CHAPTER 5

DISCUSSION

5.0 DISCUSSION

5.1 WATER CHARACTERISTICS

The environmental parameters measured at Cape Rachado, Port Dickson (Tables 8, 9; Figures 21, 22) are representative of tropical marine waters and are within the range reported by Phang (1989) and Wong (1997). The TSS values exceeded the proposed interim standard (50 mg L^{-1}) for Malaysian marine waters but were lower than that reported by Phang (1989). This is due mainly to the reduced construction activity in the area resulting in lower sediment load into the sea. Normally, seasonality of these parameters over the year is expected as a result of the rainfall, dry and wet seasons in the study area. The wet seasons of heavy rain occur during the monsoon period from November to March and from June to September each year. The dry seasons are the intermonsoon periods with convectional rain (Phang *et al.*, 1990). This distinct seasonality was however not observed for this study due to the various disturbances in the region during the study period. Haze problems brought on a prolonged drought with higher temperature. A significantly lower rainfall was experienced throughout the year as a combined consequence of the El Nino effect and the haze episode (DOE, 1997).

Temperature, salinity and pH were generally within a narrow range throughout the study period. The dissolved oxygen (DO) levels normally reflect the photosynthetic oxygenation as well as mixing due to wind and wave action. The DO varied from 4.2 to

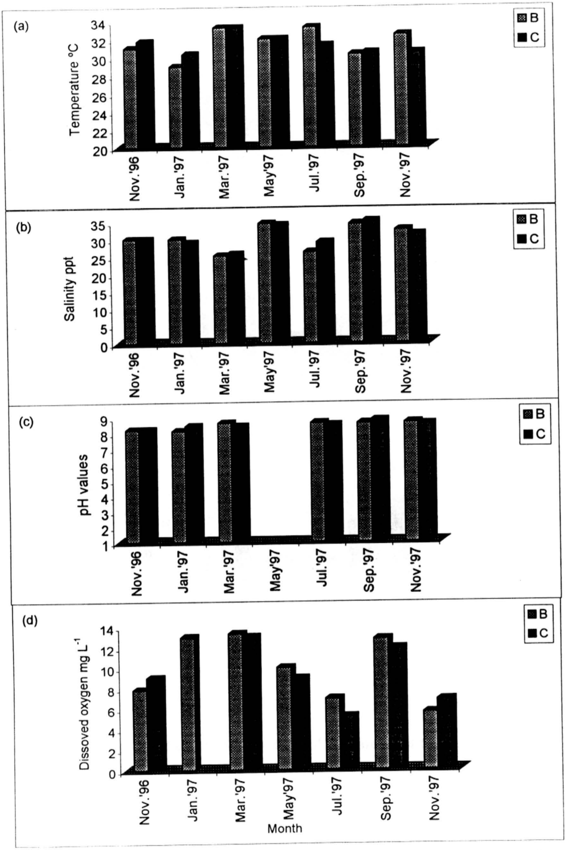

Figure 21. Physical-chemical characteristic of seawater over the study period in Sites B and C. (a) temperature (b) salinity (c) pH and (d) dissolved oxygen.

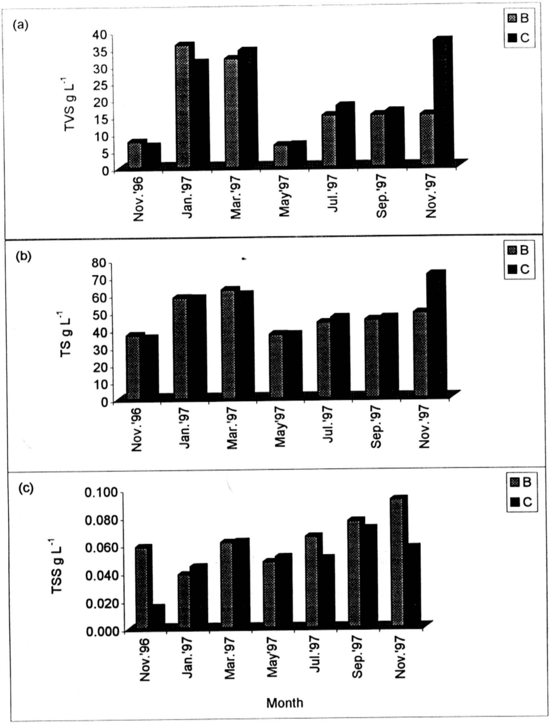

Figure 22. Physical-chemical characteristic of seawater over the study period. (a) TVS, (b) TS and (c) TSS .

14.4 mg L^{-1} indicating well oxygenated water. The Total Volatile Solids (TVS) content which reflect the organic content, was observed to fluctuate quite significantly over time. The lowest levels were in November and May and the peaks around January. These results confirm the data on thallus length (indicative of biomass and growth) increase from Wong (1997) which showed peaks around May and June and period of thallus degeneration around December to January. The biomass shed by the seaweeds (*Sargassum baccularia*) contribute to the TVS in the water.

5.2 HEAVY METAL CONCENTRATIONS

5.2.1 Metal Concentrations In Seawater

Metal concentrations in seawater at both sites showed temporal changes over the study period as a response to the short-term environmental changes over time. In general, metal concentrations peaked from March to July (Table 12; Figures 9 and 10). This could be attributed to the lower rainfall (Table 10), higher water temperature and lower dissolved oxygen (DO) levels (Tables 8 and 9) recorded in this period. The lower rainfall, higher water temperature and lower dissolved oxygen levels may result in lower oxidative state of the metals and therefore increased the metal solubility in water. Leaching or remobilisation of metals from the bottom sediment becomes enhanced (Sundby *et al.*, 1981; AcKroyd *et al.*, 1986; Izquierdo *et al.*, 1997). The results of correlation analysis (Table 21) showed an inverse relationship between DO and metal concentration in water.

The total average concentrations (Site B; Site C) of Fe (0.0128 mg L^{-1}; 0.0176 mg L^{-1}), Cu (0.0010 mg L^{-1}; 0.0010 mg. L^{-1}), Zn (0.0098 mg L^{-1}; 0.0.0104 mg L^{-1}) and Pb (0.0048 mg L^{-1}; 0.0047 mg L^{-1}) recorded in this study for both sites respectively, were lower than those reported by Ramachandran (1993); Ramacandran *et al.* (1995) for Cape Rachado (study site), Port Dickson (study area) and all over the Malaysian coastal waters. This could be attributed to the reduction in construction activity and hence lower sediment load into the area.

The concentrations of Fe and Zn in the present study were higher than those reported by Mokhtar *et al.* (1997) in Sabah coastal waters which ranged from 0.00161 to 0.00259 mg L^{-1} (Fe) with an average of 0.00225 mg L^{-1}, and from 0.00006 to 0.00009 mg L^{-1} (Zn) with an average of 0.00007 mg L^{-1}. The average Cu concentration (0.0010 mg L^{-1}) in seawater recorded in this study was lower than the concentration means of 0.0680, 0.0340 and 0.0400 mg L^{-1} recorded by Zainal *et al.* (1989) in Malaysian marine waters for 1985, 1986, 1987 respectively. Mokhtar *et al.* (1997) also reported higher Cu concentrations ranging from 0.0014 to 0.0044 mg L^{-1} with an average of 0.0023 mg L^{-1} in Sabah coastal waters. On the other hand the present Cu concentration is higher than the range (0.0006-0.0008 mg L^{-1}) recorded by Seng *et al.* (1987) in the Penang Straits waters. However, the Cu concentration in the seawater of Cape Rachado was still within the commonly reported concentrations (0.0005 to 0.0030 mg L^{-1}) of areas with no history of Cu contamination (Lewis, 1995).

The average concentration of Pb was also lower than the concentration (0.1010, 0.1320 and 0.1390 mg L^{-1}) means recorded by Zainal *et al.* (1989) for 1985, 1986 and

1987 respectively, in Malaysian coastal waters. The results at Cape Rachado suggest the area is unpolluted as far as Fe, Cu, Zn and Pb are concerned.

Seawater metal concentration ranking was in the decreasing order of:

Fe> Zn > Pb > Cu for both Sites B and C.

5.2.2 Metal Concentrations In Sediment

Metal concentrations ($\mu g\ g^{-1}$ dry wt) in sediment (Fe, Zn, Pb and Cu) recorded in this study were significantly ($P<0.05$, Table 20) higher in Site B than Site C. This significant difference between sites was mainly due to the composition of the sediment samples. Small shell fragments were abundant in the Site C sediment and contributed much to the weight of the samples subjected to heavy metal analysis. Metal concentration in the sediment can be ranked in the decreasing order of:

Fe> Zn > Pb > Cu, for both sites.

Metal concentration in the sediment of both sites were much lower than those recorded by Mat *et al.* (1994) for contaminated sediments from the western Malaysian coast in which the concentrations were 11485.0; 266.0; 43.8 and 40.8 $\mu g\ g^{-1}$ dry wt for Fe, Zn, Pb and Cu, respectively. Metal concentration in the sediment of both sites in the present study were also lower than those reported by Din and Jamaliha (1995); Ong and Din (1995); Wood *et al.* (1995); Din *et al.* (1997) in polluted sediments from various Malaysian coastal areas (Table 4). Zn, Pb and Cu were also lower than the concentrations reported by Ismail (1993); Mat and Maah (1994) in slightly contaminated coastal sediments from the western Malaysian coast and by Ismail (1993) in the east coast of Malaysia (Table 4). Moreover, the present sediment metal concentrations were lower than the minimum concentrations of those considered as unpolluted or clean areas (Table 4) reported by Shazili *et al.* (1989) or Din (1992 a); Din (1992 b) who, reported 65.90 ±24.47 μg g^{-1} dry wt for Zn; 30.17 ± 8.56 μg g^{-1} dry wt for Pb and 10.76 ± 4.30 μg g^{-1} dry wt for Cu, in the sediment of the Straits of Malacca.

Total metal concentration in sediment consists of residual and non-residual fractions (Mat and Maah, 1994). Metals in non-residual (leachable) fractions can be used to assess the anthropogenic metal pollution in the aquatic environment. This is especially true for analysis of upper surface sediment, which can be used to assess recent contamination (Wood *et al.*, 1995). Anthropogenic inputs cannot be deduced from results obtained in this study as the total metal concentration (Agemain and Chao, 1976; Chester and Voutsinou, 1981; Din, 1992(a); 1995; Ong and Din, 1995). The low metal concentration in the sediments of the study area may only be reflecting the concentrations of the dominant residual fraction (natural constituent) but which does not include the non-residual (leachable) fraction.

The fluctuation of metal concentrations in the sediment over the study period may be attributed then, to the variation of the heavy metal load in the plants and organic matter from the decomposed seaweeds or mangrove leaf litter.

In general the metal concentrations reported here indicates that the sediments at Cape Rachado are relatively uncontaminated. However, metal concentrations in the seawater suggests slight contamination compared to that in the sediment. This may due to the relatively sandy nature of the bottom sediment which has less ability to accumulate metals (Din *et al.*, 1997). Therefore based on the metal concentrations in the water and sediment, the general area of Cape Rachado may be considered as relatively unpolluted as far as metal contamination is concerned.

5.2.3 Metal Concentrations In Seaweeds

There was no significant difference (P>0.17) in the concentration means of each the four metals in each seaweed species between both study sites (Table 20). The concentration trends of the different metals in different seaweed species were different over the study period suggesting a metal-species dependent relationship. Ramachandran (1993); Ramachandran *et al.* (1994); (1995) provide the only data concerning metals in seaweeds of the study area (Table 5) which can be used to compare with the present data.

5.2.3.1 *Sargassum baccularia*

The decreasing order of metal abundance in *S. baccularia* is Fe > Zn > Pb > Cu. Fe concentration in *S. baccularia* (207.26 to 214.07μg g^{-1} dry wt) was slightly lower than the previous concentration (250.00 μg g^{-1} dry wt) reported by Ramachandran (1993); Ramachandran *et al.* (1994); (1995) for the same seaweed species in the same study area, while Cu (2.32 to 2.44 μg g^{-1} dry wt, Table 14) concentration was almost the same. Fe and Cu concentrations in *S. baccularia* were lower than the concentration of

Fe (347.80 μg g^{-1} dry wt) and Cu (5.15 μg g^{-1} dry wt) reported by Sivalingam and Bhaskaran (1978) for *Sargassum grevillei* from Penang. Zn and Pb concentrations (Table 14) were higher than the concentrations reported by Ramachandran (1993); Ramachandran *et al.* (1994); (1995) presented in Table 5

5.2.3.2 *Padina tetrastomatica*

The order of metal abundance in *Padina tetrastomatica* is Fe > Zn > Pb > Cu. Fe (1241.000 to 1452.929 μg g^{-1} dry wt) and Cu (4.279 to 4.669 μg g^{-1} dry wt) concentrations in *P. tetrastomatica*, were marginally higher than the concentrations reported for Fe (1125.0 μg g^{-1} dry wt) and Cu (3.5 μg g^{-1} dry wt) in the same seaweed species from the same study area Ramachandran (1993); Ramachandran *et al.* (1994); (1995). These concentrations were lower than the concentrations for Fe (2225.00 μg g^{-1} dry wt) and Cu (9.00 μg g^{-1} dry wt) reported for the same seaweed species from Penang (Tanjung Tokong), which is a polluted area (Ramachandran, 1993); Ramachandran *et al.* (1994); (1995). Fe and Cu concentrations in *P. tetrastomatica* were much lower than the concentrations of Fe (3328.00 μg g^{-1} dry wt) and Cu (5.69 μg g^{-1} dry wt) reported by Sivalingam and Bhaskaran (1978) for *Padina tenuis* from Penang. Fe concentrations in *P. tetrastomatica* of the present study could be attributed partially to the particulates trapped on the leaf surfaces, where a significant positive correlation ($r = 0.59$) were observed between TS and Fe concentration in water (Table 21). As such, the higher water particulate contents (TS) the higher Fe concentration in the seaweed species (Malinovskaya and Khiristoforova, 1997).

P. tetrastomatica showed higher Pb concentration (20.4 µg g^{-1} dry wt) than that (8.5 to 16.0 µg g^{-1} dry wt) reported by Ramachandran (1993); Ramachandran *et al.* (1994); (1995) at different sites along the western coast of Malaysia (Table 5) including the study site (8.5 µg g^{-1} dry wt). Zn concentration in *P. tetrastomatica* (Table 15) was lower than that (65.0 µg g^{-1} dry wt) reported by Ramachandran (1993); Ramachandran *et al.* (1994); (1995) for the same study site and much lower than those from the polluted area of Penang (Tanjung Tokong), Malaysia (Table 5). *P. tetrastomatica* had highest metal concentration of all the seaweed species studied.

5.2.3.3 *Turbinaria conoides*

The order of metal abundance in *Turbinaria conoides* is Fe > Zn > Pb > Cu. *T. conoides* in the present study (Table 16) showed increases in Cu and Pb concentration over previous studies. Fe and Zn were lower than the previous concentrations (Table 5) reported by Ramachandran (1993); Ramachandran *et al.* (1994); (1995) for *T. conoides* in the study area.

5.2.3.4 Summary of metals in seaweeds

In general, with the exception of Pb, metal concentrations in seaweeds in the present study are still within the marginal concentrations of the previous studies. The three seaweed species indicated increased Pb concentrations. This may be attributed to the geographical location of the study area, which faces the Straits of Malacca with high shipping activities and also due to the oil refinery in the vicinity. However, the Pb concentrations reported in this study were much lower than Pb concentrations in *Sargassum filipendula* (59.65 ± 6.59 μg g^{-1}dry wt) and in *Padina gymnospora* (59.04 ± 0.88 μg g^{-1}dry wt) reported from Yucatan, Mexico (Robledo and Pelegrin, 1997).

Metal concentrations in the three seaweed species from both sites showed similar patterns of metal ranking order (Fe > Zn > Pb > Cu). These ranks were similar to the ranks of the same species or other Malaysian brown seaweed species reported. The same metals were ranked in the same order for green and red seaweeds with exceptions in few species where the red seaweeds (*Amphiroa* sp.; *Laurencia* sp.; *Acanthophora* sp.) and green seaweeds (*Halimeda* sp; *Enteromorpha* sp; *Caulerpa* sp.) had different ranking order (Ramachandran, 1993); Ramachandran *et al.* (1994); (1995).

5.2.4 Metal Concentrations In Marine Animals

5.2.4.1 Soft coral

Metals in the soft coral, *Simularia* sp. (Table 17) were found in similar levels (25 mg L^{-1} dry wt) for Fe, Zn and Pb except for Cu (8 mg L^{-1} dry wt.). There was no significant difference in metal concentrations in the soft coral between both study sites (P> 0.20, Table 20). Metal concentration followed different trends over the study period (Figures 19 and 20). The concentration trends, as temporal changes, were different between metals at both sites. Cu was almost stable over the study period in both sites. It can be clearly noticed that Cu concentration in *Simularia* sp. was the highest among the ecosystem components and greater than (2 to 4 folds) the sea cucumber and the three seaweed species inhabiting the same ambient concentration indicating its ability to accumulate Cu (Table 12 to 18).

The results reported here are the first as there are no reported data on heavy metals in soft corals. However, the heavy metal concentrations of soft corals of this study were close to the range of the concentrations reported for Malaysian hard corals (Mokhtar *et al.*, 1994; 1997) (Table 6). Fe concentration in *Sinularia* sp. was much lower than Fe in the hard coral *Porites* species. (94.0 ± 23.6 μg g^{-1}dry wt) (Brown and Holley, 1982) from Phuket, Thailand and also lower than what was reported by Glynn *et al.* (1989) (94.0 μg g^{-1}dry wt) for *Porites* species from Alina's reef, USA.

5.2.4.2 Sea cucumber

Heavy metal concentrations in *Holothuria atra* were 28.543±7.745 μg g^{-1} dry wt for Fe, 37.240±29.085 μg g^{-1} dry wt for Zn, 21.433±11.756 μg g^{-1} dry wt for Pb and 2.770±0.810 μg g^{-1} dry wt for Cu. There is no previous data on heavy metals in holothurians from Malaysia or Asia for comparison. However, metals in *H. atra* reported here (Table 18) were much less than those reported for deep sea (NE Atlantic) holothurians by Moore and Roberts (1993)(Table 6), with the exception of Zn which showed almost similar results. On the other hand, Fe and Pb concentrations were higher than those reported by Everaarts and Nieuwenhuize (1995) for the Malaysian Sea urchin (*Regularia* sp.), while Cu concentration showed almost the same result (Table 6). The bivalve *Laternula elliptica* from a polluted area contained much higher concentrations of Fe, Cu and Zn , while Pb was slightly less (Ahn *et al.*, 1996) (Table 6).

Metal concentrations in *H. atra* were ranked in the order of: Zn > Fe > Pb > Cu. This ranking was different from the ranking in water and sediment (Fe >Zn > Pb.> Cu) where Zn concentration exceeded Fe concentration in *H atra.* This was opposite to what was expected for Fe (the most abundant metal in sediment) as *H. atra* is a deposit feeder. The results showed low correlation (r = 0.36) between Fe concentration in *H. atra* and sediment, but significant correlation (r = 0.98) with Fe concentration in seawater (Table 27). Cu in *H. atra* had higher correlation with water (r = 0.61) than with sediment (r = 0.45) (Table 27). These agree with the findings by Everaarts and Swennen (1987) who showed no relationship between concentration of some metals in the sediment and the benthic marine organisms. This confirms results by Jun and Fu-Shiang (1996), who showed no correlation between metal concentration in the black sea cucumber (*Holothuria leucospilota*) tissues and the degree of sediment-metal pollution or metal concentration in sediment.

5.3 HEAVY METAL DISTRIBUTION IN THE CAPE RACHADO CORAL REEF ECOSYSTEM

The four metals (Fe, Cu, Zn and Pb) investigated were distributed differently amongst the various ecosystem components (seawater, sediment, seaweeds, sea cucumber, and soft coral) (Table 37).

Table 37. Summary of metal concentration in the different components of Cape Rachado for Sites B and C ($\mu g\ g^{-1}$ dry wt)

Component	Site	Fe	Cu	Zn	Pb
Seawater*	B	0.01279	0.00096	0.00981	0.00481
	C	0.01759	0.00103	0.01038	0.00467
Sediment	B	4560.00000	1.39900	11.72000	4.83200
	C	2138.00000	0.24510	4.24800	1.33500
Sargassum baccularia	B	214.10000	2.32300	31.55000	12.29000
	C	207.30000	2.44000	34.99000	13.48000
Padina tetrastomatica	B	1241.00000	4.27900	51.55000	20.41000
	C	1452.90000	4.66900	48.19000	20.40000
Turbinaria conoides	B	78.59000	1.77100	17.41000	11.42000
	C	80.13000	1.73100	19.20000	11.46000
Sinnularia sp.	B	22.29000	7.79800	23.31000	25.34000
	C	28.59000	8.17500	25.83000	25.66000
Holothuria atra	B	...	...	...	...
	C	28.54000	2.77000	37.24000	21.43000

* $mg\ l^{-1}$

Iron was distributed through the different ecosystem components with the highest concentration recorded in the sediment followed by the seaweeds, soft corals, sea cucumber and finally, the seawater (Table 37). Fe distribution were similar in both sites (excluding sea cucumber which is not included in Site B ranking) with the following order:

Sediment > *P. tetrastomatica* > *S. baccularia* > *T. conoides* > *Sinularia* sp. > *H. atra* > seawater.

Copper was distributed similarly in both sites and differently from Fe. The highest concentration was recorded in the soft coral followed by the seaweeds, sediment and the lowest concentration was recorded in seawater (Tables 37). For Site C, sea cucumber ranked between the seaweeds. Cu distribution is shown in the following order of:

Sinularia sp.> *P.terastomatiac* > *H. atra* > *S. baccularia* > *T. conoides* > sediment > seawater.

Lead was distributed similarly in both sites through the ecosystem components. The highest concentration of Pb was recorded in soft corals followed by sea cucumber, seaweeds, sediment and lowest concentration recorded in seawater for both sites with the exception of sea cucumber ranking which is not included in Site B (Tables 37). Pb distribution is in the following order:

Sinularia sp. > *H atra* > *P. tetrastomatica* > *S. baccularia* > *T. conoides* > sediment > seawater.

Zinc distribution in Site B was similar to that in Site C with the exception of sea cucumber which was not available in Site B (Tables 37). Zinc distribution was different compared to the other metals (Fe, Cu and Pb). Zn distribution is in the following order: *P. tetrastomatica* > *H. atra* > *S. baccularia* > *Simularia* sp.> *T. conoides* > sediment > seawater.

The distribution of each metal in Site C was similar to that in Site B with the exclusion of sea cucumber which was not present in Site B. The similar metal distribution is mainly due to the similarity (no significant difference) of the ambient metal concentrations (P>0.40, Table 20) and to the similarity of most of the ambient environmental parameters of both sites as assessed by the T-test (P>0.20, Table 20) and the ANOVA test (P> 0.08, Appendix 1).

The lowest concentrations of the four metals were recorded in the seawater. This is expected as water always has the lowest metal concentrations in the marine ecosystem representing the ambient concentrations (Phillips, 1980; Raibow, 1995)

Among the four metals Fe was more concentrated in the sediment than the other components. This is mainly attributed to the higher availability of Fe in natural constituents of sediments (Engler *et al.*, 1980). Fe is abundant in the sediment as a major natural constituent. Fe is next abundant in seaweeds this due to metal being chelated to the particulates trapped on the surface of the seaweed leaves rather than accumulation within the seaweed tissues (Brown *et al.*, 1999). Significant correlation (r = 0.59) was observed between the TS and Fe concentration in water (Table 21). The concentration of Cu, Zn and Pb were second lowest in the sediment (Table 37). This could be due to the nature of sediment constituents and the sandy nature of sediment of both study sites which have less affinity to accumulate metals (Din *et al.*, 1997).

The metals were distributed differently among the biotic components according to the accumulation ability which varies from one species to another (Maher, 1985; Waheba *et al.*, 1985; Kesava Rao and Indusekhar, 1987; Murgadas *et al.*, 1995; Murgadas, 1997). The distribution patterns of the metals suggest that Cu and Pb were more accumulated in marine animals than the primary producers (seaweeds).

All four metals were distributed similarly in each seaweed species following the order: Fe >Zn > Pb > Cu, which matches the order of these metals in seawater and sediment (Table 37).

All the four metals studied were ranked similarly in their distribution within the three seaweed species (Table 37) following the order:
***P. tetrastomatica* > *S. baccularia* > *T. conoides*.**

In term of thallus surface, *P. tetrastomatica* has the largest surface followed by *S. baccularia* and then *T. conoides*. This shows that the seaweed with larger thallus surface can accumulate more metal. The results obtained here indicate that the surface area of the seaweed plays an important role in: (i) the uptake of the dissolved metals from water and (ii) adsorbing or trapping and scavenging of metals on the leaf surfaces from the particulates which in turn contributes to metal concentration measured in the seaweeds (Luma *et al.*, 1982; brown *et al.*,1999).

5.4 BIOACCUMULATION

The bioaccumulation factor of each metal in each biotic species for each site and the average of both sites are given in Table 38. The bioconcentration factors were calculated on the basis of the average concentration of each metal in each species divided by the average metal concentration in seawater of each site (Leal *et al.*, 1997). The average bioconcentration factor for each metal in both sites is considered as a general bioconcentration factor of each species for the corresponding metal. The bioconcentration factors of the metals were ranked similarly to the metal concentration ranks in the three seaweed species, where Fe > Zn > Pb > Cu. It also matches the metal concentration ranking in seawater and sediment (Fe > Zn > Pb > Cu), indicating that the higher the ambient metal concentration the higher is the metal accumulation and bioconcentration factor. Soft coral and sea cucumber show different ranking for the bioconcentration factors of the metals, where Cu > Pb > Zn > Fe in soft coral and Pb > Zn > Cu >Fe for sea cucumber suggesting some regulation of metal accumulation. Soft coral showed a particular affinity for Cu while sea cucumber showed more affinity for Pb.

P. tetrastomatica showed the highest bioconcentration factor for all metals among the seaweed species, followed by *S. baccularia* and *T. conoides* (Table 38). The

Table 38. Bioaccumulation factors for biotic species at Cape Rachado Sites B and C (n = 7)

SPECIES	SITE	Fe	Cu	Zn	Pb
Sargassum baccularia	B	16727	2323	3190	2560
	C	11776	2440	3364	2868
	Avg	14252	2382	3277	2714
Padina tetrastomatica	B	96953	4279	5260	4252
	C	82551	4669	4634	4340
	Avg	89752	4474	4947	4296
Turbinaria conoides	B	6140	1771	1777	2379
	C	4553	1730	1843	2438
	Avg	5347	1751	1810	2409
Sinnularia sp.	B	1741	7798	2379	5298
	C	1624	8175	2484	5460
	Avg	1683	7987	2432	5379
Holothuria atra	B	N/A	N/A	N/A	N/A
	C	1622	2770	3613	4560

N/A = Not available

bioconcentration factors of *P. tetrastomatica* and *S. baccularia* for all metals were higher than for soft coral and sea cucumber except Cu in soft coral and Pb which was slightly higher in sea cucumber (Table 38). Although *Padina*. And *Sargassum* species. were recommended by various studies as a good biomonitoring seaweed (Ramierez *et al.*, 1990; Zolotukhina and Radzinskaya, 1995; Amado Filho *et al.*, 1997), the bioconcentration factors obtained here are low. This is mainly due to the low ambient metal concentrations of the study area rather than the metal-species accumulation ability. Higher ambient metal concentrations lead to a greater biaoconcentration of metals in algae (Patel *et al.*, 1980; Drude de Lacerda *et al.*, 1985; Rajendran *et al.*, 1993; Jayasekera and Rossbach, 1996).

The bioconcentration results suggest a positive correlation between the ambient metal concentration and metal concentration in seaweeds. This correlation is clearly seen by comparison of the cross correlation and correlation analyses (Table 39). Higher correlation values were obtained in the cross correlation only indicating that integrated responses are more important. In *S. baccularia,* Zn was observed to show bioaccumulation after a lag period of eight months. Similarly in *Sinularia* Fe was observed to be accumulated after a lag period of 12 months.

Both correlation analyses indicated concurrent positive correlation between Cu in seawater and *S. baccularia* and between Pb in seawater and in *P. tetrastomatica* (Table 39). This confirms the ability of these two species to accumulate and reflect the concurrent ambient concentration of the two metals.

Table 39. Simple and cross correlation analyses between metal concentrations in each biotic component and seawater of Cape Rachado

Species	Heavy metal	Simple correlation	Cross correlation	
		r- value	r-value	Lag period
S. baccularia	Fe	0.13	0.32	-4
	Cu	0.44	0.47	0
	Zn	-0.11	0.31	-4
	Pb	-0.13	0.3	-5
P. tetrastomatica	Fe	0.23	0.45	-4
	Cu	0.2	0.37	-6
	Zn	-0.32	0.56	-4
	Pb	0.46	0.4	0
T. conoides	Fe	0.04	0.39	-4
	Cu	0.08	0.63	-1
	Zn	-0.23	0.23	-4
	Pb	0.01	0.42	-5
Sinularia sp.	Fe	-0.17	0.5	-6
	Cu	0.08	0.5	-4
	Zn	-0.02	0.28	-4
	Pb	-0.01	0.23	-3
H. atra	Fe	0.98	0.95	0
	Cu	0.61	0.66	0
	Zn	-0.25	0.54	-5
	Pb	-0.49	0.46	-3

1 lag period = two months

Therefore based on these results *Sargassum baccularia* and *Padina tetrastomatica* are good biomonitoring species for the two heavy metals in the coral reef ecosystem.

In general, results show that heavy metal contamination can be indicated by metal content in seaweeds. Seaweeds indicate fresh concurrent and time-integrated responses (bioaccumulation) of metal contamination in the environment.

5.5 EFFECT OF ENVIRONMENTAL PARAMETERS ON METAL ACCUMULATION IN THE CORAL REEF ECOSYSTEM AT CAPE RACHADO

Heavy metals accumulated in biotic species followed different trends over the study period. These differences are due to: (i) physiological processes of the biotic species, (ii) metal availability in terms of concentration, speciation and bioavailability. The bioavailable fraction is the more meaningful fraction in metal uptake and has higher ecotoxicological relevance (Rainbow,1995; Gledhill *et al.*, 1997). Although biological species can accumulate metals directly from seawater or through the food chain, metals in abiotic components (seawater and sediment) are considered the main sources for metal accumulation. Metals in the abiotic components exist in different forms and metal species that affect the bioavailability fraction of these metals for uptake. The environmental parameters (such as salinity, temperature, pH, TSS, TS, TVS, DO) of the marine ecosystem play an important role in metal distribution between water and sediment, and affect the metal speciation and forms, and ultimately alters the bioavailable fractions (Zirino and Yamamoto, 1972; Frostner and Prosi, 1979; Sundby *et al.*, 1981; AcKroyd *et al.*, 1986; Lobban and Harrison, 1994; Dassenkis *et al.*, 1997; Izquierdo *et al.*, 1997). The role of the environmental parameters in metal uptake, accumulation and seasonality is not easy to state because very complicated interactions between different parameters in the ecosystem that vary temporally and geographically, are involved. An attempt was made in the present study to find the parameters that contribute to metal bioaccumulation in the biotic species studied over the study period at Cape Rachado using the multiple regression analysis (Jongman *et al.*, 1995; Dytham, 1999). Statistical analysis showed that the metal concentrations in the different biotic species were differently correlated to the trend in the environmental parameters over the study period. Concurrent correlation was not exhibited between most of the environmental parameters and metal concentrations in the biotic species (Tables 23 to 27). However, Cross Correlation analyses (Tables 28 to 31) showed higher associations were observed between metal concentration and the environmental parameters with different lag periods. This indicates that the metal bioaccumulation process is more affected by the past ambient environmental parameters rather than the concurrent or present parameters.

The contribution of environmental parameters in metal bioaccumulation by the various species over the study period was varied as indicated by the Multiple Regression analysis shown in Tables 32 to 36. Results show that the effect of environmental parameters is biotic species-metal specific.

Correlation in metal concentration trends were frequently observed in both water and sediment. Table 21 shows positive correlation* between Cu and Zn in seawater. Table 22 shows positive correlation* between Fe concentration in sediment and Cu ($r = 0.78$), Zn ($r = 0.85$), and Pb($r = 0.94$) concentrations in sediment. Table 24 showed Cu concentration was positively correlated ($r = 0.59$) to Pb concentration in *P. tetrastomatic* and negatively correlated to Zn concentration in *P. tetrastomatica*. Table 26 shows positive correlation* between Cu and Zn in *Sinularia* sp.. Positive correlation* ($r =0.82$) was observed between Fe and Cu concentration in *Holothuria atra* (Table 27).

Tables 32 to 36 give results of the multiple regression analyses between metal accumulations in biotic species and environmental parameters including ambient metal concentrations (water and sediment). Results indicate that the environmental parameters including ambient metal concentrations contribute differently to metal concentration in the various biotic species. Synergistic interactions between metals were observed in the results. In *S. baccularia,* Pb had positive effect on Cu in the seaweed (Table 32). Similarly Cu in *P. tetrastomatica* had positive effect on Fe in the seaweed (Table 33). In *T. conoides,* Pb had positive effect on Fe in the seaweed (Table 34). In the soft coral *Sinularia* sp. Cu and Zn had positive effect on Fe in soft coral.(Table35). In the sea cucumber, *H atra,* Fe had positive effect on Pb in sea cucumber (Table 36). These synergistic effects metal concentrations in biotic species agree with findings by Karez *et al.* (1994) and Malea and Haitonidis (1999), and they are mainly due to the synergistic interaction with the binding sites and the increase in metal binding affinity.

5.6 APPRAISAL OF STUDY

The present study forms part of an ongoing project on heavy metal pollution in the Malaysian tropical marine ecosystem. This study focused on different aspects and was the first: (i) to investigate the distribution of heavy metals over time; amongst the various biotic and abiotic components; and between different trophic levels at the Cape Rachado coral reef ecosystem; (ii) field based heavy metal bioaccumulation study of a Malaysian coral reef ecosystem over time; between different taxa (eg. three species of Phaeophyta); and between different trophic levels (primary producers, deposit-feeder, filter-feeder); (iii) attempt to assess the effect of environmental parameters on heavy metal concentration in the various components of the Cape Rachado coral reef ecosystem; (iv) to investigate the heavy metal concentration and bioaccumulation in soft corals; and (v) to study the heavy metal concentration and bioaccumulation in tropical sea cucumbers.

Although this was an extensive field based study over one year, due to the lack of time no parallel laboratory experiments were done to confirm the field observations. Multivariate environmental analysis which may be more reliable in the assessment of the effect of environmental parameters was not included. However it is recommended that further studies in: (i) investigation of the behaviour of subtidal species, and (ii) use of biomarkers at the cellular and molecular level, be conducted.