. Change in land use within the SSB catchment from predominantly agriculture and livestock farming to manufacturing industries may possibly contribute to this change.

The fish cage farms in Hong Kong waters showed higher ammonium (0.93 – 25.64 μmol/L), lower nitrate and nitrite (0.43 – 7.14 μmol/L), phosphate (0.14 – 0.89 μmol/L) and chlorophyll *a* (0.9 – 18.4 μg/L) concentrations (Wu *et. al.*, 1994) than the Matang estuaries. Wu *et al.* (1994) concluded that the impact of mariculture on water quality was less conspicuous; the decrease in dissolved oxygen and increase in nutrients and ammonia were found at cage sites with high stocking density and poor water circulation.

Table 4.4.1 – Comparison of Nutrient and Chlorophyll *a* Concentrations among Various Water Bodies.

Location	Ammonium (µmol/L)	Nitrate (µmol/L)	Nitrite (µmol/L)	Reactive Phosphate (µmol/L)	Chlorophyll *a* (µg/L)	Remark	Reference
Matang, Malaysia SSB - inside cages SJ – inside cages SSB – outside cages SJ – outside cages SSK - non-cage	0.71 – 8.93 (3.14) 1.43 – 6.07 (2.88) 0 – 7.86 (1.56) 0 – 7.50 (1.44) 0 – 3.57 (0.71)	6.43 – 12.14 (8.71) 1.43 – 6.07 (3.57) 5.00 – 11.43 (8.18) 2.14 – 5.71 (3.90) 2.14 – 12.14 (7.55)	1.71 – 4.14 (2.63) 0.46 – 1.36 (0.86) 1.14 – 4.41 (2.59) 0.46 – 1.29 (0.83) 0.50 – 5.07 (2.66)	0.21 – 1.16 (0.66) 0.53 – 0.84 (0.68) 0.21 – 1.11 (0.62) 0.32 – 1.16 (0.58) 0.11 – 1.00 (0.53)	11.86 – 26.02 (20.16) 28.40 – 66.55 (48.78) 9.07 – 59.21 (23.20) 23.08 – 65.21 (50.12) 8.98 – 28.43 (21.06)	Mangrove estuaries, SSB & SJ with fish cage culture, SSK without cage culture	(present study, August 2000 data)
Matang, Malaysia SSB - inside cages SJ – inside cages SSB – outside cages SJ – outside cages SSK - non-cage	(6.31) (1.66) (2.83) (1.86) (0.51)	(12.15)* (5.18)* (10.11)* (6.70)* (6.48)*	-	(0.84) (0.31) (0.65) (0.30) (0.25)	(14) (22) (17) (30) (24)	Mangrove estuaries, SSB & SJ with fish cage culture, SSK without cage culture	Alongi *et. al.*, 2002 and pers. comm., April 2000 data
SSB, Matang, Malaysia	1.5 – 24.7	0 – 13.8	-	1.9 – 17.9	-	Mangrove estuary without fish cage culture	Nixon *et al.*, 1984
Ibai River estuary, Terengganu, Malaysia	1.70 – 7.20	0.90 – 1.80	0.02 – 0.12	0.22 – 1.14	-	Mangrove estuary without fish cage culture	Shamsudin, 1983
Sg. Selangor estuary, Malaysia	0.14 – 1.07	1.43 – 7.86	0.51 – 3.64	0.01 – 0.16	-	Mangrove estuary without fish cage culture	Suratman, 1997
Fish Farm in lake, Quebec, Canada	<5.56	<35.48	-	<1.26	<10	Temperate lake with fish cage culture	Cornel & Whoriskey, 1993
Fish Farms, Hong Kong	0.93 – 25.64	0.43 – 7.14*	-	0.14 - 0.89	0.9 – 18.4	Sub-tropical bays with fish cage culture	Wu *et al.*, 1994
Australia, Control Creek Sandfly Creek	(3.9) (1.9)	(5.4)* (0.6)*	-	(0.2) (0.1)	(3.1) (1.9)	Mangrove creeks	Trott & Alongi, 1999
Hinchinbrook Island, Australia	0.1 – 0.65	0 – 0.22	-	0 – 0.45	-	Mangrove creek	Boto & Wellington, 1988
Florida Bay, USA	0.02 – 11.03	0 – 6.13	0 – 0.94	0 – 0.33	0.34 – 4.86	Salt marsh	Fourqurean *et al.*, 1993
Vatuwaga, Fiji Unpolluted Polluted	(0.60) (50.94)	(0.65) (36.58)	-	(1.02) (13.39)	-	Mangrove creek	Nedwell, 1975

Note: Table modified from Alongi *et al.*, 1992. Values in parenthesis are mean values.
* values for $NO^{3-} + NO^{2-}$

The average water quality inside a rainbow trout cage farm at Lac du Passage (lake) in Quebec, Canada was recorded to be higher in ammonium (5.56 μmol/L) and nitrate (35.48 μmol/L) but lower in chlorophyll *a* (10 μg/L) levels as compared to the Matang estuaries. Clearly the major difference between the lake environment and an open system such as in the estuary is the lower flushing efficiency of the former.

Other local mangrove estuaries such as Sg. Ibai (Shamsudin & Ambak, 1983) and Sg. Selangor (Suratman, 1997) with no aquaculture activities generally show relatively lower nutrient concentrations as compared to the Matang estuaries with fish farms. In other tropical countries, lower nutrient and chlorophyll *a* levels were also recorded in the mangrove creeks such as Control and Sandfly Creeks (Trott & Alongi, 1999) and Hinchinbrook Island (Boto & Wellington, 1988) in Australia and the unpolluted creek of Vatuwaga, Fiji (Nedwell, 1975). Fourqurean *et al.* (1993) in their study of Florida Bay in the Everglades, U.S.A. reported ammonium levels of 0.02 – 11.03 μmol/L NH_4-N, which is comparable to the Matang estuaries. They also found that ammonium was the major form of dissolved inorganic nitrogen, attributable to an ammonium source in the highly reducing sediments of the mangrove fringe and the suppression of nitrification. Fourqurean *et al.* (1993) further reasoned that high (sunlight) radiation penetrating the sediment surface and high CO concentrations contributed to the suppression of nitrification process. They also found relatively lower nitrate (0.00 – 6.13 μmol/L) and nitrite (0.00 – 0.94 μmol/L) concentrations and attributed this to lack of anthropogenic input entering the bay. On the other hand, the polluted water of Vatuwaga, Fiji, recorded nutrient concentrations (Nedwell, 1975) that were 3 – 16 folds higher than the Matang estuaries.

Presently in Malaysia, the Interim National Water Quality Standards (INWQS) for freshwater have been developed and used in the classification of major rivers for specific uses, such as protection of sensitive aquatic species, water supply, fishery and recreation, etc. The Marine Water Interim Standard (MWIS) is still in the interim stage of implementation.

Under the ASEAN-Canada Cooperative Programme on Marine Science – Phase II project, an interim ASEAN Marine Water Quality Criteria was developed for 18 parameters. Table 4.4.2 shows the nutrient concentrations at the Matang estuaries compared with the ASEAN Marine Water Quality Criteria.

Table 4.4.2 - Comparison of Nutrient Concentrations at the Matang Estuaries with the ASEAN Marine Water Quality Criteria.

Item	**NH_3-N (µmol/L)**	**NO_3-N (µmol/L)**	**NO_2-N (µmol/L)**	**PO_4^{3-} (µmol/L)**
SSB – inside cages	0.71 – 8.93 (3.14)	6.43 – 12.14 (8.71)	1.71 – 4.14 (2.63)	0.21 – 1.16 (0.66)
SJ – inside cages	1.43 – 6.07 (2.88)	1.43 – 6.07 (3.57)	0.46 – 1.36 (0.86)	0.53 – 0.84 (0.68)
SSB – outside cages	0 – 7.86 (1.56)	5.00 – 11.43 (8.18)	1.14 – 4.41 (2.59)	0.21 – 1.11 (0.62)
SJ – outside cages	0 – 7.50 (1.44)	2.14 – 5.71 (3.90)	0.46 – 1.29 (0.83)	0.32 – 1.16 (0.58)
SSK – non-cage	0 – 3.57 (0.71)	2.14 – 12.14 (7.55)	0.50 – 5.07 (2.66)	0.11 – 1.00 (0.53)
ASEAN Marine Water Quality Criteria	Marine water criteria	Marine water criteria	Marine water criteria	Estuarine water criteria
	70 µg/L or 5 µmol/L (NH_3-N)$^{\Psi}$	60 µg/L or 4.29 µmol/L (NO_3-N)$^{\Omega}$	55 µg/L or 3.93 µmol/L (NO_2-N)$^{\Omega}$	45 µg/L or 1.45 µmol/L (PO_4-P)$^{\delta}$
	For protection of ASEAN marine aquatic life	For protection of coral reefs from eutrophication	For protection of coral reefs from eutrophication	For protection from eutrophication

Note:
SSB, SJ and SSK denote estuaries of Sg. Sangga Besar, Sg. Jaha and Sg. Sangga Kecil respectively.
Values in parenthesis are mean values.
$^{\Psi}$ Shazili & Tong, 1999; $^{\Omega}$ Deocadiz & Montano, 1999; $^{\delta}$ Chongprasith *et. al.*, 1999.

Generally the water quality of the Matang estuaries was fair and within the ASEAN Marine Water Quality Criteria. However, nitrate levels at SSB (inside and outside cages) and SSK exceeded the marine water criteria by more than 75%. High nitrate levels in the Matang estuarine waters may contribute to higher nitrate levels in the coastal and marine waters of the West Coast of Peninsular Malaysia. This in turn may cause eutrophication in the coastal water.

The present study gives indications of increased nutrient (especially ammonia and phosphate) and chlorophyll *a* concentrations at the aquaculture sites, though the environmental impact is more localized and do not appear to be persistent at the existing scale of aquaculture operation. With the rapid growth and increasing economic importance of the brackishwater aquaculture industry, the need for protecting this very important environment which supports the industry is most pressing.