Fishery Technology
2007, Vol. 44 (1) pp : 73 - 84

Seasonal Variation of Metal Concentration in Barnacles (*Balanus spp.*) of Cochin Estuary, South West Coast of India

Muhamed Ashraf. P.*, B. Meenakumari and Saly N Thomas
Fishing Technology Division,
Central Institute of Fisheries Technology, Cochin 682 029.

The study was conducted to evaluate the accumulation of heavy metals in barnacle shells and tissues in different seasons of the year. Heavy metal concentration was monitored in barnacle tissues and shells on a long term and short term (monthly) basis by exposing glass panels in Cochin estuary. Short term panels gave a clear idea of the dynamics of heavy metal accumulation in barnacles. Accumulation of chromium and cadmium was maximum in the tissues and shell during the monsoon season whereas lead and nickel was maximum in pre monsoon period. Selenium varied irregularly and arsenic was detected only in one sample. Higher levels of copper and manganese were observed in shells during both high and low salinity season (pre monsoon and monsoon). Manganese and iron uptake was significantly higher in the initial stages of growth and is mainly utilized for shell formation. Zinc was maximum during monsoon in short term panels whereas in soft tissues of long term panels it was detected during monsoon and pre monsoon seasons. Fouling settlement on exposed glass panels was highest during November, the transition period from monsoon to post monsoon season.

Key words: Barnacles, Heavy metal, Seasonal variation, Bioaccumulation

Bioaccumulation of pollutants can occur from suspended particles, seawater, sediments and through food chains (Bryan 1979). Marine organisms will take up metals that are adsorbed on to inorganic particles and absorbed on to organic matter as well as from solution. The filter feeders like barnacles may ingest many potential metal rich particles and they also pass large volumes of water across the permeable surface of the cirri which could facilitate further uptake at high rates (Rainbow & White, 1993). Biomonitors have been defined as the species which accumulate trace contaminants in their tissues. Barnacle has been extensively used to assess the bioavailability of metals in coastal waters of different regions. (Anil & Wagh 1988; Powell & White, 1990; Blackmore & Chan, 1997). Natural dynamics equilibrium and the biotic composition of the estuarine areas of Cochin region are disturbed due to increased human influence by different reasons. The estuarine areas flourished with heavy industries like shipping and fertilizers, tourism, hospitality industry, increased human settlements, chemical industries etc, and these activities influence the rich biological production and accumulation of pollutants in the estuary. Cochin backwaters are known to have a variety of fouling organisms and not much study have been conducted on the seasonal variation of uptake of pollutant elements in the barnacle. The present study aims to understand the dynamics of heavy metals in barnacles and variation in accumulation of heavy metals in different seasons.

* Corresponding author:

Materials and methods

Glass panels of 10x15cm were fixed on a wooden rack and exposed in the Central Institute of Fisheries Technology, test site at Cochin estuary (Fig.1). The panels were exposed during June 2000, the beginning of the monsoon season, and continued till the end of May 2001. A set of preweighed 36 glass panels were exposed in the estuary on long term basis for 12 month of which 3 panels were sampled every month. These samples described in this communication as 'long term panels'. Another set of panels were exposed in the beginning of every month and retrieved at the end of the month, denoted as 'short term panels'. The glass panels were immersed in the test site at 1m below the low tide water level. The retrieved long term and short term panels were brought to the laboratory; wet weight and qualitative species composition were recorded. Three species of barnacles were seen in Cochin estuary viz., *Balanus amphitrite, Balanus amphitrite communis and Balanus amphitrite insignis*. The sampling was done without separating the species. A visual qualitative observation was taken to evaluate different types of fouling organisms present in various seasons. The retrieved glass coupons were weighed and the fouling density was calculated based on the weight of the foulers and area of the glass plate.

The barnacles were cleaned with nylon brush for removing the attached microfoulers. The soft tissue was removed using forceps and both shell and soft tissue of all samples were dried at 65±5°C and kept in desiccators till analysis. The size of the short term barnacle was very small and separation of soft tissue is difficult hence whole barnacle was used for the analysis. 0.5 g of dried samples of tissues and shells were weighed in a Teflon reaction vessel, 6ml HNO_3: $HClO_4$ (5:1) mixture was added and it was digested using Milestone Ethos Plus Microwave Digestion System with following heating program. a) Room temperature to 150°C with pressure 7 bar for 10min b) 150 °C was maintained for 10 min with pressure 7 psi and c) vent for 10 min. The digested samples were analysed for As, Cr, Cu, Fe, Mn, Ni, Se, Pb, Zn and Cd using Labtam 8410 ICP-AES. In our laboratory the quality assurance testing relies on the control of blanks. The high purity metal powders (Alfa Aeser) purchased from MBH Analytical Ltd, England was used for preparing calibration standards. The accuracy and reproducibility of the method was tested using the certified reference material of stream sediment obtained from LGC (Teddington) Ltd, England (No. GBW 07312). The hydrographic parameters like salinity, temperature, turbidity, dissolved oxygen and pH were analysed as per Strickland & Parson (1972) on weekly basis.

Statistical analysis such as analysis of variance, correlation and t test were carried out using the spread sheet MS Excel available in MSOffice software (Microsoft Corporation). Correlation analysis was carried out between all the metals of long term shells, long term soft

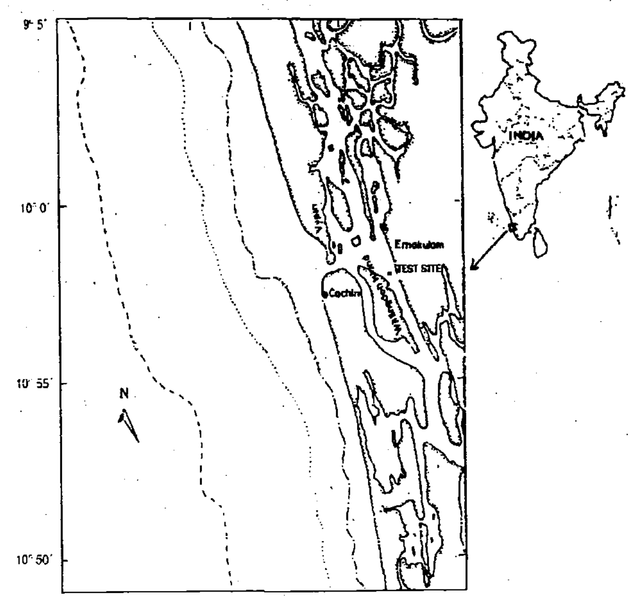

Fig. 1. Map of Cochin showing the location where the study was conducted

tissues, one month barnacle and hydrographic parameters. Correlation also was carried out between the metals of long term shells vs long term tissues, long term shells vs one month barnacle and long term tissue vs one month barnacles.

Results and discussion

Cadmium concentration varied between 0– 1.48, 0 – 4.20 and 0 – 1.48ppm respectively in long term barnacle shells, soft tissues and short term panel barnacles (Fig. 2). Cd was detected during June to August (monsoon season) in both long and short term barnacle shells. In soft tissues of long term panels Cd was detected during June to November and significantly higher concentrations of Cd were recorded during July to October. Correlation analysis of Cd present in barnacle of short term panels with

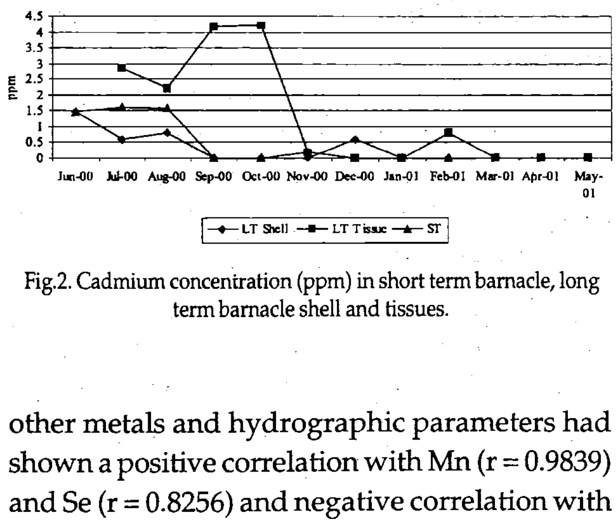

Fig.2. Cadmium concentration (ppm) in short term barnacle, long term barnacle shell and tissues.

other metals and hydrographic parameters had shown a positive correlation with Mn (r = 0.9839) and Se (r = 0.8256) and negative correlation with salinity (r = 0.7312) and seawater temperature (r = 0.715). Similarly soft tissue Cd had a positive correlation with its Cr (r = 0.8888) and Fe (r = 0.7305) and negative correlation with salinity (r = 0.758) and pH (r = 0.704). Long term shell Cd positively correlated with its own Cr, Fe, Mn and Se and also with Cd, Cr, Fe, Mn and Se present in barnacles of short term panels. Blackmore (1999) reported 8.04-13.68 ppm of cadmium in soft tissue of *Tetraclita squamosa* collected from different estuarine areas of Hong Kong but he did not find any significant seasonal variation. According to Wang *et. al.*, (1996) major source of cadmium to the marine bivalves is from aquatic solution. The primary use of Cd is in electroplating of other metals and alloys for protection from corrosion and in the manufacture of storage batteries, glass ceramics, phosphatic fertilisers and some biocides. Marcus & Thompson (1986) reported that American oyster seems to contain higher concentration of Cd in summer than spring, suggesting a seasonal effect on Cd accumulation. Cd forms strong complexes with chloride ions and in low salinity the complexation of Cd with chloride was decreased which increases more bioavailable free Cd^{2+} ions (Langston, 1986). The Cd^{2+} ion is the most easily bioavailable form of Cd and complexation with chlorides reduces its bio accumulation. pH in estuarine water will vary widely and decrease in pH increases free $Cd^{2+}$and will enhance its bioaccumulation. Stephenson & Mackey (1988) observed that there is negative correlation between pH and Cd uptake in lake waters. Low pH and salinity during monsoon is responsible for higher Cd^{2+} thereby its accumulation in barnacles. The present results agree with the above findings.

Chromium concentration varied between 0 – 24.8, 0 – 19.96 and 0 – 22.96 ppm in long term shell, soft tissue and short term barnacles respectively (Fig. 3). Increased concentrations of Cr in shells were detected during the first three months of exposure and in the case soft tissues it was first five months. The maximum chromium level was observed in monsoon season compared to pre monsoon. Barnacle settled in short term panels also recorded higher amounts of chromium in June to October period and the same was reflected in long term shells and tissues. Chromium uptake in monthly retrieved panel has positive correlation with Fe (r = 0.923), Mn (r = 0.965) and Se (r = 0.843) and

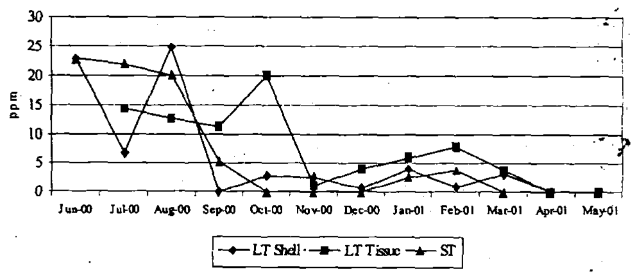

Fig. 3. Chromium concentration (ppm) in short term barnacle, long term barnacle shell and tissues

negatively correlated with seawater temperature (r = 0.763) and salinity (r = 0.746). Long term shell Cr positively correlated with Se (r = 0.753) and Cu (r = 0.726). Soft tissue Cr was positively correlated with Cd (r = 0.888) and Fe (r = 0.852). Correlation of long term barnacle shell Cr with metals present in short term barnacle showed a positive correlation with Cd (r = 0.845), Cr (r = 0.828), Fe (r = 0.774), Se (r = 0.753) and Mn (r = 0.835). These results clearly indicate that the chromium accumulation in barnacle was originated from chromium containing iron from neighbouring shipyards and industrial establishments. Chromium in seawater is known to be present in both Cr(III) and Cr (VI) ions. Maximum Cr (III) was found in top of the oxygen minimum zone and reverse in the case Cr(VI). Hem (1977) postulated that Cr in natural waters may be lowered by a mild chemical reduction involving the reduction of Fe(III) to Fe (II) hydroxide reduction process. Marine organisms living in system containing comparatively higher iron oxide particulates in seawater will accumulate relatively low concentrations of Cr in their body tissue. Weerelt *et. al.*, (1984) predicted that Cr accumulation is more if higher Cr(VI) is present and it is accumulated more in soft tissues of barnacle at much higher concentration than Cr(III). Chromium concentration in barnacles was several folds higher than the dissolved Cr in seawater and Cr(VI) was not adsorbed on the suspended particulates. On the other hand Cr(III) readily precipitated and was quietly removed from seawater. Because of the removal of Cr(III) it was not concentrated on soft tissues and moreover its release was faster than that of adsorbed Cr(VI). Bioaccumulation of Cr will decrease in reducing environment. Presence of Mn oxide may increase concentration of Cr(VI) and this in turn can enhance bioaccumulation. McLusky & Hagerman (1987) reported that the effect of salinity on metal toxicity has been clearly linked to the disruption of normal pattern of osmoregulation.

Lead was detected in barnacle shells of long term panels during August (3.0ppm), January (18.28ppm) April (13.07ppm) and May (15.2 ppm) (Fig. 4) where as in tissue it was

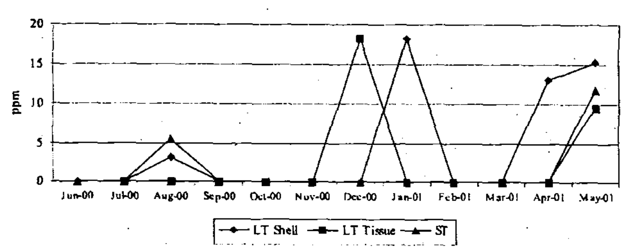

Fig. 4. Lead concentration (ppm) in short term barnacle, long term barnacle shell and tissues.

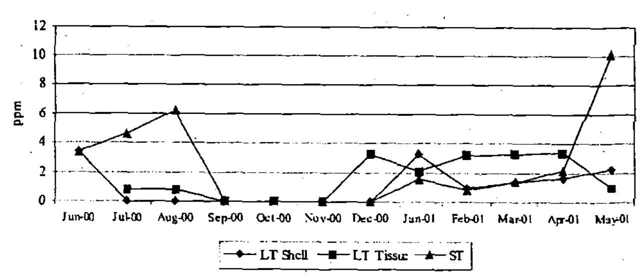

Fig. 5. Nickel concentration (ppm) in short term barnacle, long term barnacle shell and tissues during the year

detected in December (18.28ppm) and May (9.49ppm). In one month old barnacle Pb was detected only in August (5.4 ppm) and May (11.79ppm). There is no significant correlation of lead with hydrographic and other metals. Anthropogenic inputs and industrial establishments from neighbouring areas are the major sources of Pb contamination in the estuarine environment. Somero et al (1977) found that an increase in salinity accelerates Pb accumulation. It has been postulated that salinity affects the biological activity or physiological process directly leading to the alterations in the metabolic and filtration rates and the feeding habits (Bass (1977); Cotter *et. al.*, (1982)). The present data revealed that anthropological input of Pb in to the estuary and the increased salinity and reduced inflow of water during summer months would have been enhanced the dissolved Pb. If Pb supply is limited, the increased salinity increases Pb-chloro complexes without increasing the dissolved Pb and this may reduce bioaccumulation. It has been shown that Fe hydroxides synergistically enhance the precipitation of practically insoluble Pb phosphates implying that increased Fe hydroxides reduce the uptake of Pb.

Nickel was recorded in long term panel shells, soft tissues and short term barnacle mainly during January – May period. Their concentration ranged between 0 –3.25, 0 – 3.38 and 0 – 10.1 ppm in long term shell, soft tissues and short term barnacles respectively (Fig. 5). Ni in short term barnacle was recorded during June to August but the same trend was not reflected in the long term shells except in June. Patel *et. al.*, (1985) recorded 3.9 – 10.8 ppm of nickel in blood clam *Anadara granosa* in Mumbai harbour. According to Morillo *et. al.*, (2005) Ni and Mn are the metals that *Balanus balanoids* accumulated least, which may be due to lesser bioavailability of these metals compared to other metals. Nickel uptake occurred principally

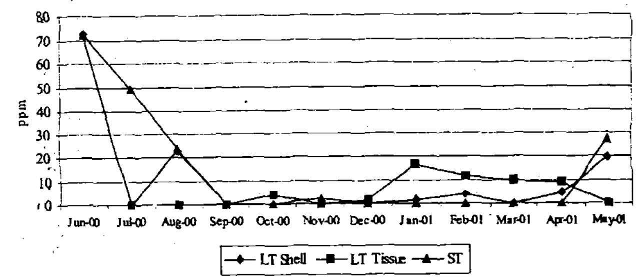

Fig.6. Selenium concentration (ppm) in short term barnacle, long term barnacle shell and tissues during the year

through the water, rather than food and the ingested particulate nickel was eliminated through the faeces. The correlation between the heavy metals and hydrographic parameters in short term barnacle revealed that nickel had strong positive association with Pb (r = 0.921), Cu (r = 0.999), As (r = 0.997) and Zn (r = 0.956). In the case of soft tissues, nickel was negatively correlated with dissolved oxygen (r = 0.778).

Selenium concentration varied irregularly in all the three samples and they ranged from 0 – 72.51, 0 – 38.36 and 0 – 72.59 ppm in long term shell, tissue and short term barnacle respectively. In barnacle shells of long term panels comparatively higher concentrations of Se was recorded during monsoon and pre monsoon seasons, whereas in soft tissue its presence was recorded during December to April (Fig. 5). Barnacle of short term panels recorded maximum Se during monsoon and in other seasons it varied irregularly. Selenium accumulation in long term shell was positively correlated with its Cd (r = 0.799), Cr (r = 0.753), Cu (r = 0.753), Fe (r = 0.932) and Mn (r = 0.923). Long term shell Se was positively correlated with Fe (r = 0.719) and Se(r = 0.802) of short term panels. Se uptake in short term barnacle was influenced by the presence of Cd (r = 0.825), Cr (r = 0.843), Fe (r = 0.948), and Mn (r = 0.857) and had negative association with salinity (r = -0.708) and pH (r = -0.674).

Copper concentration ranged from 0 – 17.6, 0 – 14.1, and 0 - 40.0ppm in long term shell, soft tissue and short term barnacles respectively. Maximum accumulation of copper in long term shells and short term barnacle was during June

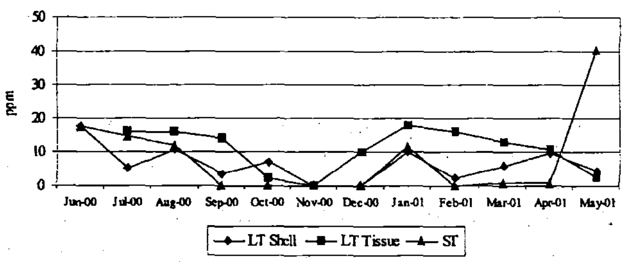

Fig. 7. Copper concentration (ppm) in short term barnacle, long term barnacle shell and tissues during the year.

to August and March to May (Fig.7) period. In soft tissues, maximum accumulation of copper was detected during December to February. There was a significant variation of Cu between the four quarters of the year in all the samples. Correlation analysis of one month old short term barnacle revealed that the copper uptake was positively influenced by the presence of Ni (r = 0.999), Pb (r = 0.909) and Zn (r = 0.970). In the case of long term shell, Cu had positive correlation with Cr (r = 0.726), Fe (r = 0.780), Mn (r = 0.707), Se (r = 0.753) and Zn (r = 0.724). Copper concentration in *T. Squamosa* reported by Blackmore (1999) in Hong Kong was 6.27 – 28.45ppm. Morillo *et. al.*, (2005) reported that the average copper in soft tissues of *B. balanoid* was 6810mg kg^{-1} during 2002. Copper is required for normal growth functions in many marine organisms such as plankton. Eaton (1979) found that a significant correlation between Fe and Cu existed in the estuarine waters of San Francisco Bay estuary and reported removal of Cu at a salinity of 5g/kg. He suspected that Fe particulates were responsible for the removal. Copper accumulation in bivalve molluscs (clam and oyster) was inversely related to salinity and positively associated with the total copper concentration in the medium. It was postulated that salinity affects biological activity or physiological processes directly leading to the alteration in the metabolic and filtration rates and the feeding habits. Zamuda *et. al.*, (1985) postulated that the bioavailability of dissolved copper was reduced due to salinity because of organic complexation. Wright & Zamuda (1987) observed in their studies on bivalve molluscs an inverse relationship between the salinity and copper bioaccumulation. Thermodynamic calculations and reports in literature indicate that Cu-Cl complexes are the most predominant chemical forms of Cu in seawater. According to them Cu bioaccumulation is not dependant on Cu^{2+} activity. Increased levels of copper in the estuarine water of Cochin (Krishnakumar *et. al.*, 2004) and low salinity during monsoon due to heavy inflow of water from rivers to the estuary might have influenced the increased bio accumulation of copper in barnacles.

Manganese is considered as nutrient element and its concentration was ranged from 39 –313.7 ppm, 38 – 161ppm and 13 –322ppm respectively (*Fig. 7*) in long term shell, soft tissues and short term barnacles. Monsoon and pre monsoon periods recorded maximum Mn concentration in long term shells, whereas in tissues it was during post monsoon. Higher levels of Mn was accumulated in barnacle shells than in soft tissues. Short term barnacle recorded significantly higher Mn concentration in monsoon (313 – 322ppm) season, whereas in post monsoon it was 51 – 71ppm. In summer months, the Mn concentration was around 19ppm. These results revealed that the Mn uptake was taking place mainly during the initial stages and was utilized for shell formation. The Mn in one-month barnacle had significant positive correlation with Cd (r = 0.983), Cr (r = 0.965), Fe (r = 0.940), and Se (r=0.857) and negatively correlated with salinity (r = -0.809), pH (r = -0.715) and seawater temperature (r = -0.744). The Mn in long term shell positively correlated with Cd (r = 0.801), Fe (r = 0.960) and Se and weak negative correlation with salinity(r = -0.59) and pH (r = -0.59). Correlation analysis of long term shell Mn with metals of short term barnacle revealed a positive correlation with Se (r = 0.831) and Fe (r = 0.705). Blackmore (1999) and Morillo et. al., (2005) reported Mn concentration of 5.87 – 82.5ppm in *T. squamosa* and 192ppm in tissues of *B. balanoids* respectively. Pingimore et. al., (1988) reported that the extent of incorporation of Mn into calcite is related to the precipitation rate with slower calcium precipitation favouring enhanced Mn incorporation. The oyster shells had calcitic structure.

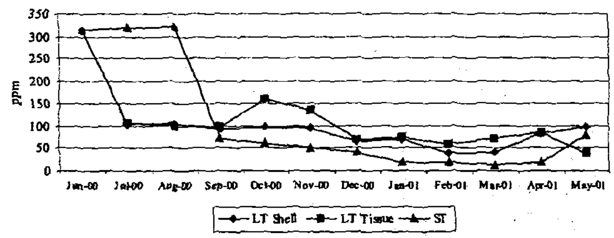

Fig.8. Manganese concentration (ppm) in short term barnacle, long term barnacle shell and tissues during the year.

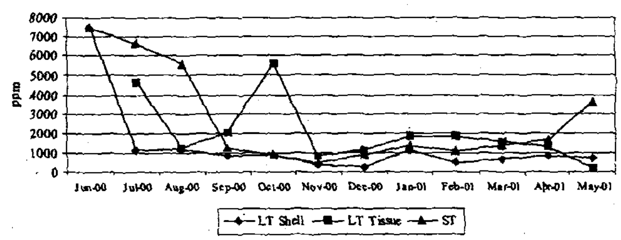

Fig. 9. Iron concentration (ppm) in short term barnacle, long term barnacle shell and tissues during the year.

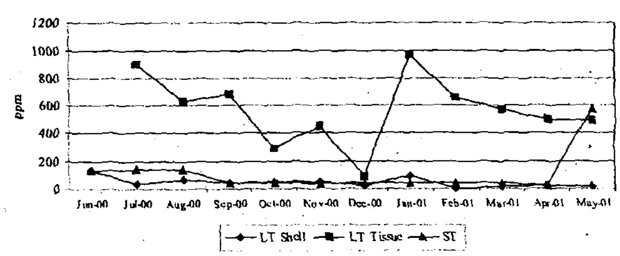

Fig. 10. Zinc concentration (ppm) in short term barnacle, long term barnacle shell and tissues during the year.

The iron concentration varied from 219 – 7444ppm, 202- 4628 and 494 – 7444 ppm in long term panel barnacle shells, soft tissues and short term barnacle respectively (Fig. 9). Highest accumulation of Fe was detected in samples of short term panels, indicating that Fe was taken up by barnacle in the initial stages of its growth. Iron accumulation in tissues was highest during the first five months and in shells for the first three months. The short term barnacle recorded maximum Fe during monsoon season (June to August) which varied between 5620 – 7444ppm. Again in summer months it increased slowly and was significantly higher in May (3592ppm). It is surprising to note that the Fe in long term shell and soft tissues was not having considerable variation. This implies that the Fe uptake in barnacles had a significant role in the first few months of its settlement. On growth the Fe accumulation is very low or the iron uptake may be restricted to first few months. Reduced Fe concentration in long term shell and tissues might have been due to the dilution with barnacle growth. Blackmore (2001) in his studies on accumulation of heavy metal in barnacles has reported very high concentration of zinc (1023-3458ppm) and he explained that barnacles are strong net metal accumulators. According to him the accumulated zinc was detoxified in inert pyrophosphate concretions which are stored either in the mid-gut region or derivatives thereof. This allows barnacles to accumulate extremely high body concentrations of zinc with apparently no adverse physiological effects. Similar type of mechanism may be operating to detoxify the heavily accumulated iron in barnacles. Higher concentrations of iron were accumulated by the barnacle as it is the major pollutant in the Cochin estuary. This further emphasise the role of barnacle as an important biomonitoring organism. The correlation of Fe in one month old short term barnacle with metals and hydrographic parameters have showed a positive correlation with Cd (r = 0.920), Mn (r = 0.940), Cr (r = 0.923) and Se (r = 0.948) and negative correlation with salinity (r = 0.777), pH (r = 0.740) and weight of fouler accumulation (r = 0.758). Fe present in soft tissue had positive correlation with its Cr (r = 0.852) and Mn (r = 0.651). This clearly indicate that the Mn and Cr was originated from iron alloys like steel and probably came from neighbouring shipyard or other industrial units. Fe in long term shell had positive correlation with Cd (r = 0.792), Cu (r = 0.780), Mn (r = 0.961), Se (r = 0.932) and Zn (r = 0.779). Long term shell Fe had positive correlation with the metal present in the short term barnacle selenium (r = 0.795). According to Vymazal (1984) the iron uptake in marine algae is rapid in many species. Iron concentration in *Eicchornia crassipes* of Hindon river was 3012ppm (Ajmal *et. al.*, 1987) and in bivalve molluscs it ranged from 250 – 700ppm in fresh weight (Dougherty 1988). Iron may react with trace elements, which exist as oxy anions (As, Cr, Mo) to form insoluble solid phases. Large quantities of iron are entering into the marine environment probably via neighbouring shipyards, boat yards, ports, municipal, industrial effluents, corrosion of under water structures, atmospheric fall out etc.

Zinc concentration varied between 16.5 - 132.2, 93 – 897 and 28–144ppm in long term shell, soft tissues and short term barnacles respectively (Fig. 10). Barnacle shell accumulated maximum zinc during June and in the later months it varied irregularly. In soft tissues it occurred in the first three months (July to September) after exposure. In short term barnacle, maximum accumulation of zinc was during monsoon season and in other months it varied between 28 – 44ppm. Zinc concentration in soft tissues was significantly higher than in shell in all season. The zinc uptake in short term barnacle samples were positively correlated with As (r = 0.956), Cu (r = 0.970), Ni (r = 0.972) and Pb (r = 0.932). In long term shells the uptake of zinc was positively correlated with Cr (r = 0.691), Cu (r = 0.724), Fe (r = 0.779) and Mn (r = 0.783). In the tissue of *T squamosa* from Hong Kong Zn concentration ranged from 1023 -3458ppm. Blackmore (1999) and Páes-Ozuna *et. al.*, (1999) reported that Zn and Fe are the most abundant elements in the 8 populations of barnacles.

Arsenic was detected only in samples collected during May and its concentration was 29.29, 37.4 and 77.6 ppm in long term shells, soft tissues and short term barnacle respectively. It might have been due to some As disposal in the estuary by neighbouring industrial units.

The fouling density in 1m^2 varied from 0.266kg to 21.331kg in long term panel and 0.266 – 6.732kg short term barnacle (Table 1). The maximum fouling was seen in both types of panels during the month of November, transition period from monsoon to pre monsoon, and in the following months fouling was less. The fouling density increased slowly from June to November and maximum fouling was observed during the period from November to January. Large number of fouling organism was seen during the month of September and their month wise distribution is given in Table.2. As seen in table 3 the fouling intensity steadily increased in the long term panel from the first month of immersion to the month of December.

Afterwards the weights were decreased due to sloughing off. The settlement was maximum during November as was observed in earlier studies by Meenakumari and Nair (1984) and Meenakumari (1992) in Cochin backwaters. Bryozoans were present in the month of June to October and were absent during November to May. Hydroids settled immediately after the monsoon and continued to be present throughout the year. Settlement of oysters was observed only during the pre monsoon and *Modiolus* sp., during post monsoon season. Accumulation of fouling organism in long term panel had significant positive correlation with salinity (r=0.8589) and pH (r=0.9206) highlighting the role of these factors in the settlement of foulers. Water samples from the test site was drawn every week and analysed for the hydrographic parameters and their average was given in Table 3. The seawater temperature, DO, salinity, pH and turbidity varied from 28 – 30.5°C, 4.6 to 5.96mg/l, 2.83 to 28.55g/l, 6.98 to 8.03 and 9.8 to 23.6 NTU respectively.

Hydrographic parameters have significant influence on the uptake of Cd, Cr, Ni and Pb in barnacle shells and tissues. Mn and Fe uptake was maximum not only in monsoon season but also during the early stages of its growth. The iron intake was mostly from the Cr and Mn

Table 1. Fouling density (kg/sq m) in glass panels exposed during the exposure period

Month	Long term panels collected corresponding month		Short term panels
Jun-2000	0.266	(01 month old)	0.266
Jul-2000	1.828	(02 month old)	0.365
Aug-2000	3.491	(03 month old)	0.365
Sep-2000	5.320	(04 month old)	0.831
Oct-2000	10.241	(05 month old)	0.565
Nov-2000	21.313	(06 month old)	6.716
Dec-2000	20.282	(07 month old)	0.498
Jan-2001	16.957	(08 month old)	0.665
Feb-2001	8.911	(09 month old)	0.532
Mar-2001	8.844	(10 month old)	0.465
Apr-2001	8.811	(11 month old)	0.299
May-2001	6.982	(12 month old)	0.266

Table 3. The average hydrographic parameters in the Cochin estuary during the experimental period

Month	Sea water temperature °C at ~ 10.30 h	Dissolved Oxygen mg/l	Salinity g/l	pH	Turbidity NTU
Jun-2000	28.0	5.75	2.83	6.98	16.5
Jul-2000	27.2	5.75	4.10	7.15	21.5
Aug-2000	27.4	5.88	3.89	7.17	18.3
Sep-2000	28.6	5.55	8.15	7.13	9.9
Oct-2000	28.8	5.96	9.84	7.36	11.9
Nov-2000	29.5	5.60	27.04	8.03	11.0
Dec-2000	28.4	5.55	26.74	7.96	11.0
Jan-2001	28.1	5.00	28.55	7.94	23.6
Feb-2001	29.4	4.60	24.67	7.81	20.8
Mar-2001	30.0	4.73	23.01	7.64	16.0
Apr-2001	30.5	4.85	19.97	7.49	19.0
May-2001	29.87	5.30	12.13	7.34	13.75

Table 2. Occurrence of other fouling organisms during the study period

Fouling organism	June-00	July-00	August-00	September-00	October-00	November-00	January-01	February-01	March-01	April-01	May-01
Bryozoans	X	X	X	X	X						
Tube worms	X			X			X			X	X
Polychaetes	X	X	X	X		X					
Hydroids		X	X	X	X	X	X	X	X		X
Isopodes		X									
Modiolus sp				X		X	X	X	X	X	
Oyster									X	X	X
Balanus sp	X	X	X	X	X	X	X	X	X	X	X

X = Presence of the organism

6.max

containing steel alloys coming in to the estuary either through corrosion of steel or through anthropogenic input. Short term monitoring (one month exposure) gave a better indication of metal concentration in barnacle than long term panels. The results reveal that the barnacle can be used for monitoring the contamination in the marine and estuarine environment.

Authors express their sincere gratitude to the Director, CIFT for his constant encouragement and guidance given through out the study. Thanks are also due to the technical staff of the laboratory for providing assistance.

References

Ajmal, M., Khan, R. and Khan. A.U. (1987). Heavy metals in water, sediments, fish and plants of river Hindon UP India. *Hydrobiologia*. **148**, pp151-157.

Anil, A.C. and Wagh. A.B. (1988) Accumulation of copper and zinc by *Balanus amphitrite* in a tropical estuary. *Marine Poll. Bull.* **19**, pp177-180.

Bass, L.E. (1977). Influence of temperature and salinity on oxygen consumption by tissue in American oyster, *Crassostea virginica*. *Comp. Biochem. Physiol.* **58B**, pp125-130.

Blackmore, G. (1999). Temporal and spatial biomonitoring of heavy metals in Hong Kong coastal waters using Tetraclita squamosa. *Environ. Pollut.* **106**, pp 273-283.

Blackmore, G. (2001). Interspecific variation in heavy metal body concentrations in Hong Kong marine invertebrates. *Environ. Pollut.* **114**, pp 303-311.

Blackmore, G. and Chan, H.M. (1997). Heavy metal concentrations in barnacles (*Tetraclita squamosa*) in Hong Kong: a revisit. In *The Marine Biology of South China Sea III, ed.* B. Morton. Proceedings of the third international conference on the Marine Biology of the South China Sea, Hong Kong, 1996. Hong Kong University Press, Hong Kong.

Bryan, G.W. (1979). Bioaccumulation of marine pollutants. *Philos. Trans. R. Soc. London [Biol]*. **286**, pp483-505.

Cotter, A.J.R., Phillips, D.J.H and Ahsanullah, M. (1982). The significance of temperature salinity and zinc as lethal factors for the mussel *Mytilus edulis* in polluted estuary. *Marine Biol.* **68**, pp135-141.

Dougherty, G. (1988). Heavy metal concentrations in bivalves from Fiji's coastal waters. *Marine Poll. Bull.* **19**, pp81-84.

Eaton, A. (1979). Observation on geochemistry of soluble Cu, Fe, Ni and Zn in the Sanfrancisco Bay Estuary. *Environ. Sci. Technol.* **13**, pp 425-432.

Hem, J.D. (1977). Reactions of metal ions at surfaces of hydrous iron oxide. *Geochim. Cosmochim. Acta.* **41**, pp 527-538.

Krishnakumar, P.K., Bhat, G.S. and Rajagopala. M. (2004) Monitoring the concentration of cadmium, lead, copper and zinc from the coastal waters of India using voltammetric technique. Presented in: International workshop on marine Pollution and ecotoxicology. 25-26 February 2004, at NIO, Goa, India.

Langston, W.J. (1986). Metals in sediments and benthic organisms in the Mersey estuary. *Estuar. Coast. Shelf Sci.* **23**, pp239-261.

Marcus, J.M. and Thompson. A.M. (1986). Heavy metal in oyster tissue around three coastal marine. *Bull. Environ. Contam. Toxicol.* **36,** pp587-594.

McLusky, D.S. and Hagerman. L. (1987). The toxicity of Cr, Ni, and Zn: Effects of salinity and temperature and osmoregulatory consequences in the mysid *Praunus flexuosus*. *Aquat. Toxicol.* **10**, pp225-238.

Meenakumari, B. (1992). Biofouling in Cochin Harbour. *Proceedings of the Academy of Environmental Biology*. **1,** pp7-18.

Meenakumari, B. and Nair, N.B. (1984). Ecology of fouling in Cochin Harbour Proceedings of the 6th International Congress on Marine Corrosion and Fouling, Athens, Greece, pp159-172.

Morillo, J., Usero, J. and Gracia, I. (2005). Biomonitoring of trace metals in a mine-polluted estuarine system (Spain). *Chemosphere*. **58,** pp1421-1430.

Páez-Osuna F., Bójorquez-Leyva H. and Ruelas Inzunza J. (1999). Regional variations of heavy metal concentrations in tissues of barnacles from the subtropical pacific coast of Mexico. *Environ. Int.* **25,** pp 647-654.

Patel, B., Bangera, V.S., Patel, S. and Balani, M.C. (1985). Heavy metals in the Bombay Harbour area. *Marine Poll. Bull.* **16,** pp22-28.

Pingimore, N., Eastman. M.P., Sandidge, M., Oden. K. and Freiha, B. (1988). The co-precipitation of Mn(II) with calcite an experimental study. *Marine Chem.* **25,** pp107-120.

Powell, M.I. and White, K.N. (1990). Heavy metal accumulation by barnacle and its implication for their use as biological monitors. *Marine Environ. Res.* **30,** pp91 – 118.

Rainbow, P.S. and White, S.L. (1993). Comparative strategies of heavy metal accumulation by crustaceans: Zinc, copper and cadmium in a decapod, an amphipod and a barnacle.*Hydrobiologia.* **174,** pp245-262.

Somero, G.N., Chow, T.J., Yancey, P.H. and Snyder, B.C. (1977). Lead accumulation rates in tissue of the estuarine teliost fish: salinity and temperature effects. Arch *Environ. Contam. Toxicol.* **6,** pp337-348.

Stephenson, M. and Mackey, G.L. (1988). Total cadmium concentration in the water and littoral sediments of Central Ontario Lakes. *Water Air Soil Pollut.* **38,** pp121-136.

Strickland, J.D.A. and Parson, T.R. (1972). A practical handbook of seawater analysis. Fisheries Research Board of Canada, Ottawa.

Vymazal, J. (1984). Short term uptake of heavy metals by periphyton algae. *Hydrobiologia*. **119**, pp171-179.

Wang, W.X., Fisher, N.S. and Luoma, S.N. (1996). Kinetic determinations of trace element bioaccumulation in the mussel *Mytilus edulis*. *Mar. Ecol. Prog. Ser.* **140,** pp91-113.

Weerelt, M.V., Pfeiffer, W.C. and Fiszman, M. (1984) Uptake and release of ^{51}Cr (VI) and ^{51}Cr (III) by barnacles (Balanus sp.). *Mar. Environ. Res.* **11,** pp201-212.

Wright, D.A. and Zamuda, C.D. (1987) Copper accumulation by two bivalve molluscs: salinity effects independent of cupric ion activity. *Mar Environ Res*. **23,** pp1-14.

Zamuda, C.D., Wright, D.A. and. Smucker, R.A. (1985) The importance of dissolved organic matter in the accumulation of copper by the American Oyster Rassostrea virginica. *Mar. Environ. Res.* **16,** pp1-12.