MAURITIUS RESEARCH COUNCIL

INNOVATION FOR TECHNOLOGY

USE OF BIOINDICATORS FOR HEAVY METAL POLLUTION STUDIES IN THE COASTAL MARINE ENVIRONMENT OF MAURITIUS

Final Report

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USE OF BIOINDICATORS FOR HEAVY METAL POLLUTION STUDIES IN THE COASTAL MARINE ENVIRONMENT OF MAURITIUS

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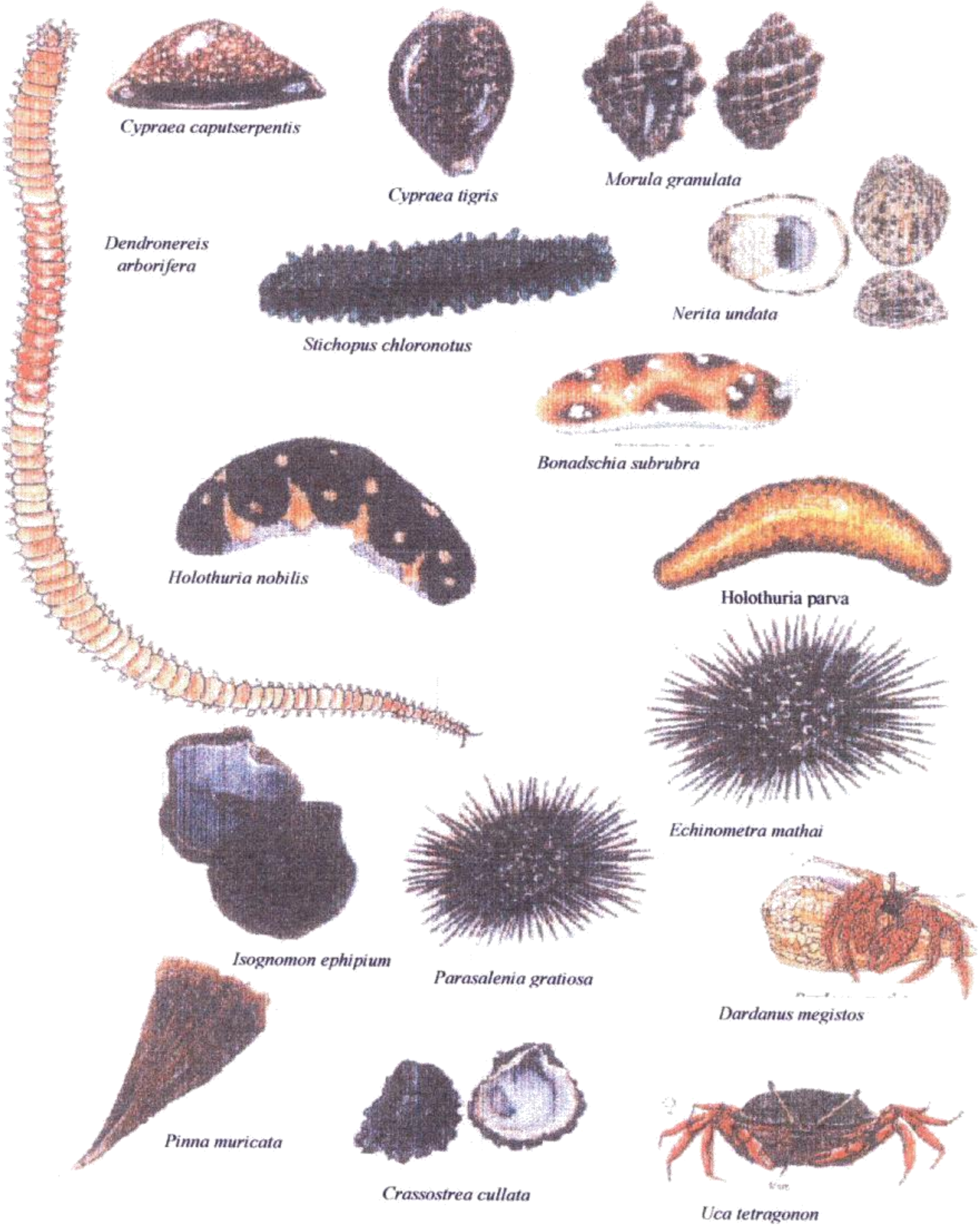
Examples of organisms used for trace metal analysis



SUMMARY

Many studies in various parts of the world have investigated the levels of pollutants in seawater, sediments and marine organisms. Such studies have been used either to describe the environmental behaviour of pollutants or to monitor the levels of contamination in those constituents of the coastal marine environment. This work relates to the levels of some trace metals in the coastal marine environment of Mauritius. Concentrations of **Cadmium, Chromium, Copper, Lead, Tin and Zinc** were measured in samples of seawater, sediment and biota from 20 sites around the island during 1998-2000. The main objectives were to identify potential bio-indicators for heavy metal contamination and pollution hot spots around the coastline and also to assess whether trace metal levels in commercial fish species represent a health hazard to the community.

The data generated indicate that the western coastline would be more vulnerable than elsewhere because of its accessability and more sheltered condition. However, elevated contamination of both seawater and sediment was localised at certain sites, the 'hot spots' normally corresponding to the sites of waste water discharge or underground seepage in the lagoons. The most contaminated zone would be Port Louis and the surrounding areas, which anyway are highly degraded due to discharge of untreated industrial and domestic wastewater. Installation islandwide of a sewerage network and wastewater treatment facilities would be the only solution to improve the environmental health of the coastal environment in Mauritius.

Comparison with levels cited in literature indicates that contamination by any of the metals investigated in this study would not be higher than elswhere in the world. The levels recorded in samples of marine biota as well as in the commercial fish species were well below the recommended limits for consumption. This work should be considered only as preliminary. The organisms which have been indentified as potential bio-indicators need to be studied much more rigorously for extended periods of time so that some of them can actually serve as real sentinels for coastal marine pollution in Mauritius.

CHAPTER ONE

1. INTRODUCTION

1.1 Principal objective of this study

Coastal pollution caused by heavy metals has never been studied in Mauritius. The main purpose of this study was to screen potential bio-indicators of heavy metal pollution from the coastal marine environment of Mauritius by analysis of samples of water, sediment and tissues of common plants and animals. The trace metals selected for investigation were **cadmium, chromium, copper, lead, tin and zinc**, which are considered to be dangerous from the environmental and human health viewpoints .

1.2 Concerns about heavy metals in the coastal marine environment.

Estuarine and coastal waters are often major recipients of heavy metals resulting from anthropogenic activities. Inputs may be in particulate or dissolved forms in urban run-off, industrial effluents, mining operations and atmospheric depositions. Above certain threshold levels, all heavy metals have the potential to become toxic to organisms despite the fact that many have some essential biological function. To avoid adverse impacts on the aquatic environment and human health, inputs must be controlled so that these limits are not exceeded. Most heavy metals are not conserved in seawater, are attached to suspended particulates and accumulate in bottom sediments. Shallow nearshore waters generally have higher concentrations of metals than open oceanic waters, and this is reflected in the higher sediment load of coastal waters. The availability of metals to organisms depends critically on their chemical form in the environment.

Among ecotoxicologists, the term 'heavy metals' is generally used to refer to metals that have been shown to cause environmental problems. Those of major concern include: cadmium, mercury, zinc, copper, nickel, chromium, lead, cobalt, vanadium, titanium, iron, manganese, silver, and tin (Rainbow, 1985; Hopkin, 1989; Bryan & Langston, 1992). Among the list of heavy metals investigated in this study (i.e. Pb, Cu, Zn, Cd, Cr and Sn), cadmium and lead are generally considered to be the most dangerous to humans and ecosystems. Apart from cadmium and lead, copper, zinc and chromium can also pose significant problems. These heavy metals are conservative pollutants and hence they are not subject to bacterial attack or other breakdown, or if they are it is on such a long time-scale that they may be categorised as permanent additions to the marine environment. The disastrous effects of heavy metals in the marine environment came to be fully realised following the Minimata disaster in 1953 (caused by the consumption of mercury contaminated shellfish), and shortly afterwards the affliction known as itai-itai (suspected to be caused by consumption of cadmium contaminated seafood), both in Japan (Clark, 1989). Since then, there has been growing concern worldwide about heavy metals in the environment and for their control. Most of the recent concern has revolved around effects on humans but heavy metals can also cause major ecological dislocations (e.g. the now famous imposex phenomenon in the UK dogwhelk *Nucella lapillus*, abnormal growths of oyster flesh and shells in natural populations as well as commercial exploitations, etc).

1.3 Heavy metal toxicity to aquatic organisms

Aquatic organisms may be adversely affected by heavy metals in the environment. Abel (1989) listed heavy metals in the appropriate order of their decreasing toxicity : Hg, Cd, Cu, Zn, Ni, Pb, Cr, Al and Co. However, this sequence is tentative and subject to change because toxicity is largely a function of the water chemistry and sediment composition in the surface water system. Moreover, toxicity of a given metal will vary with the species investigated because the biochemistry of an organism plays a vital role in its susceptibility to metal toxicity.

Goyer (1991) suggested that metals exert a wide variety of toxicity mechanisms. Generally, metals exert toxic effects on organisms if they enter into biochemical reactions in which they are normally not involved. An essential element is said to become toxic if the nutritional supply exceeds the optimal amount by a factor of 40-200. Copper is an exception. It is toxic at very low concentrations. Its toxicity is higher for lower organisms but bivalve molluscs are highly tolerant. In fact, toxicity is influenced by the chemical form of the metal. Jorgensen & Jensen (1984) classified metal forms as (1) simple hydrated metal ions, (2) metal ions complexed by inorganic anions, and (3) metals complexed with organic ligands. The high toxicity of copper is thought to be due to the electronegativity of its salts or of chelates. The very toxic metals have been observed to be soft acceptors (e.g. Cu^+, Ag^+, Hg^{2+}, CH_3Hg^+, Cd^{2+}), which prefer to bind to soft donors (e.g. SH^-, S^{2-}, alkyl or aryl-s compounds, CN^-). Toxicity is generally a function of: (1) the lifestage, (2) water hardness, (3) temperature (toxicity increases with increasing temperature above 10°C), (4) pH, (5) salinity, (6) acclimation, (7) mixtures of metals, and (8)fluctuating exposure concentrations.

In a toxicological research study to determine the relative toxicity of six heavy metals (As, Cd, Cr, Cu, Hg and Zn) to four groups of marine organisms, the following results were obtained. Each metal is listed in order of decreasing toxicity.

1.	Crustaceans	:	Hg,	Cu,	Cd,	Zn,	As,	Cr
2.	Polychaetes	:	Cu,	Hg,	Zn,	As,	Cr,	Cd
3.	Bivalves	:	Cu,	As,	Cd,	Hg,	Cr,	Zn
4.	Fish	:	Cu,	Hg,	As,	Cd,	Zn,	Cr

(Source: Bryan et al., 1992)

These results are illustrative of high variation in heavy metal toxicity among marine organisms. Some of the important effects can be summarised as follows:

(a) Crustaceans and polychaetes were the more sensitive of the four groups.

(b) bivalves and fish were more tolerant to the six metals.

(c) the order of relative toxicity of the six metals to the four animal groups was not the same.

(d) Copper was toxic to all species tested.

(e) Mercury was toxic to all but bivalves.

(f) Chromium was the least toxic to all groups.

1.4 Some human health effects.

At present, there is definitive evidence for an association between certain forms of cancer and specific pollutants (Carpenter, 1998). Environmental contaminants such as heavy metals affect many aspects of human physiology and behaviour. Ingestion of metals such as lead, cadmium, mercury, arsenic, barium and chromium may pose great risk to human health, with significant negative effects on the immune, reproductive, endocrine and nervous systems.

Exposure to heavy metals has been linked with developmental retardation, various cancers, kidney damage, and even death in some instances of exposure to very high concentrations. Exposure to high levels of Hg, Ag and Pb has been associated with the development of auto-immunity, in which the immune system starts to attack its own cells, mistaking them for foreign invaders. Auto-immunity can lead to the development of diseases of the joint and kidneys, such as rheumatoid arthritis, or diseases of the circulatory or central nervous systems. Despite abundant evidence of these deleterious health effects, exposure to heavy metals continues and may increase in the absence of control measures (Nriagu, 1996).

Tin : Organotin compounds have been the subject of numerous coastal pollution studies in many parts of the world lately. Since the organotin is not destroyed by cooking, it may get bio-concentrated up the food chain. Elevated levels of TBT (tri-butyl tin) causes damage to shell-fisheries, it may also have damaging effects on other organisms. The use of TBT-based paints in mariculture installations and on small boats has been banned in several countries including France, Ireland, the United Kingdom and the United States because of its hazard to marine organisms as well as its possible threat to human health. The problems that TBT causes are not expected to have a long lasting effect since it degrades to non-toxic compounds within a few weeks (Clark, 1989).

Copper : There is no danger to humans of copper poisoning from seafood. The lethal dose is about 100 mg but the human taste threshold for copper is low (5.0 - 7.5 μg or ppm), and the taste is repulsive. Copper in the sea is not regarded as a hazard to human health because of this ample safety margin (Clark, 1989).

Lead : Acute lead poisoning has been a problem since antiquity. Its symptoms are abdominal pain, nausea, tiny limb and numbness of the hands and feet and muscle cramps (Moore & Moore, 1976). Because of size and charge similarities, lead can substitute for calcium and get incorporated in the bone. Children are especially susceptible to lead because developing skeletal systems require high calcium levels. Lead that is stored in the bone is not harmful, but if high levels of calcium are ingested later, the lead in the bone may be replaced by calcium and mobilised. Once free in the system, lead may cause nephrotoxicity, neurotoxicity and hypertension.

Chronic effects of lead in man are currently of much greater concern than acute exposure. Most lead is obtained from food rather than water or air, although absorption through the lungs is highly efficient when environmental concentrations exceed 2 $\mu g/m^3$. Elevated blood lead levels impair the production of haemoglobin resulting in oxygen starvation and anemia. Since lead cations are prone to react with sulphydryl (-SH) groups in proteins, they are known to inhibit at least two enzymes whose catalytic function is essential for biosynthesis of heme (Moore & Moore, 1976).

It has also been suggested that blood lead levels may be associated with biochemical abnormalities in children brains. Lead is especially toxic to the growing brain and can affect the behavioural development of young even at low concentrations. This is because of the direct relationship between the activities of blood and brain enzymes (Carpenter,1998). This may account for increased hyperactive and delinquent behaviour among children and adults. The adverse effects on IQ and attention span of exposure to lead in the developing child has been well known and accepted since the work of Needleman *et al.* (1979). Children with attention deficit disorder (ADD) have higher average lead levels than. ADD is associated with motor restlessness, impulsiveness, inattention and increased distractibility, and individuals with ADD have a higher risk of antisocial personality disorder and depression. Carpenter (1998) pointed out that children with lead intoxication have a reduced attention span making it impossible for them to learn. Damage to the nervous system and gastrointestinal symptoms are the main signs of lead poisoning. In polluted cities, fumes from cars burning leaded gasoline may cause air concentrations high enough to affect children's development. Lead can pass through placenta and thus affect a growing fetus. Organic compounds are fat soluble and more toxic than other forms.

Chromium : Compounds of two species of chromium (chromium (VI) and chromium(III)) are on the **National Pollutant Inventory** list in USA. The health effects of chromium (VI) compounds are quite different from those of chromium (III) compounds. Very small quantities of chromium (III) compounds are essential for the human health and well being but, chromium (VI) compounds are usually highly toxic. Skin exposure to chromium (VI) can be especially noticed on those individuals with skin allergies. Breathing in chromium (VI) compounds can damage and irritate the nose, throat, lungs, stomach and intestines. It may lead to asthma and other allergic reactions. Exposure to chromium (VI) can cause stomach upsets, ulcers, convultions, kidney and liver damage. Long-term exposure to airborne chromium (VI) can have adverse effects on the respiratory and the immune systems and can cause cancer. Skin contact with liquids and solids may lead to skin ulcers, redness and swelling. Chromium (VI) is more toxic than chromium (III) but low levels may be tolerated sometimes.

Zinc : Eating large amounts of zinc contaminated food may cause stomach cramps, nausea and vomiting. It can also cause anemia, pancreas damage and lower levels of beneficial cholesterol, i.e. high density lipoprotein cholesterol. The long term effects of high level zinc intakes are not known.

Cadmium : Cadmium was suspected of being responsible for the outbreak of itai-itai disease in Japan in the late 1950s. This painful disease affected particularly the bones and joints resulting in many deaths. Doubts, however, exist whether itai-itai was cadmium-related or it was more likely to have been caused by malnutrition or vitamin deficiency. High concentrations of cadmium in seafood, namely bivalves, normally cause vomiting in people but not any permanent effect, hence it does not represent a special hazard.

In higher animals, cadmium accumulates in the kidneys and liver, where most of it binds to a special protein that makes the metal harmless to the animal. If the uptake is greater than this natural defense, cadmium can damage the kidneys and upset metabolism of vitamin D and calcium. Kidney damage and a decalcification of the skeleton are the serious chronic effects of high calcium exposure . Kidney damage in seabirds has been seen at cadmium levels in the tissue of 60 to 480 mg/g. Based on human toxicology, cadmium concentrations of 100 to 200 mg/g (wet weight) in the kidneys probably represent a risk for mammals. With a half-life of decades, cadmium leaves the body extremely slowly.

1.5 Some ecological effects

Heavy metals and a variety of toxins cause skeletal and spinal deformities which are relatively common in fish, particularly from polluted waters. Spicer and Weber (1991) documented that elevated concentrations of heavy metals induce marked osmoregulatory and respiratory responses in crustaceans. Hence, it may be anticipated that factors influencing these physiological processes will also affect gill ultrastructure (Taylor & Taylor, 1992). Elevated metal levels in natural waters may cause sublethal/chronic and lethal/ acute effects in aquatic organisms. The sublethal effects of heavy metals in marine organisms are manifested in the following ways: (1) histological and morphological change in tissues, (2) changes in physiology such as suppression of growth and development, poor swimming performance, changes in circulation, (3) changes in biochemistry such as enzyme activity and blood chemistry, (4) changes in behaviour, and (5) changes in reproduction (Connell, *et al.*, 1984).

Tin : It is widely accepted that tributyltin (TBT), used as a biocide in antifouling paints is one of the most toxic agents ever intentionally introduced into the coastal environment.

Table 1.1: Effect of TBT on C. gigas embryogenesis & larval development.

TBT Acetate µg/l (ppm)	Effects on Reproduction in *C. gigas* (edible oyster)
100	Inhibition of Fecundity
50	Inhibition of Segmentation
25	Partial Reduction of Segmentation
10	Absence of the Formation of Trocophores
3-5	Absence of Veligers - Malformation of Trocophores
1	Abnormal Veligers - Malformation of Trocophores
0.05	Numerous Anomalies - Total Mortality in 8 Days
0.2	Perturbation in Food Assimilation - Total Mortality After 12 Days
0.1	Normal D-Larvae : Slow Growth, Almost Total Mortality After 12 Days
0.5	Slow Growth : High Mortality Rate After 10 Days
0.02	No observable Effect

Source : Alzieu (1986) and Robert (1985).

Several field and laboratory studies have documented that extremely low environmental levels of TBT can have lethal and sublethal effects (e.g. shell malformation in the pacific oyster, *Crassostrea gigas*) on ecologically and economically important species (Larsen *et al.*, 1997). Reproductive abnormalities attributed to TBT have been documented in *C. gigas* (Table 1.1). The sublethal effect of low concentrations of TBT are of great consequence to commercial shell fisheries. The most serious problem is that gross thickening of the shells of the oysters greatly reduces the size of the animal inside, rendering them unmarketable (Clark, 1989). Gross abnormalities, shell thickening and chambering in pacific oysters (*Crassostrea gigas*) were found to occur at 50 ng/dm^3 of TBT (Waldock *et al.*, 1987).

Changes in the reproduction cycle of the European oyster *O. edulis* have been found after exposure to 0.24 ppb TBT leachates. At this TBT level there was no sexual differentiation for these hermaphroditic organisms (Thain, 1986). Fish and crustaceans have been shown to have a greater ability to metabolise TBT than molluscs. Very low levels of TBT (50 ng/dm^3) produce the phenomenon of 'imposex', the imposition of male sexual characteristics onto the female, in the dogwhelk *Nucella lapillus* (Bryan *et al.*, 1986). The female develops a penis and a vas deferens which occludes the opening of the oviduct and prevents the release of egg capsules, thus rendering the female sterile. Eventually, reproduction is impaired, resulting in a very significant decline in the dogwhelk population in the UK. Studies have suggested that as little as 3 ng/l TBT is thought to be sufficient to sterilise females, and no-effect concentration is much less than 1 ng/l (Gibbs *et al*, 1988). Observations on imposex are also provided for *Thais bituberculari*s, *T. clavigera* and *T. jubilaea* (Mollusca : Neogastropoda : Muricidae) from Singapore (Tan, 1997). Horiguchi *et al.* (1995) found thirty species (24 neogastropods and 6 mesogastropods) to be affected by imposex in the 38 species of Japanese gastropods surveyed (as of October, 1993). With regulation of TBT in 1988, imposex should have disappeared by now.

Walsh *et al.* (1985) demonstrated that 100-300 ng/l TBT reduces the growth of certain microalgal species. The most sensitive so far tested is the diatom *Skeletonema costatum*, which shows no growth at all at 100 ng/l. Microalgae are primary producers in the aquatic environment and therefore reduced growth or mortality of microalgae could have far -reaching effects on life at higher levels in the food chain. A number of crustaceans have been tested for the effects of TBT. Reduced growth was observed at 1 ppb for the larvae of *Hemarus americanus*, the American lobster (Laughlin & French, 1980), and at 0.25 ppb for juvenile of the mysid shrimp *Acanthomysis sculpta*.

Copper & Zinc : Despite the existence of a number of detoxifying and storage systems for copper, it is the most toxic metal, after mercury and silver, to a wide spectrum of marine life. Water containing more than 0.3 ppm copper was found to cause death of plankton, fish and shell fish on the Dutch coast near Noordwijk in 1965 (Clark, 1989). A sublethal copper concentration (50 µg/l) administered at 35% and 10% salinity causes extensive ultrastructural alteration to the gill cells, including a decrease in the number of plasma membrane infoldings, extensive vacuolation, a change in ribosomal distribution and disruption of the microtabular network of *Carcinus maenas*, a decapod crab (Lawson *et al.*, 1995). Research has shown that sub-lethal concentrations of copper sulphate and zinc sulphate (0.05-0.10 ppm) cause the production of abnormal larvae in the polychaete worm *Capitella capitata*. These larvae are bifurcated and fail to survive beyond the eight-segment stage (Clark, 1989). Larval bivalves are also very sensitive to copper and zinc.

The specific growth rate of coral zooxanthellae cells in culture is a suitable index to be used in the study of sublethal stress due to heavy metals. Copper and zinc elicit a synergistic effect in the reduction of the specific growth rates of zooxanthellae (Goh and Chou, 1997), the dinoflagellate *Amphidinium carterae*, and the diatoms *Skeletonema costatum* and *Thalassiosina pseudonana* cultured in enriched seawater media (Braek *et al.*, 1976).

Copper and zinc also affect shell growth in the oyster *Mytilus edulis*. Investigations on the effect of copper and zinc on shell growth measured by laser diffraction technique have revealed that 10 ppb of copper cause significant suppression of growth. Concentrations above this have a detrimental effect. In long term experiments the effects of 10 ppb added copper become more severe as exposure time increases. Copper seems to definitely affect the mean specific growth rate of the shell which drastically declines to zero until day 30. After removal of the metal, there is a gradual recovery but the animal does not return to the normal pre-exposure conditions.

Wong *et al.* (1995) reported a reduction in the development and growth rate of the prawn *Metapenaeus ensis* larvae and postlarvae in the presence of copper. Reduced growth caused by exposure to copper has also been reported in the copepods, *Tigriopus* sp. (D'Agestino & Finney, 1974) and *Eurytemora affinis* (Sullivan *et al.*, 1983), and the shrimp, *Macrobrachium rosenbergii* (Liao & Hsieh, 1990).

Cadmium : Cadmium is toxic to all forms of life. It can be taken up directly from water and to some extent from the air and via food. It has a tendency to accumulate in both plants and water. Cadmium and its compounds are included in the 'black list' of materials which by international agreement may not be discharged or dumped into the sea. However, for unknown reasons, it enhances phytoplankton photosynthesis and growth at concentrations up to 100 ppm. At high levels in the food web, fishes and sea mammals have low concentrations of cadmium, at most a few ppm., stored chiefly in the kidney, and they are able to detoxify it by the production of a metallothionein. High concentrations of cadmium (173 ppm) in oysters (e.g. *Crassostrea gigas*) has no known ecological effect but they pose great risks to human health. Cadmium usually interferes with essential nutrients of similar appearance, such as calcium and zinc. Cadmium is moderately toxic to aquatic invertebrates, reducing their growth and decreasing the survival of larvae. In fish, cadmium poisoning can lead to an ion imbalance and interfere with calcium metabolism.

In higher animals, cadmium accumulates in the kidneys and liver, where most of it binds to a special protein that makes the metal harmless to the animal. If the uptake is greater than this natural defense, cadmium can damage the kidneys and upset metabolism of vitamin D and calcium. Kidney damage and a decalcification of the skeleton are the serious chronic effects of high calcium exposure . Kidney damage in seabirds has been seen at cadmium levels in the tissue of 60 to 480 mg/g. Based on human toxicology, cadmium concentrations of 100 to 200 mg/g (wet weight) in the kidneys probably represent a risk for mammals. With a half-life of decades, cadmium leaves the body extremely slowly.

Lead : Compared with other metals, lead in the sea is not particularly toxic. In fish lead accumulates primarily in the gill, liver, kidney and bone. In juvenile fish lead causes a blackening of the tail followed by damage to the spine. It also reduces larvae survival. At concentrations up to 0.8 ppm, lead nitrate enhances the growth of the diatom *Phaeodactylum*, presumably through the nutrient effect of the nitrate. The sub-lethal effects of low concentrations of lead in the marine environment result in a depression of the growth of *Cristigera*, a ciliate protozoan (by 8.5% at 0.15 ppm and by 11.8% at 0.3 ppm). The growth of the *Artemia* is also significantly reduced at 5-10 ppm. Moreover, prolonged exposure of the mussel *Mytilus edulis* to 10 ppm or less may even increase its mortality rate (Clark, 1989).

Lead poisoning has been reported in birds which exhibited neuromuscular disorders. Birds are only sensitive to lead at very high concentrations but can get lead poisoning symptoms and eventually die from ingesting pellets of lead shots. Nevertheless, high concentrations of lead can be accumulated by some other animals with no apparent harm.

Chromium : The combined pollution by chromium and phenol may be an important factor in the decline of prawn fishery production in China (Duedall *et al.*, 1983). Low chromium and phenol treatments increase the yield of prawns (*Panaeus japonicus*), while high chromium and high phenol treatments decrease the yield (Qixing and Limei, 1995).

Some further ecological effects

Heavy metals have substantial sublethal effects on all types of marine organisms. Langston (1990) reviewed and summarised some of these important effects and are presented here in Tables 1.2, 1.3 and 1.4.

Table 7·2
SUBLETHAL EFFECTS OF METALS — GROWTH

Species	Metal concentration (μg/l) Ag	As	Cd	Cu	Hg	Ni	Pb	Zn	Response
Phytoplankton									
Natural assemblage				0.3					Reduced ^{14}C fixation
Natural assemblage			1.0	1.0	1.0				Reduced ^{14}C fixation
Natural assemblage				10.0					Reduced ^{14}C fixation
Natural assemblage		23	112	6.4	<6.0	60[a]	20	20	Reduced growth
Monochrysis lutheri				21.6 (0.07 as Cu^{2+})					Reduced division
Natural assemblage					0.8				Reduced growth
Natural assemblage					1.0				Reduced productivity
Natural assemblage								15	Reduced photosynthesis
Natural assemblage		5							Reduced growth
Macroalgae									
Laminaria saccharina									
Sporeling				10	0.5 (0.5)[b]			100	Reduced growth
Sporophyte				50	50 (5.0)[b]			1000	Reduced growth
Hydroids									
Campanularia flexuosa			195	14.3	1.6			740	Reduced growth
Mollusks									
Mytilus edulis			10	3	0.3	>200[a]	>200[a]	10	Reduced shell growth
Mercenaria mercenaria	32			16	15	5700		195	Reduced growth[c]
Crassostrea virginica	25			33	12	1200			Reduced growth[c]
Fish									
Pleuronectes platessa			5	10					Reduced growth

[a] No effect observed at this concentration.
[b] Methylmercury.
[c] For larvae: concentrations also represent LC_{50} values (8 to 12 d).

From Langston, W. J., in *Heavy Metals in the Marine Environment*, Furness, R. W. and Rainbow, P. S., Eds., CRC Press, Boca Raton, FL, 1990, 107.

Table 1.3
SUBLETHAL EFFECTS OF METALS — MORPHOLOGY

Species	Metal concentration (μg/l)										Response
	Ag	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn	
Hydroids											
Eirene viridula		300	100		10	3		300	3,000	1,500	Altered hydranth morphology[a]
Mollusks											
Crassostrea gigas	22	326	611	4538	5	7	349	476	>10,000	199	50% abnormal larvae
Mytilus edulis	14	>3,000	1200	4469	6	6	891	758	>10,000	175	50% abnormal larvae
Crassostrea virginica	24					11				206	50% abnormal larvae
Fish											
Myoxocephalus quadricornis		32	0.5		0.8	0.1		1.2		5.3	Increase in vertebral deformities[b]

[a] Lowest reported threshold concentration.
[b] Metals applied as a mixture.

From Langston, W. J., in *Heavy Metals in the Marine Environment*, Furness, R. W. and Rainbow, P. S., Eds., CRC Press, Boca Raton, FL, 1990, 109.

Table 1.4
SUBLETHAL EFFECTS OF METALS — REPRODUCTION AND DEVELOPMENT

Species	Metal concentration (μg/l)									Response
	Ag	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn	
Macroalgae										
Champia parvula		60								Inhibition of sexual reproduction
Hydroids										
Campanularia flexuosa					0.05	0.01			500	Increase in gonozooid frequency[a]
Polychaetes										
Neanthes arenaceodentata			1000	50				3100	320	Reductions in reproduction
Capitella capitata			560	100				200	560	Reductions in reproduction
Ctenodrilus serratus			2500	50	100	50	500	1000	500	Reductions in reproduction
Bivalves										
Mytilus edulis					50				200	Development of oocytes supressed
Spisula solidissima (germ cells)	9.5									Impaired embrvogenesis
Crustaceans										
Pontoporeia affinis			5.5					4.9		Fecundity reduced
Rhithropanopeus harrisii			50						25	Hatch time increased
Tigriopus japonicus			44		6.4					Generation time doubled
Echinoderms										
Sea urchin eggs (various spp.)		1500	600	1000	10	10	600	1000	30	Fertilization and development arrested[a]
Fish										
Spring-spawning herring			5		10				10	Reduced fertilization
Fundulus heteroclitus						10				Reduced hatch
Leiostomus xanthurus (eggs)					0.064[b]					Reduced hatch
Menidia menidia (eggs)					0.025[b]					Reduced hatch

[a] Lowest reported threshold concentration.
[b] Calculated as free ion (Cu^{2+}).

From Langston, W. J., in *Heavy Metals in the Marine Environment*, Furness, R. W. and Rainbow, P. S., Eds., CRC Press, Boca Raton, FL, 1990, 111.

1.6 Occurrence and input of heavy metals in the marine environment

Global budgets of metal discharge to the aquatic environment show that domestic waste water is a major source of heavy metals into rivers, lakes and oceans. So is sewage sludge. Other sources include coal-burning power plants and the metals industry. Regionally, human inputs into the aquatic environment are sufficient to elevate levels of heavy metals above natural background levels. Known global emissions or discharges to water bodies exceed those to the atmosphere.

Table 1.5 shows important information based on potential supply (natural and anthropogenic) and toxicity of the trace elements under study. The metals are listed in order of decreasing toxicity. The relative critical index denotes the volume of seawater that would be contaminated annually to the indicated level of toxicity by the specified rates of addition, both by natural processes and anthropogenic activities.

Table 1.5 : The potential supply and toxicity of heavy metals in the sea. (Source : Kennish, 1994)

	Rate of mobilization (10^9 g/year)				Relative Critical Index (km^3/year)	
Element	**A (man)** Fossil fuels	**B (natural)** River flow	**C (total)**	**D (toxicity)** μg/l	**A/D**	**C/D**
Cadmium	0.35	2.65	3.0	0.2	1750	15,000
Lead	3.6	110	113.6	10	360	11,360
Copper	2.1	250	252.1	10	210	25,210
Chromium	1.5	200	201.5	10	150	20,150
Zinc	7.0	720	727	20	330	36,350
Tin	7.0	250	257	20	350	12,850

Note : Total volume of seawater on Earth = 1,350 x 10^6 km^3.

All the known chemical elements occur naturally in seawater at varying background levels. Table 1.6 shows the typical background concentrations of the heavy metals under study in the river and ocean. Erosion of ore-bearing rocks, wind-blown dust, volcanic activity, fires and vegetation may constitute large natural inputs. This complicates the assessment of impacts resulting from anthropogenic inputs of trace metals in the marine environment. Major contributors of anthropogenic inputs of heavy metals to the sea include rivers, estuarine sedimentation processes (namely in urbanised areas), the atmosphere and direct discharges of industrial and other wastes via outfalls. Currently, anthropogenic inputs exceed natural inputs (Connell et al, 1984).

Table 1.6 : Typical river and ocean background metal concentrations

Metal	Concentration (ppb) in River	Concentration (ppb) in Ocean
Cadmium	0.03	0.05
Chromium	1.0	0.6
Copper	5.0	3.0
Lead	3.0	0.03
Tin	0.04	0.01
Zinc	10	5.0

Source: Bryan (1976) in Kennish (1994)

Figure 1.1 is a general illustration of the possible sources of inputs of heavy metals to coastal zones. Table 1.7 indicates that amongst the metals under study (i.e Pb, Cu, Zn, Cd, Cr and Sn), copper, lead and zinc occur most frequently in domestic waste water. Practically, every industry discharges one heavy metal or more into the environment. Table 1.8 shows heavy metals are released as by-products of metal, chemical and other industries. Chromium would appear to be universally present in all the different categories of industrial waste waters, and lead, copper and cadmium are also major constituents of industrial effluents.

Figure 1.1 Sources of heavy metal inputs to a coastal zone.

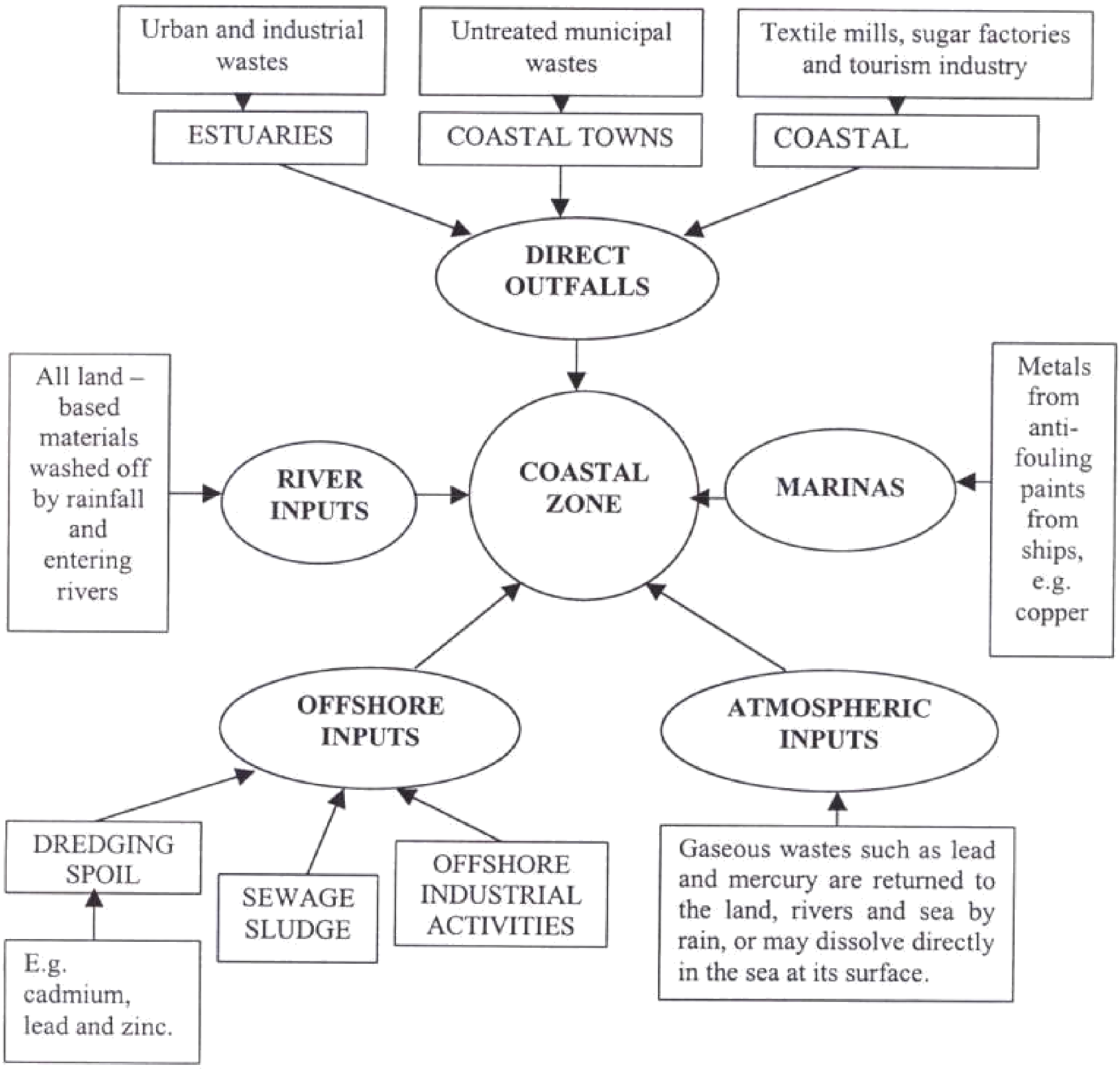


Table 1.7 : Sources of heavy metals in domestic wastewater by product type

	Al	Sb	As	Be	Bi	Cd	Cr	Co	Cu	Fe	Pb	Mn	Hg	Mo
Automotive products	x		x	x			x	x		x	x			x
Caulking compounds	x			x			x	x		x	x			
Cleaners	x						x		x	x				
Cosmetics	x			x	x	x		x	x	x	x	x	x	
Disinfectants													x	
Driers	x													
Fillers	x													
Fire extinguishers	x						x			x				
Fuel				x					x		x			
Pesticides	x		x			x	x		x	x	x	x	x	x
Inks	x								x					
Lubricants				x			x				x			x
Medicine	x	x	x		x			x	x	x				
Oils				x					x		x			
Ointments	x				x			x	x				x	
Paints	x		x	x			x	x		x	x	x	x	
Photography	x						x			x	x		x	
Pigments	x	x	x	x	x	x	x	x	x	x	x	x	x	
Polish	x			x					x					
Powders	x									x				
Preservatives										x	x			
Suppositories					x									
Water treatment	x								x	x		x		

Source : Kennish 1994

Table 1.8 : Heavy metals in wastewater from different categories of industries

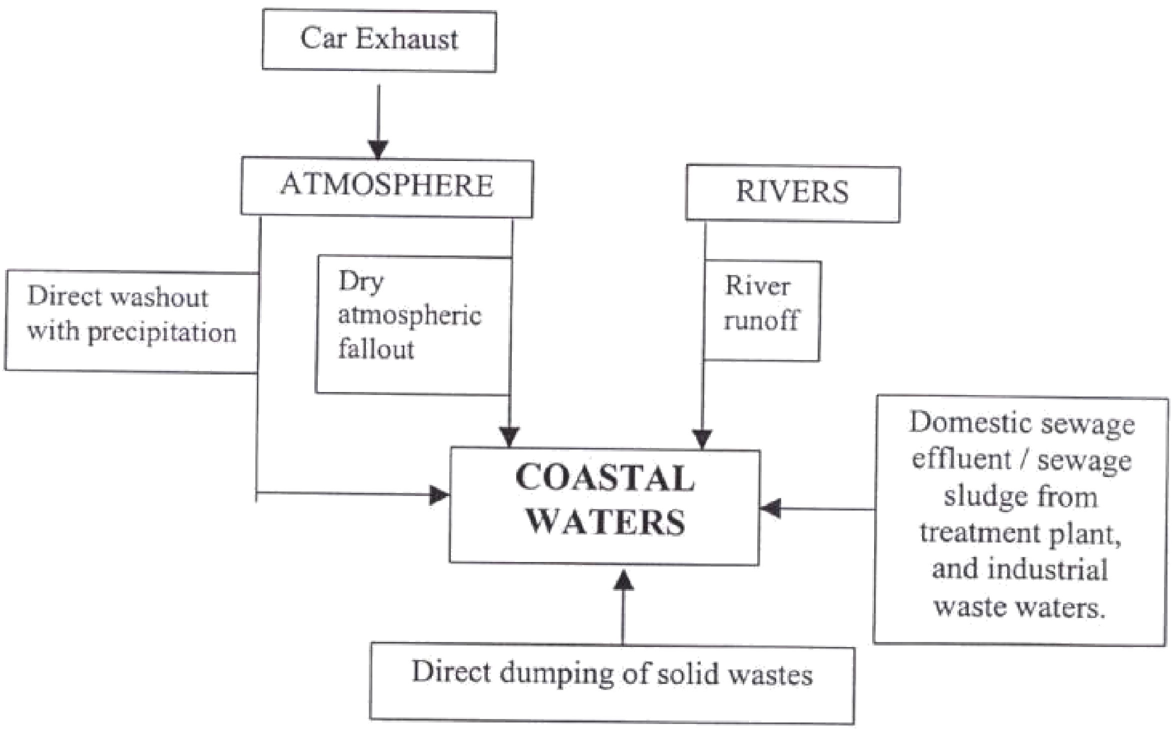
	Al	Sb	As	Bi	Cd	Cr	Co	Cu	Fe	Pb	Mn	Hg	Mo	Ni	Se	Ag	Te	Ti	Sn
Metal industries : Power plants (steam generation)						x													
Foundries - ferrous		x	x	x	x	x	x	x	x	x	x	x	x	x	x		x		x
Foundries - Nonferrous	x	x	x	x	x	x		x		x	x	x			x	x			
Plating	x				x	x		x				x		x		x		x	
Chemical industries : Cement and glass			x			x									x			x	
Organics and petrochemicals	x		x		x	x			x	x		x							x
Inorganic chemicals	x		x		x	x			x	x		x							x
Fertilizers	x		x		x	x		x	x	x				x					
Oil refining	x		x		x	x		x	x	x				x					
Others : Paper						x		x		x		x		x					
Leather						x													
Textile		x				x													
Electronics		x						x				x			x		x		x

Source : Kennish, 1994

Copper : The role of copper is the dynamic interplay of three main compartments. The first is the water matrix. The second compartment of the marine system is the marine organisms, including primary producers, primary consumers, carnivores, filter feeders and detritivores. The sediments represent the third compartment. The water matrix includes all ions, dissolved and particulate organic matter in suspension. Once copper is incorporated into the organisms, it can be released back into the seawater or it can remain as a constituent component of the organisms. When these organisms die and perish, copper again becomes part of the seawater compartment, as particulate organic matter, and either goes back to the organismal component via filter-feeders or enters the sediments. (Sida, 1996)

Lead : Another pollutant of environmental concern is lead. Lead enters the coastal zone mainly through anthropogenic activities. Leaded gasoline is the major source of increased environmental levels on a global scale. Other anthropogenic sources include mining and metallurgical industries, ammunition and trash incineration.

Sources of lead into coastal waters.



Lead in the environment is strongly absorbed by sediments and soil particles and is therefore largely unavailable to plants and animals. Many of the inorganic salts of lead (lead oxides and sulfides) are not readily soluble in water and are sequestered in sediments. In aquatic systems, uptake is influenced by various environmental factors such as temperature, salinity, pH and the presence of organic matter. It is not clear whether animals absorb lead through the skin or take it up via lungs or contaminated food. Lead accumulates in the liver, kidney, spleen and skeleton. Once it has been integrated into the skeleton, it takes several years to leave the body. Lead can also accumulate in eggs and embryos.

Cadmium : Cadmium, another metal of environmental concern, has been used widely since about 1950 in industry. The amounts of cadmium released to the environment are from a variety of diffused sources: fumes, dust and waste waters from lead and zinc mining; iron, steel and non-ferrous metal industries; pigments from plastic industry; rinsing water from electroplating industry; cadmium escaping from corrosion of zinc-galvanised coatings of metals; wear of automobile tyres; coal and heating oils and sewage sludge (Clark, 1997). Cadmium is also used in the batteries and in the electronics industry. It is a contaminant in chemical fertiliser, manure and compost.

Tin : The main sources of tin are placer deposits in or derived from rivers, estuaries and immediate offshore waters. Mining and dredging of tin are large scale operations requiring water, which inevitably causes the dispersal of tin-rich particulate matter in river and estuarine systems and, via them, to the sea. In its metallic form tin has many uses which promote virtually worldwide distribution. The main uses are as tinplate, solders and other alloys, for strenghening glass, as a colour base, in catalysts, as a stabiliser for perfumes and for sundry medical and dental applications. In recent years, synthetic tin compounds have increased to rank fourth among organometals and production of organotins is now perhaps in the region of 50,000 tonnes per year. Organotins are used as non-systemic pesticides, as catalysts, as antioxidants, in antifouling paints, and also to stabilise plastics and synthetic rubbers. Methyltins are considered biodegradable, yet complex synthetic organotins are resistant to environmental bacteria. Chemical attack requires either strongly acidic or alkaline conditions.

The passage of water through domestic plumbing and waste disposal systems greatly increases the level of tin in sewage. Trade waters from canning, dyeprinting, and laundries contain additional traces of tin. Large inputs of tin probably occur in channel and harbour dredgings which possess a high level of organic contamination.

Tributyl tin (TBT) has been used worldwide as an active ingredient in marine antifouling paints since the early 1970s. Its use has been banned in some countries. TBT is however still used in paints for larger ocean-going vessels, and can therefore be detected in the waters of most major harbours and especially in sediments in the vicinity of dockyards. Butyltins from sources other than marine paints can also enter the water column. Dibutyltin is uses as a catalyst in the plastics industry. TBT is used as an algaecide in boiler water cooling circuits. Dibutyltin is the primary degradation product of TBT, but has a comparatively minor impact on the environment. other alkyltins have been used in pesticide formulations, but none have been detected in coastal waters.

Chromium : Dangerous exposure to chromium (VI) happens mostly from breathing workplace air, from welding, chrome plating and handling some chromate chemicals.

The point sources of emissions to air and water are as follows :

- Chemical manufacturing industry e.g. dyes for paints, rubber and plastic products.
- Metal finishing industry e.g. chrome plating.
- Manufacturers of pharmaceuticals, wood, stone, clay and glass products.
- Electrical and aircraft manufacturers, steam and air conditioning supply services.
- Cement producing plants as cement contains chromium.
- Incineration of council refuse and sewage sludge.
- Combustion of oil and coal.

Chromium (VI) compounds are not found in nature. Chromium is usually found as the Cr (III) form, as the mineral Chromite and in many soils. The consumer products which may contain chromium (VI) compounds are :

- Inks, paints and paper.
- Rubber and composite floor coverings.

- Treated (preserved) timber products.
- Some toner powders used in copying machines.

Chromium may be emited to the air from the wearing down of brake lining and motor vehicle exhaust. Crude gas oil contains traces of chromium (III) compounds, these may oxidise to the chromium (VI) state during fuel combustion in vehicle engines).

Zinc : The potential sources of zinc into the environment are mainly commercial / industrial and residential. Batteries and ointments containing zinc are often used in hospitals. The other sources of zinc include floor waxes, wax strippers, stainless steel cleaners, brass polish and lubricants.

Potential sources of zinc

Commercial/ industrial	**Residential**
Hospitals	Auto Fluids
Auto Services	Cleaners
Printing Services	Plumbing

1.7 Heavy metal studies in the marine environment

A large number of heavy metals (e.g. copper, lead, zinc, nickel, chromium, tin, silver, cadmium, mercury, etc.) are highly toxic, are bioaccumulated and biomagnified in tissues of marine organisms (Leppard, 1981; Bryan, 1984; White, 1984; Mance, 1987). They move up the food chain and can represent a real health hazard to humans. The 'Mussel Watch' concept, that is, the utilisation of sentinel organisms for monitoring the concentration of selected pollutants in coastal environments and as an indicator of their bioavailability, is gaining wide acceptance and programmes are being established in many countries (Claisse, 1989).

Marine organisms accumulate stable metals present in higher than ambient concentrations (Waldichuck, 1979; Mance, 1987) and are now used effectively to study movements of metal containing pollutants in effluent receiving waters (Soule & Kleppel, 1988). There is worldwide growing interest in pollution of the marine environment by heavy metals and monitoring studies are being conducted by the use of bio-indicators, namely bivalve molluscs (Burdin, 1979; Hamilton, 1983; Orren et al, 1980; Phillips,1976). Another important practical aspect about heavy metals is the growing interest in aquaculture (Phillips & Tanabe, 1989). Not only is water quality important but the products should also be acceptable for consumption and should not present any hazard to public health. Various mussel species have been found suitable as bioindicators elsewhere and it is important for Mauritius to identify suitable indicator species to investigate and monitor marine and estuarine pollution from heavy metals (Daby, 1990).

CHAPTER TWO

2. USE OF BIOMONITORS FOR HEAVY METAL POLLUTION STUDIES

2.1 Why develop Bioindicators?

Biological indicators are used to measure changes, over time and/or space, in individual species or communities of organisms which may be associated to perturbations in the ecosystem. These indicators are generally designed to measure anthropogenic perturbations.

There is great variation over time in the quality and quantity of contaminants dumped by point sources of impact (e.g. industrial or municipal effluents). The fate of these chemical products in the environment is rather difficult to predict as to where they will end up and accumulate, and what effects they will have on organisms. Laboratory bioassays often provide unrealistic information about the acute and chronic effects of pollution in the ecosystem. Therefore, evaluation of the impacts of certain human activities on aquatic ecosystems becomes very difficult, especially when measuring only the chemical compounds in the water or sediments.

Sessile organisms and benthic invertebrates offer a more effective method for measuring anthropogenic impacts than purely chemical measurements. Such organisms serve as tools for biological measurements of impacts because they reflect the cumulative effects of human perturbations over time. They constitute good biological indicators because they are relatively immobile and easy to sample, and their short generation times make it possible to detect impacts before they affect organisms of higher trophic levels. They also make it possible to estimate the effects of bioaccumulation of contaminants.

2.2 Measures of heavy metals in the marine environment.

Heavy metals in the marine environment are measured at three different levels, namely concentrations in **waters, sediments and biota**. Analytical problems complicate measurement of dissolved metal concentrations. Such concentrations are typically low, often at the limits of analytical detection, and vary greatly over time (e.g with tidal cycle, freshwater run-off, season, etc). However, measurements of dissolved heavy metal concentrations provide an assessment of total metal present, not of that portion which is bioavailable - that is available for uptake and accumulation by marine organisms. It is the bioavailable fraction only that is potentially toxic and of ecotoxicological relevance.

Some of the above mentioned disadvantages are overcome by analysis of sediments. Heavy metals accumulate in sediments (particularly organically rich sediments) and can be measured more easily. However, accumulation by sediments is much affected by sediment characteristics (e.g. particle size, organic carbon content etc). Here again it is not the bioavailable metal that is measured.

Heavy metals are accumulated by marine organisms to high tissue and body concentrations. Generally the metal accumulated is a time-integrated measure of the supply of bioavailable metal (not of total metal). This is of direct ecological relevance. Such organisms are biomonitors or indicators and are used to establish geographical and/or temporal variations of bioavailable heavy metals in coastal and estuarine environments.

2.3 Principal characteristics of heavy metal biomonitors

Individual biomonitors respond differently to different sources of bioavailable metal (e. g. in solution, in sediment or in food). To be able to understand total heavy metal bioavailability in a coastal marine environment, it is necessary to use a suite of biomonitors which will reflect metal bioavailabilities in all available sources. Such studies can be of high academic interest but too demanding in terms of time, effort and money.

Ideally, species to be chosen as biomonitors should fulfil several criteria : (1) they should be sedentary, (2) easy to identify, (3) abundant, (4) long lived, (5) available for sampling throughout the year, (6) large enough to provide sufficient tissue for analysis, (7) resistant to handling stress caused by laboratory and/or field studies, (8) tolerant of exposure to environmental variations, and (9) net accumulators of the metal in question (i.e. a correlation should exist between metal concentration in body tissues and average ambient cocentration). It is thus insensible to think that all marine organisms can fulfil these criteria, nor indeed do all species commonly employed as biomonitors fulfil all the criteria. Most critically, a biomonitor should be a net accumulator of the relevant metal.

2.4 Choice of biomonitors

A key feature in the choice of biomonitors in any suite is a knowledge of their biology, for example method of feeding, extent of production of respiratory currents, life history and breeding season, length of life, age structure of population etc. Knowledge of kinetics of metal accumulation is also primordial, for example, does metal accumulation continue throughout life sequentially adding a new metal to an existing body load or does the body metal content equilibrate at a certain level?

An understanding of such aspects of the biology of biomonitors allows the idendification of the source of metal contamination. Seaweeds not in contact with sediments will take up metals from dissolved sources only, suspension feeders take up metals both directly from seawater and from suspended particles collected during feeding, and deposit feeders will reflect metal loadings of the sediment. It is only valid to compare **absolute accumulated concentrations** between different species, for even closely related species from the same location may have significantly different accumulated concentrations. If comparison of absolute metal bioavailabilies over large distances is required, it is necessary to use biomonitoring species which are cosmopolitan in their geographical distribution.

2.5 Examples of potential cosmopolitan biomonitors

2.5.1 *Seaweeds*

Ulva lactuca : green alga (sea lettuce), *Fucus vesiculosus* : brown alga, *Sargassum* sp. (brown alga), *Enteromorpha* sp. (green filamentous alga).

2.5.2 Bivalve molluscs : Mussels (suspension feeders)

Mytilus species (e.g. *M. edulis, M. palloprovencialis, M. trossulus*); *Perna* species (e.g. *P. viridis, P. perna, P. canaliculus*); *Septifer virgatus; Trichomya hirsuta.*

2.5.3 Bivalve Molluscs : Oysters (suspension feeders)

Crassostrea species (e.g. *C. gigas, C. virginica, C. margaritacea, C. brasiliana, C. angulata*); *Saccostrea* species (e.g. *S. cucullata, S. glomerata, S. commercialis*); *Ostrea edulis.*

2.5.4 Other Bivalve Molluscs : Surface deposit feeders

Scrobicularia plana, Macoma balthica.

2.5.5 Polychaete worms

Nereis diversicolor, and members of the family Nephtyidae

2.5.6 Barnacles

Balanus amphitrite, Balanus uligonosus; Tetraclita squamosa.

2.6 Some examples of measurements of heavy metals in the marine environment

2.6.1 SEAWATER

COUNTRY	INVESTIGATOR	SEAWATER					
		CADMIUM	COPPER	CHROMIUM	LEAD	TIN	ZINC
Northwest Portugal Matosinhos	Fernanda et al. (1997)	1.1 µg/l	1.8 µg/l		1.7 µg/l		
Madalena		1.1 µg/l	2.0 µg/l		2.4 µg/l		
Cortegaça		1.6 µg/l	1.5 µg/l		3.8 µg/l		
Malaysian Coast Mersing	Ismail et al. (1995)	0.93 µg/l	0.07 µg/l				
Kuala terengganu		0.05 µg/l	0.06 µg/l				
Melaka		0.06 µg/l	0.08 µg/l				
Tanjung keling		0.06µg/l	0.07 µg/l				
Kuala Sepetang		0.05 µg/l	0.05 µg/l				
USA Gulf of Maine	Larsen et al. (1997)					< 1 - 11 ng/l	
Atlantic Ocean	Smith and Burton (1972)					10 ng/l	
California	Hodge et al (1979)					38 ng/l	
San Diego Bay	Hodge et al (1979)					6 - 18 ng/l	

2.6.2 SEDIMENT

COUNTRY	INVESTIGATOR	SEDIMENT					
		CADMIUM	COPPER	CHROMIUM	LEAD	TIN	ZINC
Hong Kong Tolo Harbour	Chu et al. (1990) *(<2 mm fraction)*	2-7 µg/g dw	2-7 µg/g dw				10 - 180 µg/g dw
Hong Kong	Bradley *et al.* (1995)					250 - 3200 ng/g dw	
Bidasoa Estuary	Salinas et al. (1996) *(<100 µm fraction)*	1.1 µg/g dw	100 µg/g dw	56 1 µg/g dw	150 µg/g dw		410 µg/g dw
Malaysian Coast Mersing	Ismail et al. (1995)	0.38 µg/g dw	7.61 µg/g dw				
Kuala terengganu		0.28 µg/g dw	1.79 µg/g dw				
Melaka		0.54 µg/g dw	8.17 µg/g dw				
Tanjung keling		0.27 µg/g dw	3.81 µg/g dw				
Kuala Sepetang		0.35 µg/g dw	4.91 µg/g dw				
Greece	Nicolaidou & Nott (1998)	0.1 mg/g dw	13.2 mg/g dw	677.6 mg/g dw			152.5 mg/g dw

2.6.3 *SEAWEEDS AND SEAGRASSES*

COUNTRY	INVESTIGATOR	SOURCE/ MEDIUM	CADMIUM	COPPER	CHROMIUM	LEAD	TIN	ZINC
Northwest Portugal Matosinhos	Fernanda et al. (1997)	**Algae:** *Porphyra*. sp *Enteromorpha*.sp	 0.56 µg/g dw 0.90 µg/g dw	 9.0 µg/g dw 12.0 µg/g dw		 2.0 µg/g dw 4.7 µg/g dw		
Madalena		**Algae:** *Porphyra*. sp *Enteromorpha*.sp	 0.73 µg/g dw 0.88 µg/g dw	 11.0 µg/g dw 13.0 µg/g dw		 2.0 µg/g dw 4.1 µg/g dw		
Cortegaça		**Algae:** *Porphyra*. sp *Enteromorpha*.sp	 1.1 µg/g dw 0.99 µg/g dw	 7.7 µg/g dw 7.2µg/g dw		 2.8 µg/g dw 4.1 µg/g dw		
Greece	Nicolaidou & Nott (1998)	**Seagrasses:** leaves of *C. nodusata* roots of *C. nodusata* stems of *C. nodusata*	 2.3 mg/g dw 2.6 mg/g dw 0.4 mg/g dw	 23.5 mg/g dw 22.4 mg/g dw 8.9 mg/g dw	 4.8 mg/g dw 10.5 mg/g dw 9.1 mg/g dw			 147 mg/g dw 62.4 mg/g dw 7.1 mg/g dw

2.6.4 *EXAMPLES OF MARINE INVERTEBRATES*

COUNTRY	INVESTIGATOR	SOURCE/ MEDIUM	CADMIUM	COPPER	CHROMIUM	LEAD	TIN	ZINC
Hong Kong Tolo Harbour	Chu et al. (1990)	**Bivalves:** soft tissue of *Perna viridis*	0.6-8.9 µg/g dw	9.4 -35.1 µg/g dw				63 - 150
		soft tissue of *Saccostrea cucullata*	3.2-9.8 µg/g dw	149-556 µg/g dw				2082 - 3275
Delaware Bay	Burger.J (1996)	**Horseshoe Crab:** Eggs of *Limulus polyphemus*	1993 1994 1995 17 310 24 µg/g ww		1993 1994 1995 5059 699 250 µg/g ww	1993 1994 1995 558 206 87 µg/g ww		
		muscle of *Limulus polyphemus*	13 µg/g ww		131 µg/g ww	21 µg/g ww		
Bidasoa Estuary	Salinas et al. (1996)	**Clams:** *Scrobicularia plana*	0.9 µg/g dw	67 µg/g dw	3.6 µg/g dw		42 µg/g dw	1090
Bidasoa Estuary	Salinas et al. (1996)	**Worms :** *Nereis Diversicolor*	0.1 µg/g dw	21 µg/g dw	0.4 µg/g dw		2.0 µg/g dw	172
Hong Kong	Bradley *et al.* (1995)	**Clams:** (Market Purchased)					670 ng/g dw	
Western Baltic Kiel Bay	Swaleh & Adelung (1995)	**Crustacea:** *Diastylis rathkei*				7.4 µg/g dw		77.4
Malaysian Coast	Ismail et al. (1995)	**Prawn:** *Panaeus monodon*	0.09-0.8 µg/g ww	0.8-24 µg/g ww				
China Third Institute of Oceanography	Huang et al. (1998)	**Barnacles:** *Tetraclita squamosa*	5.07 µg/g dw	12.97 µg/g dw				2243.8
		Balanus amphitrite	0.87 µg/g dw	28.97µg/g dw				0.87
Hu Li Fort		**Barnacles:** *Tetraclita squamosa* *Balanus amphitrite*	4.43 µg/g dw 1.91 µg/g dw	12.36 µg/g dw 39.81 µg/g dw				2630.2 1.91

2.6.5 *GASTROPODS (Snails)*

COUNTRY	INVESTIGATOR	SOURCE/ MEDIUM	CADMIUM	COPPER	CHROMIUM	LEAD	TIN	ZINC
Greece	Nicolaidou & Nott (1998)	Gastropods: viscera of *C. vulgatum* muscle of *C. vulgatum* viscera of *M. mutabilis* muscle of *M. mutabilis*	8 mg/g dw 8.4 mg/g dw 3 mg/g dw 3.6 mg/g dw	110.3 mg/g dw 16.9 mg/g dw 222.8 mg/g dw 43.2 mg/g dw	40.5 mg/g dw 36.3 mg/g dw 9 mg/g dw			3838 mg/g dw 58 mg/g dw 88.6 mg/g dw 109 mg/g dw
Ireland	Minchia *et al.* (1997)	**Gastropods:** Eggs and juveniles of *Nucella lapillus*					61.3-713.7 g/kg dw	
		Eggs and juveniles of *Littorina littores*					19.4-203 g/kg dw	
		Shells of *Littorina littorea*					94.4-502.3 g/kg dw	
Japan	Horiguchi (1993)	**Gastropods:** *Thais clavigera*					/g dw	

2.6.6 FISH

COUNTRY	INVESTIGATOR	SOURCE/MEDIUM	CADMIUM	COPPER	LEAD	ZINC
The Philippines Manila Bay	Prudente et al. (1997)	**Demersal fish:**				
		Slipmouth *L. brevirostris*	7.5 ng/g dw	2140 ng/g dw	59.8 ng/g dw	46.7 ng/g dw
		Ponyfish *L. bondus*	21.5 ng/g dw	3460 ng/g dw	170 ng/g dw	124 ng/g dw
		Goatfish *U.moluccensis*	15 ng/g dw	2120 ng/g dw	95.1 ng/g dw	66.1 ng/g dw
		Grunt *T. jarbua*	22.9 ng/g dw	1110 ng/g dw	37.5 ng/g dw	80.4 ng/g dw
		Pomfret *A. miger*	49.1 ng/g dw	2260 ng/g dw	178 ng/g dw	75.5 ng/g dw
		Mullet *V. siheli*	10 ng/g dw	2840 ng/g dw	301 ng/g dw	62.9 ng/g dw
		Whiting *S. sihama*	6.89 ng/g dw	1680 ng/g dw	106 ng/g dw	108 ng/g dw
		Snapper *L. russeli*	6.09 ng/g dw	1190 ng/g dw	100 ng/g dw	43.9 ng/g dw
		Siganid *Siganidae*	71 ng/g dw	2480 ng/g dw	134 ng/g dw	42.3 ng/g dw
The Philippines Manila Bay	Prudente et al. (1997)	**Pelagic fish:**				
		Scad *D. macrosoma*	67.4 ng/g dw	5450 ng/g dw	58.9 ng/g dw	72.3 ng/g dw
		Sardine *S. leiogaster*	13 ng/g dw	3740 ng/g dw	271 ng/g dw	94.2 ng/g dw
		Crevalle *S. leptolepis*	26.9 ng/g dw	3400 ng/g dw	296 ng/g dw	68.9 ng/g dw
		Sardine sp. *S. punctatus*	12 ng/g dw	4070 ng/g dw	240 ng/g dw	113 ng/g dw
		Hairtail *T. lepterus*	14.9 ng/g dw	2340 ng/g dw	57.4 ng/g dw	39.0 ng/g dw
		Perch *A. testudinaus*	16.4 ng/g dw	1990 ng/g dw	81.3 ng/g dw	59.7 ng/g dw
		Mackerel *S. commerson*	9.5 ng/g dw	2750 ng/g dw	130 ng/g dw	69.5 ng/g dw
		Leather jacket *Scomberoides sp.*	2.45 ng/g dw	1880 ng/g dw	75.2 ng/g dw	55.1 ng/g dw
Western Baltic Kiel Bay	Helcom (1990)	**Liver of demersal fish:**				
		Gadus morhua (Cod)			0.17 µg/g dw	90 µg/g dw
		Platichthys flesus (Flounder)			0.17 µg/g dw	170 µg/g dw
		Limanda limanda (Dab)			2.3 µg/g dw	70 µg/g dw

2.7 Some documented levels of the heavy metals under study

2.7.1 Chromium

COUNTRY	INVESTIGATOR	SOURCE/MEDIUM	CONCENTRATIONS OF CHROMIUM RECORDED
Delaware Bay	Burger.J (1996)	**Horseshoe Crab:** Eggs of *Limulus polyphemus* Muscle of *Limulus polyphemus*	1993 1994 1995 5059 699 250 µg/g ww 131 µg/g ww
Bidasoa Estuary	Salinas *et al.* (1996)	**Clams:** *Scrobicularia plana*	3.6 µg/g dw
		Worms: *Nereis diversicolor*	0.4 µg/g dw
		Sediment (<100 µm fraction)	56 µg/g dw
Greece	Nicolaidou & Nott (1998)	**Seagrasses:** leaves of *C. nodusata* roots of *C. nodusata* stems of *C. nodusata*	4.8 mg/g dw 10.5 mg/g dw 9.1 mg/g dw
		Gastropods: viscera of *C. vulgatum* muscle of *C. vulgatum* viscera of *M. mutabilis*	40.5 mg/g dw 36.3 mg/g dw 9 mg/g dw
		Sediment	677.6 mg/g dw

2.7.2 Tin

COUNTRY	INVESTIGATOR	SOURCE/MEDIUM	CONCENTRATIONS OF TIN RECORDED
Ireland	Minchia *et al.* (1997)	**Gastropods:** Eggs and juveniles of *Nucella lapillus* Eggs and juveniles of *Littorina littores* Shells of *Littorina littorea*	61.3-713.7 g/kg dw 19.4-203 g/kg dw 94.4-502.3 g/kg dw
Japan	Horiguchi (1993)	**Gastropods:** *Thais clavigera*	20 ng/g dw
USA • Gulf of Maine	Larsen *et al.* (1997)	**Seawater**	< 1-11 ng/g dw
Hong Kong	Bradley *et al.* (1995)	**Clams:** (Market purchased)	670 ng/g dw
		Sediment	250-3200 ng/g dw

2.7.3 Lead

COUNTRY	INVESTIGATOR	SOURCE/MEDIUM	CONCENTRATIONS OF LEAD RECORDED
Delaware Bay	Burger.J (1996)	**Horseshoe Crab:** Eggs of *Limulus polyphemus* Muscle of *Limulus polyphemus*	1993 1994 1995 558 206 87 µg/g ww 21 µg/g ww
Northwest Portugal • Matosinhos	Fernanda *et al.* (1997)	**Algae:** *Porphyra.* spp *Enteromorpha.*spp	2.0 µg/g dw 4.7 µg/g dw
		Seawater	1.7 µg/l
• Madalena		**Algae:** *Porphyra.* spp *Enteromorpha.*spp	2.0 µg/g dw 4.1 µg/g dw
		Seawater	2.4 µg/l
• Cortegaça		**Algae:** *Porphyra.* spp *Enteromorpha.* spp	2.8 µg/g dw 4.1 µg/g dw
		Seawater	3.8 µg/l
Western Baltic • Kiel Bay	Swaleh & Adelung (1995)	**Crustacea:** *Diastylis rathkei*	7.4 µg/g dw
	Helcom (1990)	**Liver of demersal fish:** *Gadus morhua* (Cod) *Platichthys flesus* (Flounder) *Limanda limanda* (Dab)	0.17 µg/g dw 0.17 µg/g dw 2.3 µg/g dw
Bidasoa Estuary	Salinas *et al.* (1996)	**Clams:** *Scrobicularia plana*	42 µg/g dw
		Worms: *Nereis diversicolor*	2.0 µg/g dw
		Sediment (<100 µm fraction)	150 µg/g dw
The Philippines • Manila Bay	Prudente *et al.* (1997)	**Demersal fish:** Slipmouth *L. brevirostris* Ponyfish *L. bondus* Goatfish *U.moluccensis* Grunt *T. jarbua* Pomfret *A. miger* Mullet *V. siheli* Whiting *S. sihama* Snapper *L. russeli* Siganid *Siganidae* **Pelagic fish:** Scad *D. macrosoma* Sardine *S. leiogaster* Crevalle *S. leptolepis* Sardine sp. *S. punctatus* Hairtail *T. lepterus* Perch *A. testudinaus* Mackerel *S. commerson* Leather jacket *Scomberoides sp.*	59.8 ng/g dw 170 ng/g dw 95.1 ng/g dw 37.5 ng/g dw 178 ng/g dw 301 ng/g dw 106 ng/g dw 100 ng/g dw 134 ng/g dw 58.9 ng/g dw 271 ng/g dw 296 ng/g dw 240 ng/g dw 57.4 ng/g dw 81.3 ng/g dw 130 ng/g dw 75.2 ng/g dw

2.7.4 Cadmium

COUNTRY	INVESTIGATOR	SOURCE/MEDIUM	CONCENTRATIONS OF CADMIUM RECORDED
Hong Kong • Tolo Harbour	Chu et al. (1990)	**Bivalves:** soft tissue of *Perna viridis* soft tissue of *Saccostrea cucullata*	 0.6-8.9 µg/g dw 3.2-9.8 µg/g dw
		Sediment (<2 mm fraction)	2-7 µg/g dw
Delaware Bay	Burger.J (1996)	**Horseshoe Crab:** Eggs of *Limulus polyphemus* muscle of *Limulus polyphemus*	1993 1994 1995 17 310 24 µg/g ww 13 µg/g ww
Northwest Portugal • Matosinhos	Fernanda et al. (1997)	**Algae:** *Porphyra*. spp *Enteromorpha*.spp	 0.56 µg/g dw 0.90 µg/g dw
		Seawater	1.1 µg/l
• Madalena		**Algae:** *Porphyra*. spp *Enteromorpha*.spp	 0.73 µg/g dw 0.88 µg/g dw
		Seawater	1.1 µg/l
• Cortegaça		**Algae:** *Porphyra*. spp *Enteromorpha*.spp	 1.1 µg/g dw 0.99 µg/g dw
		Seawater	1.6 µg/l
Bidasoa Estuary	Salinas et al. (1996)	**Clams:** *Scrobicularia plana*	0.9 µg/g dw
		Worms: *Nereis diversicolor*	0.1 µg/g dw
		Sediment (<100 µm fraction)	1.1 µg/g dw
The Philippines • Manila Bay	Prudente et al. (1997)	**Demersal fish:** Slipmouth *L. brevirostris* Ponyfish *L. bondus* Goatfish *U.moluccensis* Grunt *T. jarbua* Pomfret *A. miger* Mullet *V. siheli* Whiting *S. sihama* Snapper *L. russeli* Siganid *Siganidae*	 7.5 ng/g dw 21.5 ng/g dw 15 ng/g dw 22.9 ng/g dw 49.1 ng/g dw 10 ng/g dw 6.89 ng/g dw 6.09 ng/g dw 71 ng/g dw

2.7.4 Cadmium

COUNTRY	INVESTIGATOR	SOURCE/MEDIUM	CONCENTRATIONS OF CADMIUM RECORDED
The Philippines • Manila Bay	Prudente et al. (1997)	**Pelagic fish:** Scad *D. macrosoma* Sardine *S. leiogaster* Crevalle *S. leptolepis* Sardine sp. *S. punctatus* Hairtail *T. lepterus* Perch *A. testudinaus* Mackerel *S. commerson* Leather jacket *Scomberoides sp.*	 67.4 ng/g dw 13 ng/g dw 26.9 ng/g dw 12 ng/g dw 14.9 ng/g dw 16.4 ng/g dw 9.5 ng/g dw 2.45 ng/g dw
Malaysian Coast	Ismail et al. (1995)	**Prawn:** *Panaeus monodon*	 0.09-0.8 µg/g ww
• Mersing		**Seawater**	0.93 µg/l
		Sediment	0.38 µg/g dw
• Kuala terengganu		**Seawater**	0.05 µg/l
		Sediment	0.28 µg/g dw
• Melaka		**Seawater**	0.06 µg/l
		Sediment	0.54 µg/g dw
• Tanjung keling		**Seawater**	0.06µg/l
		Sediment	0.27 µg/g dw
• Kuala Sepetang		**Seawater**	0.05 µg/l
		Sediment	0.35 µg/g dw
China • Third Institute of Oceanography	Huang et al. (1998)	**Barnacles:** *Tetraclita squamosa* *Balanus amphitrite*	 5.07 µg/g dw 0.87 µg/g dw
• Hu Li Fort		**Barnacles:** *Tetraclita squamosa* *Balanus amphitrite*	 4.43 µg/g dw 1.91 µg/g dw
Greece	Nicolaidou & Nott (1998)	**Seagrasses:** leaves of *C. nodusata* roots of *C. nodusata* stems of *C. nodusata*	 2.3 mg/g dw 2.6 mg/g dw 0.4 mg/g dw
		Gastropods: viscera of *C. vulgatum* muscle of *C. vulgatum* viscera of *M. mutabilis* muscle of *M. mutabilis*	 8 mg/g dw 8.4 mg/g dw 3 mg/g dw 3.6 mg/g dw
		Sediment	0.1 mg/g dw

2.7.5 Copper

COUNTRY	INVESTIGATOR	SOURCE/MEDIUM	CONCENTRATIONS OF COPPER RECORDED
Hong Kong • Tolo Harbour	Chu *et al.* (1990)	**Bivalve:** soft tissue of *Perna viridis* soft tissue of *Saccostrea cucullata*	 9.4 -35.1 µg/g dw 149-556 µg/g dw
		Sediment (<2 mm fraction)	2-7 µg/g dw
Northwest Portugal • Matosinhos	Fernanda *et al.* (1997)	**Algae:** *Porphyra.* spp *Enteromorpha.*spp	 9.0 µg/g dw 12.0 µg/g dw
		Seawater	1.8 µg/l
• Madalena		**Algae:** *Porphyra.* spp *Enteromorpha.*spp	 11.0 µg/g dw 13.0 µg/g dw
		Seawater	2.0 µg/l
• Cortegaça		**Algae:** *Porphyra.* spp *Enteromorpha.*spp	 7.7 µg/g dw 7.2µg/g dw
		Seawater	1.5 µg/l
Malaysian Coast	Ismail *et al.* (1995)	**Prawn:** *Panaeus monodon*	 0.8-24 µg/g ww
• Mersing		**Seawater**	0.07 µg/l
		Sediment	7.61 µg/g dw
• Kuala Terengganu		**Seawater**	0.06 µg/l
		Sediment	1.79 µg/g dw
• Melaka		**Seawater**	0.08µg/l
		Sediment	8.17 µg/g dw
• Tanjung Keling		**Seawater**	0.07µg/l
		Sediment	3.81 µg/g dw
• Kuala Sepetang		**Seawater**	0.05µg/l
		Sediment	4.91 µg/g dw
Bidasoa Estuary	Salinas *et al.* (1996)	**Clams:** *Scrobicularia plana*	 67 µg/g dw
		Worms: *Nereis diversicolor*	 21 µg/g dw

2.7.5 *Copper*

COUNTRY	INVESTIGATOR	SOURCE/MEDIUM	CONCENTRATIONS OF COPPER RECORDED
The Philippines • Manila Bay	Prudente *et al.* (1997)	**Demersal fish:** Slipmouth *L. brevirostris* Ponyfish *L. bondus* Goatfish *U.moluccensis* Grunt *T. jarbua* Pomfret *A. miger* Mullet *V. siheli* Whiting *S. sihama* Snapper *L. russeli* Siganid *Siganidae* **Pelagic fish:** Scad *D. macrosoma* Sardine *S. leiogaster* Crevalle *S. leptolepis* Sardine sp. *S. punctatus* Hairtail *T. lepterus* Perch *A. testudinaus* Mackerel *S. commerson* Leather jacket *Scomberoides sp.*	 2140 ng/g dw 3460 ng/g dw 2120 ng/g dw 1110 ng/g dw 2260 ng/g dw 2840 ng/g dw 1680 ng/g dw 1190 ng/g dw 2480 ng/g dw 5450 ng/g dw 3740 ng/g dw 3400 ng/g dw 4070 ng/g dw 2340 ng/g dw 1990 ng/g dw 2750 ng/g dw 1880 ng/g dw
China • Third Institute of Oceanography	Huang *et al.* (1998)	**Barnacles:** *Tetraclita squamosa* *Balanus amphitrite*	 12.97 µg/g dw 28.97µg/g dw
• Hu Li Fort		**Barnacles:** *Tetraclita squamosa* *Balanus amphitrite*	 12.36 µg/g dw 39.81 µg/g dw
Greece	Nicolaidou & Nott (1998)	**Seagrasses:** leaves of *C. nodusata* roots of *C. nodusata* stems of *C. nodusata*	 23.5 mg/g dw 22.4 mg/g dw 8.9 mg/g dw
		Gastropods: viscera of *C. vulgatum* muscle of *C. vulgatum* viscera of *M. mutabilis* muscle of *M. mutabilis*	 110.3 mg/g dw 16.9 mg/g dw 222.8 mg/g dw 43.2 mg/g dw
		Sediment	13.2 mg/g dw

2.7.6 *Zinc*

COUNTRY	INVESTIGATOR	SOURCE/MEDIUM	CONCENTRATIONS OF ZINC RECORDED
Hong Kong • Tolo Harbour	Chu *et al.* (1990)	**Bivalves:** soft tissue of *Perna viridis* soft tissue of *Saccostrea cucullata*	 63-150 µg/g dw 2082-3275 µg/g dw
		Sediment (<2 mm fraction)	10-180 µg/g dw
Western Baltic • Kiel Bay	Swaleh & Adelung (1995)	**Crustacea:** *Diastylis rathkei*	 77.4 µg/g dw
	Helcom (1990)	**Liver of demersal fish:** *Gadus morhua* (Cod) *Platichthys flesus* (Flounder) *Limanda limanda* (Dab)	 90 µg/g dw 170 µg/g dw 70 µg/g dw
Bidasoa Estuary	Salinas *et al.* (1996)	**Clams:** *Scrobicularia plana*	 1090 µg/g dw
		Worms: *Nereis diversicolor*	 172 µg/g dw
		Sediment (<100 µm fraction)	410 µg/g dw
The Philippines • Manila Bay	Prudente *et al.* (1997)	**Demersal fish:** Slipmouth *L. brevirostris* Ponyfish *L. bondus* Goatfish *U.moluccensis* Grunt *T. jarbua* Pomfret *A. miger* Mullet *V. siheli* Whiting *S. sihama* Snapper *L. russeli* Siganid *Siganidae* **Pelagic fish:** Scad *D. macrosoma* Sardine *S. leiogaster* Crevalle *S. leptolepis* Sardine sp. *S. punctatus* Hairtail *T. lepterus* Perch *A. testudinaus* Mackerel *S. commerson* Leather jacket *Scomberoides sp.*	 46.7 ng/g dw 124 ng/g dw 66.1 ng/g dw 80.4 ng/g dw 75.5 ng/g dw 62.9 ng/g dw 108 ng/g dw 43.9 ng/g dw 42.3 ng/g dw 72.3 ng/g dw 94.2 ng/g dw 68.9 ng/g dw 113 ng/g dw 39.0 ng/g dw 59.7 ng/g dw 69.5 ng/g dw 55.1 ng/g dw
Greece	Nicolaidou & Nott (1998)	**Seagrasses:** leaves of *C. nodusata* roots of *C. nodusata* stems of *C. nodusata*	 147 mg/g dw 62.4 mg/g dw 87.1 mg/g dw
		Gastropods: viscera of *C. vulgatum* muscle of *C. vulgatum* viscera of *M. mutabilis* muscle of *M. mutabilis*	 3838 mg/g dw 58 mg/g dw 88.6 mg/g dw 109 mg/g dw
		Sediment	152.5 mg/g dw
China • Third Institute of Oceanography	Huang *et al.* (1998)	**Barnacles:** *Tetraclita. Squamosa* *Balanus amphitrite*	 2243.8 µg/g dw 0.87 µg/g dw
• Hu Li Fort	Huang *et al.* (1998)	Barnacles: *Tetraclita squamosa* *Balanus amphitrite*	 2630.2 µg/g dw 1.91 µg/g dw

CHAPTER THREE

3. THE PROBLEM OF COASTAL POLLUTION BY INDUSTRIAL EFFLUENTS IN MAURITIUS

3.1 Background

During the 1980's the Mauritian economy underwent major structural changes successfully with a rapid phase of industrialisation and an increase in human related activities in the coastal zone. This has lead to the production of large volumes of waste products and waste water requiring major disposal facilities. Currently most of the waste water is disposed of untreated into coastal environments creating various types of conflicts resulting from the degradation of water quality. Increasing urbanization is leading to significant pollution of the lagoon. Untreated sewage is deposited in the vicinity of coral reefs and domestic sewage percolates into lagoons through the permeable substratum. Sanitary problems related to coastal recreation exist, especially in Port Louis and adjacent coastal areas.

There is no proper management of municipal, commercial and industrial wastes in Mauritius. There are also no designated areas for the disposal of hazardous wastes which do find their way to the coastal area. Such waste dumping is not only unsightly but also present a public health hazard. Lagoonal, reef and estuarine ecosystems are seriously threatened by pollution from industrial effluents (Rathnam et al, 1989). Pollution in estuaries from industrial zones and around outfalls adjacent to urbanised areas may be severe. Industries discharge substantial amounts of dyestuff, heavy metals and complex organic compounds into the waste water systems, streams and rivers. The majority of the pollutants accumulate in estuarine and lagoon sediments.

No systematic studies on water pollution sources, the pollutants involved and their impacts on the coastal marine environment have been undertaken. There are no known comprehensive reports on the waste water characteristics of industries in Mauritius. Scientifically produced data on which to base an adequate assessment of coastal water quality is critically lacking. No baseline data of pollutants in the marine environment and no monitoring data in areas where pollution is evident or expected, are available. Such data are needed to assess the impacts of the marine environment and to develop appropriate management provisions.

3.2 Industrial effluent quality and discharge

Concluding on coastal and surface water quality in Mauritius, Severn Trent International (STI) (1993) reported that (a) industrial waste waters (namely textile effluents) pose a particularly serious threat to the environment and to public health, (b) the major areas of concern are pollution of the lagoons and underground waters by human excreta, industrial effluent and agricultural chemical run-off, and (c) surface waters are also polluted by inorganic nutrients, namely nitrate and phosphate from agriculture, domestic and industrial sources, with serious implications for corals which are often overgrown by macro-algae in the lagoons.

BVI (1997) identified the "principal categories of industry in the main Export Processing Zone (EPZ) area which include textile manufacture and processing, food processing (canning, distilling, bottling) , various chemical activities (soap and detergents), laundries and light engineering. There are 64 different industries in the Coromandel industrial estate, 17 in Pailles, and 97 in Plaine Lauzun/Belle Village. The characteristics of the waste waters originating in the area are highly variable. For example, waste waters from textile dye houses have completely different characteristics compared to those from food processing plants and so on. The textile related industries produce approximately 90% of the total industrial waste water in the Pointe aux sables area, and over 50% of the total in the Fort Victoria area. In terms of water quality the textile industry waste waters are characterised by high colour and high pH from the dye houses, and high total suspended solids from the processing plants".

The principal freshwater systems of direct influence in this area include the GRNW and several streams and revulets, namely Ruisseau St. Louis, Ruisseau des Creoles, Ruisseau Latanier and Le Pouce Stream. Direct discharges of untreated effluent and overflows from sewer networks into these systems occur frequently (Magoarou & Sam-Soon, 1997) and eventually reach the sea. The area is and will most probably continue to be influenced by effluent inputs from north of Port-Louis (river, revulets, future Tombeau Bay outfall). The river flows have unknown pollution loads but are probably very high and possibly as much as the sewers at present.

Continuous monitoring of industrial effluents is not undertaken and the industries have only limited in-house treatment. Also, most industries do not report the chemical characteristics of their waste waters. This means that comprehensive reports on the waste water characteristics of specific industries in Mauritius are not available. However, some results of analysis on effluent from the existing Fort Victoria and Pointe aux Sables works reported by Magoarou & Sam-Soon (1997) and reproduced in BVI Report (1997) are shown in Table 3.1 to provide an indication of the wide range of values of the different parameters that were recorded on daily composite samples collected during a period of one week in November 1994.

The Government of Mauritius has not yet adopted effluent water quality standards for lagoon and ocean disposal and for irrigation water. For selection of the treatment processes for the proposed Montagne Jacquot works, BVI (1997) used the effluent quality standards presented by Gibb (1994), which are reproduced here in Table 3.2 for a brief comparison with the results given in Table 3.1. The most important standards used in regular monitoring of waste water are COD (chemical oxygen demand), BOD_5 (5 day biological oxygen demand) and TSS. Using the criteria of Gibb (1994), it is obvious that the concentrations of these parameters as well as of others found in the waste waters at Fort Victoria and Pointe aux Sables treatment works were far in excess of the limits cited and were unsuitable for either irrigation or discharge into the lagoon and open sea without prior treatment.

The BVI Report (1997) also provided an appended list (Appendix I, page xxxiii) showing some results of analysis of waste waters from a range of industries in Mauritius. The obvious conclusions drawn from these results were : (a) many of the industrial wastes had high levels of BOD, COD, N, P and grease (b) the wastes did not show any or appreciable levels of heavy metals/other toxic substances which would be of major environmental concern for the receiving water bodies (freshwater and marine). Whilst conclusion (a) is supported well by the data presented in Table 2.1 below and in Appendix I of BVI Report (1997), the validity of conclusion (b) can be questioned. This statement is of particular significance because evidently heavy metals do occur in industrial and domestic effluents as indicated in Tables 1.3 and 1.4, as well as in SOGETI Report (1995) which is highlighted below.

Table 3.1 : Waste water characteristics measured at Fort Victoria and Pointe aux Sables treatment works (Source : Black & Veatch, 1997)

Parameters	Fort Victoria	Pointe aux Sables
Conductivity (µS/cm)	1195 - 5950	3390 - 4540
PH	7.0 - 7.4	7.1 - 8.9
COD (mg/l)	396 - 692	197 - 964
BOD_5 (mg/l)	124 - 485	104 - 741
TKN (mg/l)	31.5 - 63	27.3 - 101.6
NH_4-N (mg/l)	3.6 - 37.3	9.8 - 84.7
Sodium (mg/l)	150 - 280	400 - 1590
Sulphate (mg/l)	0 - 19	0 - 722
Phosphorus (mg P/l)	5.5 - 10.2	7.3 - 49.5
TSS (mg/l)	38 - 800	367 - 790
Oil & Grease (mg/l)	0 - 22	6.3 - 46

Table 3.2 : Effluent quality standards presented by Gibb (1994 Master Plan Summary).

Parameter	Irrigation	Lagoon	Ocean
Temperature (°C)	30	30	50
PH	5 - 9	5 - 9	5 - 9
Colour (platinum- cobalt scale)	-	20	-
COD (mg/l)	90	60	750
BOD (mg/l)	30	-	250
TSS (mg/l)	45	15	100
Chloride (mg/l)	250	-	-
Sulphate (mg/l)	500	-	-
Nitrate-N (mg/l)	-	5	-
Ammonia-N (mg/l)	-	5	-
TDS (mg/l)	1000	-	-
Cadmium (µg/l)	20	20	20
Chromate-Cr (µg/l)	50	50	100
Copper (µg/l)	500	1000	-
Lead (µg/l)	200	2000	-
Mercury (µg/l)	20	20	20
Nickel (µg/l)	200	500	10000
Zinc (µg/l)	1000	5000	-
Oil (mg/l)	None	None	None
Detergents (mg/l)	5	5	-
Pesticides :			
Carbonate (µg/l)	100	100	-
Chlorinated (µg/l)	10	10	-
Phosphorus (µg/l)	100	100	-
Faecal coliform (x/100ml)	?	?	?

(Source : Black & Veatch, 1997)

Table 3.3 : Heavy metal concentration in the lagoon-reef sediments of Pointe aux Sables & Pointe aux Caves (SOGETI, 1995).

Transect (TR.2 - TR.5)	Outfall Distance (m)	Shore Distance (m)	Copper (µg/g)	Zinc (µg/g)	Nickel (µg/g)	Lead (µg/g)	Chromium (µg/g)	Manganese (µg/g)
TR.2	1440	409	23	699	7.4	47.8	30.4	87
	1476	274	22.3	369	10.7	26.7		73
	1515	178	23.3	325	6.7	25.8		77
	1558	142	19.8	272	4.3	22.4		
TR.3	818	544	24.8	736	10.5	25.8	26.7	89
	829	498	22.5	266	7.2	23.4		79
	925	398						
	999	281	23.5	230	2	26.5		75
	1109	117	26.5	350	18	34		86
	1109	117	32.8	540	3.2	30.7		73
TR.4	284	601	34.7	406	4.2	16.9	34.7	114
	427	459	22.9	606	7.3	34.9		101
	605	274	21	253	8.7	18.4		96
	693	171	23.5	275	23.5	25.3		100
	782	89	22.1	225	11.9	22.1		95
TR.5	398	629	23.5	404	9.4	29.1	28.2	116
	619	409	27.7	125	8.7	29.4		112
	619	409	29.4	127	8.2	29.4		120
	789	196	31.2	289	12.9	30.3		117
	843	114	34.8	438	14.3	36.6		136
Pointe Aux Caves	30 m depth		47.7	134	52	38.2	84	329
	15 m depth		23.7	118	14.3	22.2	45.4	158

3.3 Contamination of coastal waters by Heavy metals

Data on contamination of the coastal waters by heavy metals in Mauritius are seriously lacking. However, the study by SOGETI (1995) generated some data on the content of some heavy metals (copper, zinc, nickel, lead, chromium and manganese) using Flame Atomic Absorption Spectrophotometer (AAS) in sediment samples from various parts of Pointe aux Sables lagoon (stations along transects TR.2 to TR.5 shown in Figure 2.1) and two locations at Pointe aux Caves. These data do provide an idea of the nature of contamination occurring due to certain heavy metals in the vicinity of the Port Louis and lower Plaine Wilhems EPZ region. They are summarised in Table 3.3. These data indicate that there was much spatial variation in concentration of the metals at both Pointe aux Sables and Pointe aux Caves. Effluent discharge from the existing sewage outfall and inputs via the GRNW would be the principal sources of sediment contamination in Pointe aux Sables lagoon and reef and possibly at Pointe aux Caves as well due to the contaminants being carried down by the southward flowing oceanic current.

Higher levels of **copper** (>25 to 34.8 μg/g) were recorded in a triangular area from the external slope at TR.4 towards the north across TR.5 corresponding to the flow of the sewage plume emanating from the outfall at Pointe aux Sables. Lower levels (19.8 – 23 μg/g) were found across TR.2 and TR.3, but at the shore of the latter the concentration was 26.5 μg/g.

The influence of the effluent from the outfall was evident from the highest levels of **zinc** (>400 to 736 μg/g) recorded in the external zone of the lagoon. Contrary to copper, zinc was found to be at its lowest levels (about 125 μg/g) around the middle of TR.5, which was the zone of the lagoon with dense growth of *Ulva* sp. Elsewhere in the lagoon the values varied in the range of 225 – 285 μg/g.

The highest concentrations of **nickel** (about 20 μg/g) occurred along the coast and in the centre of the lagoon. These would be indicative of inputs from terrestrial sources and the GRNW.

The levels of **lead** were generally higher at the reef of Pointe aux Sables than at Pointe aux Caves. The highest level (47.8 μg/g) was recorded in the external zone of TR.2. The levels varied in the range of 29 – 35 μg/g further north in the centre of the lagoon. Nearer to the shore at TR.3 values ranged from 23.4 to 34 μg/g. Strangely, the lowest values (about 20 μg/g) were found along the whole length of TR.4.

Manganese concentration was found to increase in the direction of south to north of the lagoon. The range was 100 – 136 μg/g at TR.4 and TR.5. Elsewhere the concentration was about 75 μg/g. For all the transects the highest values always occurred in the most external zone of the lagoon, confirming once again the impact of the sewage outfall.

Generally, the sediment is quantitatively more important than the water column and biota as major reservoirs of heavy metals. However, a consistent correlation does not always exist between the body burdens of heavy metals in organisms and concentrations in the sediment. Despite these facts, some organisms are still capable of bioconcentrating heavy metals by several orders of magnitude with respect to their surrounding environment. Examples of bioconcentrating factors of some types of aquatic organisms are given in Table 3.4.

Table 3.4 : Typical bioconcentration factors of selected aquatic organisms

Metal	Phytoplankton	Zooplankton	Macrophytes	Molluscs	Fish
Ti	2700				
Cr	7800		2880	21800	
Mn	3800	3900		2300	373
Fe	28300	114600		14400	
Ni	570	560	1050	4000	235
Co					50
Cu	2800	1800	2890	3800	127
Zn	5500	8800	7000	27300	533

(Source : Kennish, 1994)

3.4 Receiving water quality

In Mauritius water quality standards have been adopted (April 1999) for coastal conservation, recreation, fisheries, and for coastal areas which act as receiving body for industrial and agricultural discharges (harbour, power generating plants and other industrial activities). The coastal water quality requirements for various categories are given in Table 3.5. The Albion Fisheries Research Centre (AFRC, 1995) reported chromium levels in the range of 0.01 - 0.02 mg/l, which were very low with reference to the prescribed standards of 1999 (Table 3.5).

3.5 Conclusion

Currently most of the industrial and domestic waste water in Mauritius generally is not or sometimes only partly treated before disposal into water courses and eventually the sea. The river flows have unknown pollution loads but are probably as high as in the sewers. Also, the waste water characteristics of specific industries are not known. The textile related industries are the biggest producers of effluents (Severn Trent International (STI), 1993) and discharge wastes characterised by high colour, pH and TSS (total suspended solids).

The Black & Veatch International (BVI) Montagne Jaquot Environmental Sewerage and Sanitation study (1997) used the standards presented by Gibb (1994) because the Mauritian government has not yet adopted effluent water quality standards for disposal. More often than not industrial effluents would carry pollutant loads far in excess of the limits cited in Gibb (1994). Indeed many of the industrial wastes seem to have high levels of BOD, COD, N, P, grease as well as heavy metals and other toxic substances.

Data on contamination of the coastal waters by heavy metals in Mauritius are seriously lacking. However, some data generated during the SOGETI study (1995) on waste water discharge into the sea indicated much spatial variation in concentration of heavy metals (Cu, Zn, Ni, Pb, Cr & Mn) at Pointe aux Sables and Pointe aux Caves. Effluent discharge from the existing sewage outfall and inputs via the Grand River North West (GRNW) would be the principal sources of sediment contamination at both sites. Aquatic organisms may be adversely affected by heavy metals in the environment and the impact depends upon metal toxicity. Consumption of metal contaminated seafood may also pose great risk to human health. In Mauritius receiving water quality standards have been adopted (April 1999) for coastal conservation, recreation, fisheries and for coastal areas which act as receiving body for industrial and agricultural discharges.

Table 3.5 : Coastal water quality requirements for various categories in Mauritius (1999).

CATEGORY		A : Conservation		B : Recreation		C : Fisheries		D:Industrial
CLASS		A1:Coral Community	A2:Natural Areas	B1:Primary Contact	B2:Secondary Contact	C1:Aqua -culture	C2:Shell-fish	D:Industrial & Others
Parameters	Unit							
PH		7.5 - 8.5						
Temperature	(°C)	Ambient	Ambient	Ambient	Ambient	Ambient	Ambient	Ambient
Suspended Solids	mg/l	5	5	5	10	15	15	15
Dissolved Oxygen	mg/l	>5	>5	>5	>5	>5	>5	>2
COD	mg/l	2	2	3	3	5	5	5
TC	CFU3/100ml	1000	1000	1000	5000	1000	70/100 ml ♣	-
FC	CFU3/100ml	200	200	200	1000	200	14/100 ml ♣	-
Nitrate-N	mg/l	0.2	0.3	0.8	0.8	0.8	0.8	1.0
Phosphate	mg/l	0.04	0.05	0.08	0.08	0.08	0.08	0.1
Oil & Grease	mg/l	Not detectable by N-Hexane extraction method						
Phenol	mg/l	0.05						
Arsenic	mg/l	0.05						
Cadmium	mg/l	0.02						
Cyanide	mg/l	0.01						
Chromium	mg/l	0.05						
Copper	mg/l	0.05						
Lead	mg/l	0.05						
Total Mercury	mg/l	0.0005						

♣ : Organisms per 100 ml by MPN method

CFU : Colony Forming Unit

CHAPTER FOUR

4. STUDY OBJECTIVES AND METHODOLOGY

4.1 The underlying rationale for using bio-indicators

Marine organisms accumulate stable metals present in higher than ambient concentrations (Waldichuck, 1979; Mance, 1987) and are now used effectively to study movements of metal containing pollutants in effluent receiving waters (Soule & Kleppel, 1988). There is worldwide growing interest in marine pollution and monitoring studies on metals are being conducted by the use of bio-indicators, namely seaweeds and bivalve molluscs (Burdin, 1979; Hamilton, 1983; Orren et al, 1980; Phillips, 1976).

Metals can be concentrated by 10^2 to 10^6 times their background level in the marine environment (Waldichuck, 1979; Mance, 1987). This is a major problem that metals pose with respect to their effects on aquatic organisms and humans as they are accumulated up the food chain. The data below illustrates the concentration factor values for some heavy metals in sea water by the Pacific Oyster, *Crassostrea gigas* (also occurs in Mauritius)

Metal	Natural concentration in Seawater $\mu g l^{-1}$ (ppb)	CF Value
Arsenic	2.6	423 - 810
Cadmium	0.11	82,000 - 182,000
Copper	4	24,000 - 35,000
Lead	0.03	7,000 - 100,000
Mercury	0.15	
Silver	0.28	
Zinc	2	172,000 - 290,000

Source : Leppard (1981)

The strategy is to analyse water and sediment samples alongside organism's tissue to determine the bioavailability as well as the CF values for the selected heavy metals by potential bio-indicators. This will enable the establishment of the most appropriate 'sentinel' in the coastal waters of Mauritius for the respective metals.

All the metals selected for study are toxic, some when present in trace amounts and others at much higher concentrations. They are all of great bioligical concern due either to their deleterious ecological impacts or human health impacts (e.g. Phillips, 1976; Burdin, 1979; Waldichuk, 1979, 1989; Orren et al, 1980; Phillips et al, 1981; Leppard, 1981; Hamilton, 1983, Bryan, 1984; Manley et al, 1984; Winddows, 1985; Mance, 1987; Waldock, 1987; Salazar et al, 1987; Beaumont, 1988; Claisse, 1989; Phillips & Tanabe, 1989; Clark, 1989; and others).

4.2 Objectives of this study

(i) To screen potential bio-indicators from our coastal environment by analysis of samples of water, sediment and organism's tissues to establish the most appropriate indicator for a particular heavy metal. This is essential because it is unrealistic to expect a single organism simultaneously to serve as 'sentinel' for all interests. The toxic metals proposed for investigation are : **lead, cadmium, copper, tin, zinc and chromium.**

(ii) To carry out simultaneous analyses in common seafood organisms, namely commercial fish.

(iii) To assess the environmental health status of the coastal environment as well as the potential impacts on human health.

(iv) To formulate appropriate control and management measures.

4.3 The choice of bioindicators or biomonitors

Rainbow and Phillips (1993) pointed out that the use of a suite of biomonitors to cover all uptake routes would provide a complete picture of bioavailable metals. Such a collection might include the following :

(i) a macrophytic algal, responding essentially to dissolved metal sources only (Phillips, 1993)

(ii) a suspension feeder, taking particles of a particular size range and responding to sources of metal in both dissolved and suspended phase; and/or

(iii) a detritivore, such as a talitrid amphipod crustacean, or a deposit-feeding polychaete or tellinid bivalve.

Constraints of time often make this impossible but a comparison of spatial and temporal patterns of accumulated trace metals in such biomonitors will provide considerable insight into the comparative inputs of trace metals into an aquatic ecosystem. Biomonitors generally accumulate trace metals to high concentrations which may be relatively easily measured, with limited risk of sample contamination. Ideal biomonitors should also meet further selection criteria, these requiring that they should be :

(1) sedentary
(2) reasonably abundant at the sites of interest
(3) easy to identify and sample
(4) large enough for analysis
(5) resistant to handling stress caused by laboratory studies or field transplantation, and
(6) tolerant of exposure to environmental variations in physicochemical parameters (Phillips, 1980)
(7) long lived
(8) able to accumulate pollutants from the environment without substantial mortality

(9) cosmopolitan

(10) hardy enough for manipulation before processing and analysis

(11) ecologically and economically important.

The use of a variety of species as biomonitors of heavy metal pollution is well established. Importantly, biomonitors of trace elements should preferably be strong net accumulators of the metals of concern and should not regulate the total concentration of an element in the body tissues when exposed to different metal bioavailabilities (Phillips and Rainbow, 1988; Rainbow *et al.* 1990).

4.4 <u>Sample collection</u>

4.4.1 Seawater

Sub-surface seawater samples were taken at the same time and place of biota collection at coastal sites around Mauritius (Figure 4.1). Duplicate samples were collected in plastic bottles of 1000 ml capacity which had been pre-treated by soaking in 10% HC (30 – 32%) for 48 hours and rinsed with distilled deionised water.

4.4.2 Sediment

Surface sediment samples were collected using a 20 cm long plastic spatula. Accessible (e.g intertidal) sediments were scraped from the top 4 cm over an area of approximately 50 cm radius and placed in plastic bags.

4.4.3 Macroalgae and seagrasses

Macroalgal samples were collected by hand randomly at several places on the beach, namely those attached to rock surfaces. The seagrass samples were taken in shallow water near the shore. Both algae and seagrasses were clipped off at substrate level, then placed in polythene bags, ice-cooled in an isotherm box and taken to the laboratory.

4.4.4 Oysters, bivalves and barnacles

Usually these occur on hard rocky surfaces or crevices. Samples were removed by dislodging with a hard plastic scraper to avoid contamination during collection.

4.4.5 Fish

Fish specimens were purchased at the points of sale to the general public, i.e at the fish market or directly from fishermen.

4.5 Laboratory procedures (treatment, processing and analysis of samples)

4.5.1 Seawater

The seawater sample was filtered through a 0.45 millipore filter and acidified with HNO_3 to pH <2. 100 ml aliquot of the filtered, acidified and well mixed sea water was placed in a beaker, 3 ml of concentrated HNO_3 was added to it and was continuously evaporated to dryness on a hot plate. After cooling another 3 ml of concentrated HNO_3 was added to the beaker and was covered with a watch glass before returning it to the hot plate. The temperature of the hot plate was increased so that a gentle reflux action take place. Additional acid was added as necessary until digestion was complete. When the sample was evaporated to near dryness the beaker was cooled and inorder to dissolve any precipitate a small quantity of HCL was added to it and was warmed. Before filtering the sample (with 0.45 millipore filter) the walls of the beaker and watchglass was washed with distilled deionised water. The volume was adjusted to 25 ml in a volumetric flask and stored until analysis.

4.5.2 Macroalgae and seagrasses

The algal and seagrass samples were cleaned, rinsed first with freshwater and then with distilled water to remove sand and salt. They were blotted dry using laboratory paper towel. After the cleaning process, the algae were dried in an oven for 24 hours at 60^0C and ground using a motar and pestle. The samples were stored dry until they were analysed.

The dried samples of algae were re-dried for one hour at 80^0C to attain constant weight. Duplicate samples (of one gram each) were used for the determination of Cu, Cd, Cr, Zn, Sn and Pb. Each sample was placed in a 500 ml kjeldhal flask with 6 ml of $H_2 O_2$ (> 30%), 10 ml distilled deionised water and 10 ml nitric acid (69.71% concentration). The mixture was then heated at 80^0C on a heating mantle for 3 hours until a clear solution was obtained. The digests were cooled and any undissolved material was filtered through 0.45 μm membrane filters. The filtrate was transferred to 50 ml volumetric flasks and deionised water was added up to the mark.

The metal (Cu, Cd, Cr, Pb, Sn & Zn) contents of the digested algae were then determined by Atomic Absorption Spectrophotometer (AAS) with flame atomisation. Cr and Sn were analysed with nitrous oxide – acetylene (N_2O-C_2H_2) flame type while the gas used for the rest of the metals (i.e Cu, Cd, Pb & Zn) was air – acetylene (air-C_2H_2). Standard solutions of known concentrations made for each metal were used to construct a standard curve. The linear area from the curve was used to determine the concentration of heavy metals in the samples. When the values were too high, the samples were diluted with distilled deionised water to bring values within the range of the linear area of the standard curve. Each of the duplicate samples were analysed three times and the mean values recorded.

4.5.3 Fish

The specimen was washed with deionised distilled water. A portion of at least 100 g of muscle tissue was separated from the fish using a clean Teflon knife and dried in an oven for 24 hours at 60^0C. The sample was ground using a motar and pestle and treated in the same way as described above.

4.5.4 Sediment samples

Sediment samples were air-dried and sieved using a 250 μm mesh nylon sieve. 1.0 g of the sieved sample sample was accurately weighed in duplicate and transferred to a 500 ml kjeldhal flask. 20 ml of HNO_3 was added and digested at 60 - 80^0C for 3 hours until a pale yellow solution was obtained. The acid was slowly evaporated and the residue was dissolved in 1 ml concentrated AR grade Hcl. The sample was then warmed, filtered through a 0.45 millipore filter and transferred to a 50 cm^3 volumetric flask where it was filled up to the mark with distilled deionised water. The solution was used for the determination of heavy metal concentration using the analysis technique of the AAS outlined in section 9.2 of the instrument manual.

4.5.5 Oyster, crab, bivalve and barnacle tissues

The oyster, crab, bivalve and barnacle specimens were washed with distilled water and allowed to drain off. After thawing they were dissected with the help of a plastic knife to separate the flesh. Their soft tissues were washed with deionised distilled water, dried at 60^0C for 24 hours and powdered. 1 g of each sample was placed in duplicate in 500 ml kjeldahl flasks and digested with a mixture of 6 ml H_2O_2, 10 ml distilled deionised water and 10 ml nitric acid at 80^0C for 3 hours. The mixture was cooled and filtered through 0.45 μm membrane filters. The filtrate was transferred to 50 ml volumetric flasks and distilled deionised water was added up to the mark. The levels of trace metals were analysed with flamed atomic absorption spectrometry.

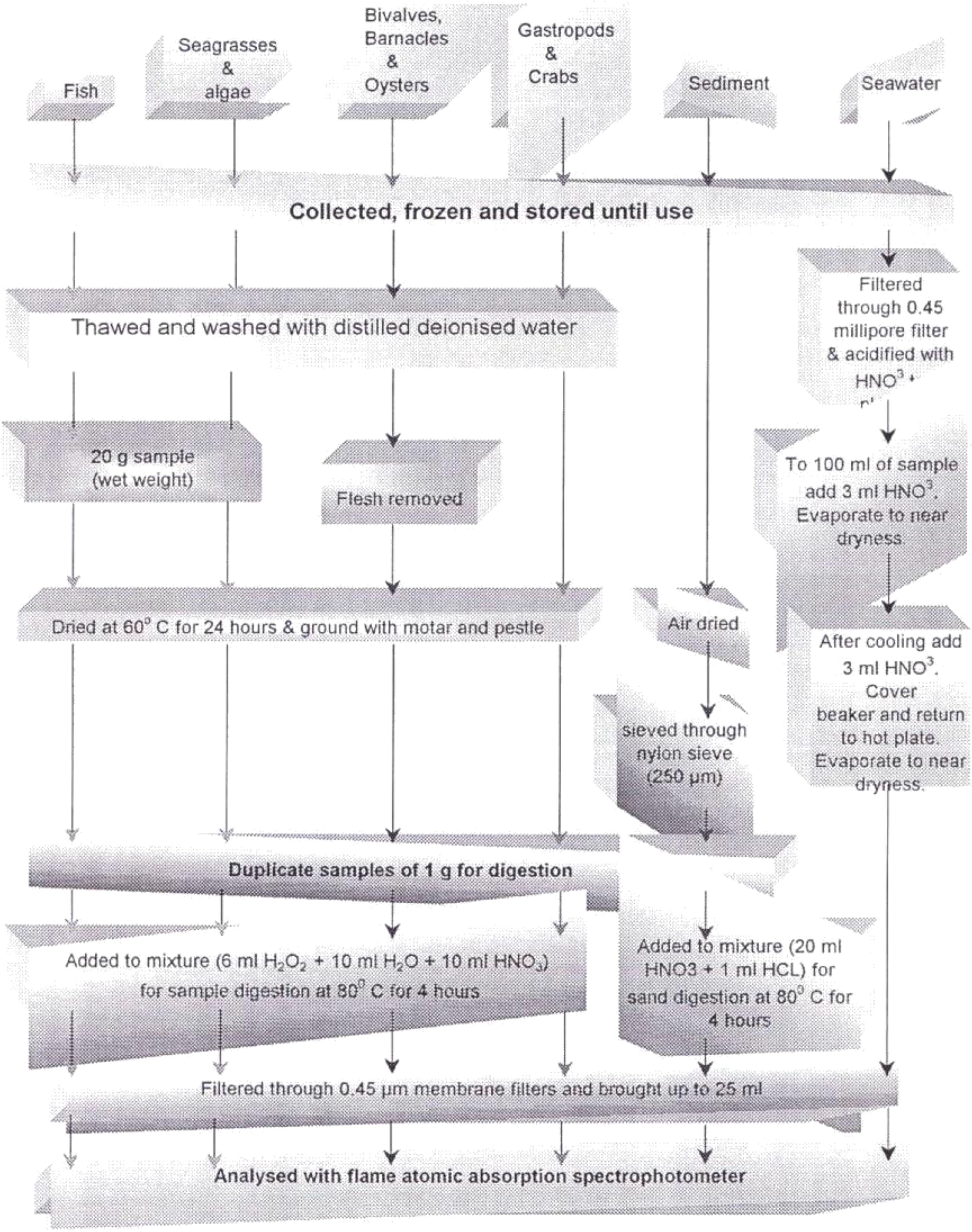
4.5.6 Molluscs

The gastropod specimens were washed with distilled water and dried for 24 hours in an oven at 60^0C. They were ground (i.e dried flesh and shell) in a porcelain motar and sieved through a nylon sieve (250 μm). Trace metal analyses were performed in the same way as described in section 9.2.

4.5.7 Summary of sample preparation and analysis

The metal levels in different media (seawater, sediment, marine biota and some common seafoods) were analysed using the different procedures for collection and analysis as summarised in figure 4.2. Once samples were retrieved and collected in metal free polyethylene bags or containers they were frozen until analysis could be performed. However, preparation and analysis of biotic and abiotic samples followed different procedures. The concentration of trace metals was determined by atomic absorption spectrophotometry and the values were generally recorded in μg/g or mg/l.

Figure 4.2 : Summary of sample processing and analysis for heavy metals.



CHAPTER FIVE

5. RESULTS

5.1 Sample types analysed

1. **Seawater** from 20 sites (Appendix 1)
2. **Lagoon sediment** from 20 sites (Appendix 2)
3. **Green macro-algae**
    a. *Ulva lactuca* from 5 sites (Appendix 3)
    b. *Ulva fasciata* from 2 sites (Appendix 3)
    c. *Ulva reticulata* from 1 site (Appendix 3)
    d. *Enteromorpha ramulosa* from 5 sites (Appendix 4)
    e. *Caulerpa sertularioides* from 2 sites (Appendix 6)
    f. *Caulerpa serrulata* from 1 site (Appendix 6)
4. **Brown macro-algae**
    a. *Sargassum binderi* from 5 sites (Appendix 5)
    b. *Padina boryana* from 4 sites (Appendix 6)
    c. *Turbinaria ornata* from 2 sites (Appendix 6)
5. **Red macro-algae**
    a. *Sarconema filiforme* from 1 site (Appendix 5)
    b. *Galaxaura oblongata* from 1 site (Appendix 5)
    c. *Galaxaura marginata* from 1 site (Appendix 5)
    d. *Gracilaria canaliculata* from 1 site (Appendix 5)
6. **Seagrasses**
    a. *Halodule uninervis* from 2 sites ((Appendix 7)

b. *Syringodium isoetifolium* from 4 sites (Appendix 7)

c. *Thalassodendron ciliatum* from 1 site (Appendix 7)

7. **Sponges**

a. *Biemna fortis* from 2 sites (Appendix 7)

b. 'Perle Bleu` from 1 site (Appendix 7)

c. 'Brown tree` from 1 site (Appendix 7)

8. **Snails**

a. *Littorina mauritiana* (3 size classes) from 6 sites (Appendix 8)

b. *Lottorina littorea* (3 size classes) from 2 sites (Appendix 9)

c. *Morula granulata* from 2 sites (Appendix 9)

d. *Nerita undata* from 1 site (Appendix 9)

e. *Cypraea tigris* from 1 site (Appendix 9)

f. *Cypraea carputserpentis* from 1 site (Appendix 9)

9. **Bivalves**

a. *Isognomon isognomon* (2 size classes) from 4 sites (Appendix 10)

b. *Pinna muricata* from 1 site (Appendix 10)

c. *Crassostrea cucullata* from 1 site (Appendix 10)

10. **Sea Urchins**

a. *Echinometra mathaei* (3 sizes , skeleton & tissue) from 5 sites (Appendix 11)

11. **Sea Cucumbers**

a. *Bonadshia subruba* from 1 site (Appendix 12)

b. *Holothuria leucopsilota* from 3 sites (Appendix 12)

c. *Holothuria parva* from 1 site (Appendix 12)

d. *Stichopus chloronatus* from 1 site (Appendix 12)

12. Edible Fish

a. 20 species (flesh, gill, liver) from many sites around Mauritius (Appendix 13).

5.2 Heavy metal concentration in *seawater* around Mauritius

The mean values of the heavy metal concentrations recorded from the 20 sites around the coast of Mauritius are given in **Table 5.1**. The variation range of these mean concentrations are also indicated. The lower detection limit for all the metals investigated was 10 ppb

5.2.1 Cadmium levels

Cadmium levels showed a variation range of 10 ppb (e.g. at Poste Lafayette : Eastern exposed coast) to 323 ppb (e.g. at Pointe Moyenne : Western sheltered coast), with a mean of 63 ± 79 ppb, showing a high variation between the sites (indicated by the higher Standard Deviation (SD) than the mean value. Generally, the lowest levels (>20 ppb) were recorded in water from sites in the north (e.g. Cap Malheureux : 18 ppb, Poudre d`Or : 12 ppb, Pointe des Lascars : 15 ppb), in the east (e.g. Poste Lafayette : 10 ppb, Belle Mare : 18 ppb, Palmar : 12 ppb) and in the south (e.g. Le Morne : 17 ppb , St Felix : 10 ppb). Higher levels (>100 ppb) were recorded from the following sites : Trou aux Biches, Ile d`Ambre, Pointe aux Sables, Bain des Dames), and levels over 100 ppb were recorded from Mon Choisy, Grand Baie, Baie du Tombeau, and Pointe Moyenne.

5.2.2 Copper levels

Copper levels varied in the range of 10 ppb (Poste Lafayette) to 352 ppb (Pointe aux sables), with a mean value of 99 ± 118 ppb (thus high variation between sites). The lowest levels were recorded from sites on the east and south coasts, and the highest levels from most of the western sites (e.g. Grand Baie : 341 ppb, Baie du Tombeau :

Table 5.1 : Heavy Metal Content (ppm) in lagoon water							
Date	**Site**	**Cd**	**Cu**	**Pb**	**Zn**	**Cr**	**Sn**
18.10.99	Trou aux Biches	0.067	0.075	0.013	0.109	0.180	0.035
18.10.99	Mon Choisy	0.112	0.088	0.022	0.116	0.210	0.021
24.03.99	Grand Bay	0.201	0.341	0.104	0.157	0.260	0.068
17.09.99	Poudre D' Or	0.012	0.025	0.031	0.242	0.290	0.031
17.09.99	Ile D'Ambre	0.041	0.083	0.051	0.256	0.260	0.022
17.09.99	Pointe des Lascars	0.015	0.028	0.029	0.061	0.190	0.019
12.10.99	Cap Malheureux	0.018	0.038	0.016	0.082	0.110	0.032
12.10.99	Baie du Tombeau	0.133	0.189	0.153	0.189	0.350	0.034
12.10.99	Albion	0.023	0.012	0.016	0.041	0.230	0.021
02.02.99	Pointe Moyenne	0.323	0.211	0.247	0.849	0.380	0.036
12.10.99	Pointe aux Sables	0.091	0.352	0.192	0.363	0.310	0.029
02.02.99	Bain des Dames	0.074	0.331	0.169	0.912	0.410	0.033
05.01.00	Grand Gaube	0.045	0.056	0.010	0.084	0.090	0.012
08.10.99	Morne	0.017	0.012	0.012	0.072	0.090	0.010
07.01.99	Flic en Flacq	0.017	0.018	0.010	0.076	0.120	0.013
25.01.00	Poste la Fayette	0.010	0.010	0.010	0.016	0.090	0.011
25.01.00	Belle Mare	0.018	0.033	0.012	0.069	0.080	0.012
25.01.99	Poste de Flacq	0.025	0.030	0.019	0.065	0.090	0.010
07.01.00	St Felix	0.010	0.023	0.016	0.010	0.020	0.017
25.01.00	Palmar	0.012	0.018	0.010	0.012	0.020	0.014
	Minimum	**0.010**	**0.010**	**0.010**	**0.010**	**0.020**	**0.010**
	Maximum	**0.323**	**0.352**	**0.247**	**0.912**	**0.410**	**0.068**
	Mean	**0.063**	**0.099**	**0.057**	**0.189**	**0.189**	**0.024**
	SD	**0.0795**	**0.1181**	**0.0734**	**0.2533**	**0.1187**	**0.0139**

189 ppb, Pointe Moyenne : 211 ppb, Pointe aux sables : 352 ppb, Bain des Dames : 331ppb).

5.2.3 Lead levels

The concentration of lead in sea water varied between 10 ppb (e.g. at Poste Lafayette, Palmar, Flic en Flac , Grand gaube) and 247 ppb (e.g. at Pointe Moyenne), with a mean value of 57 ± 73 ppb (thus high spatial variation). The higher concentrations were recorded from the following sites : Grand Baie (104 ppb), Baie du Tombeau (153 ppb), Pointe Moyenne (247 ppb), Pointe aux Sables (162 ppb) and Bain des Dames (169 ppb).

5.2.4 Zinc levels

Zinc concentrations occurred in the range of 10 ppb (e.g. St Felix) to 912 ppb (e.g. at Bain des Dames), with a mean value of 189 ± 253 ppb (thus high spatial variation). High concentrations were also recorded from Pointe Moyenne (849 ppb) and Pointe aux sables (363 ppb), Ile d`Ambre (256 ppb) and Poudre d`Or (242 ppb). Levels at other sites were generally low.

5.2.5 Chromium levels

Chromium levels were in the range of 20 ppb (e.g. at St Felix & Palmar) to 410 ppb (e.g. at Bain des Dames), with a mean value of 189 ± 118 ppb. Other sites with high levels were : Pointe aux sable (310 ppb), Pointe Moyenne (380 ppb), Baie du Tombeau (350 ppb), Ile d`Ambre & Grand Baie (260 ppb), Poudre d`Or (290 ppb) and Albion (230ppb). About 50% of the sites had chromium levels above 200 ppb, and most of these were from the western coast.

5.2.6 Tin levels

Tin concentrations varied in the range of 10 ppb (e.g. at Le Morne & Poste de Flacq) to 68 ppb (e. g. at Grand Baie), with a mean value of 24 ± 14 ppb. The higher levels generally occurred at Bain des Dames, Pointe Moyenne, Pointe aux Sables, Baie du Tombeau as well as Trou aux biches.

5.2.7 General trend of metal abundance in sea water

(1) The relative abundance of metals in sea water decreased in the order :

$$Zn > Cr > Cu > Cd > Pb > Sn.$$

(2) There was high variation between the sites surveyed. Generally higher levels of all the metals were recorded from the following sites : Pointe aux Sables, Bain des Dames, Pointe Moyenne, and Baie du Tombeau, hence they can be considered to be the **hot spots** of heavy metal pollution in Mauritius. Sites with intermediate levels were Grand Baie, Trou aux Biches, Mon Choisy in the north west, and Poudre d`Or and Ile d`Ambre in the north east. Sites on the eastern and southern coastlines had the lowest levels, hence clean.

(3) The data presented do not support any evidence of seasonal variation in heavy metal abundance.

5.3 Heavy metal concentration in coastal sediment

5.3.1 Cadmium levels

Tables 5.2 a and 5.2 b show the metal concentrations in lagoon sediment from the sites surveyed around Mauritius. Mean cadmium concentration was highest in the sediment from Pointe Moyenne (42.96 μg/g or ppm), followed by Bain des Dames (35.04 μg/g) and Pointe aux Sables (33.33 μg/g). Compared to the other sites, these were the most contaminated, being the recipients of raw sewage, untreated domestic and industrial effluents via direct outfall discharge. The lowest level (0.13 μg/g) was recorded from Trou aux Biches.

5.3.2 Copper levels

Mean copper concentration was high at the following sites : Pointe aux Sables (35.77 μg/g), Baie du Tombeau (25.96 μg/g), Pointe Moyenne (23.78 μg/g), Bain des Dames (36.04) and Grand Baie (31.24 μg/g). However, the highest levels were recorded from Poudre d`Or (81.29 μg/g) and Ile d`Ambre (41.57 μg/g). These sites also received industrial effluents and Poudre d`Or had a coastal solid waste dumping area

Table 5.2 a : Heavy Metal Content (ppm or µg/g) in Lagoon Sediment							
		Cd	Cu	Cr	Pb	Zn	Sn
05.08.98	Pointe aux Sables	53.25	31.35	24.3	11.05	661	50.2
02.11.98		38.29	42.21	43.78	24.51	412	44.27
02.02.99		24.98	23.53	61.33	26.25	548	26.81
23.07.99		30.08	48.16	23.6	38.68	438	14.52
12.10.99		20.06	33.58	47.04	45.63	397	53.29
	Mean	**33.33**	**35.77**	**40.01**	**29.22**	**491.2**	**37.82**
13.07.99	Baie du Tombeau	2.04	21.1	7.53	52.59	110.58	22.31
12.10.99		1.15	30.81	5.98	39.01	198.1	53.62
	Mean	**1.595**	**25.96**	**6.755**	**45.8**	**154.34**	**37.97**
13.07.99	Albion	0.35	6.55	10.3	4.39	23.04	4.01
12.10.99		0.49	0.66	9.52	2.71	14.05	3.38
	Mean	**0.42**	**3.605**	**9.91**	**3.55**	**18.545**	**3.695**
05.08.98	Pointe Moyenne	41.53	19.03	56.3	47.01	529.91	65.53
02.11.98		32.34	21.41	50.4	86.5	512.1	44.37
02.02.99		55.01	30.9	76.2	98.1	620	56.22
	Mean	**42.96**	**23.78**	**60.97**	**77.2**	**554**	**55.37**
05.08.99	Bain des Dames	28.31	18.11	23.88	31.2	189.4	37.1
02.11.98		43.25	62.6	27.4	28.5	393.6	42.4
02.02.99		33.57	27.4	32.56	38.18	541.33	59.53
	Mean	**35.04**	**36.04**	**27.95**	**32.63**	**374.78**	**46.34**
23.08.98	Trou aux Biches	0.32	3.21	9.4	6.05	22.78	22.7
20.01.99		0.2	3.05	6.09	4.86	37.83	13.1
24.03.99		0.05	3.65	5.9	10.01	12.78	11.35
27.07.99		0.05	6.21	13.65	18.09	24.78	18.45
18.10.99		0.03	4.12	4.01	13.09	44.49	31.73
	Mean	**0.13**	**4.048**	**7.81**	**10.42**	**28.532**	**19.47**
23.08.98	Mon Choisy	1.32	14.5	12.05	28.09	10.61	12.1
20.01.99		1.43	21.22	10.53	14.01	33.7	11.56
24.03.99		0.64	16.39	14.06	24.5	19.48	24.48
27.07.99		0.84	14.7	12.22	10.08	22.04	32.09
18.10.99		0.19	10.04	9.52	21.95	31.25	21.93
	Mean	**0.884**	**15.37**	**11.68**	**19.73**	**23.416**	**20.43**
23.08.98	Grand Baie	0.92	28.5	6.56	39.01	19.55	49.54
20.01.99		0.84	27.15	9.23	20.21	30.17	38.1
24.03.99		1.01	38.07	10.56	44.91	41.45	59.61
	Mean	**0.923**	**31.24**	**8.783**	**34.71**	**30.39**	**49.08**

Table 5.2 b : Heavy Metal Content (ppm or µg/g) in Lagoon Sediment							
		Cd	Cu	Cr	Pb	Zn	Sn
17.06.99	Poudre D' Or	3.01	69.2	54.68	65.84	132.65	42.55
17.09.99		2.51	93.38	77.46	88.23	185.8	63.01
	Mean	**2.76**	**81.29**	**66.07**	**77.035**	**159.225**	**52.78**
17.06.99	Ile D'Ambre	0.37	44.23	91.39	70.04	159.2	21.87
17.09.99		0.26	38.91	73.41	80.02	185.9	32.25
	Mean	**0.315**	**41.57**	**82.4**	**75.03**	**172.55**	**27.06**
17.06.99	Pointe des Lascars	0.22	12.33	8.16	2.95	20.11	12.38
17.09.99		0.17	23.93	12.1	10.64	48.1	21.29
	Mean	**0.195**	**18.13**	**10.13**	**6.795**	**34.105**	**16.835**
30.07.99	Cap Malheureux	0.33	6.45	15.85	11.84	87.44	6.06
12.10.99		0.25	13.38	21.5	9.69	36.56	2.28
	Mean	**0.29**	**9.915**	**18.675**	**10.765**	**62**	**4.17**
30.07.99	Grand Gaube	0.59	11.69	19.02	11.15	32.69	12.7
05.01.00		0.24	12.1	12.1	22.19	18.06	23.21
	Mean	**0.415**	**11.895**	**15.56**	**16.67**	**25.375**	**17.955**
13.07.99	Morne	0.24	4.33	23.93	11.58	40.46	15.23
08.10.99		0.17	8.27	31.99	22.81	34.56	21.96
	Mean	**0.205**	**6.3**	**27.96**	**17.195**	**37.51**	**18.595**
20.08.99	Flic en Flacq	0.61	6.04	28.31	12.54	35.53	21.3
07.01.99		0.49	4.05	19.73	11.56	51.6	34.1
	Mean	**0.55**	**5.045**	**24.02**	**12.05**	**43.565**	**27.7**
27.08.99	Poste Lafayette	0.16	1.07	3.28	5.39	12.48	14.89
25.01.00		0.28	0.89	4.64	3.85	9.85	13.63
	Mean	**0.22**	**0.98**	**3.96**	**4.62**	**11.165**	**14.26**
27.08.99	Belle Mare	0.4	2.08	5.38	21.6	15.19	11.93
25.01.00		0.21	0.97	8.66	38.75	11.5	18.25
	Mean	**0.305**	**1.525**	**7.02**	**30.175**	**13.345**	**15.09**
27.08.99	Poste de Flacq	0.69	9.16	5.34	11.93	28.37	15.21
25.01.99		0.78	16.9	6.39	9.85	19.85	12.88
	Mean	**0.735**	**13.03**	**5.865**	**10.89**	**24.11**	**14.045**
27.08.99	St Felix	0.14	2.1	4.99	5.64	17.43	33.61
07.01.00		0.32	4.12	9.37	4.07	23.09	28.47
	Mean	**0.23**	**3.11**	**7.18**	**4.855**	**20.26**	**31.04**
27.08.99	Palmar	1.08	10.9	6.32	11.34	40.89	23.09
25.01.00		0.98	21.68	5.66	15.05	32.34	17.35
	Mean	**1.03**	**16.29**	**5.99**	**13.195**	**36.615**	**20.22**

which must be contaminating the lagoon. The lowest levels were recorded from Poste Lafayette (0.98 μg/g), Belle Mare (1.52 μg/g) and St Felix (3.11 μg/g).

5.3.3 Chromium levels

As for copper, high chromium concentrations were recorded from Ile d`Ambre (82.4 μg/g) and Poudre d'Or (66.07 μg/g). The other sites with high levels were Pointe Moyenne (60.97 μg/g) and Pointe aux Sables (40.01 μg/g). The lowest levels were recorded from Poste Lafayette (3.96 μg/g) and Poste de Flacq (5.86 μg/g).

5.3.4 Lead levels

The lowest mean concentrations of lead were recorded from Poste Lafayette (4.62 μg/g) and St Felix (4.85 μg/g). About 20 times higher concentrations were recorded from Poudre d`Or (77.04 μg/g), Ponite Moyenne (77.2 μg/g) and Ile d`Ambre (75.03 μg/g). Intermediate levels were recorded from Baie du Tombeau (45.8 μg/g) and Grand Baie (34.71 μg/g).

5.3.5 Zinc levels

Mean concentration of zinc was highest at Pointe Moyenne (554 μg/g) , Pointe aux Sables (491.2 μg/g), and Bain des Dames (374.8 μg/g). Levels at Poudre d`Or (159.2 μg/g) and Ile d`Ambre (172.5 μg/g) were also high compared to the clean site such as Poste Lafayette (11.16 μg/g).

5.3.6 Tin levels

The highest level of tin was recorded from Grand Baie (49.08 μg/g), Pointe Moyenne (55.37 μg/g), Bain des Dames (46.34 μg/g) and Poudre d`Or (52.78 μg/g). The lowest levels were from Cap Malheureux (4.17 μg/g) and Albion (3.69 μg/g).

5.3.7 General trend of metal abundance in coastal sediment

(1) The relative abundance of metals in coastal sediment decreased in the order :

$$Zn > Cr > Cu > Pb > Sn > Cd.$$

(2) The hot spots of sediment contamination would generally be similar to those of water contamination.

(4) No seasonal trend is evident from the data presented.

5.4 Metal abundance in marine biota

The concentrations of metals in marine plant and animal tissues analysed are given in **Tables 5.3 to 5.8 (a &b)**, and for edible fish in **Appendix 13 (a-e).** These data are also presented graphically as bar charts for better visual interpretation, as follows: **Figures 5.1 to 5.13** (marine plants), Figures **5.14 to 5.21** (marine invertebrate animals) and Figures **5.22 a & b** (edible fish species).

5.4.1 Potential plant bio-indicator candidates for cadmium (Table 5.3 a)

Amongst the marine plants from all the sites around Mauritius, *Ulva lactuca* (sea lettuce) had the highest concentration of cadmium (range = 0.19 - 8.12 μg/g; mean = 3.13 ± 3.24 μg/g), followed by *Enteromorpha ramulosa* (range = 0.16 - 2.48 μg/g; mean = 1.02 ± 0.98 μg/g). Generally, these are also the first seaweeds to proliferate in contaminated coastal waters, especially in eutrophic conditions with high nitrate and phosphate levels. *Ulva lactuca* could thus be a potential bio-indicator candidate for cadmium. Samples for analysis were collected from Mon Choisy, Trou aux Biches, Bain des Dames, Pointe aux Sables and Pointe Moyenne.

The highest concentration of cadmium in both seawater (i.e. 323 ppb) and sediment (i.e. 42.96 ppm) was obtained from Pointe Moyenne, but *U. lactuca* from this site showed a mean concentration of 4.09 μg/g of Cd whereas the highest concentration (8.275 μg/g) was recorded in *U. lactuca* collected from Pointe aux Sables on 12.10.99 (Appendix 3). The latter site also had high cadmium both in seawater (91 ppb) and sediment (33.33 μg/g), exhibiting a **Concentration Factor (CF) of 90.** Other candidates of lesser importance would be *Enteromorpha ramulosa* (green alga), *Padina boryana* (brown alga) and *Biemia fortis* (sponge)

U. lactuca has been used widely as a heavy metal indicator (such as Fe, Mn, Cu, Pb, Zn) (e.g. Boyden, 1975; Seeliger & Edwards, 1977; Talbot & Chegwiden, 1982; Ho, 1990). In Mauritius, *U. lactuca* appears to be a suitable indicator organism as it is of

Table 5.3 a : Variation of Cadmium concentration (ppm) in marine plants																					
Cadmium : Sites	**Water**	**Sediment**	***Ulva lactuca***	***Ulva fasciata***	***Ulva reticulata***	***Enteromorpha ramulosa***	***Sargassum binderi***	***Padina boryana***	***Turbinaria ornata***	***Thalassodendron ciliatum***	***Halodule uninervis***	***Syringodium isoetifolium***	***Caulerpa sertularoides***	***Caulerpa serrulata***	***Sarconema filiforme***	***Galaxaura oblongata***	***Galaxaura marginata***	***Galaxaura canaliculata***	***Biemia fortis (sponge)***	***Perle bleu (sponge)***	***Brown tree (sponge)***
Cap Malheureux	0.018	0.29																0.23			
Mon Choisy	0.112	0.884	2.82								1.59	0.36									
Trou aux Biches	0.067	0.13	0.19			0.16		0.88	0.87												
Baie du Tombeau	0.133	1..595		0.55																	
Bain des dames	0.074	35.04	0.41			1.5															
Pointe aux Sables	0.091	33.33	8.12			0.22									0.63						
Albion	0.023	0.42									0.63										
Pointe Moyenne	0.323	42.96	4.09			2.48															
Flic en Flacq	0.017	0.55					0.4	1								0.98					
Le Morne	0.017	0.205					1.48		0.51												
Poste de Flacq	0.025	0.735		0.77								1.06					0.9				
Belle Mare	0.018	0.305							0.68												0.38
Poste la Fayette	0.01	0.22					1.89	1.58		0.52		1.64									
Pointe des Lascars	0.015	0.195				0.73													1.87		
Poudre d'Or	0.012	2.76			0.29		0.42					0.32							2.88	0.62	
Ile d'Ambre	0.041	0.315					1.26	2.44					0.79								
Grand Gaube	0.045	0.415											0.72	0.97							
Minimum	0.01	0.13	0.19	0.55	0.29	0.16	0.4	0.88	0.51	0.52	0.63	0.32	0.72	0.97	0.63	0.98	0.9	0.23	1.87	0.62	0.38
Maximum	0.323	42.96	8.12	0.77	0.29	2.48	1.89	2.44	0.87	0.52	1.59	1.64	0.79	0.97	0.63	0.98	0.9	0.23	2.88	0.62	0.38
Mean	0.061	7.422	3.13	0.66	0.29	1.02	1.09	1.48	0.69	0.52	1.11	0.85	0.76	0.97	0.63	0.98	0.9	0.23	2.38	0.62	0.38
Stand Dev	0.077	14.86	3.24	0.16	####	0.98	0.66	0.71	0.18	####	0.68	0.63	0.05	####	####	####	###	####	0.71	####	####

reasonable size, sedentary, easily collectable and bioaccumulates metals (Brix et al., 1983).

5.4.2 Potential animal bio-indicator candidates for cadmium (Table 5.3 b)

The marine snail *Morula granulata* (a carnivorous species living on and under rocks in the sub-littoral zone) collected from Mon Choisy had a cadmium concentration of 0.34 µg/g whereas samples from Pointe aux Sables had 6.59 µg/g of the metal in the tissue. This was also the highest concentration recorded from analysis of the various animals listed in Table 5.3 b and Appendix 9. Another organism which would appear to be important was the common black sea urchin *Echinometra mathaei* (flesh and skeleton of medium and large sized individuals), with a concentration reaching 5.49 µg/g. These urchins were collected from Trou aux Biches, Flic en Flac, Le Morne and St Felix (Appendix 11). More and sophisticated investigations would confirm their suitability as bio-indicators of cadmium metal.

5.4.3 Potential plant bio-indicator candidates for copper (Table 5.4 a)

The highest concentrations of copper were recorded in *Enteromorpha ramulosa* (23.3 µg/g), *Ulva lactuca* (16.1 µg/g), *Biemia fortis* (10.7 µg/g) and *Padina boryana* (9.14 µg/g). *E. ramulosa* collected from Pointe des Lascars (clean site with 28 ppb in seawater and 18.13 µg/g in sediment) had the lowest concentration (3.37 µg/g) and that from Bain des Dames (highly contaminated site with 331 ppb in seawawter and 36.04 µg/g in sediment) had the highest (23.3 µg/g). This seaweed could thus be considered to serve as bio-indicator of copper contamination. *Ulva lactuca* also would be a suitable candidate because it too had the highest concentration (16.1 µg/g) in samples from Bain des Dames. *Biemia fortis* indicated high input of copper in Poudre d'Or lagoon (81.29 µg/g in sediment) and *Padina boryana* indicated high copper input in Ile d'Ambre lagoon (41.57 µg/g in sediment).

5.4.4 Potential animal bio-indicator candidates for copper (Table 5.4 b)

The oyster *Crassostrea cucllata* collected from Poudre d'Or showed a maximum and mean concentration of 154.9 and 99.6 µg/g of copper (Appendix 10 and Table 5.4 b), respectively. The bivalve *Isognomon isognomon* (collected from 4 sites : Appendix 10) collected from Mon Choisy had the highest concentration of copper (29.5 µg/g) in

Table 5.3 b : Variation of Cadmium concentration (ppm) in marine animals

Cadmium : Sites	*Morula granulata*	*Nerita undata*	*Cypraea tigris*	*Cypraea caputserpentis*	*Littorina littorea(0.5-1 cm)*	*Littorina littorea (1.1-1.5 cm)*	*Littorina littorea (1.5-2.0 cm)*	*Isognomon isognomon (0-2.5 cm)*	*Isognomon isognomon (2.6-5.0 cm)*	*Pinna muricata*	*Crassostrea cucullata*	*Littorina mauritiana (0.6-1.0 cm)*	*Littorina mauritiana (1.1-1.5 cm)*	*Littorina mauritiana (1.6-2.0 cm)*	*E. mathaei skeleton (0-2.5 cm)*	*E. mathaei flesh (0-2.5 cm)*	*E. mathaei skeleton (2.6-5.0 cm)*	*E. mathaei flesh (2.6-5.0 cm)*	*E. mathaei skeleton (5.1-7.5 cm)*	*E. mathaei flesh (5.1-7.5 cm)*
Cap Malheureux					3.81	4.04	2.4													
Mon Choisy	0.34	0.1		0.64	-	3.41	3.54	3.15	3.65											
Trou aux Biches															3.84	3.53	4.7	4.74	4.94	4.84
Baie du Tombeau																				
Bain des dames																				
Pointe aux Sables	6.59																			
Albion																				
Pointe Moyenne																				
Flic en Flacq																	3.8	3.79		
Le Morne															0.95	1.4	4.6	5.49	4.76	5.48
Poste de Flacq																				
Belle Mare			0.65					0.65	0.5											
Poste la Fayette																				
Pointe des Lascars																				
Poudre d'Or								2.1	0.64		0.42	1.5	1.57	0.37						
Ile d'Ambre										4.24										
Grand Gaube												0.36	0.25	0.37						
Palmar												3.47	3.2	0.29						
St Felix												0.1	0.1	0.25	0.05	0.23	0.1	0.54	3.75	3.78
Minimum	0.34	0.1	0.65	0.64	3.81	3.41	2.4	0.65	0.5	4.24	0.42	0.36	0.25	0.37	0.95	1.4	3.8	3.79	4.76	4.84
Maximum	6.59	0.1	0.65	0.64	3.81	4.04	3.54	3.15	3.65	4.24	0.42	1.5	1.57	0.37	3.84	3.53	4.7	5.49	4.94	5.48
Mean	3.465	0.1	0.65	0.64	3.81	3.73	2.97	1.97	1.6	4.24	0.42	0.93	0.91	0.37	2.4	2.47	4.4	4.67	4.85	5.16
Stand Dev	4.419	#####	####	####	####	0.45	0.81	1.26	1.78	####	####	0.81	0.93	0	2.04	1.51	0.5	0.85	0.13	0.45

Table 5.4 a : Variation of Copper concentration (ppm) in marine plants

Copper : Sites	Water	Sediment	*Ulva lactuca*	*Ulva fasciata*	*Ulva reticulata*	*Enteromorpha ramulosa*	*Sargassum binderi*	*Padina boryana*	*Turbinaria ornata*	*Thalassodendron ciliatum*	*Halodule uninervis*	*Syringodium isoetifolium*	*Caulerpa sertularoides*	*Caulerpa serrulata*	*Sarconema filiforme*	*Galaxaura oblongata*	*Galaxaura marginata*	*Galaxaura canaliculata*	*Biemia fortis (sponge)*	*Perle bleu (sponge)*	*Brown tree (sponge)*
Cap Malheureux	0.038	9.915																2.22			
Mon Choisy	0.088	15.37	7.16								1.78	2.54									
Trou aux Biches	0.075	4.048	8.38			6.07		1.24	2.72												
Baie du Tombeau	0.189	25.96		1.93																	
Bain des dames	0.331	36.04	16.1			23.3															
Pointe aux Sables	0.352	35.77	3.14			4.13									0.71						
Albion	0.012	3.605									4.4										
Pointe Moyenne	0.211	23.78	5.54			8.57															
Flic en Flacq	0.018	5.045					5.94	2.74								0.82					
Le Morne	0.012	6.3					4.65		0.32												
Poste de Flacq	0.211	13.03		0.84								2.35					1.3				
Belle Mare	0.033	1..525							1.17												1.51
Poste la Fayette	0.01	0.98					3.93	1.16		1.45		0.79									
Pointe des Lascars	0.028	18.13				3.37													8.83		
Poudre d'Or	0.025	81.29			6.74		3.13					5.34							10.7	4.96	
Ile d'Ambre	0.083	41.57					5.49	9.14					3.15								
Grand Gaube	0.056	11.9											2.5	1.8							
Minimum	0.01	0.98	3.14	0.84	6.74	3.37	3.13	1.16	0.32	1.45	1.78	0.79	2.5	1.8	0.71	0.82	1.3	2.22	8.83	4.96	1.51
Maximum	0.352	81.29	16.1	1.93	6.74	23.3	5.94	9.14	2.72	1.45	4.4	5.34	3.15	1.8	0.71	0.82	1.3	2.22	10.7	4.96	1.51
Mean	0.1042	20.8	8.05	1.39	6.74	9.09	4.63	3.57	1.4	1.45	3.09	2.76	2.83	1.8	0.71	0.82	1.3	2.22	9.75	4.96	1.51
Stand Dev	0.1122	20.5	4.88	0.77	####	8.2	1.14	3.78	1.22	####	1.85	1.89	0.46	####	####	####	###	####	1.29	####	####

Table 5.4 b : Variation of Copper concentration (ppm) in marine animals																				
Copper : Sites	*Morula granulata*	*Nerita undata*	*Cypraea tigris*	*Cypraea caputserpentis*	*Littorina littorea(0.5-1 cm)*	*Littorina littorea (1.1-1.5 cm)*	*Littorina littorea (1.5-2.0 cm)*	*Isognomon isognomon (0-2.5 cm)*	*Isognomon isognomon (2.6-5.0 cm)*	*Pinna muricata*	*Crassostrea cucullata*	*Littorina mauritiana (0.6-1.0 cm)*	*Littorina mauritiana (1.1-1.5 cm)*	*Littorina mauritiana (1.6-2.0 cm)*	*E. mathaei skeleton (0-2.5 cm)*	*E. mathaei flesh (0-2.5 cm)*	*E. mathaei skeleton (2.6-5.0 cm)*	*E. mathaei flesh (2.6-5.0 cm)*	*E. mathaei skeleton (5.1-7.5 cm)*	*E. mathaei flesh (5.1-7.5 cm)*
Cap Malheureux					24	11.8	8.58													
Mon Choisy	13.1	3.28		17		1.74	5.51	28.3	29.5											
Trou aux Biches															0.15	1.23	0.2	1.22	0.21	2.01
Baie du Tombeau																				
Bain des dames																				
Pointe aux Sables	4.14																			
Albion																				
Pointe Moyenne																				
Flic en Flacq																				
Le Morne															2.19	3.02				
Poste de Flacq																				
Belle Mare			19.1					12	13.6											
Poste la Fayette																				
Pointe des Lascars																				
Poudre d'Or								23.1	26.3		99.6	22.3	21.3	36.6						
Ile d'Ambre										23.7										
Grand Gaube												12.6	15.1	13.6						
Palmar												3.57	11.4	8.81						
St Felix												3.93	7.38	7.98	8.61	0.7	5.1	0.65	0.04	0.8
Minimum	4.14	3.28	19.1	17	24	1.74	5.51	12	13.6	23.7	99.6	3.57	7.38	7.98	0.15	0.7	0.2	0.65	0.04	0.8
Maximum	13.1	3.28	19.1	17	24	11.8	8.58	28.3	29.5	23.7	99.6	22.3	21.3	36.6	8.61	3.02	5.1	1.22	0.21	2.01
Mean	8.62	3.28	19.1	17	24	6.79	7.05	21.1	23.1	23.7	99.6	10.6	13.8	16.7	3.65	1.65	2.6	0.94	0.13	1.41
Stand Dev	6.336	#####	####	####	####	7.13	2.17	8.33	8.41	####	####	8.83	5.94	13.5	4.41	1.22	3.5	0.4	0.12	0.86

the tissue. However, the larger individuals of the gastropod *Lottorina mauritiana* (i.e. size 1.6 – 2.0 cm) contained even higher levels of the metal (e.g. 36.6 µg/g), but it is useful to note that copper is a common constituent of the gastropod respiratory pigment. *Pinna muricata* (bivalve) also had rather high copper content (e.g. 23.7 µg/g). Undoubtedly, all the potential candidates for copper were from the mollusc group.

5.4.5 Potential plant bio-indicator candidates for chromium (Table 5.5 a)

The green seaweed *Enteromorpha ramulosa* collected from Pointe des Lascars had the highest concentration of chromium (maximum of 19.8 µg/g, mean of 9.15 ± 7.85 µg/g). The next most important levels of cadmium were recorded in the seagrass *Syringodium isoetifolium* (maximum of 16.7 µg/g) and the brown seaweed *Sargassum binderi* (maximum of 15.1µg/g). *Ulva lactuca* could also serve as bio-indicator. The sediment from Ile d`Ambre (adjacent to Pointe des Lascars) had the highest chromium concentration (82.4 µg/g). *Enteromorpha ramulosa* would thus appear to be the most suitable candidate for chromium.

5.4.6 Potential animal bio-indicator candidates for chromium (Table 5.5 b)

The marine snail *Morula granulata* from Mon Choisy had the highest concentration of chromium (39.9 µg/g) in the tissue. Other snails which also had high concentrations were the different size groups of *Littorina mauritiana* (Grand Gaube), *Littorina littorea* (Cap Malheureux) and *Nerita undata* (Mon Choisy). Overall chromium concentrations in the marine animals analysed varied in the range of 13 – 39.9 µg/g (mean = 25.9 µg/g) (Appendix 9). These sites, however, are not hot spots of chromium contamination in Mauritius.

5.4.7 Potential plant bio-indicator candidates for lead (Table 5.6 a)

The concentration of lead in seawater around Mauritius varied in the range of 10 – 247 ppb and in sediment it occurred in the range of 3.55 – 77.2 µg/g. Amongst the marine plants, the highest mean concentration of lead (44.2 µg/g) was recorded in *Enteromorpha ramulosa* from Bain des Dames (a pollution hot spot), followed by *Ulva lactuca* (36.4 µg/g) from the same site. The sponge *Biemia fortis* from Pointe des Lascar had a much lower concentration (10.8 µg/g) of the metal.

Table 5.5 a : Variation of Chromium concentration (ppm) in marine plants																					
Chromium : Sites	Water	Sediment	*Ulva lactuca*	*Ulva fasciata*	*Ulva reticulata*	*Enteromorpha ramulosa*	*Sargassum binderi*	*Padina boryana*	*Turbinaria ornata*	*Thalassodendron ciliatum*	*Halodule uninervis*	*Syringodium isoetifolium*	*Caulerpa sertularoides*	*Caulerpa serrulata*	*Sarconema filiforme*	*Galaxaura oblongata*	*Galaxaura marginata*	*Galaxaura canaliculata*	*Biemia fortis (sponge)*	*Perle bleu (sponge)*	*Brown tree (sponge)*
Cap Malheureux	0.11	18.68																0.25			
Mon Choisy	0.21	11.68	12.6								4.42	0.22									
Trou aux Biches	0.18	7.81	0.4			0.61		2.05	0.98												
Baie du Tombeau	0.35	6.78		3.26																	
Bain des dames	0.41	27.95	2.68			7.23															
Pointe aux Sables	0.31	40.01	2.7			14.4									1.17						
Albion	0.23	9.91									1.8										
Pointe Moyenne	0.38	60.97	1.74			3.74															
Flic en Flacq	0.12	24.02					1.74	0.18								3.28					
Le Morne	0.09	27.96					3.23		0.77												
Poste de Flacq	0.09	5.87		0.59								1.64					1.1				
Belle Mare	0.08	7.02							0.98												1.79
Poste la Fayette	0.09	3.96					0.24	0.32		0.52		0.34									
Pointe des Lascars	0.19	10.13				19.8													3.89		
Poudre d'Or	0.29	66.07			8.95		15.1					16.7							12	3.46	
Ile d'Ambre	0.26	82.4					3.75	2.29					1.65								
Grand Gaube	0.09	15.56											2.19	0.05							
Minimum	0.08	3.96	0.4	0.59	8.95	0.61	0.24	0.18	0.77	0.52	1.8	0.22	1.65	0.05	1.17	3.28	1.1	0.25	3.89	3.46	1.79
Maximum	0.41	82.4	12.6	3.26	8.95	19.8	15.1	2.29	0.98	0.52	4.42	16.7	2.19	0.05	1.17	3.28	1.1	0.25	12	3.46	1.79
Mean	0.205	25.1	4.02	1.93	8.95	9.15	4.82	1.21	0.91	0.52	3.11	4.72	1.92	0.05	1.17	3.28	1.1	0.25	7.94	3.46	1.79
Stand Dev	0.112	23.76	4.87	1.89	####	7.85	5.93	1.11	0.12	####	1.85	7.99	0.38	####	####	####	###	####	5.73	####	####

Table 5.5 b : Variation of Chromium concentration (ppm) in marine animals																				
Chromium : Sites	*Morula granulata*	*Nerita undata*	*Cypraea tigris*	*Cypraea caputserpentis*	*Littorina littorea(0.5-1 cm)*	*Littorina littorea (1.1-1.5 cm)*	*Littorina littorea (1.5-2.0 cm)*	*Isognomon isognomon (0-2.5 cm)*	*Isognomon isognomon (2.6-5.0 cm)*	*Pinna muricata*	*Crassostrea cucullata*	*Littorina mauritiana (0.6-1.0 cm)*	*Littorina mauritiana (1.1-1.5 cm)*	*Littorina mauritiana (1.6-2.0 cm)*	*E. mathaei skeleton (0-2.5 cm)*	*E. mathaei flesh (0-2.5 cm)*	*E. mathaei skeleton (2.6-5.0 cm)*	*E. mathaei flesh (2.6-5.0 cm)*	*E. mathaei skeleton (5.1-7.5 cm)*	*E. mathaei flesh (5.1-7.5 cm)*
Cap Malheureux					32.7	32.4	36.4													
Mon Choisy	39.9	25.6		21.9		17.7	13	6.32	7.15											
Trou aux Biches																				
Baie du Tombeau																				
Bain des dames																				
Pointe aux Sables	25.6																			
Albion																				
Pointe Moyenne																				
Flic en Flacq																				
Le Morne																				
Poste de Flacq																				
Belle Mare			14.3					9.8	11.4											
Poste la Fayette																				
Pointe des Lascars																				
Poudre d'Or								8.74	10.8		8.3	7.27	7.17	14.3						
Ile d'Ambre										13.2										
Grand Gaube												25.9	32.4	33.6						
Palmar												8.61	9.43							
St Felix												5.36	4.11							
Minimum	25.6	25.6	14.3	21.9	32.7	17.7	13	6.32	7.15	13.2	8.3	5.36	4.11	14.3	0	0	0	0	0	0
Maximum	39.9	25.6	14.3	21.9	32.7	32.4	36.4	9.8	11.4	13.2	8.3	25.9	32.4	33.6	0	0	0	0	0	0
Mean	32.75	25.6	14.3	21.9	32.7	25.1	24.7	8.29	9.78	13.2	8.3	11.8	13.3	24	####	####	####	####	####	####
Stand Dev	10.11	#####	####	####	####	10.4	16.5	1.78	2.3	####	####	9.52	12.9	13.6	####	####	####	####	####	####

Table 5.6 a : Variation of Lead concentration (ppm) in marine plants																					
Lead : Site	Water	Sediment	*Ulva lactuca*	*Ulva fasciata*	*Ulva reticulata*	*Enteromorpha ramulosa*	*Sargassum binderi*	*Padina boryana*	*Turbinaria ornata*	*Thalassodendron ciliatum*	*Halodule uninervis*	*Syringodium isoetifolium*	*Caulerpa sertularoides*	*Caulerpa serrulata*	*Sarconema filiforme*	*Galaxaura oblongata*	*Galaxaura marginata*	*Galaxaura canaliculata*	*Biemia fortis (sponge)*	*Perle bleu (sponge)*	*Brown tree (sponge)*
Cap Malheureux	0.016	10.77																6.22			
Mon Choisy	0.022	19.73	6.32								3.75	8.83									
Trou aux Biches	0.013	10.42	3.18			2.26		7.64	5.74												
Baie du Tombeau	0.153	45.8		3.7																	
Bain des dames	0.169	32.63	36.4			44.2															
Pointe aux Sables	0.192	29.22	2.16			3.63									1.63						
Albion	0.016	3.55									4.02										
Pointe Moyenne	0.247	77.2	4.25			1.65															
Flic en Flacq	0.01	12.05					1.94	8.64								5.33					
Le Morne	0.012	17.2					2.14		3.45												
Poste de Flacq	0.019	10.89		2.41								1.94					5				
Belle Mare	0.012	30.18							0.8												1.83
Poste la Fayette	0.01	4.62					1.74	7.34		1.98		3.22									
Pointe des Lascars	0.029	6.795				4.66													10.8		
Poudre d'Or	0.031	77.04			3.62		5.92					7.06							4.04	4.59	
Ile d'Ambre	0.051	75.03					8.48	9.06					4.68								
Grand Gaube	0.01	16.67											5.05	8.3							
Minimum	0.01	3.55	2.16	2.41	3.62	1.65	1.74	7.34	0.8	1.98	3.75	1.94	4.68	8.3	1.63	5.33	5	6.22	4.04	4.59	1.83
Maximum	0.247	77.2	36.4	3.7	3.62	44.2	8.48	9.06	5.74	1.98	4.02	8.83	5.05	8.3	1.63	5.33	5	6.22	10.8	4.59	1.83
Mean	0.06	28.22	10.5	3.06	3.62	11.3	4.04	8.17	3.33	1.98	3.89	5.26	4.87	8.3	1.63	5.33	5	6.22	7.43	4.59	1.83
Stand Dev	0.078	25.55	14.6	0.91	####	18.4	3.02	0.81	2.47	####	0.19	3.22	0.26	####	####	####	###	####	4.79	####	####

Enteromorpha ramulosa was analysed from five sites, with mean concentrations of lead varying in the range of 1.65 – 44.2 µg/g (Appendix 4). The highest concentrations were in the range of 36.7 – 52.2 µg/g (mean = 44.2 µg/g), all recorded from Bain des Dames. *Ulva lactuca* also was analysed from five sites, with mean concentrations of lead varying in the range of 2.15 – 36.4 µg/g (Appendix 3). Again, the highest concentrations were recorded from Bain des Dames (17.5 – 46.01 µg/g).

5.4.8 Potential animal bio-indicator candidates for lead (Table 5.6 b)

Pinna muricata (bivalve) collected from Ile d`Ambre contained a mean concentration of lead of 13.6 µg/g (maximum of 15.8 µg/g) (Appendix 10). Other marine animals with higher lead content were the common sea urchin *Echinometra mathaei* (skeleton and flesh) collected mostly from Le Morne (not a pollution hot spot), and the *Littorina littorea* collected from Mon Choisy (10.4 – 13.5 µg/g) (Appendix 9). Lead was analysed in *E. mathaei* from four sites (Appendix 11). The highest concentrations (10.64 – 12.96 µg/g) were recorded in the skeleton and tissue of the organism from Le Morne.

5.4.9 Potential plant bio-indicator candidates for tin (Table 5.7 a)

Tin concentration in seawater around Mauritius varied in the range of 10 – 220 ppb (mean = 34 ± 49 ppb) and in sediment it occurred in the range of 3.7 – 55.37 µg/g (mean = 25.09 ± 15.81 µg/g). The most important concentrations of tin were recorded in the green seaweed *Ulva lactuca* with a range of 6.83 – 139 µg/g and mean of 36 ± 57.6 µg/g. Other important concentrations were recorded in the brown seaweed *Sargassum binderi* (concentration range of 0.39 – 58.6 µg/g), *Enteromorpha ramulosa* (concentration range of 5.33 – 28.6 µg/g) and *Ulva reticulata* (mean concentration of 20.5 µg/g, range = 17.23 – 24.67 µg/g) from Poudre d`Or.

Tin was analysed in *Ulva lactuca* from five sites, and the highest mean concentration (138.9 µg/g) was recorded from Bain des Dames (range 121.3 – 162.4 µg/g) (Appendix 3). The highest concentration of tin in *Enteromorpha ramulosa* was obtained from Bain des Dames (range = 24.6 –35.3 µg/g; mean = 28.6 µg/g) (Appendix 4). *Sargassum binderi* was analysed for tin from five sites (Appendix 5),

Table 5.6 b : Variation of Lead concentration (ppm) in marine animals

Lead : Sites	*Morula granulata*	*Nerita undata*	*Cypraea tigris*	*Cypraea caputserpentis*	*Littorina littorea(0.5-1 cm)*	*Littorina littorea (1.1-1.5 cm)*	*Littorina littorea (1.5-2.0 cm)*	*Isognomon isognomon (0-2.5 cm)*	*Isognomon isognomon (2.6-5.0 cm)*	*Pinna muricata*	*Crassostrea cucullata*	*Littorina mauritiana (0.6-1.0 cm)*	*Littorina mauritiana (1.1-1.5 cm)*	*Littorina mauritiana (1.6-2.0 cm)*	*E. mathaei skeleton (0-2.5 cm)*	*E. mathaei flesh (0-2.5 cm)*	*E. mathaei skeleton (2.6-5.0 cm)*	*E. mathaei flesh (2.6-5.0 cm)*	*E. mathaei skeleton (5.1-7.5 cm)*	*E. mathaei flesh (5.1-7.5 cm)*
Cap Malheureux					7.48	6.44	3.18													
Mon Choisy	1.86	1.34		3.35		13.5	10.4	5.45	3.68											
Trou aux Biches																				
Baie du Tombeau																				
Bain des dames																				
Pointe aux Sables	6.35																			
Albion																				
Pointe Moyenne																				
Flic en Flacq																	8.1	8.08		
Le Morne															7.35	6.86	13	10.7	12.7	10.6
Poste de Flacq																				
Belle Mare			1.54					1.33	0.91											
Poste la Fayette																				
Pointe des Lascars																				
Poudre d'Or								5.53	2.25		2.47	6.34	6.74	9.43						
Ile d'Ambre										13.6										
Grand Gaube												2.18	1.81	3.84						
Palmar												5.85	5.79	8.15						
St Felix												1.28	1.13	1.05	3.78	3.68	4.7	3.9	7.66	3.73
Minimum	1.86	1.34	1.54	3.35	7.48	6.44	3.18	1.33	0.91	13.6	2.47	1.28	1.13	1.05	3.78	3.68	4.7	3.9	7.66	3.73
Maximum	6.35	1.34	1.54	3.35	7.48	13.5	10.4	5.53	3.68	13.6	2.47	6.34	6.74	9.43	7.35	6.86	13	10.7	12.7	10.6
Mean	4.105	1.34	1.54	3.35	7.48	9.97	6.79	4.1	2.28	13.6	2.47	3.91	3.87	5.62	5.57	5.27	8.5	7.55	10.2	7.19
Stand Dev	3.175	#####	####	####	####	4.99	5.11	2.4	1.39	####	####	2.55	2.81	3.87	2.52	2.25	4	3.42	3.57	4.89

Tin : Sites	Water	Sediment	*Ulva lactuca*	*Ulva fasciata*	*Ulva reticulata*	*Enteromorpha ramulosa*	*Sargassum binderi*	*Padina boryana*	*Turbinaria ornata*	*Thalassodendron ciliatum*	*Halodule uninervis*	*Syringodium isoetifolium*	*Caulerpa sertularoides*	*Caulerpa serrulata*	*Sarconema filiforme*	*Galaxaura oblongata*	*Galaxaura marginata*	*Galaxaura canaliculata*	*Biemia fortis (sponge)*	*Perle bleu (sponge)*	*Brown tree (sponge)*
Table 5.7 a : Variation of tin concentration (ppm) in marine plants																					
Cap Malheureux	0.032	4.17																1.17			
Mon Choisy	0.021	20.43	6.83								4.69	11.1									
Trou aux Biches	0.035	19.47	10			12.1		15.2	3.77												
Baie du Tombeau	0.034	37.97		11.5																	
Bain des dames	0.033	46.34	139			28.6															
Pointe aux Sables	0.029	37.82	11.1			13.2									5.25						
Albion	0.021	3.7									5.14										
Pointe Moyenne	0.036	55.37	13.1			12.4															
Flic en Flacq	0.013	27.7					4.3	14.5								6.6					
Le Morne	0.01	18.6					2.64		4.14												
Poste de Flacq	0.01	11.05		9.73								2.85					2				
Belle Mare	0.012	15.09							8.11												10.3
Poste la Fayette	0.011	14.26					0.39	5.91		2.12		7.57									
Pointe des Lascars	0.019	16.84				5.33													9.95		
Poudre d'Or	0.031	52.78			20.5		58.6					21.6							8.2	13.5	
Ile d'Ambre	0.22	27.06					31.1	6.9					4.31								
Grand Gaube	0.012	17.96											4.2	4.67							
Minimum	0.01	3.7	6.83	9.73	20.5	5.33	0.39	5.91	3.77	2.12	4.69	2.85	4.2	4.67	5.25	6.6	2	1.17	8.2	13.5	10.3
Maximum	0.22	55.37	139	11.5	20.5	28.6	58.6	15.2	8.11	2.12	5.14	21.6	4.31	4.67	5.25	6.6	2	1.17	9.95	13.5	10.3
Mean	0.034	25.09	36	10.6	20.5	14.3	19.4	10.6	5.34	2.12	4.92	10.8	4.26	4.67	5.25	6.6	2	1.17	9.08	13.5	10.3
Stand Dev	0.049	15.81	57.6	1.22	####	8.58	25.2	4.89	2.41	####	0.32	7.98	0.08	####	####	####	###	####	1.24	####	####

and the highest mean concentrations were recorded from Poudre d'Or (58.6 μg/g) and Ile d'Ambre (31.1 μg/g).

5.4.10 Potential animal bio-indicator candidates for tin (Table 5.7 b)

The highest mean concentration of tin (13.9 ± 3.67 μg/g) was recorded in the sea urchin *Echinometra mathaei* flesh (size 2.6 – 5.0 cm). The snails *Littorina littorea* and *Littorina mauritiana* also had comparable levels of the metal.

5.4.11 Potential plant bio-indicator candidates for zinc (Table 5.8 a)

Zinc concentration in seawater around Mauritius varied in the range of 16 – 912 ppb (mean = 212 ± 268 ppb), and in the sediment it occurred in the range of 11 – 554 ppb (mean = 139 ± 173 ppb). In terms of maximum concentration accumulated, the following plants were the most important in decreasing order : *Enteromorpha ramulosa* (261 μg/g), *Ulva fasciata* (189 μg/g), *Padina boryana* (171 μg/g), *Ulva lactuca* (146 μg/g) and *Ulva reticulata* (111 μg/g). In terms of mean concentration, the following list is more relevant : *Enteromorpha ramulosa* (171 ± 84 μg/g), *Ulva fasciata* (167 ± 31 μg/g) and Padina boryana (89.4 ± 55.3 μg/g). *E. ramulosa* was examined from five sites, and the maximum concentration was recorded from Bain des Dames (239.5 – 300.4 μg/g; mean = 261.2 μg/g) (Appendix 4). *Ulva fasciata* was analysed from Baie du Tombeau (140.9 – 213.4 μg/g; mean = 189.2 μg/g) and Poste de Flacq (78.9 – 192.1 μg/g; mean = 145.3 μg/g) (Appendix 3). *Padina boryana* from Ile d'Ambre had the highest concentration of zinc (95 – 246.6 μg/g; mean = 170.8 μg/g) and that from Flic en Flac had the lowest (48.1 – 54.9 μg/g; mean = 51.5 μg/g).

5.4.12 Potential animal bio-indicator candidates for zinc (Table 5.8 b)

The highest concentration of zinc was obtained in the bivalve *Isognomon isognomon*, different sizes of which were collected from four sites (Appendix 10). The concentration varied in the range of 153.2 μg/g (Belle Mare) to 563.1 μg/g (Mon Choisy). Levels were equally high in both of the 0 – 2.5 cm and 2.6 – 5.0 cm size classes. The bivalves *Pinna muricata* and *Crassostrea cucullata* (Appendix 10) as well as the snails *Cypraea tigris* and *Cypraea caputserpentis* (Appendix 9) also contained important levels of the metal.

Table 5.7 b : Variation of Tin concentration (ppm) in marine animals																				
Tin : Sites	*Morula granulata*	*Nerita undata*	*Cypraea tigris*	*Cypraea caputserpentis*	*Littorina littorea(0.5-1 cm)*	*Littorina littorea (1.1-1.5 cm)*	*Littorina littorea (1.5-2.0 cm)*	*Isognomon isognomon (0-2.5 cm)*	*Isognomon isognomon (2.6-5.0 cm)*	*Pinna muricata*	*Crassostrea cucullata*	*Littorina mauritiana (0.6-1.0 cm)*	*Littorina mauritiana (1.1-1.5 cm)*	*Littorina mauritiana (1.6-2.0 cm)*	*E. mathaei skeleton (0-2.5 cm)*	*E. mathaei flesh (0-2.5 cm)*	*E. mathaei skeleton (2.6-5.0 cm)*	*E. mathaei flesh (2.6-5.0 cm)*	*E. mathaei skeleton (5.1-7.5 cm)*	*E. mathaei flesh (5.1-7.5 cm)*
Cap Malheureux					9.08	8.9	14.5													
Mon Choisy	4.7	2.54		3.01		2.65	1.97	0.84	1.02						11.9	14.4	11	16.1	11.8	11.8
Trou aux Biches																				
Baie du Tombeau																				
Bain des dames																				
Pointe aux Sables	3.12																			
Albion																				
Pointe Moyenne																				
Flic en Flacq																	18	17.8		
Le Morne															7.79	9.89	10	10	11.6	11.8
Poste de Flacq																				
Belle Mare			3.25					1.98	3.21											
Poste la Fayette																				
Pointe des Lascars																				
Poudre d'Or								0.66	0.81		1.11	10.7	3.26	14.7						
Ile d'Ambre										2.51										
Grand Gaube												9.08	8.9	9.66						
Palmar												5.65	8.08	12.1						
St Felix												4.12	12.1	6.32	9.2	10.4	11	11.6	14.2	16.8
Minimum	3.12	2.54	3.25	3.01	9.08	2.65	1.97	0.66	0.81	2.51	1.11	4.12	3.26	6.32	7.79	9.89	10	10	11.6	11.8
Maximum	4.7	2.54	3.25	3.01	9.08	8.9	14.5	1.98	3.21	2.51	1.11	10.7	12.1	14.7	11.9	14.4	18	17.8	14.2	16.8
Mean	3.91	2.54	3.25	3.01	9.08	5.78	8.24	1.16	1.68	2.51	1.11	7.38	8.09	10.7	9.64	11.6	12	13.9	12.5	13.5
Stand Dev	1.117	#####	####	####	####	4.42	8.86	0.716	1.3292	####	####	3.02	3.65	3.56	2.1	2.48	3.7	3.67	1.45	2.9

Table 5.8 a : Variation of zinc concentration (ppm) in marine plants																					
Zinc : Site	**Water**	**Sediment**	***Ulva lactuca***	***Ulva fasciata***	***Ulva reticulata***	***Enteromorpha ramulosa***	***Sargassum binderi***	***Padina boryana***	***Turbinaria ornata***	***Thalassodendron ciliatum***	***Halodule uninervis***	***Syringodium isoetifolium***	***Caulerpa sertularoides***	***Caulerpa serrulata***	***Sarconema filiforme***	***Galaxaura oblongata***	***Galaxaura marginata***	***Galaxaura canaliculata***	***Biemia fortis (sponge)***	***Perle bleu (sponge)***	***Brown tree (sponge)***
Cap Malheureux	0.082	62																52.9			
Mon Choisy	0.116	23.42	46								32	46.2									
Trou aux Biches	0.109	28.53	146			180		76.4	40												
Baie du Tombeau	0.189	154.3		189																	
Bain des dames	0.912	374.8	33.1			261															
Pointe aux Sables	0.363	491.2	90.4			194									72.1						
Albion	0.041	18.55									36.2										
Pointe Moyenne	0.849	554	30.1			32.1															
Flic en Flacq	0.076	43.57					51	51.5								26.6					
Le Morne	0.072	24.11					48.1		64.7												
Poste de Flacq	0.065	13.35		145								84.6					93				
Belle Mare	0.069	11.17							36												32.4
Poste la Fayette	0.016	34.11					49.4	58.8		70.8		42.2									
Pointe des Lascars	0.061	159.2				187													36.7		
Poudre d'Or	0.242	172.4			111		59.7					74.7							38.5	67.2	
Ile d'Ambre	0.256	172.4					89.9	171					60.8								
Grand Gaube	0.084	25.38											71.9	103							
Minimum	0.016	11.17	30.1	145	111	32.1	48.1	51.5	36	70.8	32	42.2	60.8	103	72.1	26.6	93	52.9	36.7	67.2	32.4
Maximum	0.912	554	146	189	111	261	89.9	171	64.7	70.8	36.2	84.6	71.9	103	72.1	26.6	93	52.9	38.5	67.2	32.4
Mean	0.212	139	69	167	111	171	59.6	89.4	46.9	70.8	34.1	61.9	66.4	103	72.1	26.6	93	52.9	37.6	67.2	32.4
Stand Dev	0.268	173	49.1	31	####	84	17.5	55.3	15.6	####	3.01	20.9	7.83	####	####	####	###	####	1.29	####	####

Table 5.8.b : Variation of Zinc concentration (ppm) in marine animals

Zinc : Sites	*Morula granulata*	*Nerita undata*	*Cypraea tigris*	*Cypraea caputserpentis*	*Littorina littorea(0.5-1 cm)*	*Littorina littorea (1.1-1.5 cm)*	*Littorina littorea (1.5-2.0 cm)*	*Isognomon isognomon (0-2.5 cm)*	*Isognomon isognomon (2.6-5.0 cm)*	*Pinna muricata*	*Crassostrea cucullata*	*Littorina mauritiana (0.6-1.0 cm)*	*Littorina mauritiana (1.1-1.5 cm)*	*Littorina mauritiana (1.6-2.0 cm)*	*E. mathaei skeleton (0-2.5 cm)*	*E. mathaei flesh (0-2.5 cm)*	*E. mathaei skeleton (2.6-5.0 cm)*	*E. mathaei flesh (2.6-5.0 cm)*	*E. mathaei skeleton (5.1-7.5 cm)*	*E. mathaei flesh (5.1-7.5 cm)*
Cap Malheureux					22.4	14.7	24													
Mon Choisy	18.75	19.48		199		83.2	96.2	552.1	563.1											
Trou aux Biches															32	16.1	36	36.5	53.8	15.4
Baie du Tombeau																				
Bain des dames																				
Pointe aux Sables	52.75																			
Albion																				
Pointe Moyenne																				
Flic en Flacq																	47	47.4		
Le Morne															5.1	17.4	67	61.8	86.6	61.8
Poste de Flacq																				
Belle Mare			167					153.3	166.58											
Poste la Fayette																				
Pointe des Lascars																				
Poudre d'Or								248.1	277.45		203	20.7	22.9	22.3						
Ile d'Ambre										195										
Grand Gaube												16.5	17.2	34.5						
Palmar												11	15.5	11.7						
St Felix												11	19.7	53.6	20.4	6.61	34	15.2	55.4	20.4
Minimum	18.75	19.48	167	199	22.4	14.7	24	153.3	166.58	195	203	11	15.5	11.7	5.1	6.61	34	15.2	53.8	15.4
Maximum	52.75	19.48	167	199	22.4	83.2	96.2	552.1	563.1	195	203	20.7	22.9	53.6	32	17.4	67	61.8	86.6	61.8
Mean	35.75	19.48	167	199	22.4	49	60.1	317.8	335.71	195	203	14.8	18.9	30.5	19.2	13.4	46	40.2	65.3	32.5
Stand Dev	24.04	#####	####	####	####	48.5	51.1	208.4	204.58	####	####	4.73	3.2	18	13.5	5.88	15	19.7	18.5	25.5

Figure 5.1 : Metal concentration (µg/g or ppm) in *Ulva lactuca*

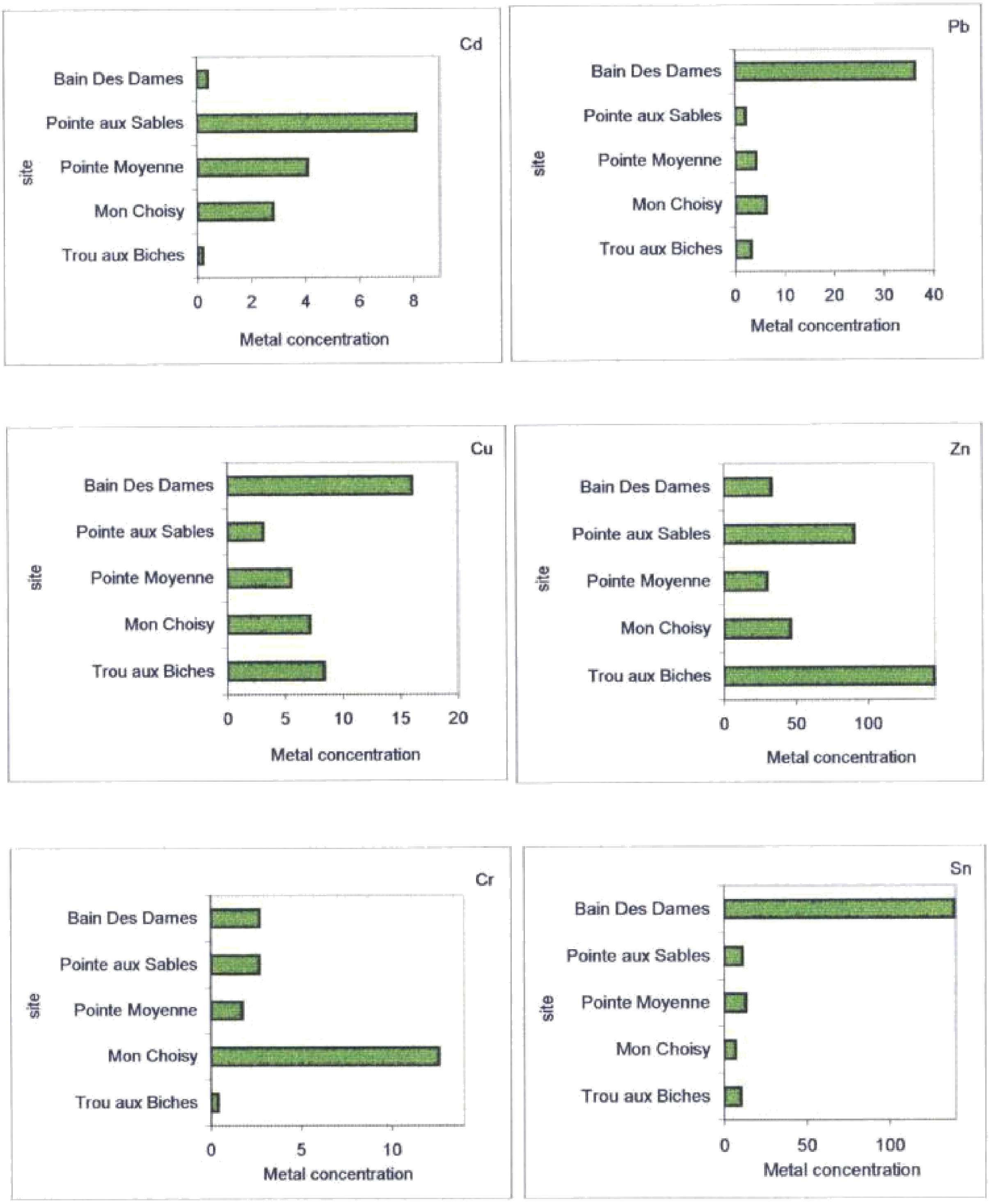


Figure 5.2 : Metal concentration (µg/g or ppm) in *Ulva fasciata*

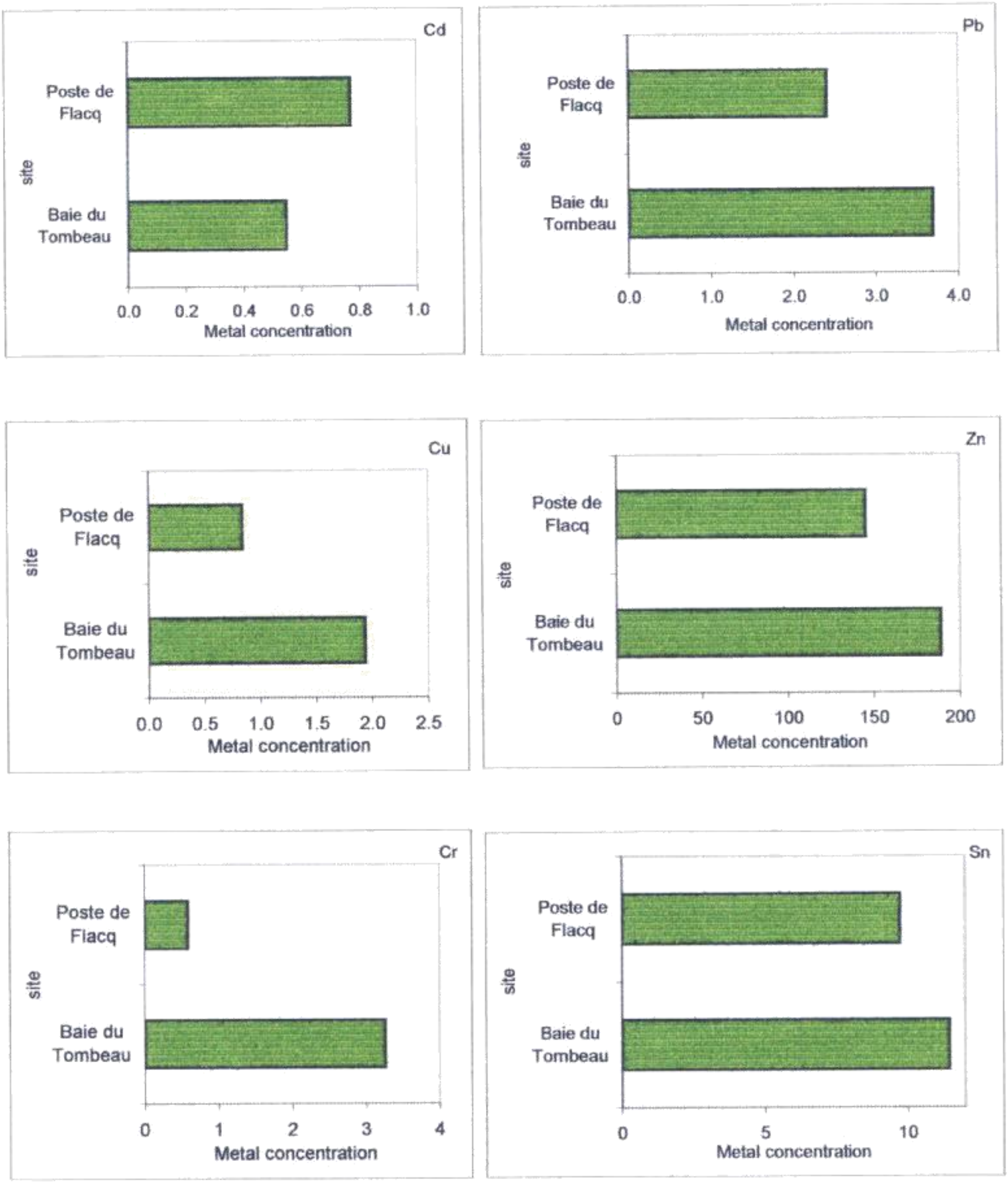


Figure 5.3 : Metal concentration (µg/g or ppm) in *Ulva reticulata*

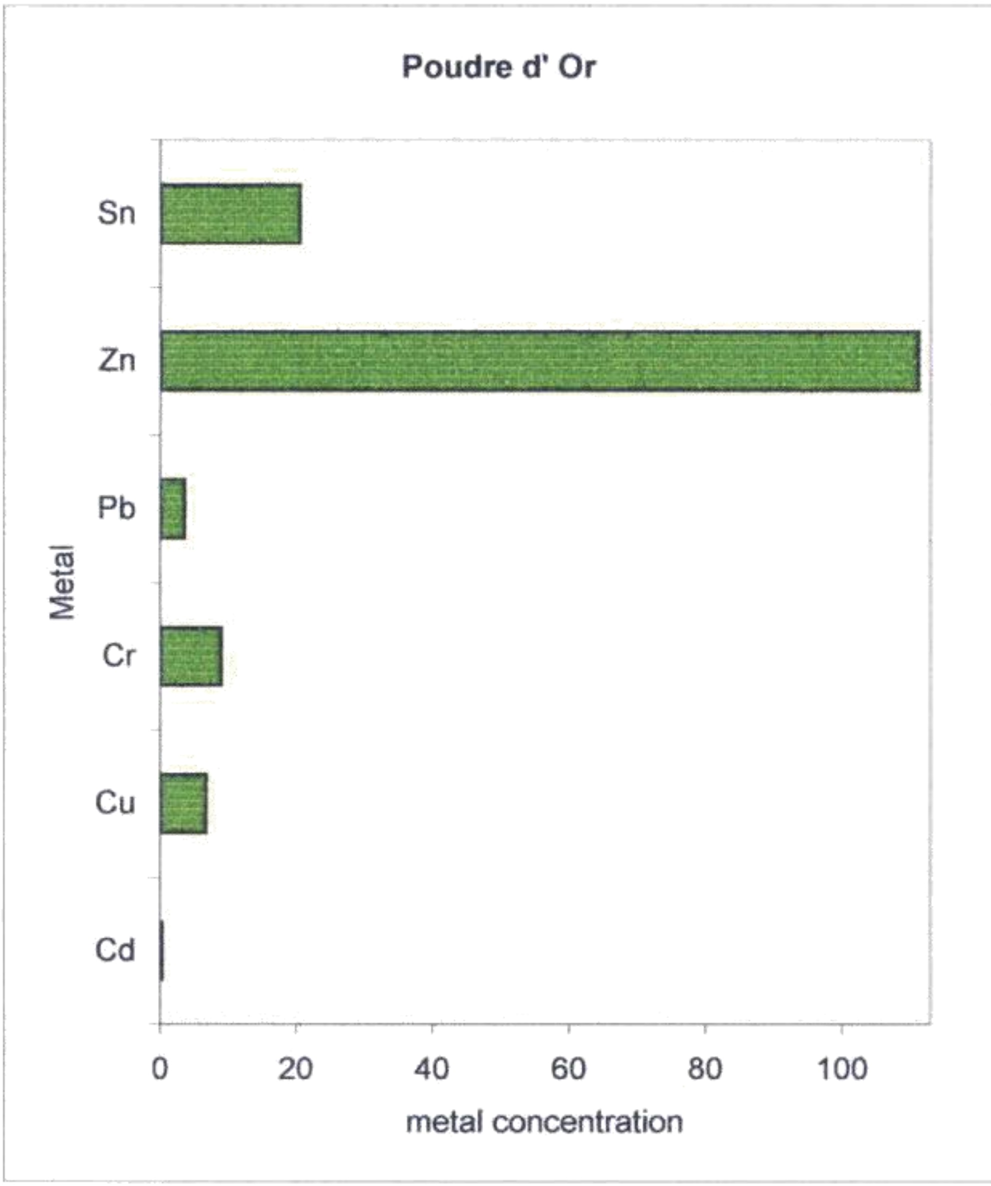


Figure 5.4 : Metal concentration (µg/g or ppm) in *Enteromorpha ramulosa*

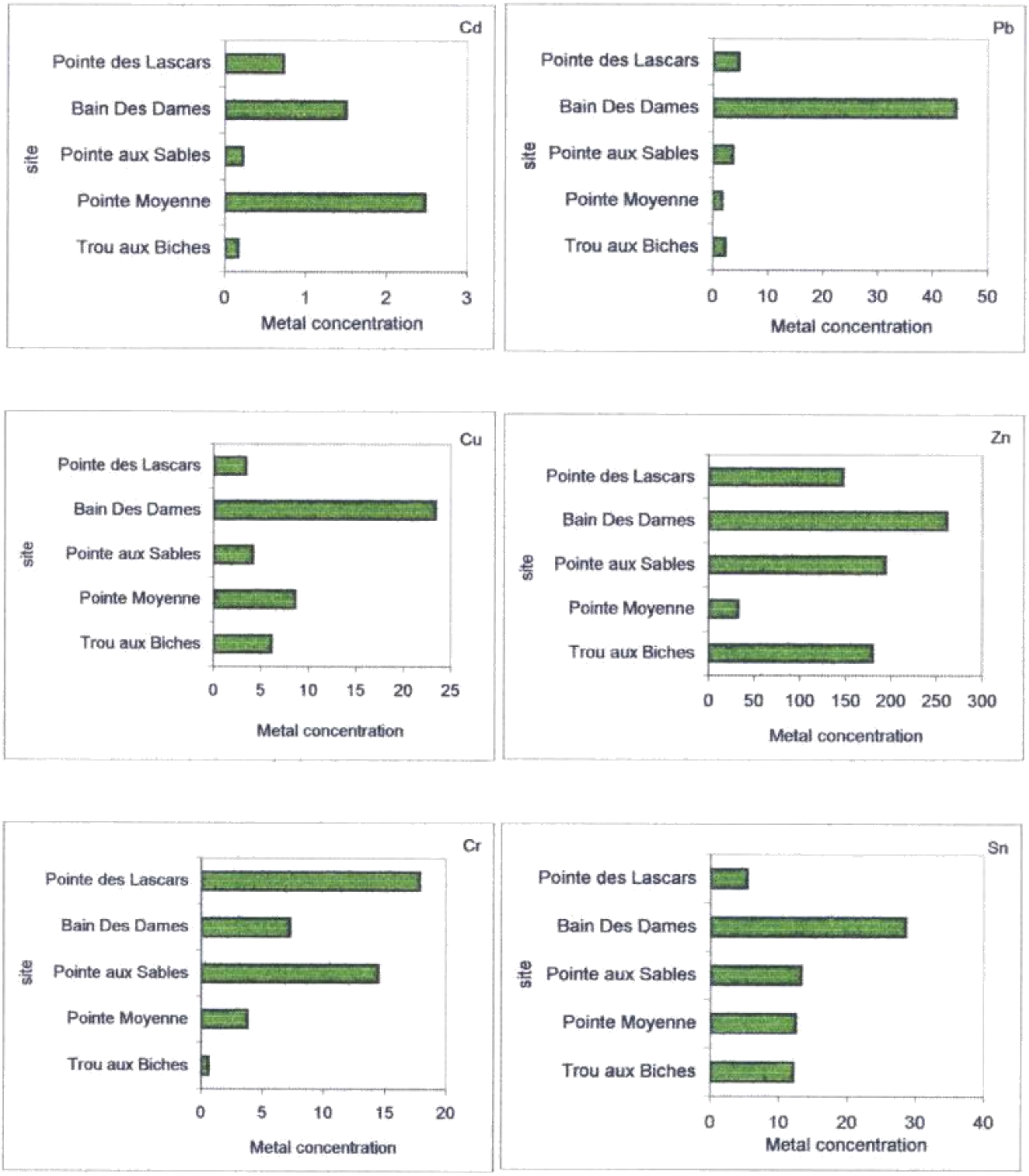


Figure 5.5: Metal concentration (µg/g or ppm) in *Sargassum binderi*

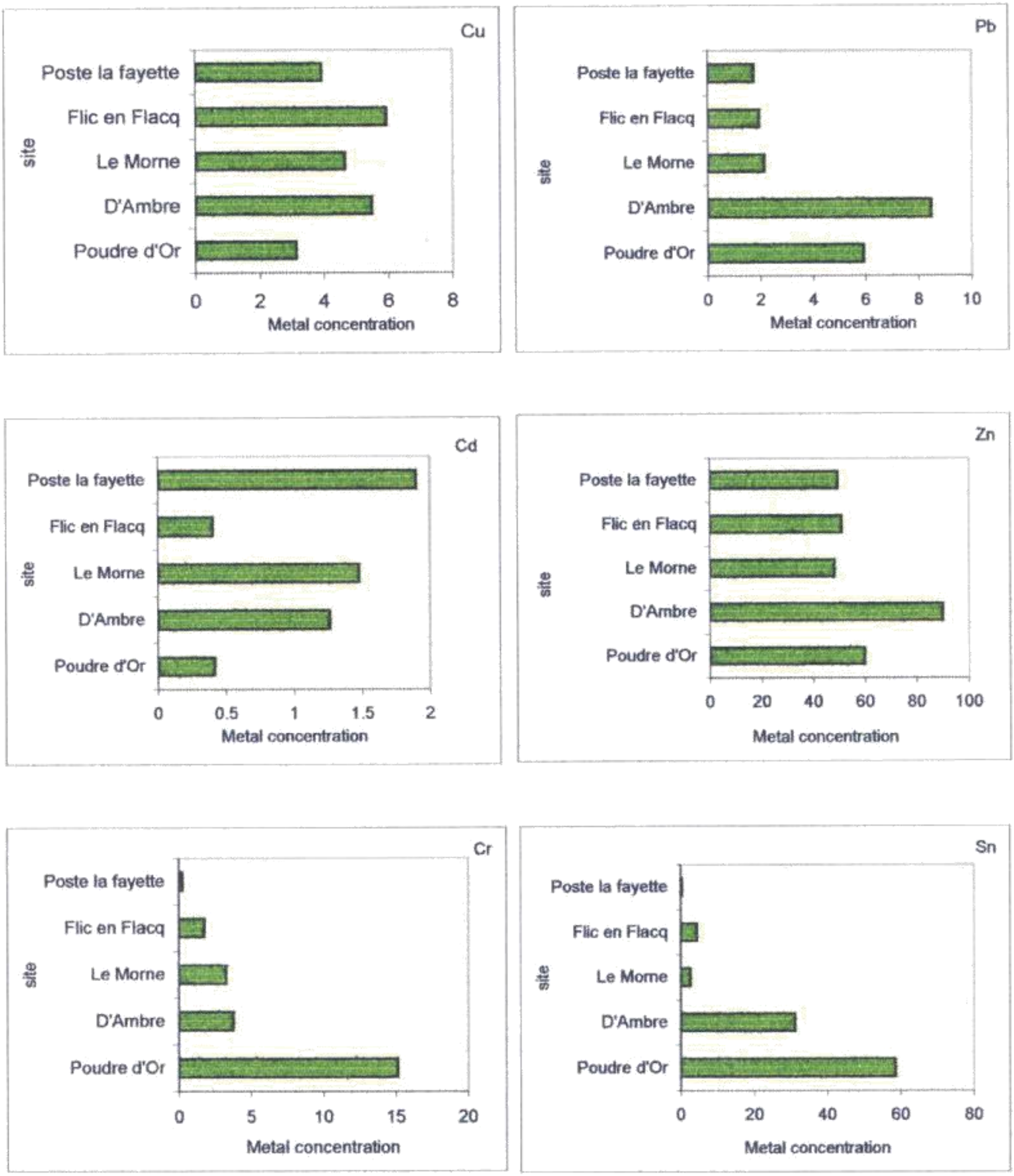


Figure 5.6 : Metal concentration (µg/g or ppm) in *Padina·boryana*

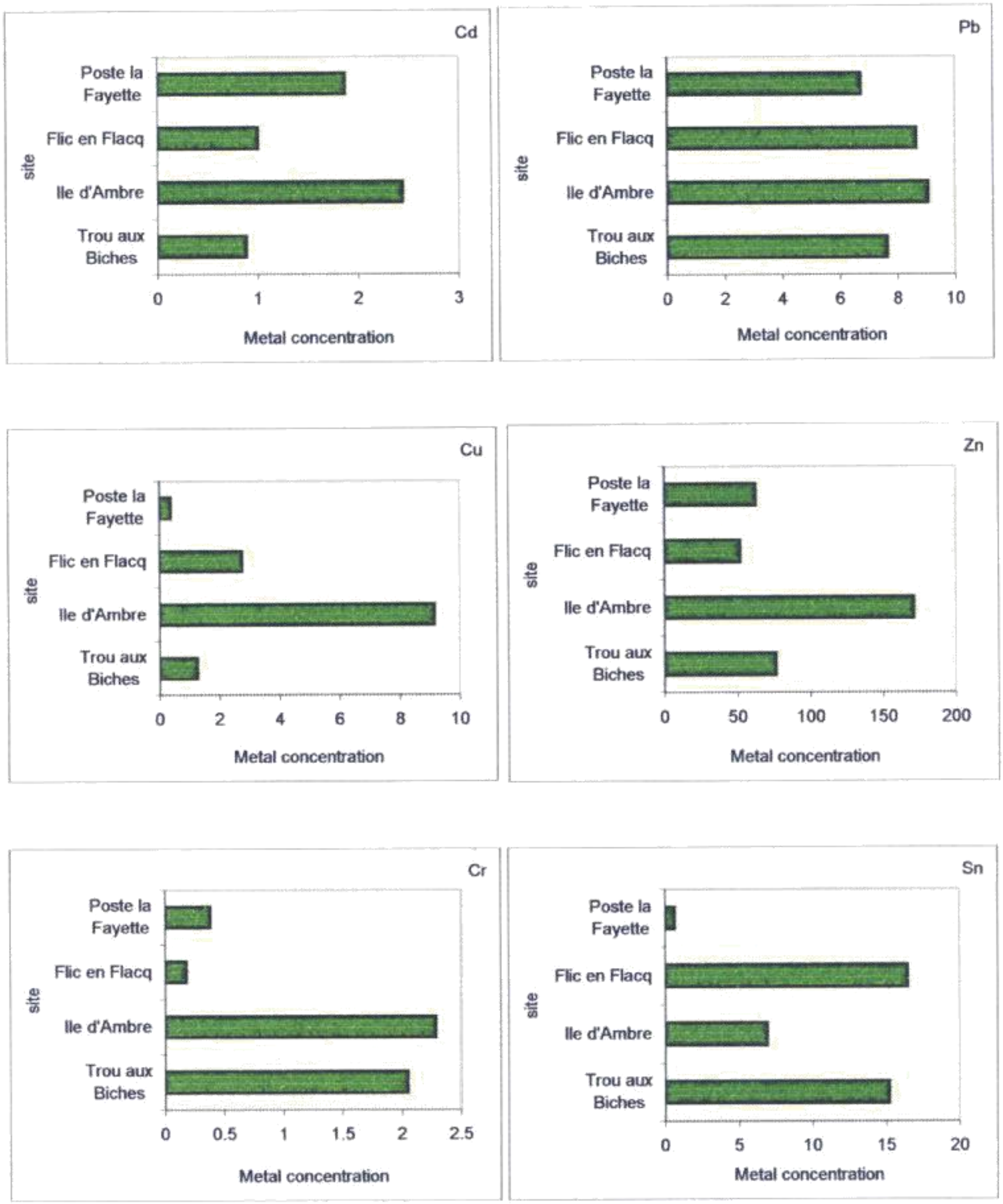


Figure 5.7 : Metal concentration (µg/g or ppm) in *Turbinaria ornata var. serrata*

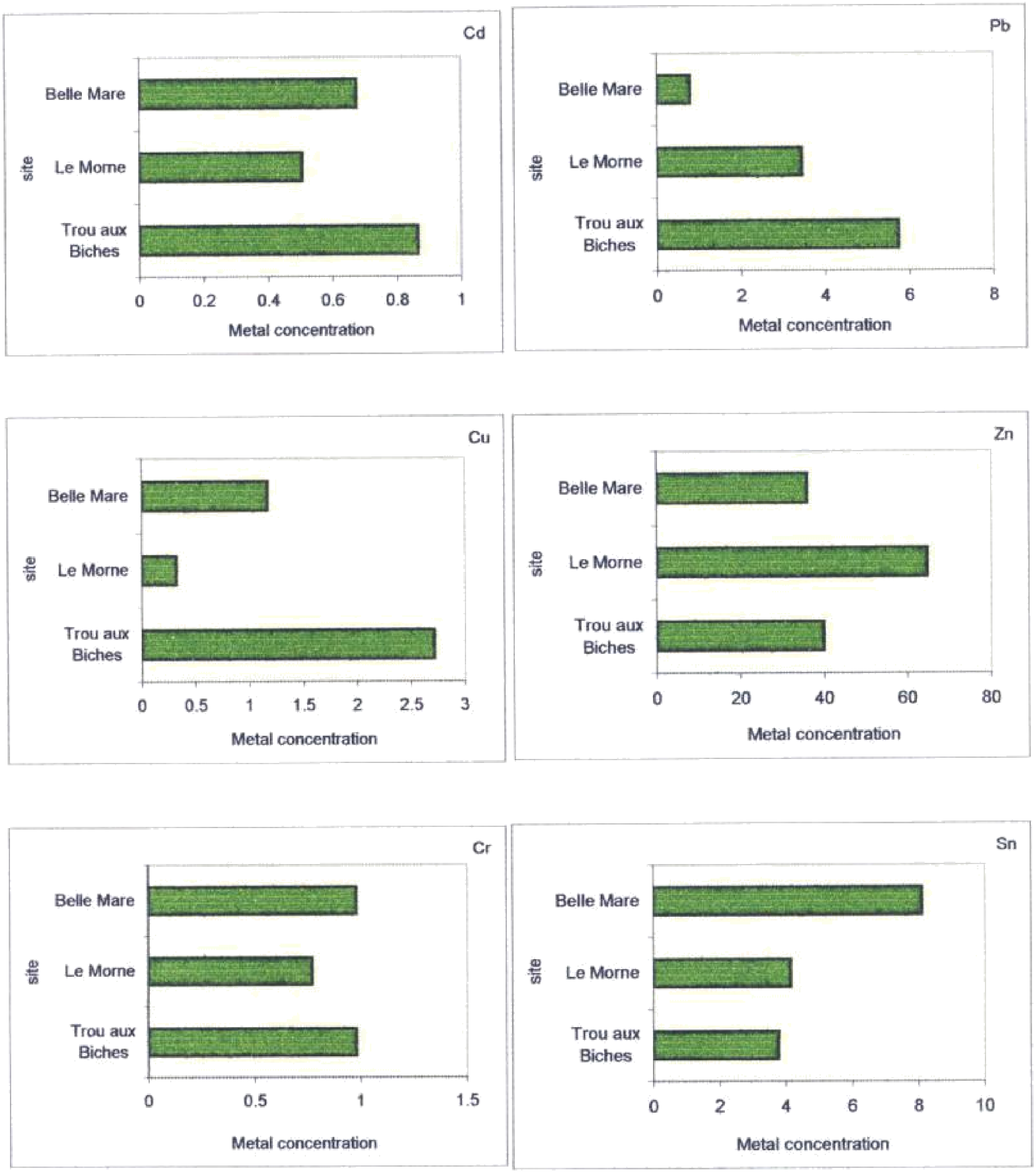


Figure 5.8 : Metal concentration (µg/g or ppm) in *Thalassodrendron ciliatum* (Poste la Fayette) and *Halodule uninervis* (Mon Choisy and Albion).

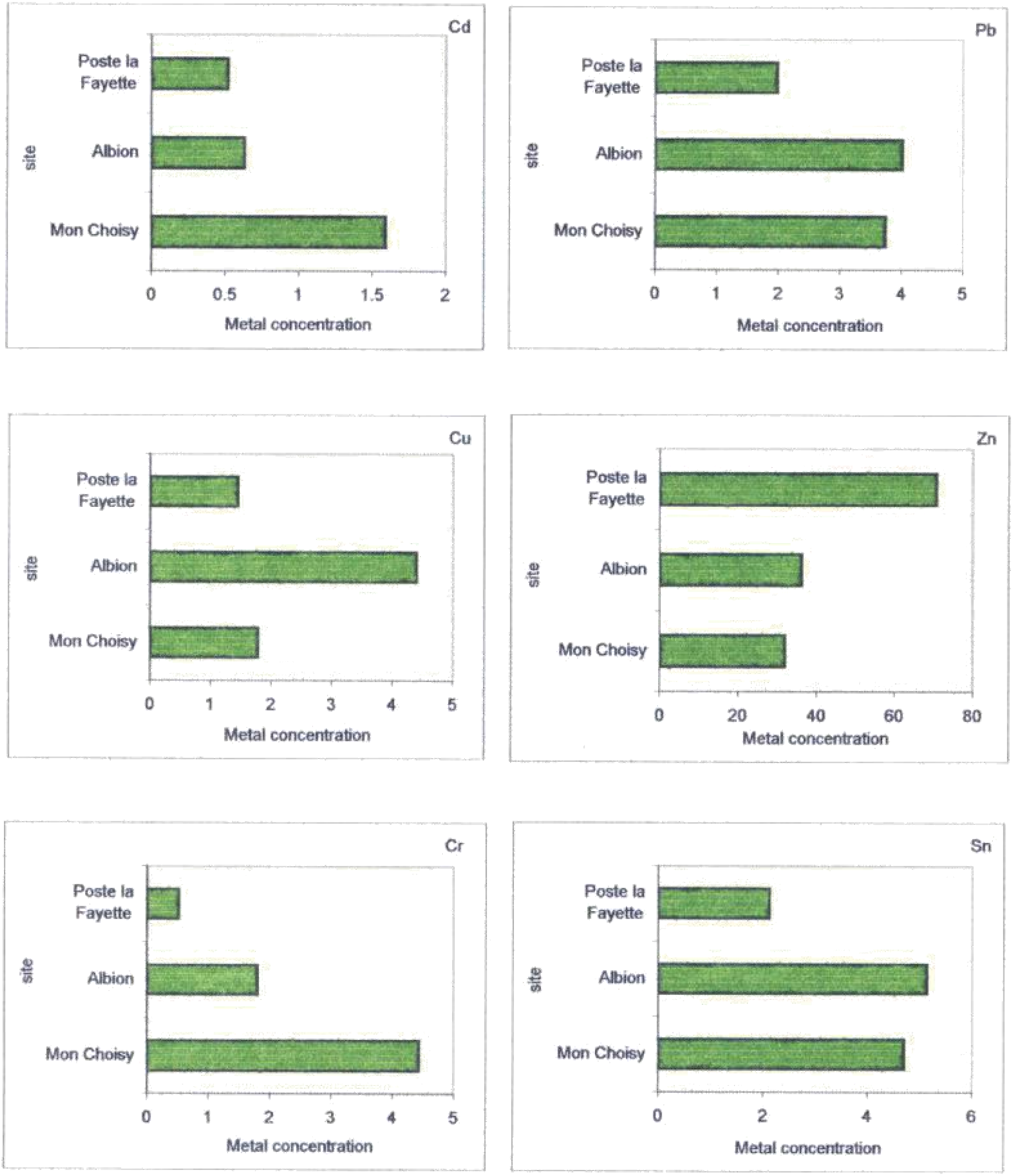


Figure 5.9 : Metal concentration (µg/g or ppm) in *Syringodium isoetifolium*

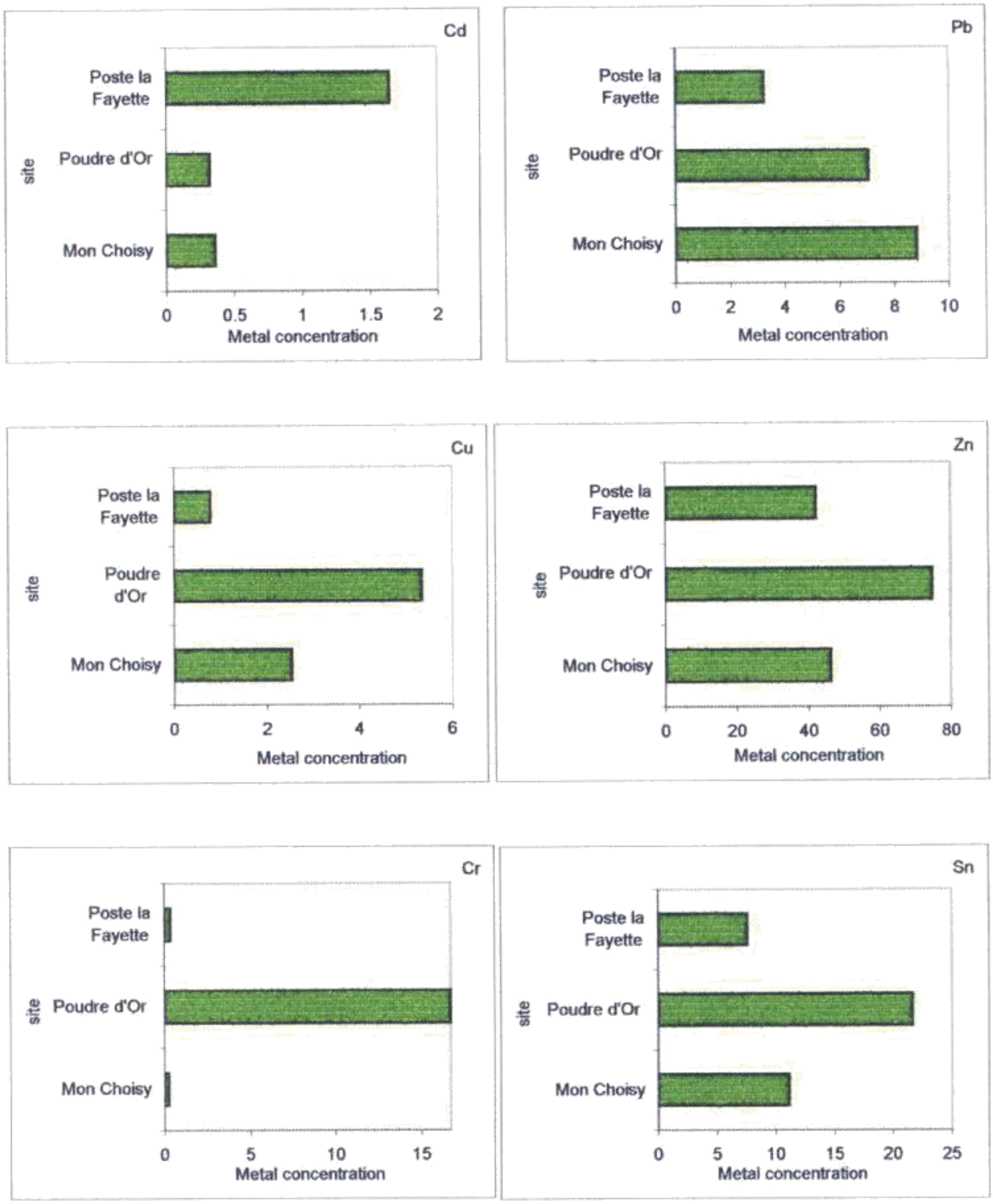


Figure 5.10 : Metal concentration (µg/g or ppm) in *Caulerpa sertularoides* (Ile d'Ambre, G. Gaube) and *C. serrulata* (G. Gaube)

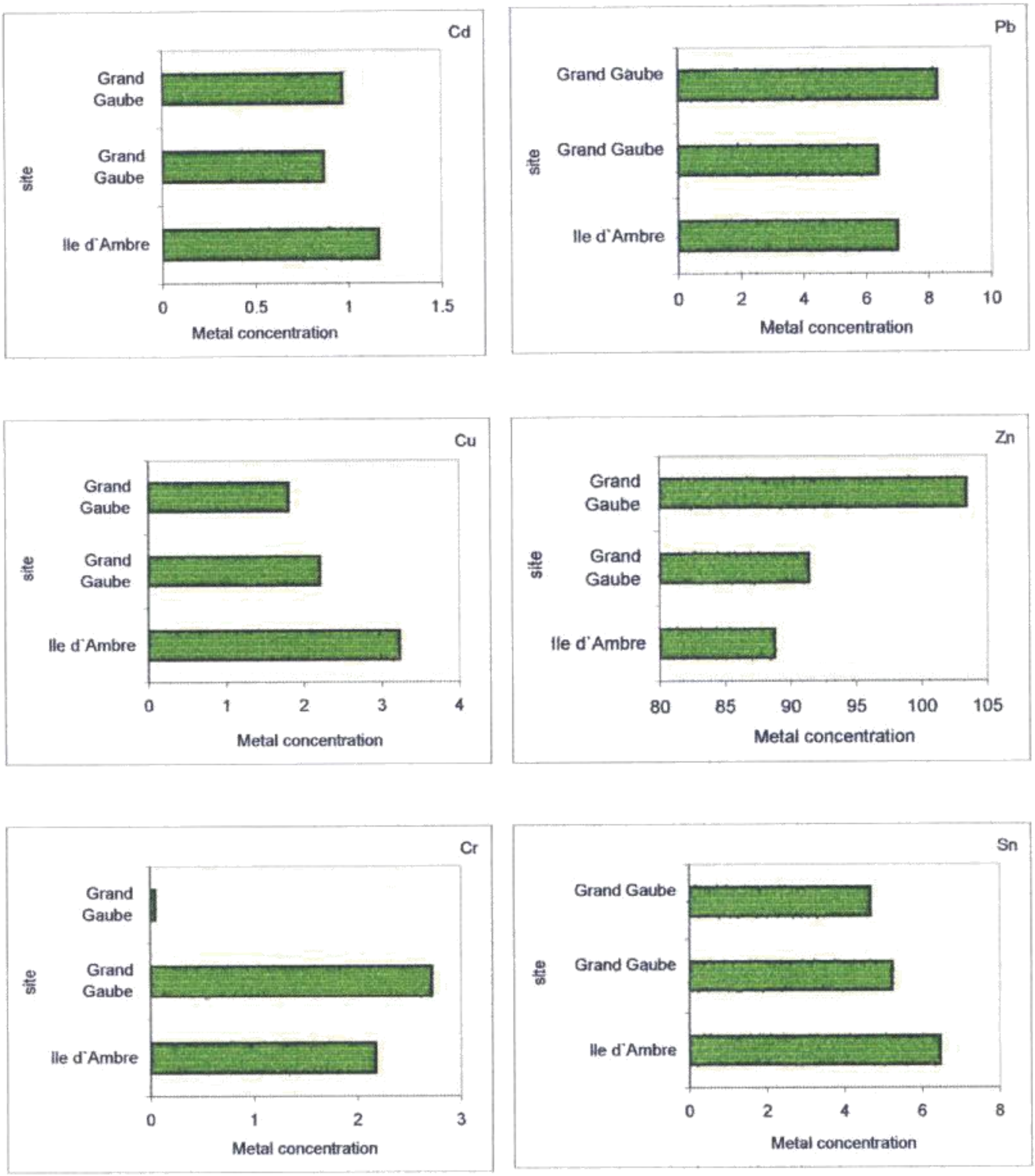


Figure 5.11 : Metal concentration (µg/g or ppm) in *Galaxaura canaliculata* (Cap Malheureux), *G. marginata* (Poste de Flacg), *G. oblongata* (Flic en Flacq) and *Sarconema filiforme* (Pointe aux Sables)

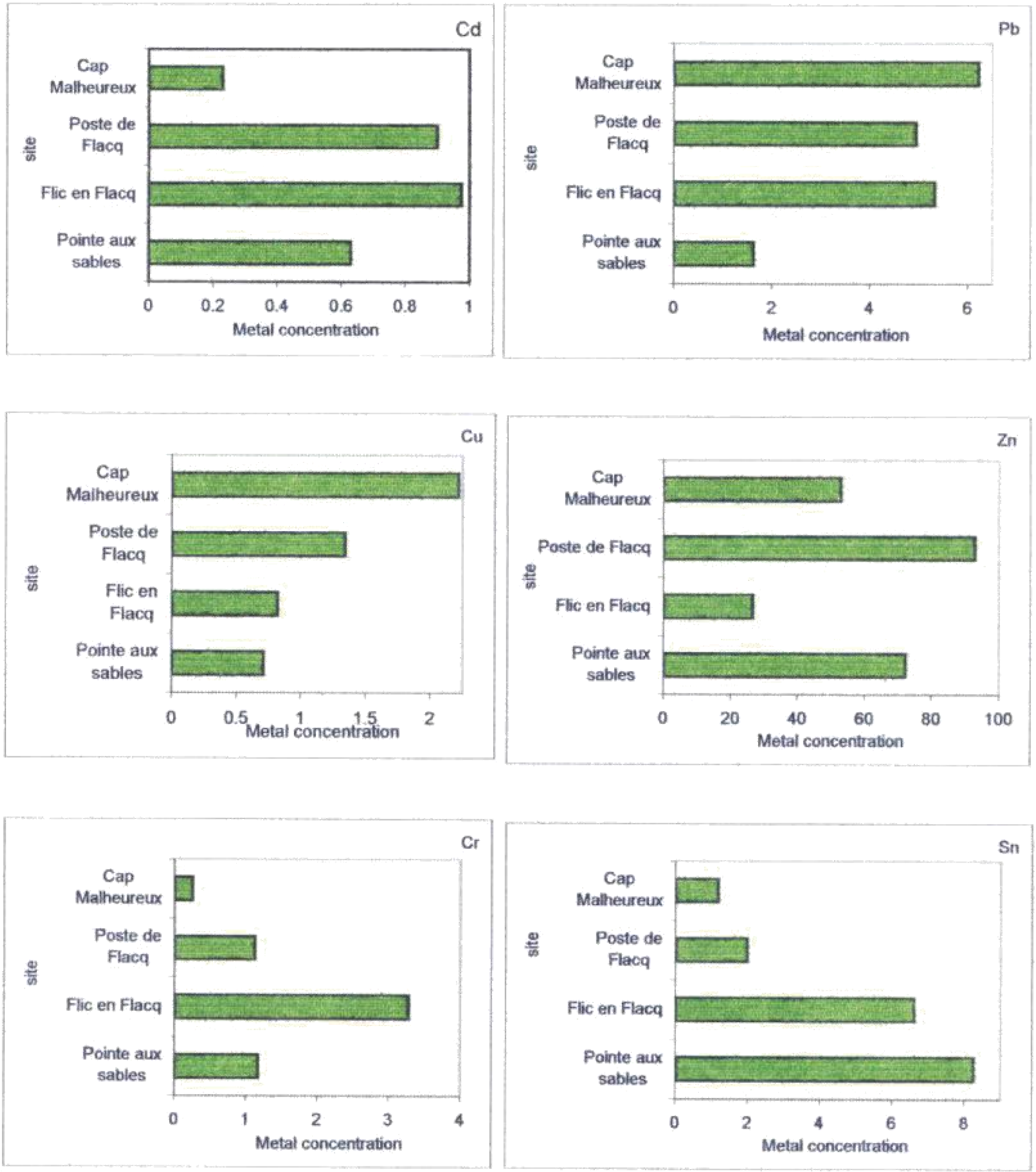


Figure 5.12 : Metal concentration (µg/g or ppm) in *Biemia fortis*

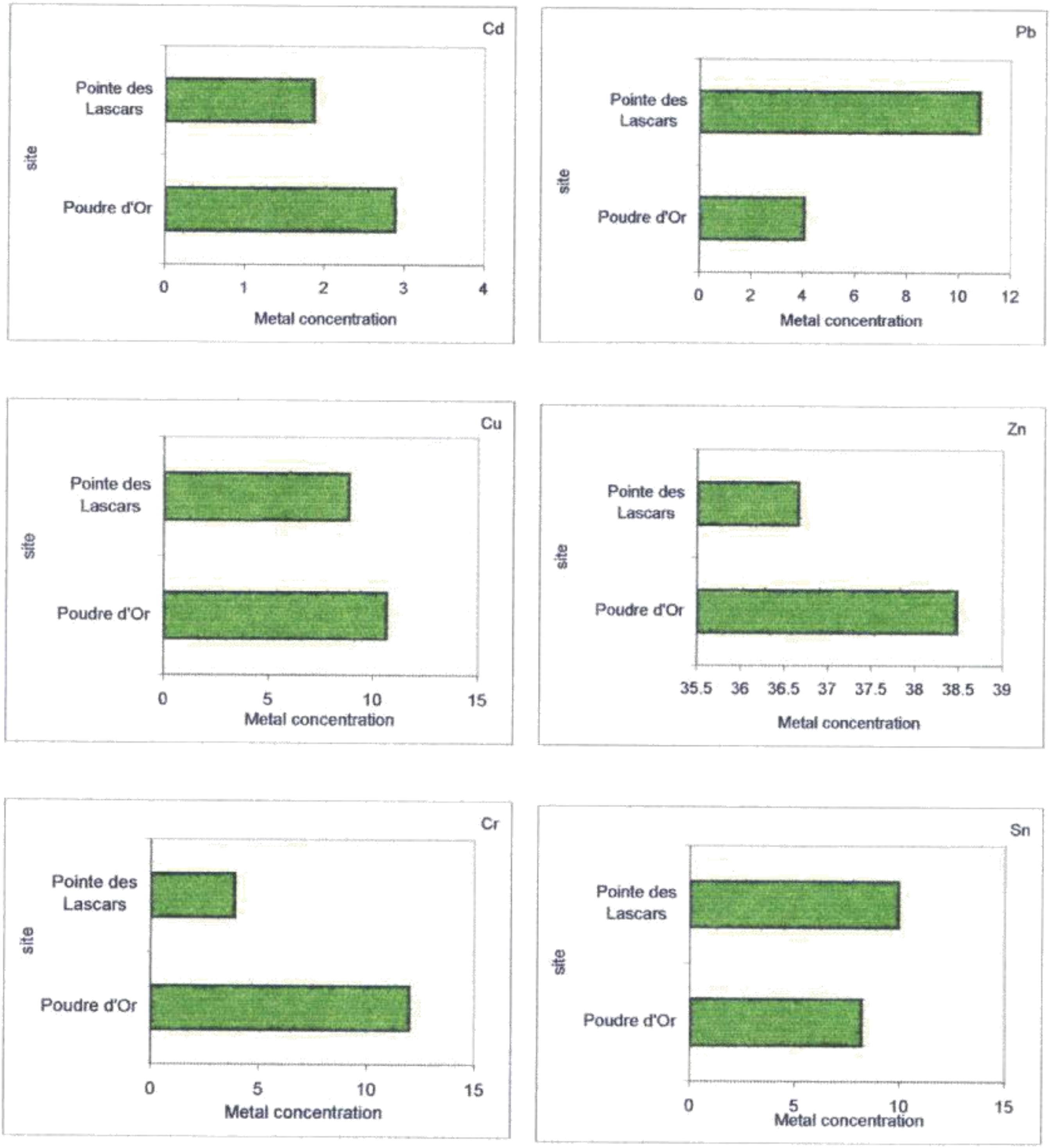


Figure 5.13 : Metal concentration (µg/g or ppm) in "Perle bleu" (Poudre d' Or) and "Brown tree" (Belle Mare)

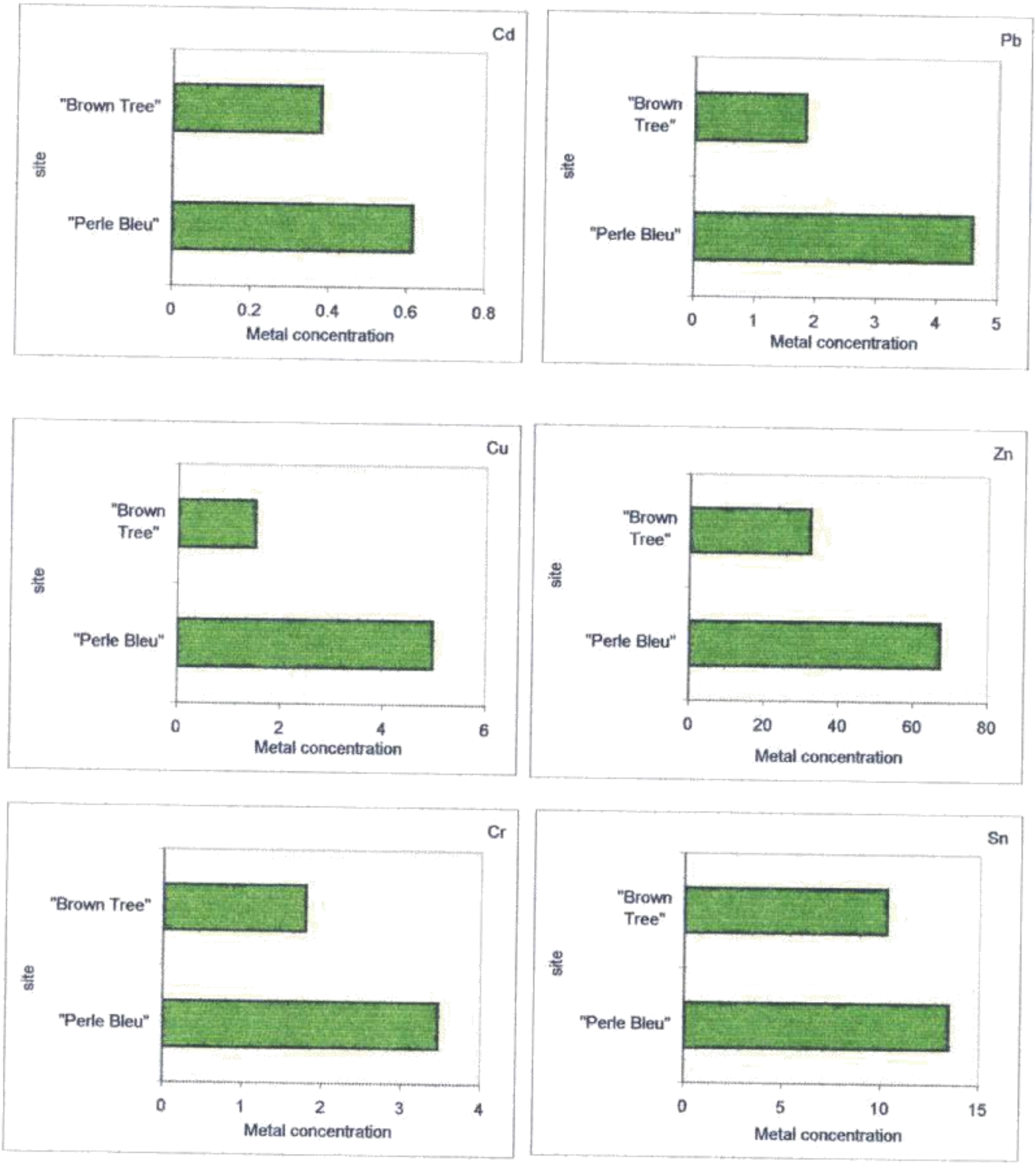


Figure 5.14 : Metal concentration (µg/g or ppm) in *Morula granulata*

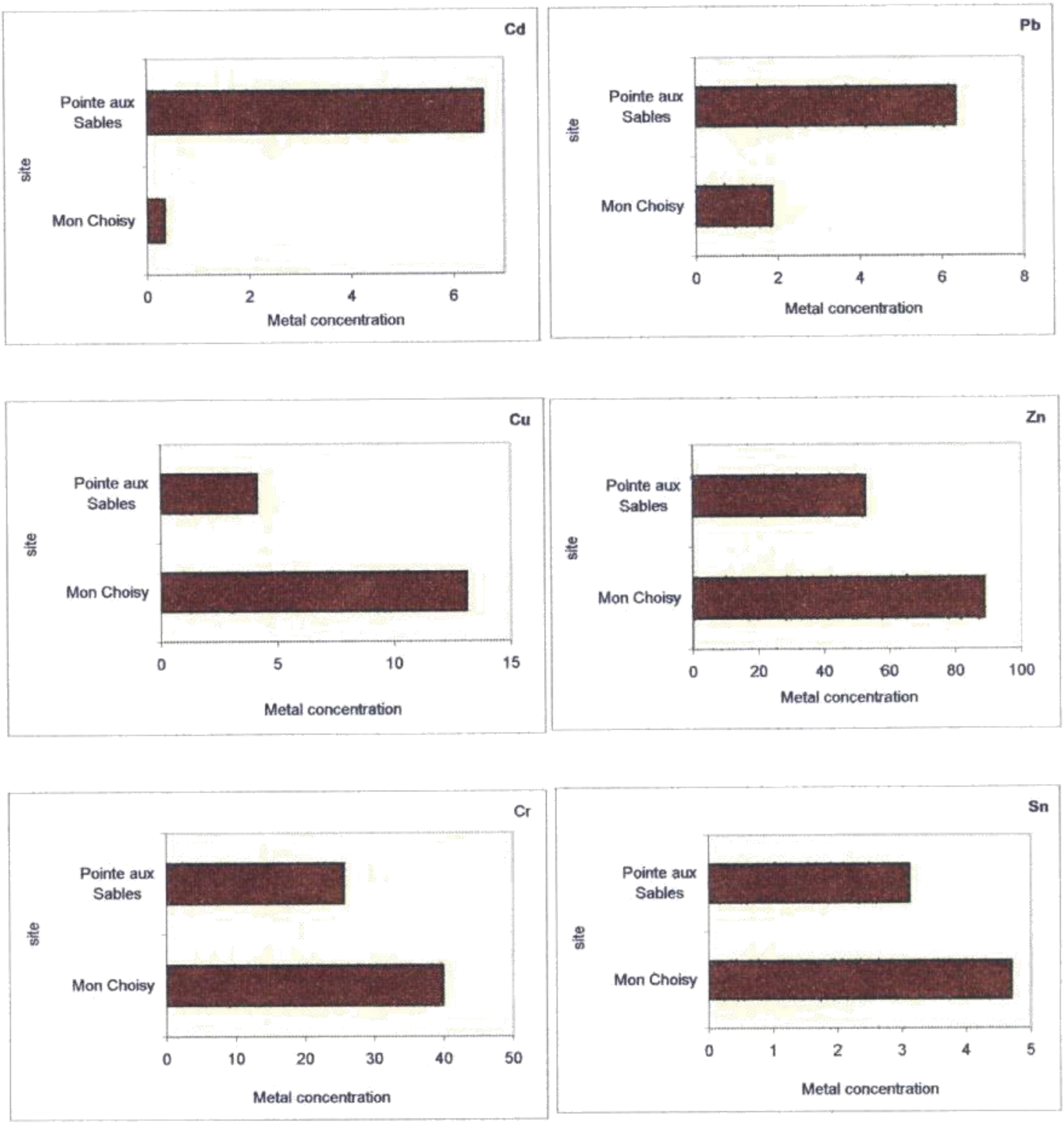
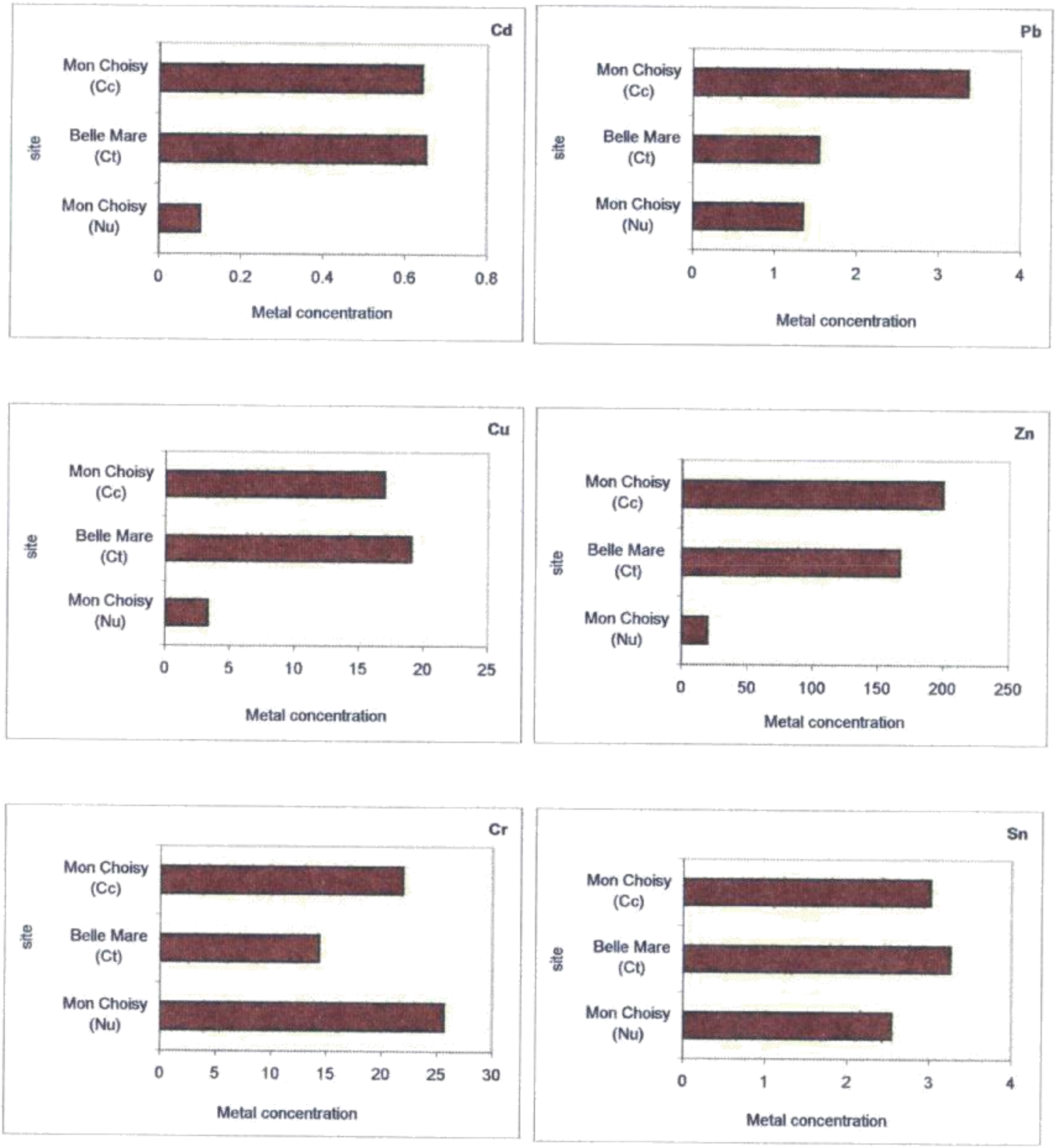


Figure 5.15 : Metal concentration (µg/g or ppm) in *Nerita undata* (Mon Choisy), *Cypraea tigris* (Belle Mare) and *C. carputserpentis* (Mon Choisy)



(Nu) : *Nerita undata*

(Ct) : *Cypraea tigris*

(Cc) : *Cypraea carputserpentis*

Figure 5.16 : Metal concentration (µg/g or ppm) in three size classes of *Littorina littorea lime*

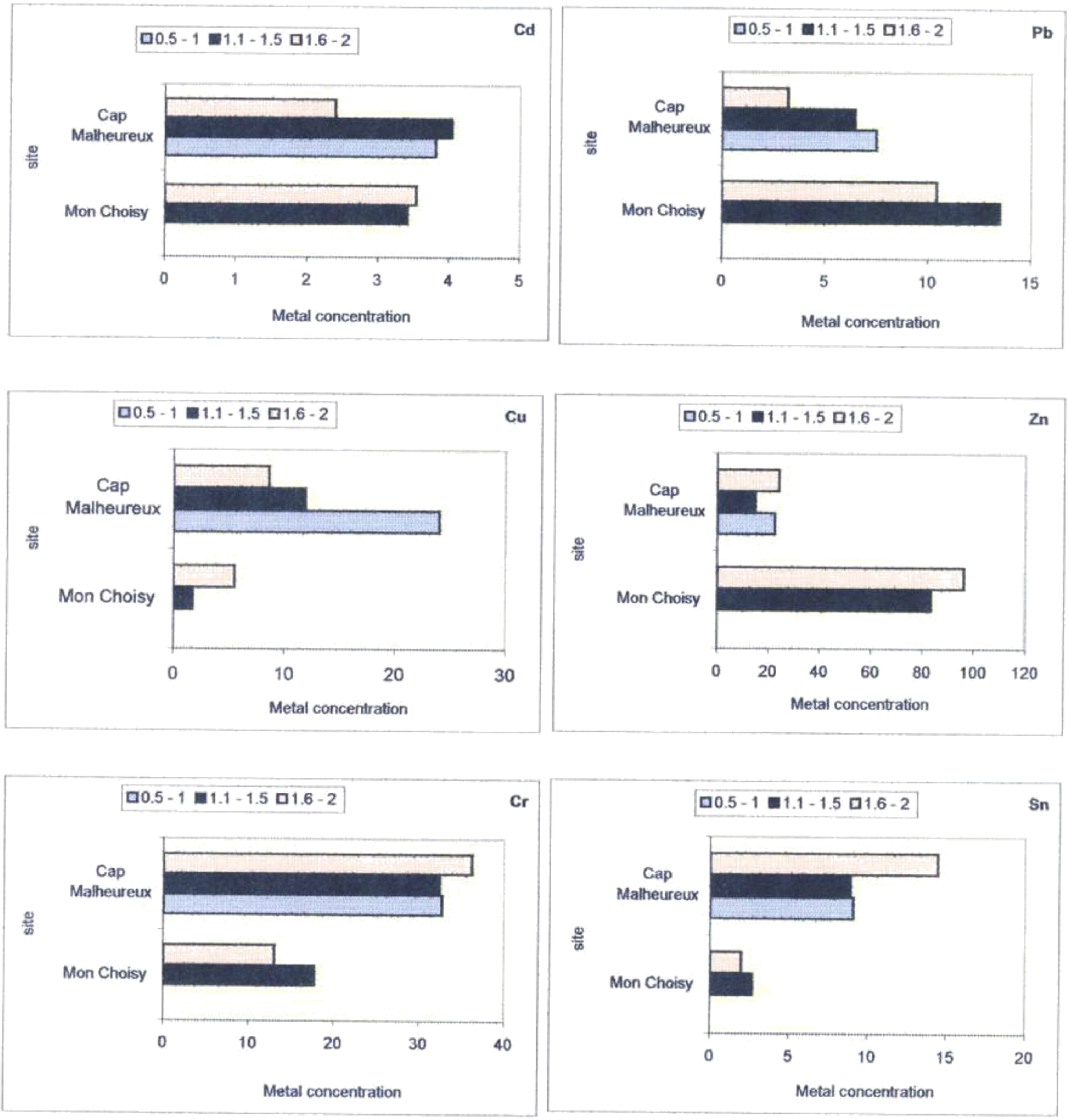


Figure 5.17 : Metal concentration (μg/g or ppm) in two size classes of *I. isognomon*

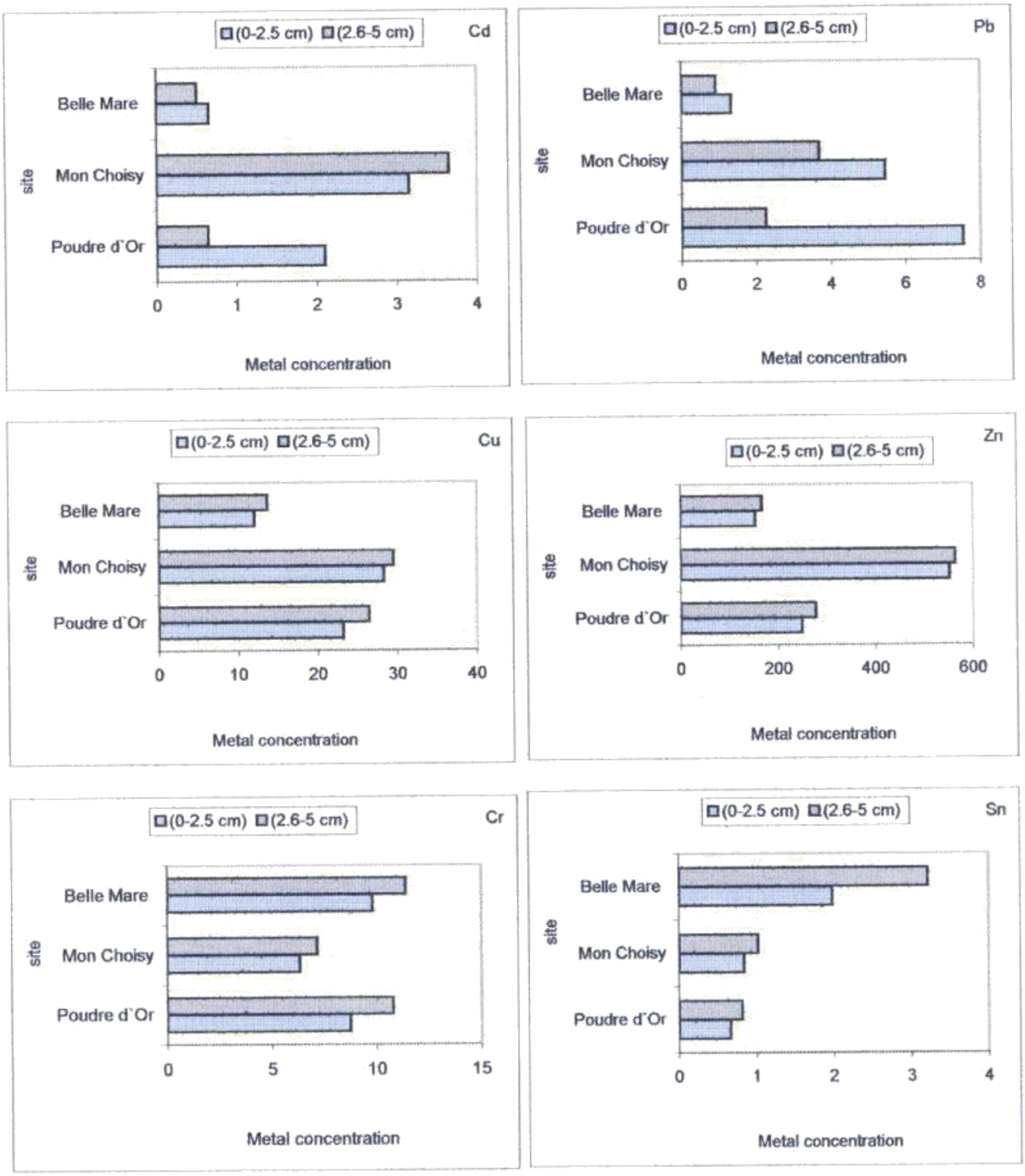


Figure 5.18 : Metal concentration (µg/g or ppm) in *Crassostrea cucullata* (Poudre d'Or) and *Pinna muricata* (Ile d'Ambre)

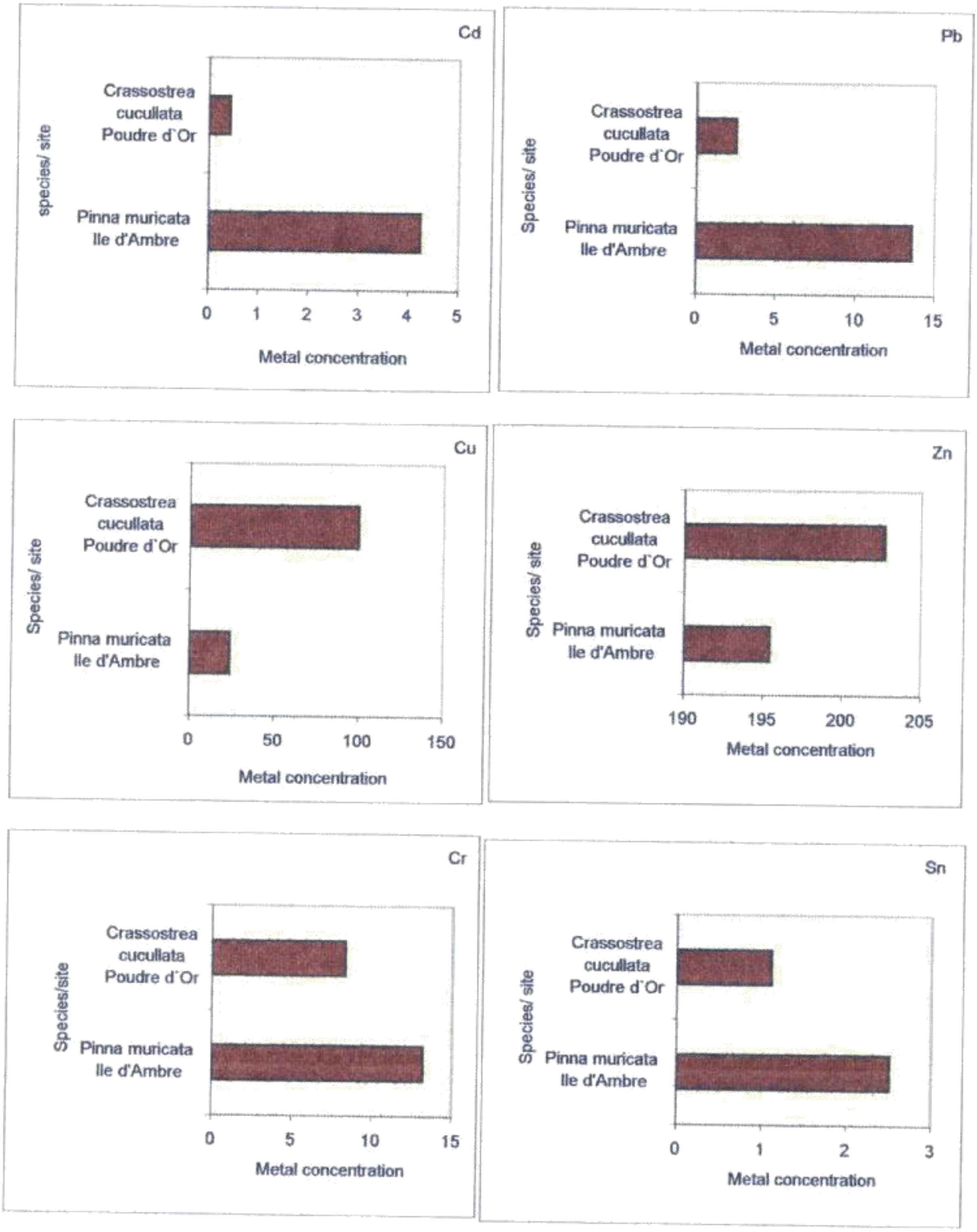


Figure 5.19 : Metal concentration (μg/g or ppm) in three size classes of *Littorina mauritiana*

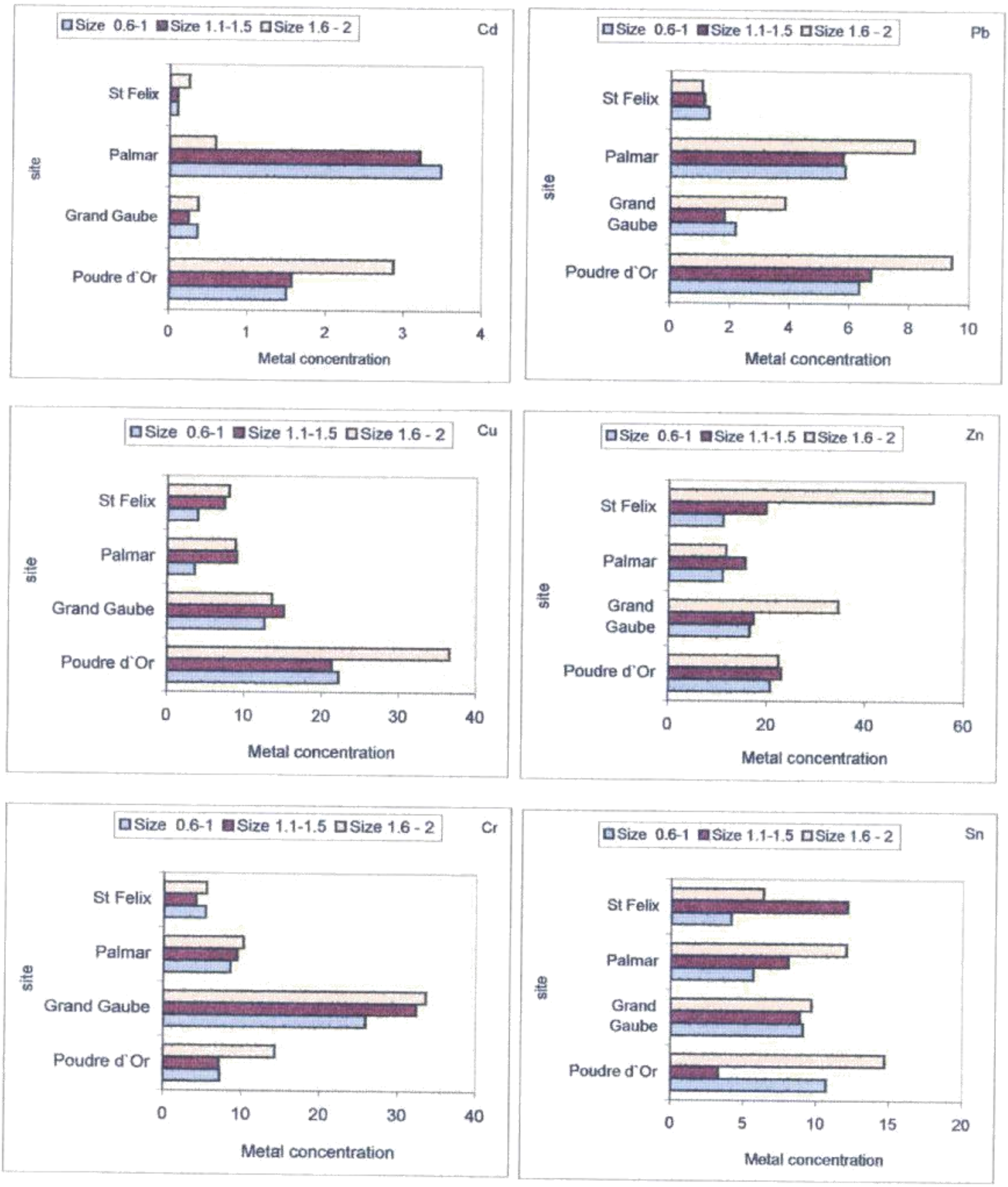


Figure 5.20 : Metal concentration (μg/g or ppm) in the skeleton of three size classes of sea urchin, *Echinometra mathaei*

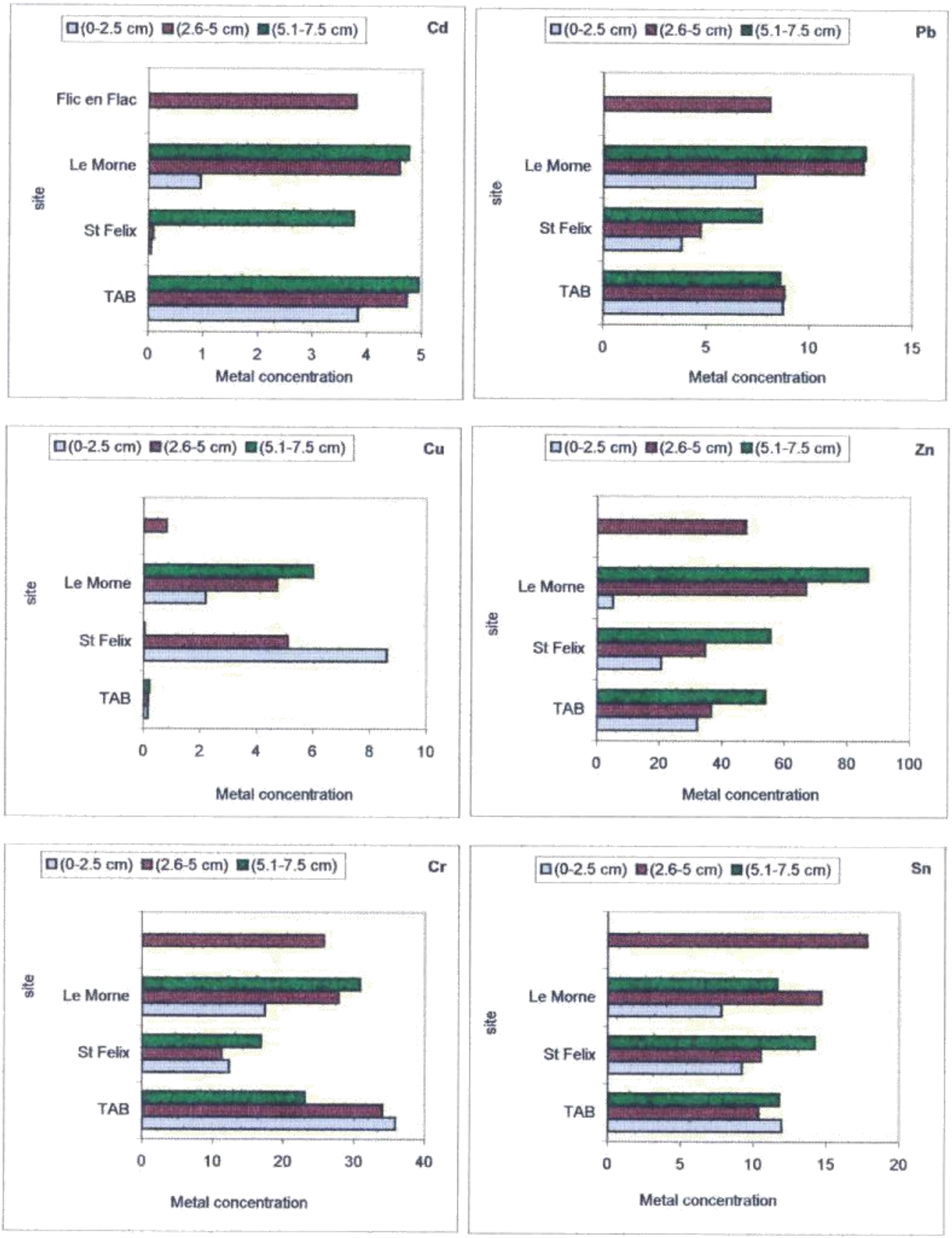
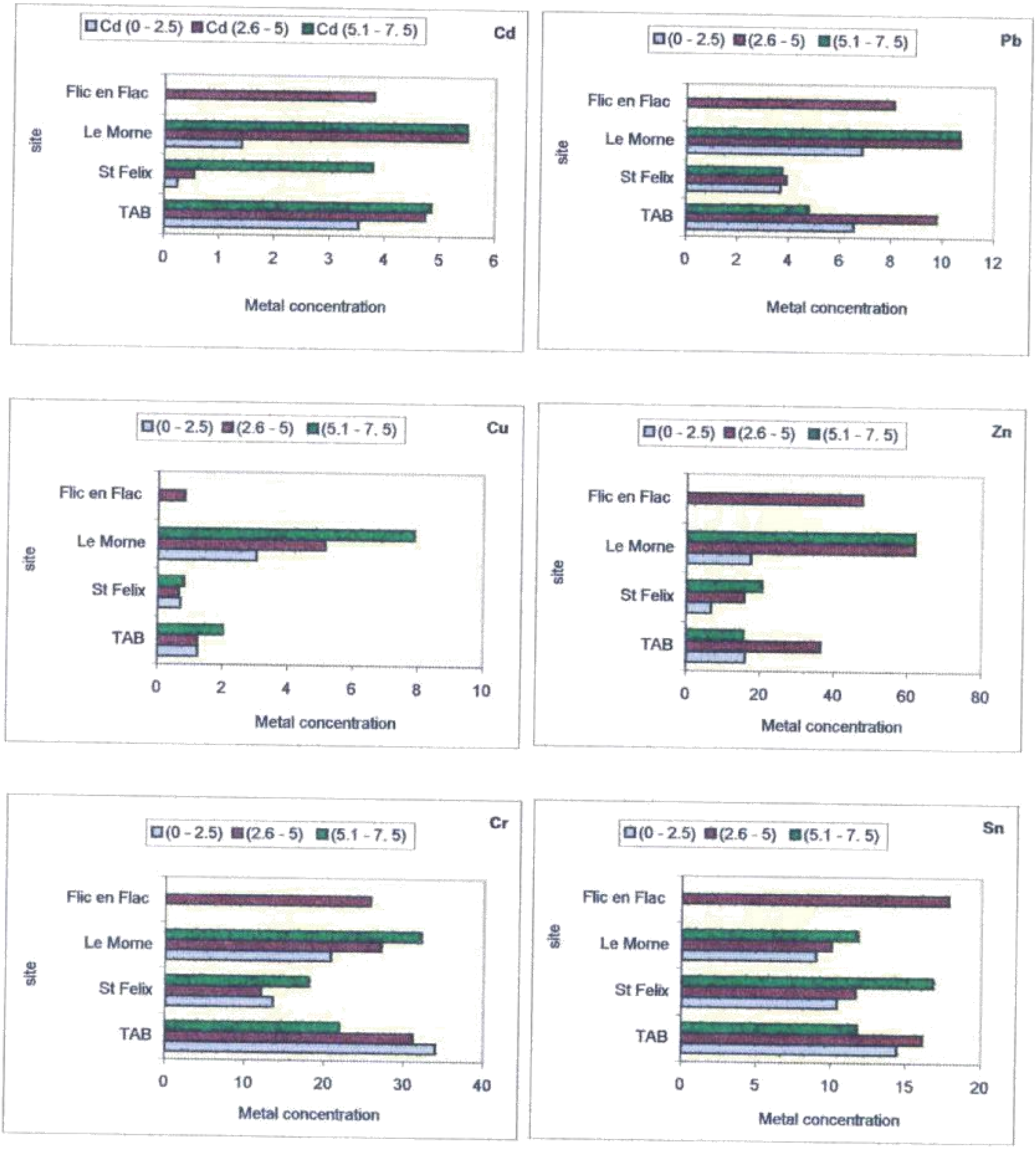


Figure 5.21 : Metal concentration (µg/g or ppm) in the flesh of three size classes of sea urchin, *Echinometra mathaei*



5.5 Metal abundance in commercial fish

Data on metal concentration in fish are given in Appendix 13 (a-e) and displayed graphically in Figure 5.22 (a-b). Analysis was performed on twenty species procured from various placers around the island during the study. Analysis work focused mainly on flesh but at times gill and liver tissue were also analysed. The graphical presentation in Figure 5.22 gives a better idea of metal abundance recorded in the flesh in decreasing order of importance. Appendix 14 gives the scientific names of the fish species on which the work was done.

5.5.1 Cadmium (Fig. 5.22 a)

The highest **mean** level of cadmium was recorded in Pavillon with 1.18 μg/g, followed by Lion (0.93 μg/g), Carpe (0.73 μg/g), Vieille (0.72 μg/g), Kaya (0.7 μg/g) and Batarde (0.65 μg/g). In Pavillon the highest levels were recorded from Baie du Tombeau (5.01 μg/g) and Pointe aux Sables (3.02 μg/g). The highest levels in Lion were also recorded from Pointe aux Sables (1.33 & 0.91 μg/g). The highest level in Carpe (1.23 μg/g) was from Mahebourg, in Vieille (8.45 μg/g) also from Mahebourg, in Kaya (1.05 μg/g) from Tamarin and in Batarde (4.13 μg/g) from Poudre d`Or. Species containing the lowest cadmium levels were Bretere, Berry, Mulet and Breton.

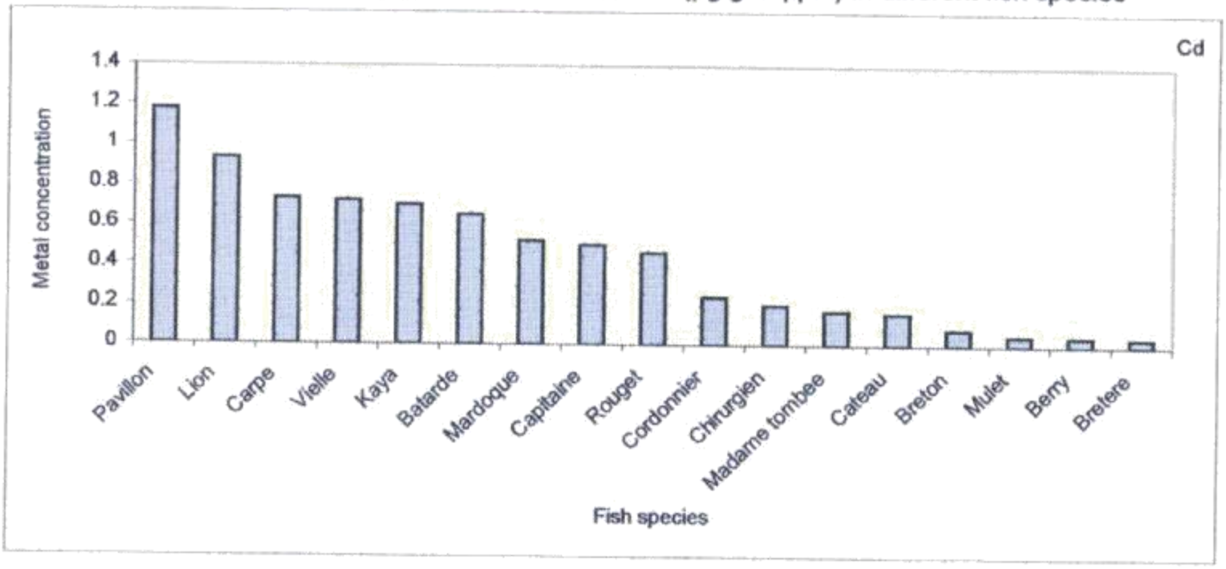
5.5.2 Copper (Fig. 5.22 a)

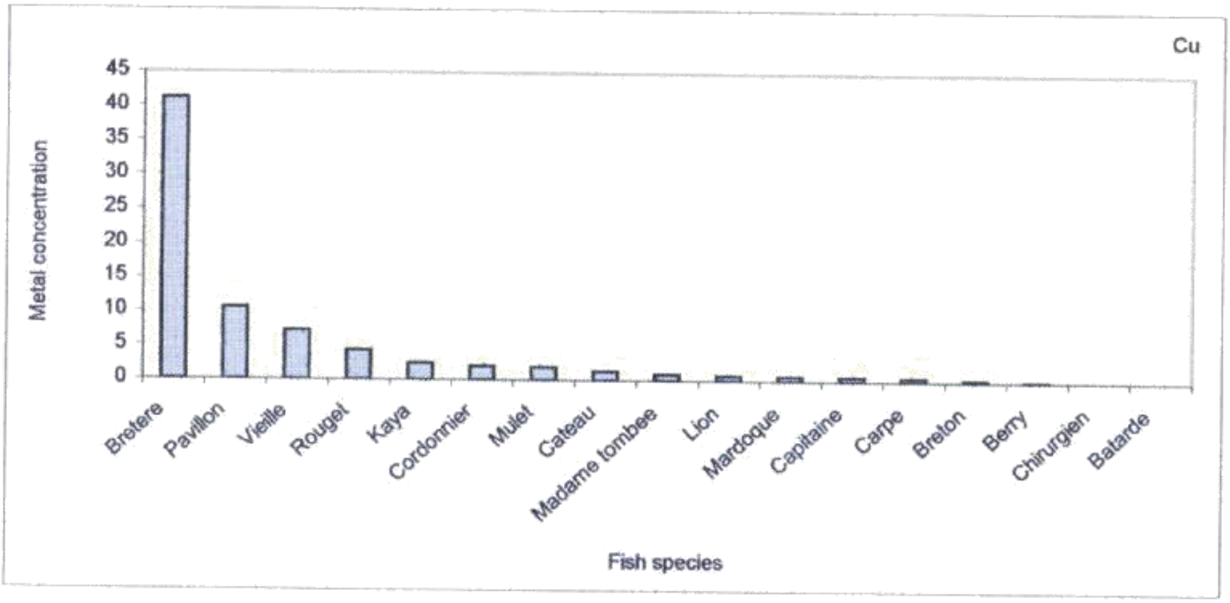
Bretere from Poudre d`Or had the highest mean level of copper (41.8 μg/g). Generally, copper level was less than 10 μg/g, except for Pavillon which showed 10.5 μg/g.

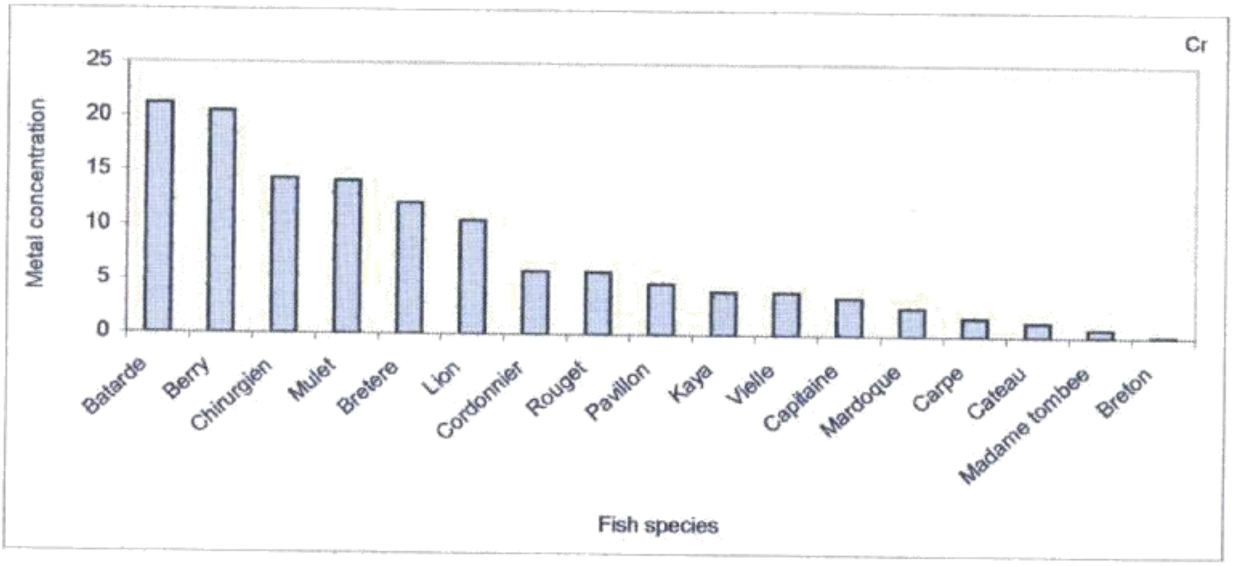
5.5.3 Chromium (Fig. 5.22 a)

Batarde from Poudre d`Or had the highest mean level of chromium (21.2 μg/g), followed by Berry from Trou d`Eau Douce (20.5 μg/g), Chirurgien (14.3 μg/g) and Mulet (14.1 μg/g). The lowest levels of chromium occurred in Breton, Madame Tombee and Cateau.

Figure 5.22 (a) : Metal concentration (µg/g or ppm) in different fish species







5.5.4 Lead (Fig. 5.22 b)

Batarde and Bretere from Poudre d`Or had the highest mean levels of lead (33.73 μg/g and 13.68 μg/g, respectively), followed by Vieille and Pavillon (10.65 μg/g and 7.78 μg/g, respectively). In fact the highest absolute levels of the metal were recorded in Vieille from Souillac (76.18 μg/g) and Poudre d`Or (55.93 μg/g) (Appendix 13 c). Chirurgien, Carpe and Breton had the lowest levels of lead.

5.5.5 Zinc (Fig. 5.22 b)

Mean zinc concentration was highest in Bretere (117.9 μg/g), Pavillon (90.47 μg/g), Mullet (76.25 μg/g) and Cordonnier (59.51 μg/g). In fact the highest absolute levels of zinc were recorded in Cordonnier (161.25 μg/g) from Souillac and Rouget (162.88 μg/g) also from Souillac. Madame Tombee, Vieille and Mardoque had the lowest concentrations of zinc.

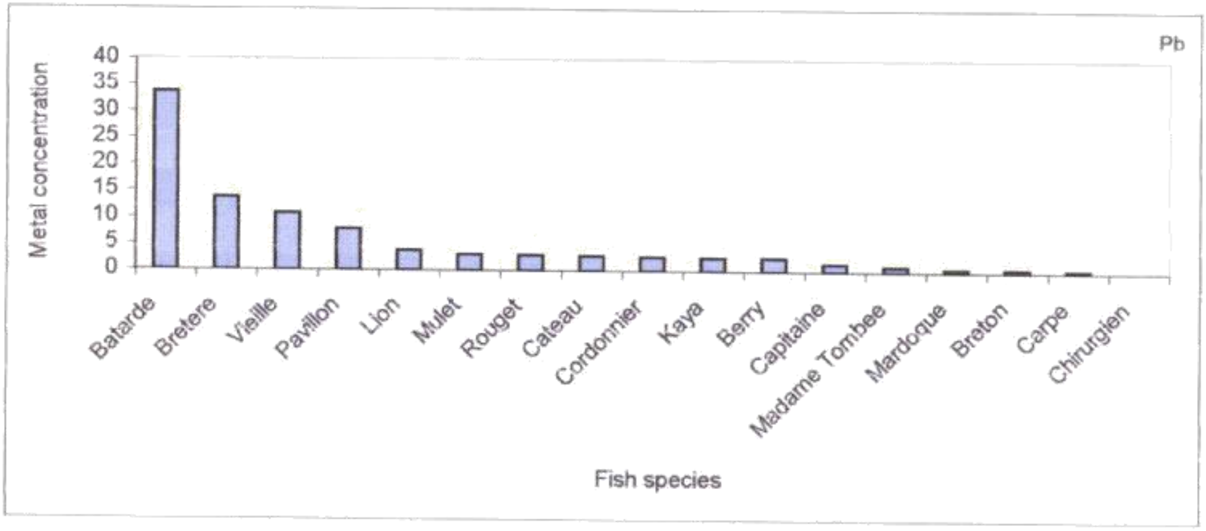
5.5.6 Tin (Fig. 5.22 b)

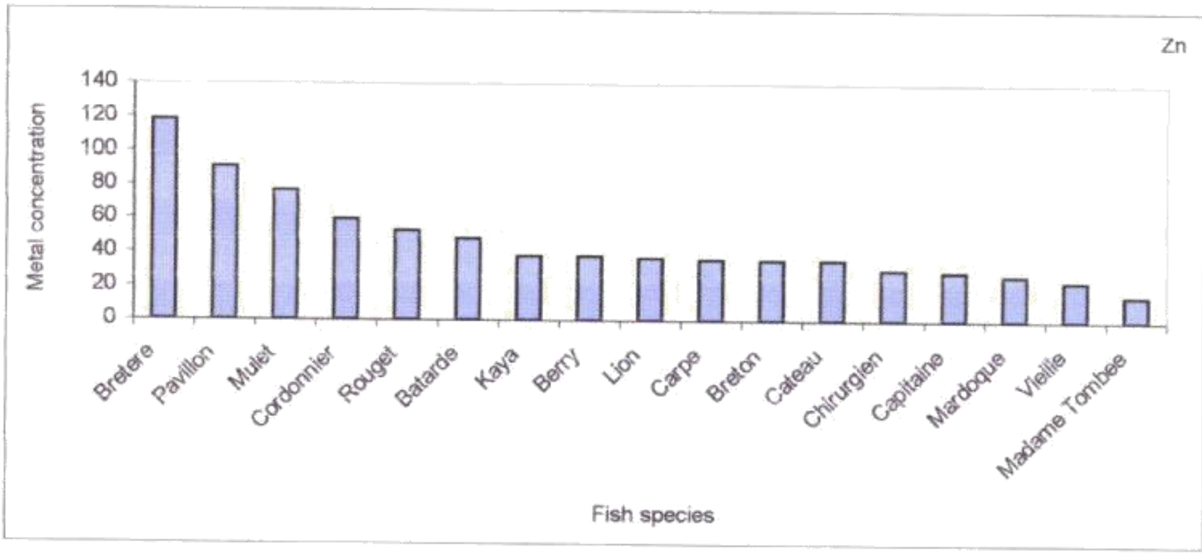
Lion was found to concentrate the highest mean level of tin (25.17 μg/g), followed by Carpe (22 μg/g), Vieille (12.71 μg/g) and Breton (12.1μg/g) from Mahebourg. The highest absolute levels were recorded in Lion (45.36 μg/g) from Pointe aux sables and Vieille (36.12 μg/g) from Roche Bois. The lowest concentrations were recorded in Batarde, Bretere, Mullet and Kaya.

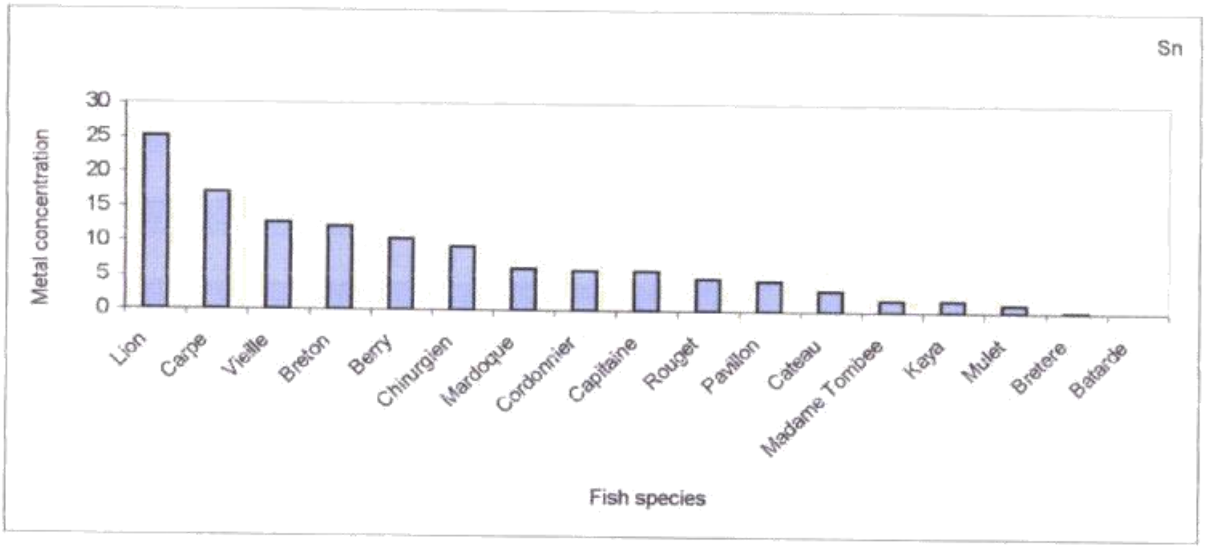
5.5.7 Abundance Rank of Metals in fish (Fig. 5.22 a & b)

In general the metal concentration ranks in fish in order of decreasing importance was as follows : Zn > Cu > Lead > Tin > Cr > Cd. The maximum mean concentrations of these metals recorded were as follows : Zn (117.9 μg/g), Cu (41.8 μg/g), Lead (33.73 μg/g), Tin (25.17 μg/g), Cr (21.2 μg/g) and Cd (1.18 μg/g).

Figure 5.22 (b) : Metal concentration (µg/g or ppm) in different fish species







CHAPTER SIX

6. SUMMARY AND CONCLUSION

6.1 Metal Concentrations recorded in coastal seawater of Mauritius

Metal	Concentration Range	Site For Maximum Level
Cadmium	10 – 323 ppb	Pointe Moyenne
Copper	10 – 352 ppb	Pointe aux Sables
Lead	10 – 247 ppb	Pointe Moyenne
Zinc	10 – 912 ppb	Bain des Dames
Chromium	20 – 410 ppb	Bain des Dames
Tin	10 – 68 ppb	Grand Baie

Zn > Cr > Cu > Cd > Pb > Sn

6.2 Typical river and ocean background metal concentrations

Metal	Concentration (ppb) in River	Concentration (ppb) in Ocean
Cadmium	0.03	0.05
Chromium	1.0	0.6
Copper	5.0	3.0
Lead	3.0	0.03
Tin	0.04	0.01
Zinc	10	5.0

6.3 Metal Concentrations recorded in coastal sediment of Mauritius

Metal	Highest Mean Concentrations & Sites
Cadmium	Pointe Moyenne (42.96 µg/g), Bain Des Dames (30.04 µg/g)
Copper	Pointe aux Sables (35.77 µg/g), Baie du Tombeau (25.96 µg/g)
Lead	Pointe Moyenne (77.2 µg/g), Poudre d'Or (77.04 µg/g)
Zinc	Pointe Moyenne (554 µg/g), Pointe aux Sables (491.2 µg/g)
Chromium	Ile d'Ambre (82.4 µg/g), Poudre d'Or (66.07 µg/g)
Tin	Grand Baie (49.08 µg/g), Pointe Moyenne (55.37 µg/g)

Zn > Cr > Cu > Pb >Sn > Cd

6.4 Potential plant bio-indicators identified

Metal	Plant Species	Highest Concentration or Range
Cadmium	*Ulva lactuca*	0.19 – 8.12 µg/g
	Enteromorpha ramulosa	0.16 – 2.48 µg/g
Copper	*Enteromorpha ramulosa*	23.3 µg/g
	Ulva lactuca	16.1 µg/g
	Biemia fortis	10.7 µg/g
	Padina boryana	9.14 µg/g
Chromium	*Enteromorpha ramulosa*	19.8 µg/g
	Syringodium isoetifolium	16.7 µg/g
	Sargassum binderi	15.1 µg/g
Lead	*Enteromorpha ramulosa*	44.2 µg/g
	Ulva lactuca	36.4 µg/g
	Biemia fortis	10.8 µg/g
Tin	*Ulva lactuca*	6.83 – 139 µg/g
	Sargassum binderi	0.39 – 58.6 µg/g
	Enteromorpha ramulosa	5.33 – 28.6 µg/g
	Ulva reticulata	17.23 – 24.67 µg/g
Zinc	*Enteromorpha ramulosa*	261 µg/g
	Ulva fasciata	189 µg/g
	Padina boryana	171 µg/g
	Ulva lactuca	146 µg/g
	Ulva reticulata	111 µg/g

6.5 Potential invertebrate animal bio-indicators identified

Metal	Animal Species	Highest Concentration or Range
Cadmium	*Morula granulata*	6.59 µg/g
	Echinometra mathaei	5.49 µg/g
Copper	*Crassostrea cucullata*	154.9 µg/g
	Isognomon isognomon	29.5 µg/g
	Littorina mauritiana	36.6 µg/g
	Pinna muricata	23.7 µg/g
Chromium	*Morula granulata*	39.9 µg/g
Lead	*Pinna muricata*	15.8 µg/g
	Littorina littorea	10.4 – 13.5 µg/g
	Echinometra mathaei	10.64 – 12.96 µg/g
Tin	*Echinometra mathaei*	18 µg/g
	Littorina littorea	14.7 µg/g
Zinc	*Isognomon isognomon*	153.2 – 563.1 µg/g
	Pinna muricata	160.83 µg/g
	Crassostrea cucullata	203.94 µg/g

6.6 Highest concentrations recorded in commercial fish

Metal	Fish Species	Mean Concentration	Highest concentration	Site
Cadmium	Pavillon	1.18 µg/g	5.01 µg/g	Baie du Tombeau
	Lion	0.93	1.33 µg/g	Pointe aux sables
	Carpe	0.73	1.23 µg/g	Mahebourg
	Vieille	0.72	8.45 µg/g	Mahebourg
Copper	Bretere	41.8 µg/g	45.3 µg/g	Poudre d'Or
	Pavillon	10.5 µg/g	17.3 µg/g	Pointe aux sables
Chromium	Batarde	21.2 µg/g	21.2 µg/g	Poudre d'Or
	Berry	20.5 µg/g	20.5 µg/g	Trou d'Eau Douce
Lead	Batarde	33.73 µg/g		Poudre d'Or
	Bretere	13.68 µg/g		Poudre d'Or
	Vieille		76.18 µg/g	Souillac
	Vieille		55.93 µg/g	Poudre d'Or
Zinc	Bretere	117.9 µg/g		
	Pavillon	90.47 µg/g		
	Cordonnier		161.25 µg/g	Souillac
	Rouget		162.88 µg/g	Souillac
Tin	Lion	25.17 µg/g	45.36 µg/g	Pointe aux sables
		22 µg/g		Pointe aux sables
	Vieille		36.12	Baie du Tombeau

6.7 Conclusion

- Concentrations of heavy metals recorded in the coastal seawaters of Mauritius were considerably higher than those normally found in the open seawater, but this is as would be expected anywhere in the world.

- Contamination by heavy metals both of seawater and sediment however remains localised at certain sites around the coast as highlighted in the above summary.

- Such 'hot spots' would normally correspond to the sites of waste water discharge or seepage of contaminated underground water around the coast.

- The most contaminated zone would be Port Louis and the surrounding areas, which anyway are highly degraded due to discharge of untreated industrial and domestic waste water.

- Generally, the western coastline would be more vulnerable than elsewhere because of its accessability and more sheltered condition..

- Remedial action would reside in an island-wide engineered sewerage sytem to cope with all waste water and the monitoring of coastal water quality.

- However, contamination by any of the metals investigated in this study would not appear to be higher than elswhere in the world (Re: Chapter 2).

- The levels recorded in the marine biota as well as in the commercial fish species were well below the recommended limits for consumption.

- This work should be considered only as preliminary. The organisms which have been indentified as potential bio-indicators need to be studied much more rigorously and for much longer periods of time so that some of them can actually serve as real sentinels for coastal marine pollution in Mauritius.

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Appendix 1 : Heavy Metal Content (ppm) in lagoon water							
Date	**Site**	**Cd**	**Cu**	**Pb**	**Zn**	**Cr**	**Sn**
18.10.99	Trou aux Biches	0.067	0.075	0.013	0.109	0.180	0.035
18.10.99	Mon Choisy	0.112	0.088	0.022	0.116	0.210	0.021
24.03.99	Grand Bay	0.201	0.341	0.104	0.157	0.260	0.068
17.09.99	Poudre D' Or	0.012	0.025	0.031	0.242	0.290	0.031
17.09.99	Ile D'Ambre	0.041	0.083	0.051	0.256	0.260	0.022
17.09.99	Pointe des Lascars	0.015	0.028	0.029	0.061	0.190	0.019
12.10.99	Cap Malheureux	0.018	0.038	0.016	0.082	0.110	0.032
12.10.99	Baie du Tombeau	0.133	0.189	0.153	0.189	0.350	0.034
12.10.99	Albion	0.023	0.012	0.016	0.041	0.230	0.021
02.02.99	Pointe Moyenne	0.323	0.211	0.247	0.849	0.380	0.036
12.10.99	Pointe aux Sables	0.091	0.352	0.192	0.363	0.310	0.029
02.02.99	Bain des Dames	0.074	0.331	0.169	0.912	0.410	0.033
05.01.00	Grand Gaube	0.045	0.056	0.010	0.084	0.090	0.012
08.10.99	Morne	0.017	0.012	0.012	0.072	0.090	0.010
07.01.99	Flic en Flacq	0.017	0.018	0.010	0.076	0.120	0.013
25.01.00	Poste la Fayette	0.010	0.010	0.010	0.016	0.090	0.011
25.01.00	Belle Mare	0.018	0.033	0.012	0.069	0.080	0.012
25.01.99	Poste de Flacq	0.025	0.030	0.019	0.065	0.090	0.010
07.01.00	St Felix	0.010	0.023	0.016	0.010	0.020	0.017
25.01.00	Palmar	0.012	0.018	0.010	0.012	0.020	0.014
	Minimum	**0.010**	**0.010**	**0.010**	**0.010**	**0.020**	**0.010**
	Maximum	**0.323**	**0.352**	**0.247**	**0.912**	**0.410**	**0.068**
	Mean	**0.063**	**0.099**	**0.057**	**0.189**	**0.189**	**0.024**
	SD	**0.07948**	**0.118061**	**0.073386**	**0.253313**	**0.118672**	**0.013928**

Appendix 2 a : Heavy Metal Content (ppm or µg/g) in Lagoon Sediment							
		Cd	Cu	Cr	Pb	Zn	Sn
05.08.98	Pointe aux Sables	53.25	31.35	24.3	11.05	661	50.2
02.11.98		38.29	42.21	43.78	24.51	412	44.27
02.02.99		24.98	23.53	61.33	26.25	548	26.81
23.07.99		30.08	48.16	23.6	38.68	438	14.52
12.10.99		20.06	33.58	47.04	45.63	397	53.29
	Mean	**33.332**	**35.766**	**40.01**	**29.224**	**491.2**	**37.818**
13.07.99	Baie du Tombeau	2.04	21.1	7.53	52.59	110.58	22.31
12.10.99		1.15	30.81	5.98	39.01	198.1	53.62
	Mean	**1.595**	**25.955**	**6.755**	**45.8**	**154.34**	**37.965**
13.07.99	Albion	0.35	6.55	10.3	4.39	23.04	4.01
12.10.99		0.49	0.66	9.52	2.71	14.05	3.38
	Mean	**0.42**	**3.605**	**9.91**	**3.55**	**18.545**	**3.695**
05.08.98	Pointe Moyenne	41.53	19.03	56.3	47.01	529.91	65.53
02.11.98		32.34	21.41	50.4	86.5	512.1	44.37
02.02.99		55.01	30.9	76.2	98.1	620	56.22
	Mean	**42.96**	**23.78**	**60.9667**	**77.2033**	**554.003**	**55.3733**
05.08.99	Bain des Dames	28.31	18.11	23.88	31.2	189.4	37.1
02.11.98		43.25	62.6	27.4	28.5	393.6	42.4
02.02.99		33.57	27.4	32.56	38.18	541.33	59.53
	Mean	**35.0433**	**36.0367**	**27.9467**	**32.6267**	**374.777**	**46.3433**
23.08.98	Trou aux Biches	0.32	3.21	9.4	6.05	22.78	22.7
20.01.99		0.2	3.05	6.09	4.86	37.83	13.1
24.03.99		0.05	3.65	5.9	10.01	12.78	11.35
27.07.99		0.05	6.21	13.65	18.09	24.78	18.45
18.10.99		0.03	4.12	4.01	13.09	44.49	31.73
	Mean	**0.13**	**4.048**	**7.81**	**10.42**	**28.532**	**19.466**
23.08.98	Mon Choisy	1.32	14.5	12.05	28.09	10.61	12.1
20.01.99		1.43	21.22	10.53	14.01	33.7	11.56
24.03.99		0.64	16.39	14.06	24.5	19.48	24.48
27.07.99		0.84	14.7	12.22	10.08	22.04	32.09
18.10.99		0.19	10.04	9.52	21.95	31.25	21.93
	Mean	**0.884**	**15.37**	**11.676**	**19.726**	**23.416**	**20.432**
23.08.98	Grand Baie	0.92	28.5	6.56	39.01	19.55	49.54
20.01.99		0.84	27.15	9.23	20.21	30.17	38.1
24.03.99		1.01	38.07	10.56	44.91	41.45	59.61
	Mean	**0.92333**	**31.24**	**8.78333**	**34.71**	**30.39**	**49.0833**

Appendix 2 b : Heavy Metal Content (ppm or µg/g) in Lagoon Sediment							
		Cd	Cu	Cr	Pb	Zn	Sn
17.06.99	Poudre D' Or	3.01	69.2	54.68	65.84	132.65	42.55
17.09.99		2.51	93.38	77.46	88.23	185.8	63.01
	Mean	**2.76**	**81.29**	**66.07**	**77.035**	**159.225**	**52.78**
17.06.99	Ile D'Ambre	0.37	44.23	91.39	70.04	159.2	21.87
17.09.99		0.26	38.91	73.41	80.02	185.9	32.25
	Mean	**0.315**	**41.57**	**82.4**	**75.03**	**172.55**	**27.06**
17.06.99	Pointe des Lascars	0.22	12.33	8.16	2.95	20.11	12.38
17.09.99		0.17	23.93	12.1	10.64	48.1	21.29
	Mean	**0.195**	**18.13**	**10.13**	**6.795**	**34.105**	**16.835**
30.07.99	Cap Malheureux	0.33	6.45	15.85	11.84	87.44	6.06
12.10.99		0.25	13.38	21.5	9.69	36.56	2.28
	Mean	**0.29**	**9.915**	**18.675**	**10.765**	**62**	**4.17**
30.07.99	Grand Gaube	0.59	11.69	19.02	11.15	32.69	12.7
05.01.00		0.24	12.1	12.1	22.19	18.06	23.21
	Mean	**0.415**	**11.895**	**15.56**	**16.67**	**25.375**	**17.955**
13.07.99	Morne	0.24	4.33	23.93	11.58	40.46	15.23
08.10.99		0.17	8.27	31.99	22.81	34.56	21.96
	Mean	**0.205**	**6.3**	**27.96**	**17.195**	**37.51**	**18.595**
20.08.99	Flic en Flacq	0.61	6.04	28.31	12.54	35.53	21.3
07.01.99		0.49	4.05	19.73	11.56	51.6	34.1
	Mean	**0.55**	**5.045**	**24.02**	**12.05**	**43.565**	**27.7**
27.08.99	Poste Lafayette	0.16	1.07	3.28	5.39	12.48	14.89
25.01.00		0.28	0.89	4.64	3.85	9.85	13.63
	Mean	**0.22**	**0.98**	**3.96**	**4.62**	**11.165**	**14.26**
27.08.99	Belle Mare	0.4	2.08	5.38	21.6	15.19	11.93
25.01.00		0.21	0.97	8.66	38.75	11.5	18.25
	Mean	**0.305**	**1.525**	**7.02**	**30.175**	**13.345**	**15.09**
27.08.99	Poste de Flacq	0.69	9.16	5.34	11.93	28.37	15.21
25.01.99		0.78	16.9	6.39	9.85	19.85	12.88
	Mean	**0.735**	**13.03**	**5.865**	**10.89**	**24.11**	**14.045**
27.08.99	St Felix	0.14	2.1	4.99	5.64	17.43	33.61
07.01.00		0.32	4.12	9.37	4.07	23.09	28.47
	Mean	**0.23**	**3.11**	**7.18**	**4.855**	**20.26**	**31.04**
27.08.99	Palmar	1.08	10.9	6.32	11.34	40.89	23.09
25.01.00		0.98	21.68	5.66	15.05	32.34	17.35
	Mean	**1.03**	**16.29**	**5.99**	**13.195**	**36.615**	**20.22**

Appendix 3 : Heavy metal concentration (ppm) in *Ulva* species.								
Date	Site	Species	Heavy Metal					
			Cd	Cu	Cr	Pb	Zn	Sn
Conc. In Oceanic water (ppb)			**0.05**	**3**	**0.6**	**0.03**	**5**	**0.01**
28.08.98	Trou aux Biches		0.21	6.22	0.45	3.04	121	9.5
20.01.99		*Ulva*	0.09	5.41	0.41	2.52	165.21	11.4
24.06.99		*lactuca*	0.11	9.8	0.33	2.6	120.61	10.1
13.11.99			0.36	12.09	0.39	4.56	175.2	8.98
	Mean Concentration		**0.19**	**8.38**	**0.40**	**3.18**	**145.51**	**10.00**
28.08.99	Mon Choisy		2.07	6.25	12.05	2.12	30.42	6.55
20.01.99		*Ulva*	2.61	6.19	10.53	3.14	43.7	3.04
24.06.99		*lactuca*	1.98	8.12	14.56	12.05	60.1	8.5
13.11.99			4.63	8.09	13.12	7.98	49.87	9.23
	Mean Concentration		**2.8225**	**7.1625**	**12.565**	**6.3225**	**46.0225**	**6.83**
05.08.98	Pointe Moyenne		2.31	4.51	0.98	0.35	23.01	11.26
02.11.98		*Ulva*	6.6	6.6	3.65	5.2	16	9.64
02.02.99		*lactuca*	3.05	4.21	0.19	5.06	36.1	13.33
23.07.99			4.39	6.85	2.13	6.37	45.12	18.34
	Mean Concentration		**4.0875**	**5.5425**	**1.7375**	**4.245**	**30.0575**	**13.1425**
05.08.98	Pointe aux Sables		7.62	1.9	0.8	1.86	60.86	15.7
02.11.98		*Ulva*	4..52	2.1	0.5	2.62	121.73	10.3
02.02.99		*lactuca*	9.28	6.48	2.75	2.01	65.01	13.6
23.07.99			6.81	3.75	4.4	3.38	78.85	11.5
12.10.99			8.275	0.23	3.15	0.61	96.06	9.07
	Mean Concentration		**8.1217**	**3.14**	**2.7**	**2.155**	**90.4125**	**11.1175**
05.08.98	Bain des Dames		0.37	13.6	2.3	17.5	30.5	128
02.11.98		*Ulva*	0.29	21.2	1.03	43.2	23.7	121.33
02.02.99		*lactuca*	0.46	10.5	2.06	46.01	37.06	143.9
23.07.99			0.51	18.9	5.32	38.72	41.3	162.4
	Mean Concentration		**0.41**	**16.05**	**2.68**	**36.36**	**33.14**	**138.91**
02.11.98			0.56	3.24	4.03	4.92	213.4	12.98
13.07.99	Baie du Tombeau	*Ulva*	0.4	2.75	2.5	6.1	193.1	10.1
12.10.99		*fasciata*	0.45	0.65	2.61	2.11	140.9	6.52
20.05.00			0.78	1.09	3.91	1.65	209.5	16.21
	Mean Concentration		**0.55**	**1.93**	**3.26**	**3.70**	**189.23**	**11.45**
27.08.99	Poste de Flacq		1.71	1.21	0.88	2.71	78.95	7.51
25.01.00		*Ulva*	0.11	0.36	0.13	1.02	164.95	9.22
14.06.00		*fasciata*	0.49	0.94	0.76	3.49	192.1	12.46
	Mean Concentration		**0.77**	**0.84**	**0.59**	**2.41**	**145.33**	**9.73**
17.06.99	Poudre d' Or		0.5	7.46	10.39	3.56	134.05	19.72
19.09.99		*Ulva*	0.15	7.13	8.98	2.51	87.2	17.23
25.08.00		*reticulata*	0.23	5.63	7.48	4.79	112.41	24.67
	Mean Concentration		**0.29**	**6.74**	**8.95**	**3.62**	**111.22**	**20.54**

Appendix 4 : Metal concentration in *Enteromorpha ramulosa*								
Date	**Site**	**Species**	**Heavy Metal**					
			Cd	Cu	Cr	Pb	Zn	Sn
Conc. In Oceanic water (ppb)			**0.05**	**3**	**0.6**	**0.03**	**5**	**0.01**
28.08.98	Trou aux	***Enteromorpha***	0.15	5.82	0.51	2.51	178.4	9.5
20.01.99	Biches	***ramulosa***	0.09	5.71	0.73	2.11	160.4	12.1
24.03.99			0.25	6.69	0.6	2.15	201.56	14.74
	Mean		**0.16**	**6.07**	**0.61**	**2.26**	**180.12**	**12.11**
05.08.98	Pointe		2.51	6.32	4.32	1.7	23.8	15.02
02.11.98	Moyenne		1.88	10	5.15	0.25	32.61	9.64
02.02.98			3.04	9.4	1.75	3	40	12.55
	Mean		**2.48**	**8.57**	**3.74**	**1.65**	**32.14**	**12.40**
05.08.98	Pointe		0.13	4.23	2.23	3.49	223	13.6
02.11.98	aux Sables		0.7	2.58	9.13	5.94	144.63	11.5
02.02.99			0.29	8.41	22.04	3.5	405.6	16.01
23.07.99			0.1	3.75	12.13	3.38	78.85	12.7
25.02.00			0.28	0.23	9.06	4.01	96.06	11.01
	Mean		**0.22**	**4.13**	**14.41**	**3.63**	**193.50**	**13.24**
05.08.98	Bain des		1.52	15.09	5.34	36.7	243.6	24.6
02.11.98	Dames		0.38	23.8	2.9	43.7	239.5	25.9
02.02.99			2.61	31.08	13.45	52.2	300.4	35.3
	Mean		**1.50**	**23.32**	**7.23**	**44.20**	**261.17**	**28.60**
17.06.99	Pointe des		1.25	6.53	20.34	6.31	156.46	5.7
17.09.99	Lascars		0.2	0.2	15.21	3.01	137.4	4.96
	Mean		**0.73**	**3.37**	**17.78**	**4.66**	**146.93**	**5.33**

Appendix 5 : Heavy metal concentration (ppm) in *Sargassum binderi, Sarconema filiforme, Galaxaura oblongata, marginata* and *canaliculata.*								
			Metal Species					
Date	Site	Species	Cd	Cu	Cr	Pb	Zn	Sn
Conc. In Oceanic water (ppb)			0.05	3	0.6	0.03	5	0.01
17.06.99	Poudre		0.49	5.15	19.47	7.47	95.85	67.32
21.04.00	D'Or		0.34	1.11	10.8	4.36	23.63	49.8
	Mean		**0.415**	**3.13**	**15.135**	**5.915**	**59.74**	**58.56**
17.06.99	D'Ambre		1.55	6.61	2.17	9.02	94.15	40.07
21.04.00			0.98	4.36	5.32	7.93	85.69	22.12
	Mean		**1.265**	**5.485**	**3.745**	**8.475**	**89.92**	**31.095**
13.07.99	Le Morne		2	7.18	1.78	2.5	51.45	2.11
12.06.00		*Sargassum*	0.95	2.11	4.67	1.78	44.83	3.16
	Mean	*binderi*	**1.475**	**4.645**	**3.225**	**2.14**	**48.14**	**2.635**
20.08.99	Flic en		0.59	3.65	0.91	2.51	43.58	4.91
04.05.00	Flacq		0.21	8.23	2.57	1.36	58.38	3.69
	Mean		**0.4**	**5.94**	**1.74**	**1.935**	**50.98**	**4.3**
27.08.99	Poste la		3.26	2.58	0.21	2.96	48.46	0.27
14.10.00	Fayette		0.53	5.27	0.26	0.51	50.24	0.51
	Mean		**1.895**	**3.925**	**0.235**	**1.735**	**49.35**	**0.39**
02.11.98	Pointe aux	*Sarconema*	0.68	0.53	1.38	2.39	69.41	6.88
09.09.99	Sables	*filiforme*	0.58	0.89	0.96	0.87	74.84	9.62
	Mean		**0.63**	**0.71**	**1.17**	**1.63**	**72.125**	**8.25**
20.08.99	Flic en	*Galaxaura*	0.36	0.66	2.93	8.35	32.28	8.66
04.05.00	Flacq	*oblongata*	1.59	0.98	3.62	2.31	20.89	4.54
	Mean		**0.975**	**0.82**	**3.275**	**5.33**	**26.585**	**6.6**
27.08.99	Poste de	*Galaxaura*	1.5	1.71	1.01	3.15	91.64	2.01
14.10.00	Flacq	*marginata*	0.3	0.97	1.25	6.75	93.96	1.94
	Mean		**0.9**	**1.34**	**1.13**	**4.95**	**92.8**	**1.975**
30.07.99	Cap	*Galaxaura*	0.34	3.11	0.21	8.23	57.16	0.97
25.06.00	Malheureu	*canaliculata*	0.12	1.33	0.29	4.21	48.63	1.37
	Mean		**0.23**	**2.22**	**0.25**	**6.22**	**52.895**	**1.17**

Appendix 6 : Heavy metal concentration (ppm or µg per g) in seaweeds								
Date	Site	Species	Heavy Metal Species					
			Cd	Cu	Cr	Pb	Zn	Sn
Conc in oceanic water (ppb)			**0.05**	**3**	**0.6**	**0.03**	**5**	**0.01**
17.06.99	Ile d'Ambre	*Caulerpa*	2.08	3.35	2.34	10.26	97.18	8.75
25.08.00		*sertularoides*	0.24	3.11	2.01	3.75	80.33	4.18
	Mean		**0.79**	**3.15333**	**1.65**	**4.68**	**60.8367**	**4.313333**
30.07.99	Grand	*Caulerpa*	0.84	1.45	1.28	9.91	111.18	2.41
05.01.00	Gaube	*sertularoides*	0.31	0.92	5.23	1.64	76.93	5.54
	Mean		**0.71833**	**2.49722**	**2.185**	**5.045**	**71.9094**	**4.200556**
30.07.99	Grand	*Caulerpa*	0.73	1.3	0.04	9.63	94.25	3.33
05.01.00	Gaube	*serrulata*	1.21	2.3	0.05	6.97	112.6	6.01
	Mean		**0.97**	**1.8**	**0.045**	**8.3**	**103.425**	**4.67**
27.07.99	Trou aux	*Padina*	1.03	1.5	3.85	8.48	73.23	0.18
05.01.00	Biches	*boryana*	0.73	0.98	0.25	6.79	79.63	30.2
	Mean		**0.88**	**1.24**	**2.05**	**7.635**	**76.43**	**15.19**
17.06.99	Ile d' Ambre	*Padina*	4.15	5.98	3.55	14	246.6	10.18
13.07.00		*boryana*	0.73	12.3	1.02	4.11	95.01	3.61
	Mean		**2.44**	**9.14**	**2.285**	**9.055**	**170.805**	**6.895**
20.08.99	Flic en	*Padina*	1.06	3.38	0.16	9.68	54.96	15.67
	Flacq	*boryana*	0.94	2.1	0.2	7.59	48.1	17.25
	Mean		**1**	**2.74**	**0.18**	**8.635**	**51.53**	**16.46**
27.08.99	Poste la	*Padina*	1.71	0.12	0.73	9.5	65.9	1.02
	Fayette	*boryana*	2.03	0.61	0.04	3.94	58.85	0.26
	Mean		**1.58**	**1.15667**	**0.316667**	**7.35833**	**58.76**	**5.913333**
27.07.99	Trou aux		1.18	2.15	0.89	9.46	12.6	2.41
	Biches		0.55	3.28	1.07	2.01	67.38	5.12
	Mean		**0.865**	**2.715**	**0.98**	**5.735**	**39.99**	**3.765**
13.07.99	Le Morne	*Turbinaria*	0.38	0.43	0.91	4.58	62.23	2.09
		ornata var.	0.63	0.21	0.63	2.31	67.24	6.19
	Mean	*serrata*	**0.505**	**0.32**	**0.77**	**3.445**	**64.735**	**4.14**
27.08.99	Belle Mare		1.3	0.94	0.94	1.31	35.53	3.28
			0.05	1.39	1.02	0.28	36.43	12.93
	Mean		**0.675**	**1.165**	**0.98**	**0.795**	**35.98**	**8.105**

Appendix 7 : Heavy metal concentration (ppm) in Seagrasses								
			Heavy Metal					
Date	Site	Species	Cd	Cu	Cr	Pb	Zn	Sn
Conc in oceanic water (ppb)			0.05	3	0.6	0.03	5	0.01
27.07.99	Mon Choisy	*Halodule uninervis*	1.81	2.62	3.21	2.98	30.1	2.99
			1.06	1.52	3.91	5.05	27.36	4.27
			1.9	1.2	6.15	3.21	38.5	6.82
	Mean		**1.59**	**1.78**	**4.423333**	**3.7467**	**31.987**	**4.69333**
13.07.99	Albion		0.93	2.96	3.24	3.06	41.26	2.67
			0.33	5.83	0.35	4.98	31.21	7.61
	Mean		**0.63**	**4.395**	**1.795**	**4.02**	**36.235**	**5.14**
27.07.99	Mon Choisy	*Syringodium isoetifolium*	0.38	2.98	0.23	10.03	27.98	12.8
			0.34	2.09	0.21	7.62	64.48	9.45
	Mean		**0.36**	**2.535**	**0.22**	**8.825**	**46.23**	**11.125**
17.06.99	Poudre D'Or		0.45	3.31	14.71	5.77	121.62	18.87
			0.19	7.37	18.63	8.35	27.69	24.39
	Mean		**0.32**	**5.34**	**16.67**	**7.06**	**74.655**	**21.63**
27.08.00	Poste la Fayette		2.81	0.56	0.43	2.51	51.13	5.78
			0.48	1.01	0.24	3.93	33.28	9.36
	Mean		**1.645**	**0.785**	**0.335**	**3.22**	**42.205**	**7.57**
27.08.00	Poste de Flacq		1.14	1.68	2.64	1.83	42.05	3.09
			0.97	3.02	0.63	2.04	127.06	2.61
	Mean		**1.055**	**2.35**	**1.635**	**1.935**	**84.555**	**2.85**
27.08.00	Poste la Fayette	*halassodrendron ciliatum*	1.01	2.01	0.73	1.23	79.54	3.62
			0.03	0.89	0.3	2.73	62.11	0.61
	Mean		**0.52**	**1.45**	**0.515**	**1.98**	**70.825**	**2.115**
17.06.99	Poudre D'Or	*Biemia fortis*	0.74	8.39	2.93	4.39	66.36	3.08
			5.03	12.92	21.05	3.69	10.6	13.31
	Mean		**2.885**	**10.655**	**11.99**	**4.04**	**38.48**	**8.195**
17.06.99	Pointe des Lascars	*Biemia fortis*	1.04	3.34	5.38	5.68	40.65	6.39
			2.69	14.32	2.39	15.94	32.67	13.51
	Mean		**1.865**	**8.83**	**3.885**	**10.81**	**36.66**	**9.95**
17.06.99	Poudre D'Or	"Perle Bleu" (Sponge)	0.54	6.31	3.29	5.19	68.56	2.58
			0.69	3.61	3.63	3.99	65.88	24.36
	Mean		**0.615**	**4.96**	**3.46**	**4.59**	**67.22**	**13.47**
27.08.99	Belle Mare	"Brown Tree" (Sponge)	0.71	2.07	1.73	2.74	34.68	7.78
			0.05	0.94	1.85	0.91	30.1	12.79
	Mean		**0.38**	**1.505**	**1.79**	**1.825**	**32.39**	**10.285**

Appendix 8 : Heavy metal concentration (ppm) in three size classes of *Littorina mauritiana*.

Date	Site	Size class	Heavy Metal					
		(cm)	Cd	Cu	Cr	Pb	Zn	Sn
17.06.98	Poudre d`Or	0.6 - 1	2.51	36.42	8.52	9.08	38.58	11.78
17.09.00	Poudre d`Or		0.48	8.09	6.01	3.6	2.81	9.55
30.07.99	Grand Gaube		0.36	12.59	25.93	2.18	16.49	9.08
27.08.99	Palmar		4.55	4.48	9.23	8.61	3.03	4.32
27.08.99	Palmar		2.39	2.65	7.99	3.08	18.88	6.97
27.08.00	St Felix		0.1	3.93	5.36	1.28	10.96	4.12
	Mean		**1.731667**	**11.36**	**10.50667**	**4.638333**	**15.125**	**7.636667**
17.06.98	Poudre d`Or	1.1 - 1.5	2.63	29.31	8.93	9.52	20.11	2.31
17.09.00	Poudre d`Or		0.5	13.35	5.4	3.96	25.69	4.2
30.07.99	Grand Gaube		0.25	15.13	32.38	1.81	17.24	8.9
27.08.99	Palmar		3.76	6.66	10.23	7.73	9.31	6.33
27.08.99	Palmar		2.64	11.35	8.62	3.84	21.74	9.83
27.08.00	St Felix		0.1	7.38	4.11	1.13	19.73	12.1
	Mean		**1.646667**	**13.863333**	**11.61167**	**4.665**	**18.97**	**7.278333**
17.06.98	Poudre d`Or	1.6 - 2	2.87	36.57	14.31	9.43	22.39	14.7
30.07.99	Grand Gaube		0.34	18.35	39.05	1.59	17.63	10.7
05.01.00	Grand Gaube		0.4	8.8	28.1	6.09	51.33	8.61
27.08.99	Palmar		0.59	8.81		8.15	11.65	12.05
27.08.00	St Felix		0.25	7.98		1.05	53.6	6.32
	Mean		**0.89**	**16.102**	**27.15333**	**5.262**	**31.32**	**10.476**

Appendix 9 : Heavy metal concentration (ppm) in some marine snails									
Date	**Site**	**Species**	**Size class (cm)**	**Heavy Metal**					
				Cd	**Cu**	**Cr**	**Pb**	**Zn**	**Sn**
27.07.99	Mon Choisy	*Morula granulata*		0.34	13.1	39.9	1.86	88.75	4.7
12.10.99	Pointe aux Sables	*Morula granulata*		6.59	4.14	25.6	6.35	52.75	3.12
27.07.99	Mon Choisy	*Nerita undata*		0.1	3.28	25.6	1.34	19.48	2.54
27.07.99	Mon Choisy	*Cypraea carputser-pentis*		0.64	16.95	21.9	3.35	199.2	3.01
25.01.00	Belle Mare	*Cypraea tigris*		0.65	19.05	14.3	1.54	166.6	3.25
27.07.99	Mon Choisy	*Littorina littorea lime*	1.1 - 1.5	3.41	1.74	17.7	13.5	83.23	2.65
			> 1.5	3.54	5.51	13	10.4	96.21	1.97
12.10.99	Cap Malheureux	*Littorina littorea lime*	0.5 - 1	3.81	23.99	32.7	7.48	22.44	9.08
			1.1 - 1.5	4.04	11.83	32.4	6.44	14.71	8.9
			1.6 - 2	2.4	8.58	36.2	3.18	24	14.5
			Minimum	0.1	1.74	13	1.34	14.71	1.97
			Maximum	6.59	23.99	39.9	13.5	199.2	14.5
			Mean	2.55	10.82	25.9	5.55	76.74	5.37

Appendix 10 : Heavy metal concentration (ppm) in *Isognomon isognomon*.

Date	Site	Species	Size class (cm)	Heavy Metal Cd	Cu	Cr	Pb	Zn	Sn
17.06.99	Poudre	***Isognomon***	**0 - 2.5**	3.46	24.41	7.49	11.1	273.88	0.54
17.09.99	D' Or	***Isognomon***	**0 - 2.5**	0.74	21.95	9.98	3.96	222.39	0.78
17.06.99	Cap		**2.6 - 5**	0.6	28.5	9.99	0.86	330.21	0.79
17.09.99	Malheureux		**2.6 - 5**	0.68	24.26	11.58	3.64	224.69	0.83
27.07.99	Mon Choisy		**0 - 2.5**	3.15	28.29	6.32	5.45	552.13	0.84
			2.6 - 5	3.65	29.53	7.15	3.68	563.13	1.02
27.08.99	Belle Mare		**0 - 2.5**	0.65	12.04	9.8	1.33	153.25	1.98
			2.6 - 5	0.5	13.64	11.38	0.91	166.58	3.21
17.06.99	D'Ambre	***Pinna muricata***		4.78	16.18	9.18	15.8	160.83	1.32
17.06.99	Poudre	***Crassostrea***		1.05	154.88	8.85	2.18	203.94	1.24
	D' Or	***cucullata***		0.21	44.28	7.75	2.76	201.39	0.98

Appendix11 : Heavy metal concentration (ppm) in *Echinometra mathaei.*									
Date	Site	Species	Size class (cm)	Heavy Metal					
				Cd	Cu	Cr	Pb	Zn	Sn
27.07.99	Trou aux Biches	***E. mathaei***	**0 - 2.5**	3.84	0.15	35.83	8.74	31.99	11.93
		(skeleton)	**2.6 - 5**	4.73	0.17	34.03	8.79	36.49	10.32
			5.1 - 7. 5	4.94	0.21	23.03	8.59	53.84	11.77
		E. mathaei	**0 - 2.5**	3.53	1.23	33.95	6.55	16.09	14.42
		(tissue)	**2.6 - 5**	4.74	1.22	31.18	9.76	36.48	16.1
			5.1 - 7. 5	4.84	2.01	21.92	4.79	15.43	11.75
	St Felix	***E. mathaei***	**0 - 2.5**	0.05	8.61	12.3	3.78	20.4	9.2
		(skeleton)	**2.6 - 5**	0.09	5.1	11.2	4.71	34.45	10.51
			5.1 - 7. 5	3.75	0.04	16.8	7.66	55.41	14.2
		E.mathaei	**0 - 2.5**	0.23	0.7	13.54	3.68	6.61	10.4
		(tissue)	**2.6 - 5**	0.54	0.65	12	3.9	15.73	11.62
			5.1 - 7. 5	3.78	0.8	18.06	3.73	20.4	16.8
13.07.99	Le Morne	***E. mathaei***	**0 - 2.5**	1.55	1.56	18.02	12.05	2.89	8.21
08.10.99		(skeleton)	**0 - 2.5**	0.34	2.81	16.7	2.64	7.31	7.36
			2.6 - 5	4.59	4.71	27.8	12.61	66.84	14.65
			5.1 - 7. 5	4.76	5.99	30.85	12.71	86.59	11.63
13.07.99		***E. mathaei***	**0 - 2.5**	2.05	2.58	22.1	10.75	4.38	9.56
08.10.99		(tissue)	**0 - 2.5**	0.75	3.45	19.41	2.96	30.36	8.4
			2.6 - 5	5.49	5.13	27.03	10.68	61.84	10.01
			5.1 - 7. 5	5.48	7.87	32.15	10.64	61.79	11.8
07.01.99	Flic en Flac	***E. mathaei*** (tissue)	**2.5 - 5**	3.83	1.53	28.35	8.49	39.45	16.45
		E. mathaei (skeleton)	**2.5 - 5**	3.75	0.08	23.08	7.66	55.41	19.13

Appendix 12 : Heavy metal concentration (ppm) in sea cucumbers

Date	Site	Species	Size class (cm)	Heavy Metal Cd	Cu	Cr	Pb	Zn	Sn
13.07.99	Le Morne	*Bonadshia*		2.48	0.9	22.46	11.19	24.76	3.51
		subruba		0.39	0.15	15.63	0.96	32.78	2.78
			Mean	**1.435**	**0.525**	**19.045**	**6.075**	**28.77**	**3.145**
27.07.99	Mon Choisy	*Holothuria*	10.5 - 20	0.22	1.24	16	4.1	42.36	5.4
		leucopsilota	21 - 30	0.26	0.54	29.48	1.1	14.9	1.55
07.01.99	Flic en Flac		0 - 10	0.34	1.09	17.7	3.14	27.41	3.38
13.07.99	Le Morne		0 - 10	0.3	1.24	10.1	1.03	42.36	0.325
			10.5 - 20	0.25	1.09	16	3.14	33.53	5.4
			21 - 30	0.38	0.54	29.48	1.1	34.56	1.55
08.10.99	Le Morne		10.5 - 20	0.06	0.96	12.3	1.76	30.31	4.73
			Mean	**0.2586**	**0.9571**	**18.723**	**2.19571**	**32.20429**	**3.190714**
13.07.99	Le Morne	*Holothuria*		0.31	0.81	31.55	2.12	34.04	2.825
	Mon Choisy	*parva*		0.05	0.08	24.01	1.41	23.65	1.85
			Mean	**0.18**	**0.445**	**27.78**	**1.765**	**28.845**	**2.3375**
13.07.99	Le Morne	*Stichopus*		0.34	0.7	23.14	1.31	31.14	2.08
08.10.99	TAB	*chloronatus*		0.23	0.51	17.31	1.28	27.05	1.96
			Mean	**0.285**	**0.605**	**20.225**	**1.295**	**29.095**	**2.02**
Overall Mean for all species				**0.457**	**0.7284**	**20.643**	**2.64534**	**30.45672**	**2.825483**

Appendix 13 a : Heavy Metal Content (µg/g) in edible fish species								
Date	Site	Species	Heavy Metal					
			Cd	Cu	Cr	Pb	Zn	Sn
24.06.99	Poudre D'Or	**Madame Tombee**	0.05	0.05	0.08	0.48	13.75	0.74
18.01.00	Poudre D'Or	**(Flesh)**	0.01	4.43	0.19	1.58	17.2	1.05
17.09.99	La Gaulette		0.68	0.98	0.36	3.17	20	0.89
15.10.00	Mahebourg		0.03	0.05	0.53	0.28	4.83	3.21
24.03.00	Mahebourg		0.01	0.01	0.09	0.01	12	1.1
12.11.99	Roche Bois,		0.33	0.3	2.33	0.04	5	2.36
21.02.00	Baie du Tombeau		0.41	2.52	1.99	1.68	12.7	5.01
12.05.00	Pte aux Piments		0.01	0.01	0.81	0.01	33.33	0.88
15.10.99	Souillac		0.01	0.01	0.09	1	13.03	0.17
		Mean	**0.1711**	**0.9289**	**0.719**	**0.9167**	**14.6489**	**1.71222**
24.06.00	Poudre D'Or	**Cordonnier**	0.18	0.58	2.68	1.27	23.63	15.58
13.07.99	Albion	**(Flesh)**	0.01	3.9	0.08	0.95	74.9	9.34
25.02.00	Pte aux Sables		1.23	1.67	12.31	4.69	96.23	5.39
06.08.99	Cap Malheureux		0.58	4.6	0.53	0.01	21.9	2.99
09.02.00	Albion		0.01	1.56	0.64	0.99	99.37	3.98
20.07.99	Pte aux Sables		0.4	0.53	18.06	0.01	21.2	12.63
03.03.00	Cap Malheureux		0.01	0.4	1.02	1.85	21.35	3.05
20.08.99	Trou d' Eau Douce		0.73	10.08	4.39	1.75	197.1	4.67
17.09.99	La Gaulette		0.63	5.95	1.01	9.85	171.1	2.13
15.10.00	Mahebourg		0.1	0.3	0.93	2.75	5.03	1.05
24.03.00	Mahebourg		0.18	0.01	0.09	2.93	11.52	0.93
15.10.99	Souillac		0.01	3.78	0.12	8.95	161.25	0.09
12.11.99	Baie du Tombeau		0.02	0.01	9.98	1.98	9.48	8.56
19.11.00	Bain des Dames		0.01	0.58	31.2	2.55	19.88	13.21
19.11.00	GRNW		0.01	0.3	12.6	3.68	21.95	8.77
12.05.00	Pte aux Piments		0.01	0.11	1.38	0.01	45.12	2.13
20.06.00	Pte aux Piments		0.01	0.01	2.01	1.76	10.75	5.17
		Mean	**0.2429**	**2.0218**	**5.825**	**2.7047**	**59.5153**	**5.86294**
13.07.99	Albion	**Gill**	1.73	38.3	7.78	14.98	142.4	8.28
20.07.99	Pte aux Sables		0.48	0.6	21.04	0.01	138.95	32.22
06.08.99	Cap Malheureux		2	15.28	3.21	1.88	100	10.2
		Mean	**1.4033**	**18.06**	**10.68**	**5.6233**	**127.117**	**16.9**

Appendix 13 b : Heavy Metal Content (µg/g) in edible fish species								
			Cd	Cu	Cr	Pb	Zn	Sn
24.06.99	Poudre D'Or	**Cateau**	0.23	0.01	2.03	3	10.83	8.06
06.08.99	Cap Malheureux	**(Flesh)**	0.58	0.6	0.68	0.01	18.93	0.09
03.03.00	Cap Malheureux		0.02	0.01	0.93	3.45	13.23	1.02
20.08.99	Trou d' Eau Douce		0.38	2.15	1.08	1.48	55.48	2.6
10.03.00	Trou d' Eau Douce		0.01	0.01	2.3	3.13	5.13	1.93
17.09.00	La Gaulette		0.23	4.45	0.12	1.9	34.28	0.12
10.03.00	La Gaulette		0.01	1.15	0.32	3.77	12.58	0.13
17.09.00	La Gaulette		0.23	4.45	0.11	1.9	34.28	0.23
10.03.00	La Gaulette		0.01	1.15	0.61	3.77	12.58	0.56
15.07.00	Mahebourg		0.9	2.88	2.31	3.73	68.1	0.25
24.03.00	Mahebourg		0.01	1.18	1.93	4.87	108.2	0.38
15.10.99	Souillac		0.05	2.75	0.08	0.5	8.15	0.11
21.04.00	Souillac		0.01	0.01	0.12	1.45	12.58	0.09
12.11.99	Baie du Tombeau		0.01	0.25	2.39	0.75	5.23	6.39
19.06.00	Bain des Dames		0.01	0.01	2.78	1.45	11.4	7.69
19.03.00	GRNW		0.01	0.15	1.99	0.8	16.95	7.22
12.05.00	Pte aux Piments		0.01	0.23	1.02	0.01	19.25	2.37
20.08.99	Belle Mare		0.38	2.15	0.51	1.48	55.48	0.29
13.07.99	Albion		0.01	1.99	0.59	0.54	100.25	0.31
20.07.99	Pointe aux Sables		0.01	1.46	4.38	18.3	104.75	21.54
		Mean	**0.1555**	**1.352**	**1.314**	**2.8145**	**35.383**	**3.069**
24.06.99	Poudre D'Or	**Gill**	4.08	280	27	105.73	452.5	4.4
06.08.99	Cap Malheureux		1.9	2.9	5.02	0.01	61.13	9.31
20.08.99	Trou d' Eau Douce		2.6	18.8	9.36	9.7	216.65	5.39
20.08.99	Belle Mare		2.6	18.8	2.04	9.7	216.65	0.87
24.06.99	Poudre D'Or	**Liver**	3.7	179	29.4	75.23	351.75	0.77
21.04.00	Souillac		3.65	9.61	2.37	11.45	12.58	0.63
		Mean	**3.08833**	**84.85167**	**12.5317**	**35.30333**	**218.5433**	**3.5616667**
24.06.99	Poudre D'Or		0.08	1.05	0.32	4.9	19.8	3.79
18.01.00	Poudre D'Or		0.01	0.88	0.08	2.73	62.8	9.32
11.01.99	Cap Malheureux		5	1.37	1.93	0.98	6.75	14.1
06.08.99	Cap Malheureux	**Rouget**	0.33	1.58	1.05	0.01	16.53	6.97
03.03.00	Cap Malheureux	**(Flesh)**	0.01	0.01	0.07	1.13	0.01	8.82
20.07.99	Pte aux Sables		0.7	47.15	28.31	0.13	80.38	6.65
13.07.99	Albion		0.01	0.5	3.94	2.38	103.9	1.23
09.02.00	Albion		0.01	0.48	7.32	1.85	85.97	3.24
25.02.00	Pte aux Sables		0.01	0.49	32.56	1.99	52.8	15.36
20.08.99	Trou d' Eau Douce		0.05	1.22	8.94	3.13	30.13	3.89
17.09.00	La Gaulette		0.63	1.28	0.81	1.2	11.27	0.63
10.03.00	La Gaulette		0.01	5.52	0.09	11.08	194.7	0.08
15.10.99	Souillac		0.01	4.15	0.69	7.8	162.88	1.28
21.04.00	Souillac		0.01	5.58	0.98	5.63	21.77	2.3
12.05.00	Pte aux piments		0.01	0.4	1.37	3.25	2.1	2.09
15.10.00	Mahebourg		0.87	1.22	3.12	1.33	8.45	1.07
		Mean	**0.48438**	**4.555**	**5.72375**	**3.095**	**53.765**	**5.05125**
24.06.99	Poudre D'Or	**Gill**	1.73	1.15	13.1	9.8	61.68	22.3
06.08.99	Cap Malheureux		1.1	4.13	3.22	0.01	200.45	1.29
13.07.99	Albion		1.2	86.5	1.3	36.4	175.2	2.68
25.02.00	Pte aux Sables		0.43	1.23	31.54	0.01	77.15	9.88
20.08.99	Trou d' Eau Douce		1.83	3.45	12.35	0.01	142.73	3.65
20.07.99	Pte aux Sables		0.85	67.98	24.79	25.4	151.6	12.67
		Mean	**1.19**	**27.40667**	**14.3833**	**11.93833**	**134.8017**	**8.745**

Appendix 13 c : Heavy Metal Content (µg/g) in edible fish species								
			Cd	Cu	Cr	Pb	Zn	Sn
24.06.99	Poudre D'Or		0.63	103.08	0.54	55.93	25.88	15.03
18.01.00	Poudre D'Or		0.01	0.25	6.54	2.2	20.38	9.37
13.07.99	Albion	**Vieille**	0.23	0.01	0.87	0.01	16.1	6.32
06.08.99	Cap Malheureux	**Flesh**	0.95	0.55	1.23	0.01	18.33	4.12
20.08.99	Trou d' Eau Douce		0.25	0.27	3.26	1.18	14.28	29.38
10.03.00	Trou d' Eau Douce		0.01	1.15	0.77	6.3	91	15.07
17.09.99	La Gaulette		0.23	0.88	1.02	3.53	40.28	3.44
10.03.00	La Gaulette		0.01	0.01	1.53	2.2	15.27	2.93
15.10.00	Mahebourg		8.45	0.48	0.45	3.83	25.08	8.55
24.03.00	Mahebourg		0.01	0.65	0.98	1.1	15.93	5.87
15.10.00	Souillac		0.01	0.25	1.32	76.18	13.13	8.33
21.04.00	Souillac		0.01	0.23	2.96	3.5	15.23	12.45
12.11.99	Roche Bois,		0.01	0.03	12.51	2.2	11.43	36.12
19.11.00	Bain des Dames		0.01	0.01	21.84	1.48	3.23	24.14
12.05.00	Pte aux Piments		0.01	0.18	3.27	0.12	21.42	9.53
		Mean	**0.722**	**7.202**	**3.939**	**10.651**	**23.1313**	**12.71**
13.07.99	Albion	**Gill**	1.5	0.21	9.72	8.78	564.5	12.2
24.06.99	Poudre D'Or		2.75	119.33	12.9	49	249.63	21.27
06.08.99	Cap Malheureux		0.83	5.68	1.33	0.31	79.75	3.01
		Mean	**1.6933**	**41.74**	**7.983**	**19.363**	**297.96**	**12.16**
24.06.99	Poudre D'Or		0.73	1.63	3.5	4.85	22.7	12.04
20.07.99	Pte aux Sables	**Lion**	1.33	0.25	12.39	7.41	69.87	36.35
25.02.00	Pte aux Sables	**Flesh**	0.91	0.66	18.29	2.68	64.89	45.36
15.10.00	Mahebourg		1.1	1.25	2.13	1.2	9.95	12.82
19.11.00	GRNW		0.58	0.18	15.94	2.53	15.65	19.28
		Mean	**0.93**	**0.794**	**10.45**	**3.734**	**36.612**	**25.17**
20.07.99	Pte aux Sables	**Gill**	1.5	5.35	7.13	12.01	358	31.27
2.06.99	Poudre D'Or		0.13	0.18	1.05	1.2	10.33	12.34
06.08.99	Cap Malheureux		0.4	0.33	0.62	0.01	25.35	0.12
03.03.00	Cap Malheureux	**Mardoque**	1.03	2.93	0.39	0.02	57.58	1.03
20.08.99	Trou d' Eau Douce	**Flesh**	1.4	0.55	4.99	0.02	40.55	2.33
12.11.99	Baie duTombeau		0.21	0.02	3.51	1	3.48	14.14
19.11.00	Bain des Dames		0.19	0.02	12.38	1.38	6.25	21.95
		Mean	**0.56**	**0.6717**	**3.823**	**0.605**	**23.9233**	**8.65167**
06.08.99	Cap Malheureux	**Gill**	1	4.5	0.39	1.03	22.23	9.39
03.03.00	Cap Malheureux		0.98	2.02	0.61	1.5	11.98	12.11
		Mean	**0.99**	**3.26**	**0.5**	**1.265**	**17.105**	**10.75**
13.07.99	Albion	**Pavillon**	2.1	18	2.22	17.05	106.98	4.31
03.06.00	Albion	**Flesh**	0.11	25.08	5.36	10.68	118.55	0.93
25.10.00	Albion		0.53	0.89	2.85	2.35	147.2	2.33
09.02.00	Pte aux Sables		3.02	10.01	3.17	4.78	58.69	12.56
12.11.99	Baie du Tombeau		5.01	7.02	3.29	4.08	20.93	15.09
		Mean	**2.154**	**12.2**	**3.378**	**7.788**	**90.47**	**7.044**
13.07.99	Albion	**Gill**	1.32	124.83	3.22	48.45	331	11.98
03.06.00	Albion		1.62	124.83	1.33	48.45	331	18.3
		Mean	**1.47**	**124.83**	**2.275**	**48.45**	**331**	**15.14**

Appendix 13 d : Heavy Metal Content (µg/g) in edible fish species								
			Cd	Cu	Cr	Pb	Zn	Sn
24.06.99	Poudre D' Or		0.01	0.03	5.32	2.48	50.88	3.81
06.08.99	Cap Malheureux	***Capitaine***	0.01	0.03	1.98	1.88	19.3	1.33
17.09.99	Tamarin	**Flesh**	0.65	0.6	2.65	1.55	20.18	5.98
15.10.00	Mahebourg		1.3	2.1	2.22	1.98	23.9	4.53
20.08.99	Trou d' Eau Douce		0.01	0.55	4.63	0.8	48.38	2.11
06.08.99	Cap Malheureux		1.28	0.73	2.15	0.02	35.83	0.57
20.08.99	Trou d' Eau Douce		1.28	0.83	6.52	0.03	28.83	1.75
17.09.99	Tamarin		0.55	0.98	1.39	1.63	21.2	7.64
15.10.00	Mahebourg		0.2	0.03	1.84	1.75	12.95	4.66
12.05.00	Pte aux Piments		0.04	0.21	1.05	0.02	14.33	5.91
24.06.99	Poudre D' Or		0.01	0.03	3.67	2.48	50.88	9.14
06.08.99	Cap Malheureux		0.01	0.03	0.86	1.88	19.3	3.28
17.09.99	Tamarin		0.65	0.6	1.35	1.55	20.18	1.22
06.08.99	Cap Malheureux		1.28	0.73	2.09	0.02	35.83	2.01
20.08.99	Trou d' Eau Douce		1.28	0.83	5.14	0.03	28.83	11.54
17.09.99	Tamarin		0.55	0.98	4.07	1.63	21.2	5.33
15.10.00	Mahebourg		0.2	0.03	1.22	1.75	12.95	2.37
12.05.00	Pte aux Piments		0.04	0.21	2.34	0.02	14.33	4.27
17.09.99	Tamarin		1.05	2.68	2.99	4.4	80.65	1.32
19.11.00	Bain des Dames		0.01	0.05	11.5	1.8	22.95	24.55
12.11.99	Baie du Tombeau		0.02	0.35	8.36	2.78	17.5	18.24
		Mean	**0.4967**	**0.6005**	**3.492**	**1.4514**	**28.5895**	**5.78857**
03.03.00	Cap Malheureux	**Gill**	0.98	0.02	1.45	1.5	11.98	8.32
06.08.99	Cap Malheureux		1	4.5	0.96	0.03	122.23	5.11
		Mean	**0.99**	**2.26**	**1.205**	**0.765**	**67.105**	**6.715**
13.07.98	Cap Malheureux	***Pavillon***	0.11	18	0.83	17.05	106.98	1.51
19.09.99	Pointe aux Piments	**Flesh**	0.24	25.08	1.98	10.68	118.55	0.53
15.05.00	Tamarin		0.21	0.89	3.24	2.35	147.2	0.77
09.02.00	Trou d`Eau Douce		0.32	0.01	15.24	4.78	58.69	2.76
12.11.99	Grand Gaube		0.11	0.02	8.99	4.08	20.93	3.81
		Mean	**0.198**	**8.8**	**6.056**	**7.788**	**90.47**	**1.876**
13.07.98	Albion	**Gill**	1.32	24.83	12.44	48.45	65.23	14.28
19.09.99	Albion		1.81	14.45	5.36	18.25	331	7.55
		Mean	**1.565**	**19.64**	**8.9**	**33.35**	**198.115**	**10.915**

Appendix 13 e : Heavy Metal Content (µg/g) in edible fish species

			Cd	Cu	Cr	Pb	Zn	Sn
20.08.99	Trou d' Eau Douce	**Kaya**	0.01	6.73	3.17	1.05	30.9	1.28
17.09.99	Tamarin	**Flesh**	1.05	2.68	1.01	4.4	80.65	0.14
19.11.00	Bain des Dames		1.01	0.05	5.39	1.8	22.95	3.11
12.11.99	Baie du Tombeau		0.72	0.35	6.52	2.78	17.5	1.97
		Mean	**0.7**	**2.453**	**4.02**	**2.508**	**38**	**1.625**
			Cd	**Cu**	**Cr**	**Pb**	**Zn**	**Sn**
24.06.99	Poudre D'Or	Bretere (F)	0.04	41.8	12.1	13.68	117.9	0.09
24.06.99	Poudre D'Or	Bretere (G)	8.3	31.6	2.95	13.8	78.58	1.27
13.07.99	Albion	Chirurgien (F)	0.2	0.02	14.3	0.01	29.73	9.25
13.07.99	Albion	Chirurgien (G)	1.45	0.02	3.65	0.01	43.8	12.45
20.07.99	Pte aux Sables	Carpe (F)	0.23	0.01	0.14	0.01	21.2	21.99
15.10.00	Mahebourg	Carpe (F)	1.23	1.03	3.29	0.8	50.48	12.14
20.08.99	Trou d' Eau Douce	Berry (F)	0.08	0.1	25.1	1.4	40.58	18.34
10.03.00	Trou d' Eau Douce	Berry (F)	0.01	0.01	15.9	3.57	35.35	2.43
15.10.00	Mahebourg	Breton (F)	0.08	0.28	0.11	0.55	35.73	12.08
20.08.99	Trou d' Eau Douce	Mulet (F)	0.05	1.9	14.1	2.97	76.25	1.07
24.06.99	Poudre D'Or	Batarde (F)	0.65	0.01	21.2	33.73	47.98	0.04
24.06.99	Poudre D'Or	Batarde (G)	4.13	10.36	0.03	75.98	178	5.7

LISTING BY COMMON NAME

CARTILAGINOUS FISHES

Aigle de mer	*Aetobatus narinari* (Euphrasen 1790)
Diable de mer	*Manta birostris* (Walbaum 1792)
L'endormi	*Poroderma africanum* (Gmelin 1789)
La raie	*Raja clavata* (Linnaeus 1758)
La raie blanche	*Dasyatis uarnak* (Forsskal 1775)
Lézard	*Loxodon macrorhinus* (Müller & Henle 1841)
Raie chauve-souris	*Aetomylus maculatus* (Gray 1834)
Requin baleine	*Rhiniodon typus* (Smith 1828)
Requin demoiselle	*Carcharinus limbatus* (Valenciennes in
Requin malais	*Notorynchus cepedianus* (Peron 1807)
Requin marteau	*Sphyrna lewini* (Griffith & Smith 1834)
Requin marteau	*Sphyrna mokarran* (Rüppell 1837)
Requin marteau	*Sphyrna zygaena* (Linnaeus 1758)
Requin scie	*Pristis zijsron* (Bleeker 1851)
Requin tigre	*Galeocerdo cuvieri* (Peron & Lesueur 1822)
Requin tigre	*Isurus oxyrinchus* (Rafinesque 1809)
Requin tigre	*Stegostoma fasciatum* (Hermann 1783)
Requin trois piquants	*Squalus megalops* (Mc Leay 1881); *acutipinnis* (Regan 1908)
Trembleur	*Torpedo marmorata* (Risso 1810)
Violon	*Squatina africana* (Regan 1908)

BONY FISHES

Aiguille	*Platybelone aegulus platyura* (Bennett 1837)
Aiguille	*Strongylura leiyra* (Bleeker 1850)
Aiguille plate	*Ablennes hians* (Valenciennes 1846)
Anguille congre	*Conger cinereus cinereus* (Rüppell 1828)
Anguille d'eau douce	*Anguilla bicolor bicolor* (McClelland 1844)
Anguille de sable	*Hippocampus hystrix* (Kaup 1856)
Anguille deux taches	*Myrichthys colubrinus* (Boddaert 1781)
Anguille lamandia, petit chien	*Lycodontis undulatus* (Lacépède 1803)
Anguille morel grise	*Echidna nebulosa* (Ahl 1789)
Anguille patna	*Siderea grisea* (Lacépède 1803)
Arna salace	*Saurida gracilis* (Quoy & Gaimard 1824)
Baise dame	*Synodus varius* (Steindachner 1901)= *variegatus* (Lacépède 1803)
Balao	*Hemiramphus far* (Forsskal 1775)= *commersonii* (Gunther 1846)
Balao	*Hemiramphus marginatus* (Forsskal 1775)
Banane	*Albula glossodonta* (Forsskal 1775)= *vulpes* (Linnaeus 1758)
Barbé	*Polynemus indicus* (Shaw)
Barbé	*Polynemus plebejus* (Broussonet 1782)
Barbé	*Polynemus sexfilis* (Valenciennes 1831)
Bardé	*Rhinomuraena quaesita* (Garman 1889)
Barrois	*Lethrinus xanthochilus* (Klunzinger 1871)
Battardet	*Lethrinus harak* (Forsskal 1775)
Bécune blanche	*Scomberomorus commersoni* (Lacépède 1802)
Bécune grosse race	*Acanthocybrium solandri* (Cuvier 1831)
Bigorneau, cancrelat	*Pristipomoides typus* (Bleeker, 1852)
Black marlin	*Makaira indica* (Cuvier 1832)= *mazara* (La Monte 1855)
Blue marlin	*Makaira mazara* (Jordan & Snyder 1801)= *ampla* (La Monte 1955)

Bonite folle	*Euthynnus affinis* (Cantor 1850)
Borer	*Gymnocaesio gymnopterus* (Bleeker 1856)
Bouletangue goëmon	*Cathigaster valentini* (Bleeker 1853)
Bouletangue; bouletane	*Diodon hystrix* (Linnaeus 1758)
Bourrique; cateau rayé	*Hemigymnus fasciatus* (Bloch 1792)
Bourse	*Arothron hispidus* (Lacépède 1802)
Bourse	*Arothron mappa* (Lesson 1830)
Bourse	*Arothron nigropunctatus* (Bloch & Schneider 1801)
Bourse	*Pseudobalistes flavomarginatus* (Rüppell 1828)
Bourse barrois	*Balistoides veridescens* (Schneider 1801)
Bourse boutan	*Lagocephalus lagocephalus* (Linnaeus 1758)
Bourse café au lait	*Sufflamen bursa* (Bloch 1801)
Bourse capitaine	*Sufflamen fraenatus* (Bloch & Schneider 1801)
Bourse corail; Bourse mayar	*Rhinecanthus rectangulus* (Bloch & Schneider 1801)
Bourse de fond	*Triodon bursaris* (Reinwardt 1825)
Bourse de sable	*Rhinecanthus cinereus* (Bonnaterre 1788)
Bourse éventail	*Aluterus scripta* (Osbeck 1765)
Bourse goëmon	*Arothron immaculatus* (Bloch & Schneider 1801)
Bourse la plaine	*Rhinecanthus aculeatus* (Linnaeus 1758)
Bourse manan.	*Odonus niger* (Rüppell 1835)
Bourse Marie Louise	*Oxymonacanthus longirostris* (Bloch 1801)
Bourse pavillon	*Cantherines pardalis* (Rüppell 1835)
Bourse piastre	*Balistoides conspicillum* (Schneider 1801)
Bourse poule	*Pseudobalistes fuscus* (Bloch 1801)
Bourse toto	*Lagocephalus spadiceus* (Richardson 1844)
Breton	*Gerres acinaces* (Bleeker 1854)
Breton	*Gerres oyena* (Forsskal 1775)
Breton long	*Gerres filamentosus* (Cuvier 1829)= *punctatus* (Cuvier 1830)
Cablé, sardine carré	*Sardinella dayi* (Regan 1917)
Cabot	*Eleotriodes helsdingenii* (Bleeker 1858)
Cabot	*Eleotriodes strigatus* (Broussonet 1782)
Cabot	*Heterelеotris vinsoni* (Hoese 1986)
Cabot	*Heterelеotris zanzibarensis* (Smith 1958)
Cabot	*Hypseleotris cyprinoides* (Valenciennes 1837)
Cabot	*Nemateleotris decora* (Randall & Allen 1973)
Cabot	*Nemateleotris magnificus* (Fowler 1938)
Cabot	*Paragobiodon echinocephalus* (Rüppell 1828)
Cabot	*Periophthalmus koelreuteri africanus* (Eggert 1935)
Cabot	*Ptereleotris evides* (Jordan & Hubbu 1925)
Cabot	*Ptereleotris grammatica melanota* (Randall & Lubbock 1982)
Cabot	*Ptereleotris heteropterus* (Bleeker 1855)= *microlepis* (Bleeker)
Cabot	*Ptereleotris zebra* (Fowler 1938)
Cabot	*Sicyopterus lagocephalus* (Pallas 1874)
Cabot brisant	*Malacanthus latovittatus* (Lacépède 1802)
Cabot d'eau douce	*Eleotris fusca* (Bloch & Schneider 1801)
Cabot des Seychelles	*Ophiocara porocephala* (Valenciennes 1837)
Cabot goemon	*Leptoscarus vaigiensis* (Quoy & Gaimard 1824)= *caeruleopunctatus* (Rüppell)
Canard; canard vert	*Gomphrosus caeruleus caeruleus* (Lacépède 1801)
Capitaine	*Lethrinus nebulosus* (Forsskal 1775)= *opercularis* (Valenciennes 1830)
Capitaine blanc	*Gymnocranius griseus* (Schlegel 1843)
Capitaine grosse race	*Gymnocranius robinsoni* (Gilchrist & Thompson 1908)
Capitaine grosse tête	*Monotaxis grandoculis* (Forsskal 1775)
Capitaine longue bouche	*Lethrinus elongatus* (valenciennes 1830)= *longirostris* (Playfair 1888)= *miniatus* (Schneider 1801)
Carandine	*Gnathanodon aurolineatus* (Lacépède 1802)
Carandine de fond	*Scolopsis personatus* (Cuvier 1830)
Carandine roche	*Scolopsis frenatus* (Cuvier 1830)
Carangue chasseur	*Caranx sexfasciatus* (Quoy & Gaimard 1824)

Carangue de fond	*Caranx lugubris* (Poey 1800)
Carangue flamme	*Alectis ciliaris* (Bloch 1788)
Carangue jaune; carangue gueule pavée (old ones)	*Gnathanodon speciosus*
Carangue l'amoureux	*Carangoides gymnostethus* (Cuvier 1831)= *C. gymostethoides* (Bleeker)
Carangue la gueule pourrie	*Carangoides fulvoguttatus* (Forsskal 1775)
Carangue la Nation	*Carangoides chrysophrys*
Carangue pièce noire	*Caranx ignobilis* (Forsskal 1775)
Carangue ronde	*Carangoides armatus* (Rüppell 1830)
Carangue ronde	*Trachinotus baillonii* (Lacépède 1802)
Carangue sardine	*Caranx melampygus* (Cuvier & Valenciennes 1833)
Carangue saumon	*Elagatis bipinnulata* (Quoy & Gaimard 1824)
Carpe bète	*Plectorhinchus gibbosus* (Lacépède 1802)= *Pristipoma nigrus* (Cuvier)
Carpe d'eau douce	*Kuhlia mugil* (Schneider 1801)
Carpe de mer	*Kyphosus bigibbus* (Lacépède 1802)
Carpe de mer	*Kyphosus cinerascens* (Forsskal 1775)
Carpe kallory	*Plectorhinchus picus* (Cuvier 1830)= *punctatissimus* (Playfair 1867)
Casse poignet	*Gymnocranius lethrinoides* (Bleeker 1850)
Castor	*Cheilinus fasciatus fasciatus* (Bloch 1791)
Cateau bleu	*Scarus enneacanthus* (Lacépède 1802)
Cateau boeuf	*Scarus rubroviolaceus* (Bleeker 1847)= *africanus* (Smith)
Cateau bosse	*Bolbometopon muricatum* (Valenciennes 1840)
Cateau bosse	*Scarus gibbus* (Rüppell 1828)= *microrhinus* (Bleeker 1862)
Cateau cambarre	*Calotomus carolinus* (Valenciennes 1840)
Cateau colombine	*Hologymnosus annulatus* (Lacépède 1802)
Cateau garde police	*Thalassoma purpureum* (Forsskal 1775)
Cateau gras vert	*Scarus scaber* (Valenciennes 1840)= *pectoralis* (Valenciennes)
Cateau patna	*Anampses meleagrides* (Valenciennes 1839)
Cateau rouget	*Hipposcarus harid* (Forsskal 1775)= *cyanurus* (Valenciennes)
Caya	*Lethrinus reticulatus* (Valenciennes 1830)
Chauffe soleil	*Abudefduf sexfasciatus* (Lacépède 1801)= *coelestinus* (Cuvier 1830)
Chemise	*Lutjanus gibbus* (Forsskal 1775)
Cheval de mer	*Hippocampus borboniensis* (Duméril)
Cheval de mer	*Hippocampus camelopardalis* (Bianconi 1853)
Cheval de mer	*Hippocampus kuda* (Bleeker 1852)
Chirurgien	*Acanthurus bariene* (Lesson 1830)
Chirurgien	*Acanthurus guttatus* (Schneider 1801)
Chirurgien	*Acanthurus leucosternon* (Bennett 1832)= *delisiani* (Cuvier & Valenciennes 1829)
Chirurgien	*Acanthurus lineatus* (Linnaeus 1758)
Chirurgien	*Acanthurus mata* (Cuvier 1835)= *blochii* (Cuvier 1835)
Chirurgien	*Acanthurus tennentii* (Gunther 1861)= *plagiatus* (Peters 1876)
Chirurgien	*Acanthurus thompsoni* (Fowles 1923)
Chirurgien deux taches	*Acanthurus polyzona* (Bleeker 1868)
Chirurgien grande queue	*Acanthurus nigricauda* (Duncker & Mohr) = *nigricans* (Linnaeus 1758)
Chirurgien riflé	*Ctenochaetus strigosus* (Bennett 1828)
Chirurgien roi	*Acanthurus olivaceus* (Schneider 1861)
Chitte	*Agnostomus telfairii* (Bennett 1832)= *dobuloides* (Gunther)
Clarisse	*Coris aygula* (Lacépède 1802)
Clarisse	*Coris gaimard africana* (Smith 1857)
Coffre	*Lactoria diaphana* (Bloch 1785)
Coffre	*Lactoria fornasini* (Bianconi 1846)
Coffre; corne mouton	*Ostracion meleagris* (Shaw 1796)
Colombine	*Cheilio inermis* (Forsskal 1775)
Colombine	*Hologymnosus doliatus* (Lacépède 1802)
Cordonnier camard	*Siganus sutor* (Valenciennes 1835)
Cordonnier casier	*Siganus stellatus* (Forsskal 1775)
Cordonnier grosse tête	*Siganus luridus* (Rüppell 1828)
Cordonnier long	*Siganus argenteus* (Quoy & Gaimard 1825)= *rostratus* (Valenciennes)
Corne (Licorne) mouton	*Naso vlamingii* (Valenciennes 1835)

Corne (Licorne) vache	*Naso unicornis* (Forsskal 1775)
Corne (Licorne) velours	*Naso vomer* (Klungzinger 1871)
Corne chameau; corne roi	*Naso lituratus* (Bloch & Schneider 1801)
Coupe couillon de fond	*Trichonotus setigerus* (Bloch 1801)
Cous-cous	*Abudefduf septemfasciatus* (Gunther 1881)
Cous-cous	*Abudefduf sordidus* (Forsskal 1775)= *Glyphisodon geant* (Lienard)
Créole	*Lethrinus variegatus* (Valenciennes 1830)
Croissant queue blanche	*Variola albimarginata* (Baissac 1953)
Croissant queue jaune	*Variola louti* (Forsskal 1775)
Dame berri	
Deboëtteur	*Amphiprion chrysogaster* (Cuvier 1830)
Deboëtteur bleu	*Amphiprion clarkii* (Bennett 1830)
Deboëtteur bleu	*Chrysoptera biocellata* (Quoy & Gaimard 1824)
Deboetteur cannonier; Pilote	*Naucrates ductor* (Linnaeus 1758)
Dorade	*Coryphaena equiselis* (Linnaeus 1758)
Dorade	*Coryphaena hippurus* (Linnaeus 1758)
Empereur	*Xiphias gladius* (Linnaeus 1758)
Empereur voilier	*Istiophorus platypterus* (Shaw & Nodder 1792)
Germon	*Thunnus alalunga* (Bonnaterre 1788)
Giblot	*Lutjanus monostigmus* (Cuvier 1828)
Gourami de mer	*Epibulus insidiator* (Pallas 1770)
Gros yeux blanc	*Paracirrhites forsteri* (Bloch & Schneider 1801)
Gros yeux rose	*Pamperis oualensis* (Cuvier 1831)= *otaitens* (Cuvier 1831)
Grosse aiguille	*Tylosurus crocodilus* (Peron & Lesueur 1821)
Grosse bonite	*Katsuwonus pelamis* (Linnaeus 1758)
Guele pavée de fond	*Argyrops filamentosus* (Valenciennes 1830)
Gueule pavée	*Rhabdosargus sarba* (Forsskal 1775)
Gueule pavée dorée	*Polysteganus baissaci* (M. Smith 1978)
Guingham de fond	*Pomacanthus semicirculatus* (Cuvier 1831)
Laf de fond	*Sebastapistes sp.*
Laffe cinq doigts	*Antennarius commersoni* (Latrielle 1804)
Laffe cinq doigts	*Antennarius hispidus* (Schneider 1801)= *pinniceps* (Gunther)
Laffe cochon	*Antennarius coccineus* (Lesson & Garman 1831)
Laffe de boue	*Synanceja verrucosa* (Bloch & Schneider 1801)
Laffe de fond	*Paracentropogon longispinis* (Cuvier 1829)
Laffe volant	*Pterois antennata* (Bloch 1787)
Laffe volant	*Pterois radiata* (Cuvier 1829)
Laffe volant	*Pterois russellii* (Bennett 1831)= *lunulata* (Bleeker)
Laffe volant	*Pterois volitans* (Linnaeus 1758)= *miles* (Bennett 1837)
Lalo	*Coris caudimacula* (Quoy & Gaimard 1834)
Lalo	*Halichoeres scapularis* (Bennett 1831)
Lalo	*Thalassoma lunare* (Linnaeus 1758)
Lamame long	*Hypoatherina temminckii* (Bleeker 1853)= *afra* (Peters 1855)
Lamame; prètre	*Atherinomorus lacunosus* (Forster 1801)
Lamandia morue	*Lycodontis pikei* (Bliss 1883)
Lascar	*Plectorhinchus orientalis* (Bloch 1793)
Latanier	*Apsilus fuscus* (Valenciennes 1930)
Le chien	*Bodianus opercularis* (Guinchenot 1847)
Lézard	*Parapercis punctulata* (Cuvier 1828)
Lézard	*Synodus indicus* (Day 1873)
Lion	*Sargocentron caudimaculatum* (Rüppell 1835)
Lion	*Sargocentron ittodai* (Jordan & Fowler 1903)
Lion aux ailes rouges	*Sargocentron punctatissimus* (Cuvier 1829)
Lion baroque	*Sargocentron diadema* (Lacépède 1802)
Lion baroque	*Sargocentron spiniferum* (Fowler 1775)
Lion blanc	*Macolor niger* (Forsskal 1775)
Longchamp	*Acanthurus triostegus* (Linneaus 1758)
Lubine	*Chanos chanos* (Forsskal 1775)

Lubine male	*Elops machnata* (Forsskal 1775)= *saurus* (Linnaeus 1776)
Machoiran	*Plotosus limbatus* (Valenciennes 1840)
Machoiran	*Plotosus lineatus* (Thunberg 1791)= *anguillaris* (Bloch 1794)
Madame tombée	*Anampses twistii* (Bleeker 1859)
Madras	*Lutjanus kasmira* (Forsskal 1775)
Maïs vert; cateau colombine	*Halichoeres hortulanus certriquadrus* (Lacépède 1801)
Maldaque	*Bodianus anthioides* (Bennett 1830)
Maldaque	*Bodianus perditio* (Quoy & Gaimard 1835)
Maldaque de fond	*Bodianus bilunulatus* (Lacépède 1802)
Maldaque la chaux	*Choerodon robustus* (Gunther 1862)
Maman rose	*Cheilinus trilobatus* (Lacépède 1802)
Maman rouge	*Epinephelus retouti* (Bleeker 1874)= *mauritianus* (Baissac 1962)
Mandecdec	*Megalops cyprinoides* (Broussonet 1782)
Maquereau	*Rastelliger kanagurta* (Cuvier 1831)
Maquereau de fond	*Paraceasio xanthurus* (Bleeker 1869)
Marie Jeanne	*Apogon fraenatus* (Valenciennes 1832)
Marlin rayé	*Tetrapturus audax* (Philippi 1887)= *mitsukurii* (La Monte 1955)
Marquereau bleu	*Caesio caerulaureus* (Lacépède 1802)
Marquereau la boëtte tortue	*Pterocaesio tile* (Cuvier 1830)
Mozambique pointillé	*Anampses caeruleopunctatus* (Rüppell 1828)
Mulet bête	*Crenimugil crenilabis* (Forsskal 1775)
Mulet grosses écailles	*Valamugil buchanani* (Bleeker 1853)
Mulet roche	*Liza alata* (Steindachner 1892)= *Pteromugil diadema* (Smith)
Mulet sec; Mulet queue bleue	*Valamugil seheli* (Forsskal 1775)= *axillaris* (Bleeker)
Mulet voilé	*Mugil cephalus* (Linnaeus 1758)= *cūr* (Forsskal 1775)
Mulleton de sable	*Valamugil robustus* (Gunther 1861)
Neplie	*Stolephorus commersonii*
Neplie	*Stolephorus holodon* (Boulanger 1900)
Neplie	*Stolephorus indicus* (van Hasselt 1823)
Pavillon	*Chaetodon chrysurus* (Desjardins 1833)= *mertense* (Cuvier)= *xanthurus* (Bleeker)
Pavillon	*Chaetodon dolosus* (Ahl 1923)
Pavillon	*Chaetodon falcula* (Bloch 1793)
Pavillon	*Chaetodon fasciatus* (Forsskal 1775)
Pavillon	*Chaetodon guttatissimus* (Bennett 1832)
Pavillon	*Chaetodon kleinii* (Bloch 1790)= *virecens* (Cuvier & Valenciennes 1831)
Pavillon	*Chaetodon lineolatus* (Cuvier 1831)
Pavillon	*Chaetodon lunula* (Lacépède 1803)
Pavillon	*Chaetodon melannotus* (Bloch 1801)= *abhortani* (Cuvier 1831)
Pavillon	*Chaetodon meyeri* (Bloch & Schneider 1801)
Pavillon	*Chaetodon mitratus* (Gunther 1860)
Pavillon	*Chaetodon trifasciatus* (Park 1797)
Pavillon	*Chaetodon unimaculatus* (Bloch 1787)
Pavillon	*Chaetodon vagabundus* (Linneaus 1858)
Pavillon	*Chaetodon xanthocephalus* (Benntt 1832)
Pavillon	*Chaetodon zanzibariensis* (Playfair 1866)= *speculum* (Cuvier & Valenciennes 1831)
Pavillon cocher; pavillon boeuf	*Zanclus cornutus* (Linnaeus 1758)
Petit cous-cous	*Segastes nigricans* (Lacépède 1803)
Petit rouge	*Apogon aureus* (Lacépède 1802)
Petite mangouste	*Leiognathus elongatus* (Gunther 1870)
Petite sardine, Sardine batarde	*Thryssa baelama* (Forsskal 1775)
Pierre à boire	*Rhonciscus anas* (Valenciennes 1830)
Pintade	*Halichoeres marginatus* (Rüppell 1834)
Poisson pilote	*Echeneis naucrates* (Linnaeus 1778)
Poisson volant	*Cheliopogon furcatus* (Mitchill 1815)= *unicolor* (Valenciennes 1846)
Poule d'eau	*Platax orbicularia* (Forsskal 1775)= *vespertilio* (Bleeker 1877)
Ripé	*Acanthurus xanthopterus* (Valenciennes 1855)= *matoides* (Cuvier & Valenciennes)
Robinne	*Scarus ghobban* (Forsskal 1775)= *guttatus* (Bloch & Schneider)
Rouge gorge	*Plectorhinchus gaterinus* (Forsskal 1775)

Rouger deux frère	*Parupenaeus cyclostomus* (Lacépède 1801)= *chryseredros* (Lacépède 1801)
Rouget cancrelat	*Parupenaeus rubescens* (Lacépède 1801)= *fraterculus* (Valenciennes 1831)
Rouget chinoix	*Parupenaeus barberinus* (Lacépède 1801)
Rouget fayan	*Mulloides flavolineatus* (Lacépède 1801)
Rouget queue grise	*Upeneus vittatus* (Forsskal 1775)
Rouget queue jaune	*Mulloides vanicolensis* (Valenciennes 1891)= *eurytrinus*= *auriflamma*
Rouget tache	*Parupenaeus macronema* (Lacépède 1801)
Sabre	*Chirocentrus dorab* (Forsskal)
Sacré chien	*Aphareus rutilans* (Cuvier 1830)
Sacré chien blanc	*Pristipomoides filamentosus* (Valenciennes 1830)
Sacré chien grande queue	*Etelis carbunculus* (Cuvier 1828)
Sacré chien grosses écailles	*Pristipomoides typus* (Bleeker 1852)
Sacré chien rouge	*Etelis marshi* (Jenkins 1908)
Samedi	*Apogon taeniopterus* (Bennett 1835)
Sans culotte	*Branchiostegus doliatus* (Valenciennes 1830)
Sap-sap	*Leiognathus equulus* (Forsskal 1775)
Sap-sap	*Leiognathus fasciatus* (Lacépède 1803)
Sap-sap lé dents	*Gazza minuta* (Bloch 1797)
Sap-sap long	*Secutor insiadiator* (Bloch 1787)
Sarde	*Lutjanus argentimaculatus* (Forsskal 1775)
Sardine de France	*Sardinella fimbriata* (Valenciennes 1847)
Sardine de France	*Sardinella jussieu* (Valenciennes 1847)
Sardine goëmon	*Herklotsichthys punctatus* (Rüppell 1837)
Sardine queue noire	*Sardinella melanura* (Cuvier 1829)
Savon	*Kuhlia rupestris* (Lacépède 1801)
Sissard; Carangue maquereau (old)	*Selar crumenophthalmus* (Bloch 1793)
Sole	*Bothus mancus* (Broussonet 1752)
Sole de lait	*Solea pardachirus* (Lacépède 1802)
Sorqier la chaux	*Xyrichtys pavo* (Valenciennes 1839)
Tazar goëmon	*Sphyraena flavicauda* (Rüppell 1835)= *langsar* (Bleeker)
Tazard bécune	*Sphyraena jello* (Cuvier 1829)
Tazard chien	*Sphyraena barracuda* (Walbaum 1782)
Tazard clair	*Sphyraena obtusata* (Cuvier 1829)= *chrysotaenia* (Dutt 1967)
Thon blanc	*Gymnosarda unicolor* (Rüppell 1837)
Thon gros yeux	*Thunnus obesus* (Lowe 1835)
Thon jaune	*Thunnus* (Neothunnus) albacares (Bonnaterre 1788)
Vacoa	*Aprion virescens* (Valenciennes 1830)
Varavara	*Lutjanus bohar* (Forsskal 1775)
Vieille la boue	*Epinephelus morrhua* (Valenciennes 1833)
Vieille Saint Silac	*Plectropomus laevis* (Lacépède 1802)
Vielle ananas	*Cephalopholis miniata* (Forsskal 1775)
Vielle babonne	*Plectropomus punctatus punctatus* (Quoy & Gaimard 1924)
Vielle cabas	*Paracirrhites arcatus* (Cuvier 1829)= *Gymnocirrhites arcatus* (Smith)
Vielle cheval de bois	*Cephalopholis sonnerati* (Valenciennes 1828)
Vielle chinois	*Pogonaperca punctata* (Cuvier 1830)= *reticolata* (Schneider)
Vielle chinois rosée	*Epinephelus hexagonatus* (Schneider 1801)= *megachir* (Richardson)
Vielle faraud	*Epinephelus areolatus* (Forsskal 1775)= *angularis* (Cuvier 1828)
Vielle fou-fou	*Epinephelus miliaris* (Valenciennes 1830)= *fario* (Thunberg 1793)
Vielle grise	*Epinephelus fuscoguttatus* (Forsskal 1775)
Vielle loutre	*Epinephelus tukula* (Morgans 1959)
Vielle loutre, tukula	*Epinephelus fasciatus* (Forsskal 1775)
Vielle plate	*Anyperodon leucogrammicus* (Valenciennes 1828)
Vielle rouge	*Epinephelus coeruleopunctatus* (Bloch 1790)
Vielle tacamaca	*Cirrhitus pinnulatus* (Bloch 1802)= *maculatus* (Lacépède)
Vivano	*Tropidinius zonatus* (Valenciennes 1830)
Vivano la flamme	*Etelis oculatus* (Cuvier 1828)
Zèbre	*Geniacanthus caudovittatus* (Gunther 1860)= *melanospilos* (Bleeker 1851)
Zozo	*Dactyloptena orientalis* (Cuvier 1829)

MINISTRY OF ENVIRONMENT, HUMAN RESOURCE DEVELOPMENT & EMPLOYMENT

DEPARTMENT OF ENVIRONMENT

Guidelines for coastal water quality

The following guidelines are hereunder published for the information of the public with regards to coastal water quality requirements for various activities around the Republic of Mauritius.

Classification	*Principal beneficial uses/objectives*
Category A - Conversation	
Class A1 - Conversation of coral community	A1 - Conversation of coral community
Class A2 - Conservation of natural areas	A2 - Conservation of natural areas such as mangroves, sea grass, wildlife habitat and marine spawning, nursing and feeding grounds.
Category B - Recreation	
Class B1 - Primary contact	B1 - Water sports like swimming, diving, surfing where there is direct contact.
Class B2 - Secondary contact	B2 - Water sports such as boating, fishing and other activities involving less body contact or where direct contact with water may occur but the probability of body immersion is minimal.
Category C - Fisheries	
Class C1 - Aqua-culture	C1 - Propagation of marine life such as fish, crabs, shrimps and other marine fauna.
Class C - Shellfish	C2 - Culture of shellfish - oysters, mussels, clams.
Category D - Industrial	
Class D - Industrial and others	D - Natural water resources used as a receiving water body for industrial and agricultural discharges (harbour, power station and other industrial activities). There should be no unpleasant odour to people residing nearby.

Each activity requires different water quality and this is indicated underneath.
Category A is meant for the conservation of the coral community and natural areas.
Class A1 is entended for the coral ecosystem and requires seawater quality that will not hamper healthy coral growth.
Class A2 is for the conservation of natural areas as mentioned in the table above and requires a slightly less stringent water quality.
Category B is intended for recreation purposes.
Class B1 defines the water quality needed for sports such as swimming, diving, surfing, etc., where there is maximum body contact with the water. For this class the potential health hazards due to pathogenic micro-organisms have been considered.
Class B2 is intended for water sports as boating, fishing, etc., where there is likely to be minimal body contact with water, and so the quality of the water is less stringent especially with ragards to pathogenic micro-organisms.
Category C concerns fisheries.
Class C1 is intended for the production of fish, crabs, shrimps, etc.
Class C2 is for the culture of shellfish where the requirements for pathogenic organisms are very stringent.
Category D comprises the remaining coastal areas, which act as receiving body for industrial and agricultural discharges and include the harbour, power generating plants, and other industrial activities. No limits are imposed for pathogenic micro-organisms but there should be no unpleasant odour to people residing nearby.
Date : 16 April 1999.

Coastal water quality requirements for various categories

CATEGORY		A Conservation		B Recreation		C Fisheries		D Industrial
Class		A1 Coral Community	A2 Natural Areas	B1 Primary Contact	B2 Secondary Contact	C1 Aqua-culture	C2 Shellfish	D Industrial & others
Parameters	Unit							
pH	-	7.5-8.5	7.5-8.5	7.5-8.5	7.0-8.5	7.5-8.5	7.0-8.5	7.0-9.0
Temperature	°C	ambient	ambient	ambient	ambient	ambient	ambient	ambient
Suspended Solids	mg/l	5	5	5	10	15	15	15
Dissolved Oxygen	mg/l	>5	>5	>5	>5	>5	>5	>2
Chemical Oxygen Demand[1]	mg/l	2	2	3	3	5	5	5
Total Coliforms	CFU3/100ml	1000	1000	1000	5000	1000	70[2]	—
Faecal Coliforms	CFU3/100ml	200	200	200	1000	200	14[2]	—
Nitrate-Nitrogene	mg/l	0.2	0.3	0.8	0.8	0.8	0.8	1.0
Phosphate	mg/l	0.04	0.05	0.08	0.08	0.08	0.08	0.1
Oil & Grease	mg/l	Not detectable by N-hexane extraction method						
Phenol	mg/l	0.05						
Arsenic	mg/l	0.05						
Cadmium	mg/l	0.02						
Cyanide	mg/l	0.01						
Chromium	mg/l	0.05						
Copper	mg/l	0.05						
Lead	mg/l	0.05						
Total Mercury	mg/l	0.0005						

[1] by alkaline potassium permanganate method
[2] organisms per 100 ml by MPN method
[3] CFU : Colony Forming Unit