CHAPTER 1

INTRODUCTION

1.0 Introduction

In recent years, a number of pollutants have been identified in the marine environment. The pollutants could be grouped accordingly as inorganic and organic compounds, heavy metals, pesticides, polychlorinated biphenyls (PCBs) and petroleum hydrocarbons or any of their derivatives. The nature and character of these pollutants have changed over the years, as has the relative importance once attached to them. In recent times, most of the pollutants are generated through man made activities, mainly domestic and industrial activities.

Besides being hazardous to the general ecosystem health, marine pollutants are also known for their persistence in the environment. This is clearly evident in heavy metals, pesticides and PCBs. Heavy metals are persistent due to their long biological half lives. Environmental persistence of pesticides is facilitated by the low water solubility of many pesticides and high solubility in lipid or fat tissues of organisms. PCBs in the environment are prolonged by their non-ionic and lipophilic nature together with their low solubility and volatility and resistance to degradation. The literature also reports that these pollutants are either bioconcentrated or biomagnified in tissues of living organisms. Biocencentration is the process of elements being concentrated in living tissues solely from the surrounding water body itself, while biomagnification is the process where elements are concentrated in living tisues via food ingestion through the food chain. These processes are mainly dependent on the feeding nature of the organisms. Once the pollutant is in the organism, it is either eliminated or undergo certain changes, resulting in the species becoming acclimated to the stresses and thus surviving the adverse situations (Mhatre, 1991).

1.1 Bioindication and Biomonitoring of Marine Pollution

As the complexity of human impact on the marine environment increases and ecological capital shrinks, the need to manage natural resources becomes increasingly critical. The nature of environmental impact has changed radically since the beginning of the industrial revolution. In an effort to characterise more accurately the cumulative impact of environmental degradation, environmental indication has shifted away from a sole reliance on chemical indicators and towards the increasing use of biological indicators (McCormick & Cairns, 1994).

A bioindicator is an organism whose presence indicates certain more or less well defined environmental conditions.

Kovacs & Podani (1986) specifically termed such organisms as indirect bioindicators. Bioindicators has also taken on the meaning of an integrator, over time, of contaminant load on a system (Wilson, 1994).

The use of organisms *in situ* to identify and quantify pollutants in an environment is referred to as biomonitoring (Chaphekar, 1991). Biomonitoring takes advantage of the ability of organisms to accumulate contaminants in their tissues through bioconcentration or biomagnification. Helawell (1986) termed the organisms with the accumulative ability as bioaccumulative indicators while Kovacs & Podani (1986) called them direct bioindicators. The primary objective of a biomonitoring investigation is to assess the quality of water in an area by relating observed responses of organisms that live within a suspected polluted site to the concentration of contaminants detected within their tissues (Chaphekar, 1991; Doust *et al.*, 1994).

The general acceptance of the advantages inherent in the use of organisms to monitor marine pollution has given rise to the establishment of national and international programmes employing such species in many parts of the world over the years.

1.2 Aquatic organisms as bioindicators or biomonitors of marine pollution

Organisms used to quantify bioavailability of pollutants are now employed widely, particularly in temperate waters. Lange and Lambert (1994) reviewed a range of organisms from microorganisms, mammals to plant species that have been identified as biomonitors of aquatic pollution in the temperate region. A list of the identified biomonitors is shown in Table 1.1.

Table 1.1 : Biomonitors of aquatic pollution in the temperate region

Biomonitor organism	Pollutant
Seals, dolphins, fin whales, herring gulls, turtles, fish, protozoan, crustaceans, bivalves, seaweeds, seagrass, benthic diatom, mayfly, microalgae, periphyton, macrophytes, duckweed, aquatic moss, water hyacinth	Heavy metals
Whales, dolphins, otters, seals, fish, bivalves, seaweeds, planktonic algae, zooplankton, periphytic community	Organic compounds
Phytoplanktonic community, bacteria, bivalves	Wastewater outfalls
Shrimp, bloodworm, blue-green algae, phytoplankton, macrophytes, algae, protozoan, oligochaete worms	Inorganic compounds
Macrobenthic and macroinvertebrate communities, coral reef, fiddler crabs, sea birds, bacteria	Petroleum

Source : Lange & Lambert (1994).

Biomonitors have the ability to accumulate pollutants from the marine environment. This bioaccumulative attribute allows marine organisms to take up pollutants from both solution and particulates. Based on this, biomonitors could be grouped accordingly to their feeding nature. Such grouping might include the following (Rainbow and Phillips, 1993):

- a macrophytic alga, responding essentially to dissolved metal sources only.
- a suspension feeder, taking particles of a particular size range and responding to pollutant sources in both dissolved and suspended phase; and/or
- a detrivore, such a talitrid amphipod crustacean or a deposit-feeding polychaeta or tellinid bivalve.

1.3 Bioaccumulation attribute of a biomonitor

All bioaccumulation studies represent the measurement of the concentration of chemicals in organisms. A prerequisite for using the bioaccumulation attribute is the selection of species that are capable of accumulating relatively large concentrations of a given pollutant without being damaged. This method, necessitates field and laboratory observations and experiments. Also, bioaccumulation studies may complement physical and chemical measurements for the preparation of pollution maps. Bioaccumulation offers a possibility for detecting a chemical if its concentration in the environment is below the detection level of the equipment (Kovacs & Podani, 1986).

1.4 Marine pollution in Malaysia

Malaysia's marine water quality has been seriously affected by pollution from 1977 to 1994. This was mainly due to the advocation of industrialisation by the Malaysian government since the early 70's. Coastal water is contaminated mainly by silt, sewage, oil and grease and heavy metals according to the Department of Environment (DOE, 1996). Figure 1.1 shows the Status of Marine Water Quality of Malaysia in 1995. The inappropriate positioning of many industrial sites in Malaysia and siltation caused by construction activities have detrimental effects on the marine environment. Besides facing pollution from land based sources, the marine waters also receive direct discharge of industry effluent and indirect discharge (via polluted rivers from inland, domestic and pollution from industrial outfall and combustion of fossil fuels). Oil spills in the marine waters were also reported to be on the rise.

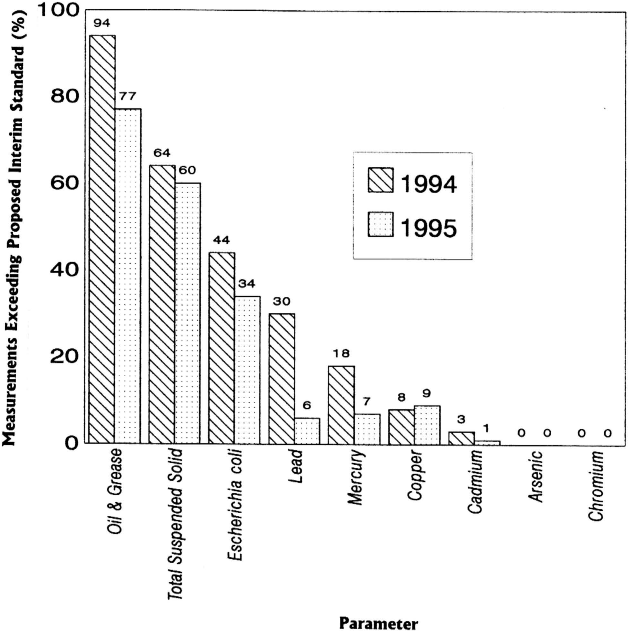

Fig 1.1 : Malaysia : Status of Marine Water Quality, 1994 and 1995 (DOE, 1995 & 1996).

1.5 Heavy metal pollution in coastal waters and sediments of Malaysia

Heavy metals have cumulative biological effects on living organisms. The effect on marine ecosystem has been considered in the Department of Environment (DOE) of Malaysia's Water Quality Surveillance Programmes in the form of the "Interim Standards for Marine Water Quality". It is based upon the People's Republic of China and Japan's Water Quality Standards.

The major contributors to heavy metal pollution in Malaysian waters have been identified as the electroplating, semiconducting and rubber product industries. Chemical, rubber, plastics, printing, tannery, pharmaceutical industries, textile mills, food processing, breweries, chloro-alkali plants, sulphuric acid plants and tin mining operations also contribute to heavy metal pollution in Malaysia. These industries discharge waste containing various inorganic compounds especially heavy metals into water courses without prior treatment. Wastes from the industry are either in the form of solution or sludge containing heavy metals.

The impact of heavy metal pollution in Malaysia today is great in the estuarine and in shore coastal areas. In

1992, the Department of Environment of Malaysia, reported that coastal fringes of nine rivers in Malaysia registered high Hg concentrations from industrial activities. Johor and Penang recorded the highest incidence of Hg in their coastal waters, while significant levels of Pb were found along the Perak and Sabah coastline (DOE, 1993).

In 1993, heavy metal measurements showed that Perak and Sabah recorded highest incidence of Pb in their coastal waters, the latter also recording high As content with 100% non-compliance with the proposed Interim Standard of 0.1 mgl^{-1}. Meanwhile, significant levels of Hg were found along the Johor coastline (DOE, 1994).

In 1994, more occurences of Pb levels exceeding the Proposed Interim Standard of 0.1 mgL^{-1} were recorded in the coastal waters off Perak, Pulau Pinang and Kelantan. For Hg, levels exceeding the Proposed Interim Standard of 0.001 mgL^{-1} were most frequently observed in coastal waters off Johor (DOE, 1995). Levels of other heavy metals monitored such as Cd, Cr, As and Cu were within the Interim Standards (Figure 1.1).

In 1995, there was improvement in the marine water quality compared to 1994 (Figure 1.1). Less occurences of Pb, Hg and Cd levels exceeding the Interim Standard were recorded in the coastal waters off Malaysia. This is partly due to

Table 1.2 : Heavy metal concentration in marine waters of Malaysia 1995 (DOE, 1996)

State	Measurement of average by parameter					
	Cd (mgL^{-1})	Cr (mgL^{-1})	Hg (mgL^{-1})	Pb (mgL^{-1})	As (mgL^{-1})	Cu (mgL^{-1})
Johor	0.005	0.001	0.002	0.008	0.4004	0.0064
Kelantan	0.010	0.008	0.001	0.008	0.002	0.036
Melaka	0.001	0.001	0.0014	0.003	0.002	0.002
Negeri Sembilan	0.001	0.001	0.001	0.004	0.001	0.006
Pahang	0.000	0.000	0.0000	0.002	0.000	0.000
Perak	0.089	0.099	0.001	0.098	0.009	0.036
Pulau Pinang	0.007	0.110	0.0007	0.060	0.0008	0.310
Sabah	0.017	0.032	0.000	0.045	0.000	0.011
Sarawak	0.004	0.039	0.0002	0.047	0.0060	0.059
Selangor	0.001	0.007	0.001	0.012	0.003	0.117
Terengganu	0.009	0.017	0.0010	0.009	0.0014	0.058
Malaysia	**0.013**	**0.029**	**0.001**	**0.027**	**0.039**	**0.058**

great enforcement carried out by DOE over the past year (DOE, 1996). DOE (1996) reported metal concentrations in coastal waters of Malaysia in 1995 as shown in Table 1.2.

Monitoring of heavy metal content in sediments of coastal waters of Malaysia has also been reported by several authors (Sivalingam *et al.*, 1980; Seng *et al.*, 1987; Ismail *et al.*, 1989; Ismail, 1993; Ismail and Jamil, 1994). Results of these studies also indicate that sediment based heavy metal input into the marine environment has increased over the years. Table 1.3 shows the Interim Water Quality Standards Proposed for Malaysia (DOE, 1996).

Table 1.3 : Interim Water Quality Standards Proposed for Malaysia

Metal (mgL^{-1})	#Interim National Water Quality Standards for Freshwater	Interim Standards for Marine Water Quality
Cr	0.05	**0.50
Cd	0.01	**0.10
Cu	0.20	**0.10
Fe	0.30	NA
Pb	0.02	**0.10
Mn	0.10	NA
Hg	0.004	**0.001
Ni	0.05	*NA
Zn	0.4	NA
As	0.4	**0.10

NA : Not available
* - Type 1 : For the conservation of marine aquatic resources and safe utilisation by humans (includes salt field, food processing, desalination, fisheries, aquaculture and marine parks)
** - Type 2 : For recreation.
# - Class IIA : Water supply II - Conventional treatment required.
Fishery II - Sensitive aquatic species.

1.6 Biomonitoring of heavy metal pollution in marine waters

Heavy metals are toxic and therefore of potential danger to life in aquatic habitats receiving metal rich inputs. It is thus neccesary for marine biologists and government scientists to make an assessment of toxic metal pollution in local coastal waters.

Biomonitors denote those aquatic species which accumulate heavy metals in their tissues and may therefore be analysed to monitor the bioavailability of such contaminants in riverine, estuaries or coastal ecosystems (Rainbow and Phillips, 1993).

The use of biomonitors to establish geographical and/or temporal variations in the bioavailable concentrations of heavy metals in coastal and estuarine waters is now well established (Rainbow and Phillips, 1993; Rainbow, 1993). The reasons for this are as follows (Guilizzoni, 1991) :

1. The potential hazard for aquatic organisms from the continuous release of large amounts of heavy metals into water systems is great. Heavy metals pose a serious water pollution problem because of their toxicity. To ascertain the extent of the pollution, biomonitors have been widely used, as they are able to integrate and rapidly monitor variations in the concentrations of elements in water.

2. The role played by aquatic plants in the biogeochemical cycling of elements is important. The many questions about the processes of metal uptake, the amount, forms, and sites of element release, and toxic effect in plant metabolism are of growing interest to researchers.

3. The availability of new analytical instruments utilising techniques such as atomic absorption spectrometry (AAS), inductively coupled plasma-atomic emission spectrometry (ICP-AES) , X-ray fluorescense, pulse polarography, etc. increases the sensitivity precision for studying heavy metal and toxic material cycling.

Rainbow and Phillips (1993) identified some species of seaweed, seagrass, mussel, oyster, tellinid bivalve, polychaete and crustacean that could be considered as cosmopoliton biomonitors of heavy metal pollution in the aquatic environment. Research on the use of marine organisms as biomonitors of heavy metal pollution are more extensive in the temperate region compared to the tropics.

1.7 Seaweeds as biomonitors of heavy metal pollution

Seaweeds representing the macro class of the marine algae have been commonly used as biomonitors of heavy metal pollution, especially in the temperate waters. They are known to respond almost entirely to metals in solution. Based on this, heavy metals which exist primarily in solution should be monitored adequately by organisms such as seaweeds. The time-integration of ambient soluble concentrations of metals in water appears to be high in seaweeds; this is due to the extremely long biological half lives of bound metals (Phillips, 1977) and the non-regulative nature of metal uptake in most seaweeds.

Brown seaweeds such as *Fucus vesiculosus* and *Ascophyllum nodosum* are amongst the common littoral flora of temperate coastal region (Rainbow and Phillips, 1993) and this suits their use as biomonitors of heavy metal pollution in the coastal environment. Much less is known of heavy metal kinetics in seaweeds from warmer areas, and in many instances, species are ephemeral in their distribution in such regions (Kafanov and Zhukov, 1988). However, brown seaweeds of the genus *Sargassum*, the green *Ulva lactuca* and several other species have been used to advantage in certain locations (Denton and Burdon-Jones, 1986; Ho, 1987; Catsiki *et al.*, 1991; Ganesan *et al.*, 1991; Kureishy, 1991; Jayasekera and Rossbach, 1996).

Seaweeds are primary producers and contribute significantly to marine ecosystem energetics. They play important biogeochemical roles in term of nutrient fixation and cycling within the ecosystem (McCormick and Cairns, Jr., 1994). Seaweeds also provide both a breeding habitat and a refuge for various animals (Power, 1990). This makes them an integral part of marine monitoring programmes.

Research has focussed on the use of seaweeds as biomonitors of heavy metal pollution for the last two decades. This focus has been supplemented by the fact that seaweeds fulfill several characteristics of a good biomonitor listed by Phillips (1977; 1980). McCormick and Cairns (1994) also discussed a proposed list of 16 generic attributes for biological indicators using algae, in general.

1.8 Heavy metal contents in marine organisms in Malaysia

Studies of heavy metal contents in marine organisms of Malaysia have been confined to shellfish, fin fish, fish and seaweeds. A few of the published studies are listed in Table 1.4.

Several authors have studied the contents of heavy metals in Malaysian seaweeds (Sivalingam, 1978 and 1980 ; Sheila, 1993 ; Sheila *et al.*, 1994), with the view to use them as biomonitors of heavy metal pollution. A selection of published values for metal content of selected seaweed species of Malaysia are shown in Table 1.5. It is evident that different species at different localities accumulate various heavy metals to different levels.

Table 1.4 : Studies of heavy metal contents in marine organisms of Malaysia

Organism	Metals	Location	Reference
Mussel			
Perna viridis	Pb, Cu,Ni, Cd, Zn	Penang	Sivalingam & Baskaran, 1980
Perna viridis	Cd, Co, Cr, Cu, Mn, Ni, Pb, Zn, Fe	Penang	Sivalingam, 1985
Perna viridis	Cu, Zn, Cd, Pb, Hg	Perak	Shahunthala, 1986
Finfish			
Liza subviridis	Cd, Co, Cr, Cu, Mn, Ni, Pb, Zn, Fe	Penang	Sivalingam, 1985
Oyster			
Ostrea folium *Crassosrea cucullata*	Cd, Cu, Pb, Zn	Malacca	Liong, 1986
Crassostrea cucullata	Cu, Zn, Cd, Pb, Hg	Perak	Shahunthala, 1986
Clam			
Paphia undulata *Paphia sp.*	Cu, Zn, Cd, Pb, Hg	Perak	Shahunthala, 1986
Cockles			
Anadora granosa	Cu, Zn, Cd, Pb, Hg	Penang Perak Selangor	Shahunthala, 1986
Fish			
Epinephalus chlorostigma *Plotosus anquillaris* *Sciaena russelli* *Sillago sihana* *Tachysarus maculatus*	Pb,Hg,Cd, Zn	Peninsular Malaysia	Babji *et al.* 1986
Seaweeds (See Table 1.5)			Sivalingam, 1978 Sivalingam, 1980 Sheila, 1993 Sheila *et al.*1994

Table 1.5 : Heavy metal content of selected seaweed species of Malaysia

Metal ($\mu g\ g^{-1}$ dry weight)	Fe	Zn	Pb	Cd	Cu	Cr	Mn	Hg	Author
Species									
Chlorophyceae									
Ulva fasciata	1500	35	11	2	8.5	5	70	-	(1,4)
	1425	135	15	2.5	3	4	150	-	(1,4)
Ulva reticulata	-	-	-	-	-	-	-	0.0635	(2)
Cladophora fascicularis	4735.49	38.85	12.95	9.25	7.40	33.30	92.49	-	(3)
Cladophora prolifera	4600	50	16	2	12.5	8	110	-	(1,4)
Caulerpa racemosa	5106.23	71.97	41.12	10.28	6.85	54.83	137.08	-	(3)
	1125	47.5	7	1.1	2.5	2.5	74	-	(1,4)
	1075	167	8.5	2	3.5	4.5	55	-	(1,4)
Caulerpa peltata	825	20	4.5	1	2.5	15	110	-	(1,4)
	207	70.3	5.7	2.51	12.39	2.11	34.6	-	(1)
	115	128.9	6.2	0.13	5.75	2.03	17.2	-	(1)
Caulerpa lentillifera	3875	70	12	1.5	3.5	5	110	-	(1,4)
Enteromorpha flexuosa	7117.26	104.47	58.77	16.32	26.12	58.77	127.33	-	(3)
Enteromorpha intestinalis	-	-	-	-	-	-	-	0.15	(2)
	2454	243.5	8.8	0.5	9.5	1.75	47.2	-	(1)
Enteromorpha clathrata	2793	64.8	13.8	0.58	40	5.5	31.3	-	(1)
	3485	27.3	11.8	0.75	7	3.3	31.5	-	(1)
Chaetomorpha linum	8790	68	14.3	2	4.5	20	120.5	-	(1)
Valonia fastigiata	5821.06	47.99	14.61	10.43	16.69	Trace	125.18	-	(3)
	-	-	-	-	-	-	-	0.0635	(2)
Valonia aegagropila	2800	70	11	2	6	10	135	-	(1,4)

Valoniopsis pachynema	13816	58.03	19.34	8.29	11.05	Trace	221.06	-	(3)
	6487.53	64.88	21.63	9.27	Trace	Trace	123.57	-	(3)
	5225	130	18.5	4.5	12	12	190	-	(1,4)
Phaeophyceae									
Padina tetrastomatica	1575	180	9	5.5	3.5	2.5	105	-	(1,4)
	2255	125	12.5	5	9.5	11	80	-	(1,4)
	3325	67.5	13	1	4	7.5	1200	-	(1,4)
	1125	65	8.5	2.5	3.5	7	8.5	-	(1,4)
	2700	40	16	4.5	9	13.5	88.5	-	(1,4)
	726	28.3	9.5	2	6.5	1.5	160.8	-	(1)
	1348	19.5	7.3	1.25	2.7	1.5	18.5	-	(1)
	1576	93.3	12.8	1.38	6.18	4.58	71.3	-	(1)
Padina tenuis	3327.72	45.51	17.06	7.11	5.69	25.6	284.42	-	(3)
	-	-	-	-	-	-	-	1.025	(2)
Padina australis	1098	60	7	1	3.83	1.5	41.8	-	(1)
Padina sp.	-	-	-	-	-	-	-	0.1	(2)
Sargassum grevillei	347.84	15.46	5.15	6.44	5.15	20.61	90.18	-	(3)
Sargassum siliquosum	425	32	5	2	1.5	2	130	-	(1)
	725	35	5	1.5	2	3	82.5	-	(1,4)
	350	38	9	1	3.5	2.5	66.5	-	(1,4)
	498	21.3	4.3	0.75	1.75	0.2	67.2	-	(1)
	632	25.5	3.5	1	1.75	0.4	107	-	(1)
Sargassum baccularia	250	17.5	3.5	1.5	2	2	25	-	(1,4)
	381	19.5	4.8	0.75	1.3		91.3	-	(1)
	152	26	3.8	0.45	1.7	0.4	56.7	-	(1)
Dictyota bartayresii	15473.92	210	49.74	13.82	49.74	Trace	248.69	-	(3)
Dictyota divaricata	1650	69	9	2	3.5	4.5	60	-	(1,4)
	1455	22.8	9	2.75	3.75	2.2	76.8	-	(1)
Dictyota friabilis	1900	27.5	9.5	1.5	2	4	105	-	(1,4)
Turbinaria conoides	100	10	3.5	1.5	1.5	2.5	15	-	(1,4)

Rhodophyceae									
Gracilaria edulis	900	90	3.5	1.5	3.5	1	130	-	(1,4)
	650	100	3.5	1.5	4	1.5	70	-	(1,4)
	700	65	3.5	1.5	5	0.5	55	-	(1,4)
	3250	60	12	1	2	2		-	(1,4)
Gracilaria salicornia	450	40	2	1	1	1	345	-	(1,4)
	2733	49.5	7	0.4	2.4	6.3	69	-	(1)
Gracilaria changii	1200	20	2	1	1	1	475	-	(1,4)
	535	34.3	13.7	-	2.2	-	44.5	-	(1)
Gracilaria sp.	1214.37	19.83	44.61	7.43	Trace	39.65	24.78	-	(3)
Gracilaria sp.	631.92	63.19	31.6	13.17	10.53	42.13	315.96	-	(3)
Gracilaria sp.	2301.86	22.73	9.95	7.11	2.84	Trace	42.63	-	(3)
Gracilaria sp.	-	-	-	-	-	-	-	0.2	(2)
Gracilaria sp.	-	-	-	-	-	-	-	0.175	(2)
Gracilaria textorii	-	-	-	-	-	-	-	0.0125	(2)
Acanthophora orientalis	-	-	-	-	-	-	-	0.125	(2)
	486.29	34.32	5.72	7.15	Trace	Trace	71.51	-	(3)
Acanthophora spicifera	2850	20	10.5	1	5	4.5	70	-	(1,4)
	978	45.7	5.5	0.5	8.5	0.05	26	-	(1)
Hypnea sp.	1008.59	59.77	44.83	3.74	Trace	Trace	37.36	-	(3)
Hypnea sp.	-	-	-	-	-	-	-	0.35	(2)
Hypnea sp.	-	-	-	-	-	-	-	0.0775	(2)
Laurencia glandulifera	1612.13	60.45	1.68	8.4	13.43	Trace	50.38	-	(3)
Laurencia pinnata	1007.23	14.22	8.3	5.93	4.74	21.33	23.7	-	(3)
Laurencia concreta	778	34.3	4.2	0.4	2.6	0.4	48.2	-	(1)
Laurencia obtusa	51	14.5	15.6	1.25	7.01	5.43	6.8	-	(1)

Amphiroa sp.	-	-	-	-	-	-	-	0.2	(2)
Amphiroa foliacea	50	5	21.5	1.5	8	6	10	-	(1,4)
Amphiroa fragillisima	86.4	4.5	21	1	7	5	15	-	(1,4)
	154.5	14	24.5	0.83	7	3.7	8	-	(1)
Amphiroa beauvoisii	158	9	22.3	1.25	6.7	3.6	8	-	(1)

Source : 1 - Sheila, 1993 ; 2 - Sivalingam, 1980 ;
3 - Sivalingam, 1978 ; 4 - Sheila *et al.*, 1994

Much of the literature on heavy metal contents in marine organisms contains lists of data, with authors not in a position to comment on the significance of results (Rainbow *et al.*, 1990). This view point suggest that laboratory experiments as a necessary complement to field data to gain more information on the responses of organisms within a range of concentrations of a single pollutant, for various time periods under controlled conditions. The responses would provide information in the metal accumulation strategies available to marine organisms.

The use of seaweeds as potential biomonitors of heavy metals in Malaysia is based on their high accumulating abilities and survival in metal stressed conditions. As well as using them as biomonitors of heavy metal pollution, they also could be involved in toxicity tests. As an integral part of marine community system, researchers would welcome the development of toxicity data of heavy metals for seaweeds. More recently, much greater use has been made of seaweeds as experimental test organisms in laboratory studies of marine pollutants/toxicants; prior to this, algal toxicity tests routinely employed planktonic microalgae (Fletcher, 1991). This could be attributed to the great economic potential of products derived from seaweeds. The test would also be of great importance in developing Malaysia's very own Interim Standards of Marine Water Quality for Marine Life Conservation.

1.9 Objectives of study

The objective of this study is to establish the potential of using Malaysian seaweeds as biological monitors of heavy metal pollution. The investigations were conducted with the following aims :

I) To characterise the bioaccumulation of selected heavy metals by selected seaweed species over the time course of exposure in laboratory studies. This was achieved by;

i) exposing seaweeds to 24 h single metal exposure with varying initial ambient metal concentrations.

Outputs :

- heavy metal bioaccumulation patterns in seaweeds throughout the 24 h metal exposure.
- net accumulation of metals over the 24 h exposure period in the seaweeds.
- correlation relationships between;
    - i) Time of exposure and metal accumulated in seaweeds over the initial ambient metal concentration range.
    - ii) Initial metal concentration of solution and metal

accumulated in seaweeds after 24 h.
        iii) Metal accumulated in seaweeds and final metal concentration in seawater after 24 h.

ii) Exposing seaweeds to 2 h single metal exposure with varying initial salinities.

Outputs :

- net accumulation of metal over the the 2 h exposure period in the seaweeds.
- correlation relationships between;
    - i) Time of exposure and metal accumulated in seaweeds over the initial external salinity range.
    - ii) Initial salinity of solution and metal accumulated in seaweeds after 2 h.
    - iii) Metal accumulated in seaweeds and final metal concentration in seawater after 2 h.

iii) Exposing seaweeds to 2 h single metal exposure with varying initial pH.

Outputs :

- net accumulation of metal over the the 2 h exposure period in the seaweeds.
- correlation relationships between;
    - i) Time of exposure and metal accumulated in seaweeds over the initial external pH range.
    - ii) Initial pH of solution and metal accumulated in

seaweeds after 2 h.

iii) Metal accumulated in seaweeds and final metal concentration in seawater after 2 h.

II) To use young growing seaweed plants as possible test species in selected heavy metal toxicity testing. This was achieved by determining the IC_{50} of the respective metal species in selected seaweeds over varying exposure periods. The LOEC and NOEC values are also tabulated. The endpoint measurements include chlorophyll-a content and dry weight.