

## Bioconcentration of trace metals by *Saccostrea cucullata* (von Born 1778) from Andaman waters

Abhilash K.R.<sup>1</sup>, Gireeshkumar T.R.<sup>2</sup>, Venu S.<sup>3</sup> & Raveendran T.V.<sup>1\*</sup>

<sup>1</sup>National Institute of Oceanography (Council of Scientific & Industrial Research), Regional Centre, Dr. Salim Ali Road, Kochi- 682018, India.

<sup>2</sup>Dept. of Chemical Oceanography, School of Marine Sciences, Cochin University of Science & Technology, Kochi- 682016, India.

<sup>3</sup>Department of Ocean Studies and Marine Biology, Pondicherry University, Port Blair, Andamans, India.  
[E-mail: tvravi@nio.org]

Received 21 January 2012; revised 21 February 2012

Assessment of trace metals (Zn, Cu, Fe, Pb and Ni) in water, sediment and an oyster, *Saccostrea cucullata*, was carried out in five stations around Port Blair. Concentration of these metals in water, sediment and the oyster exhibited wide variations. Among the selected locations, Fisheries Jetty exhibited the highest concentration of trace metals, as a consequence of the numerous fishing vessels harboured at this station. Zinc was the highest bioconcentrated trace metal ( $BCF_{mw}$ , 460.39 – 2474.72;  $BCF_{ms}$ , 24.60 – 641.96) in all the five stations, probably due to the role of several zinc metalloenzymes in shell mineralization of oysters. Unlike this, the bioconcentration factor of Pb was very low in spite of its relatively high concentrations in both, water as well as sediment.

**[Keywords:** Andaman Sea, Trace metals, Zinc, *Saccostrea cucullata*, Bioconcentration factor]

### Introduction

Trace metals, as the name signifies, are metals present in extremely small quantities in a given environment. Their distinct property of being toxic above a specific threshold of bioavailable level is significant in determining the overall health of the ecosystem<sup>1,2</sup>. They are introduced into the water bodies mainly through anthropogenic activities including discharge of domestic sewage, industrial effluents, petroleum and mining wastes<sup>3,4</sup>. Over the years, with the advancements in development, the accumulation of trace metals in the marine environment has shown an increasing trend.

The sediment and biota in the aquatic environment act as reservoirs for trace metals<sup>5</sup>. Therefore, the extent of trace metal pollution in a specific locality can be assessed by the analysis of water<sup>6,7</sup>, sediment<sup>8,9</sup> and indigenous biota<sup>10,11</sup>. Among biota, the bivalves (including mussels and oysters) have a pronounced ability for bioconcentrating heavy metals<sup>12</sup> and hence, have extensively been used in biomonitoring programmes<sup>13,14</sup>. The concentration of trace metals in water, sediment as well as an

indigenous rock oyster, *Saccostrea cucullata*, was evaluated from five stations in and around Port Blair, Andaman Islands.

### Materials & Methods

Andaman and Nicobar archipelago, comprising over 570 Islands, is located in the Bay of Bengal (Lat 6° to 14° N, Long 92° to 94° E). It is spread over an area of about 700 km<sup>2</sup> from north to south with 36 inhabited islands. *Saccostrea cucullata*, sediment and water samples were collected from North Bay, Aberdeen Jetty, Fisheries Jetty, Rose Island and Corbyn's Cove (Fig. 1) during October 2008. These sites were selected based on human recreational and developmental activities. Aberdeen Jetty and Fisheries Jetty are fishery harbours, while North Bay, Ross Island and Corbyn's Cove are tourist spots with several resorts and other facilities.

The oysters were first washed free of extraneous matter and the flesh was removed from the shells and freeze-dried. Approximately 1 g of this sample was digested with nitric and phosphoric acid (2 mL each) for analysis of various trace metals such as Zinc (Zn), Copper (Cu), Iron (Fe), Lead (Pb) and Nickel (Ni). All measurements were made in triplicates by Atomic

\*Corresponding author:

Absorption Spectrophotometer (Perkin-Elmer Model 3110). Accuracy of the analytical methods was monitored by repeated analysis of standard reference materials (SRM 1566b from the National Institute of Standard and Technology and BCSS-1 from the National Research Council of Canada) together with batch of sediment samples. The calculated metal content was represented as  $\mu\text{g g}^{-1}$  of sample on a wet weight basis. Sediment and water samples collected from these stations were also analysed for trace metals using standard procedures<sup>15,16</sup>. Thereafter, the bioconcentration factor (BCF), i.e. the concentration

of a particular metal in a biological tissue relative to the surrounding medium (seawater,  $\text{BCF}_{\text{mw}}$  or sediment,  $\text{BCF}_{\text{ms}}$ ) was calculated. Correlations between metal concentrations in *S. cucullata* tissue were analysed by Spearman's rank correlations (SPSS version 10).

**Results**

The concentration of trace metals in seawater showed considerable variation in the different sampling locations: Zn,  $0.77\pm0.02$  (Ross Island) to  $2.67\pm0.47$  (Fisheries Jetty); Cu,  $2.45\pm0.11$  (Ross Island) to  $13.01\pm0.69$  (Fisheries Jetty); Fe,  $0.09\pm0.05$  (Ross Island) to  $0.46\pm0.10$  (Fisheries Jetty); Pb,  $2.84\pm0.74$  (North Bay) to  $13.54\pm1.03$  (Corbyn's Cove) and Ni,  $0.07\pm0.02$  (Corbyn's Cove) to  $0.15\pm0.02$  (Fisheries Jetty). Highest concentration of all the metals, except Pb, was observed at Fisheries Jetty (Table 1).

The trace metal concentration in sediment also exhibited wide variations between the stations: Zn,  $2.97\pm0.37$  (Ross Island) to  $27.45\pm1.39$  (Corbyn's Cove); Cu,  $3.15\pm0.57$  (Aberdeen Jetty) to  $19.34\pm0.69$  (Fisheries Jetty); Fe,  $474.23\pm6.96$  (Aberdeen Jetty) to  $3686.43\pm13.48$  (Fisheries Jetty); Pb,  $12.54\pm0.57$  (Corbyn's Cove) to  $34.87\pm11.34$  (Ross Island) and Ni,  $16.38\pm0.88$  (North Bay) to  $37.41\pm0.91$  (Fisheries Jetty). In general, the sediments showed higher concentration of metals than the overlying water column (Table 2).

As in the case of seawater and sediments, the oyster tissue collected from the different stations also

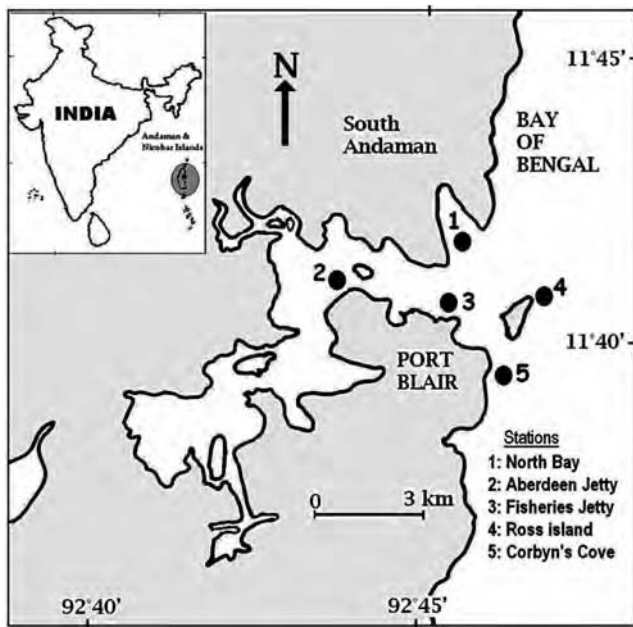


Fig.1—Sampling locations around Port Blair, Andaman

Table 1—Metal concentrations in seawater (in  $\mu\text{g/ml}$  wet weight with SD); n=3 replicates

|                 | Zn            | Cu             | Fe            | Pb             | Ni            |
|-----------------|---------------|----------------|---------------|----------------|---------------|
| North Bay       | $1.09\pm0.06$ | $2.76\pm0.77$  | $0.40\pm0.18$ | $2.84\pm0.74$  | $0.08\pm0.01$ |
| Aberdeen Jetty  | $1.02\pm0.19$ | $3.55\pm0.60$  | $0.12\pm0.02$ | $4.65\pm0.30$  | $0.12\pm0.12$ |
| Fisheries Jetty | $2.67\pm0.47$ | $13.01\pm0.69$ | $0.46\pm0.10$ | $4.24\pm0.43$  | $0.15\pm0.02$ |
| Ross Island     | $0.77\pm0.02$ | $2.45\pm0.11$  | $0.09\pm0.05$ | $4.08\pm0.71$  | $0.14\pm0.04$ |
| Corbyn's cove   | $0.89\pm0.07$ | $7.93\pm0.82$  | $0.11\pm0.04$ | $13.54\pm1.03$ | $0.07\pm0.02$ |

Table 2—Metal concentrations in sediment (in  $\mu\text{g/g}$  wet weight with SD); n=3 replicates

|                 | Zn             | Cu             | Fe                | Pb              | Ni             |
|-----------------|----------------|----------------|-------------------|-----------------|----------------|
| North Bay       | $21.35\pm1.17$ | $4.34\pm0.07$  | $1325.75\pm6.05$  | $13.54\pm1.25$  | $16.38\pm0.88$ |
| Aberdeen Jetty  | $8.73\pm0.38$  | $3.15\pm0.57$  | $474.23\pm6.96$   | $15.87\pm0.11$  | $16.54\pm0.80$ |
| Fisheries Jetty | $16.28\pm0.85$ | $19.34\pm0.69$ | $3686.43\pm13.48$ | $17.67\pm1.03$  | $37.41\pm0.91$ |
| Ross Island     | $2.97\pm0.37$  | $10.01\pm0.67$ | $501.43\pm12.69$  | $34.87\pm11.34$ | $20.65\pm0.24$ |
| Corbyn's cove   | $27.45\pm1.39$ | $6.01\pm0.11$  | $1878.56\pm3.79$  | $12.54\pm0.57$  | $22.17\pm0.72$ |

exhibited significant variations in the concentration of trace metals: Zn, 467.76±20.72 (Aberdeen Jetty) to 3262.02±16.56 (Fisheries Jetty); Cu, 0.72±0.11 (Aberdeen Jetty) to 154.11±1.18 (Fisheries Jetty); Fe, 11.04±0.43 (Aberdeen Jetty) to 114.95±1.93 (Fisheries Jetty); Pb, 2.99±0.05 (Aberdeen Jetty) to 8.25±1.18 (North Bay) and Ni, 0.00±0.00 (Aberdeen Jetty) to 4.08±0.18 (Fisheries Jetty). Relatively very high concentration of Zn and Cu in oyster tissue than that of water and sediment is notable (Table 3). Significant positive correlations ( $P<0.05$ ; spearman's rank correlations; SPSS version 10) were observed for (Zn, Fe), (Cu, Pb), (Cu, Ni) and (Pb, Ni) in *S. cucullata* tissue. Among the various metals studied, the BCF<sub>mw</sub> and BCF<sub>ms</sub> value of Zn was the highest in all the stations (Table 4). Unlike this, the BCF<sub>mw</sub> and BCF<sub>ms</sub> value of Pb was very low compared to that of Zn, in spite of its higher concentration in both, water as well as sediment.

## Discussion

Among the five stations examined during the present study, the highest concentrations of Zn, Cu, Fe and Ni in water, sediment as well as biota were recorded at the Fisheries Jetty. This may possibly be due to the continuous leaching of antifouling paints applied on the numerous small, medium and large sized vessels harboured in this station<sup>20, 21</sup>.

Zinc was the maximum bioconcentrated metal among the five trace metals studied. High levels (4522 µg g<sup>-1</sup> dry wt.) of Zn from Indian waters have already been reported by Krishna Kumari and Nair

(1992)<sup>22</sup>. Although, high concentrations of Pb and Cu were also available in the water, the oyster preferentially accumulated Zn. Pequignat *et al.*<sup>23</sup> has calculated that 2.7 ppm of Zn in live marine organism represented the theoretical maximum biochemical requirements. In the present study, the lowest concentration of Zn recorded in *S. cucullata* was as much as 173 times more than the required level. Oysters, in general, have a very high ability to accumulate Zn (Table 5)<sup>22, 24-34</sup>, probably because several zinc metalloenzymes are involved in their shell mineralization<sup>28</sup>.

Molluscs, in general, seem to have high bioconcentration potential for Zn compared to the other trace metals. Abdullah *et al.*<sup>32</sup> have made similar observations and reported that *Meretrix meretrix* was able to accumulate higher quantity of Zn than Cu and Pb. Zn concentration is closely related to gonadal development and spawning, either through direct incorporation into gametes or through functional requirements of gonadal tissue during development<sup>35, 36</sup>. Copper seems to be the next preferred metal for accumulation in *S. cucullata*. Similar observations were made by Krishna Kumari and Nair (1992)<sup>22</sup>. Hung and Han<sup>37</sup> have indicated a Cu concentration of 2100-4400 µg g<sup>-1</sup> dry wt. being responsible for the mortality of adult *Crassostrea gigas*. Though, no similar data is available for *S. cucullata*, it appears that the present Cu concentration of 0.72-154.11 µg g<sup>-1</sup> wet weight may not be harmful to the adult oysters. Lead exhibited relatively low BCF factor in all the five stations, in spite of its high

Table 3—Metal concentrations in *S. cucullata* (in µg/g wet weight with SD); n=3 replicates

|                 | Zn            | Cu          | Fe          | Pb        | Ni        |
|-----------------|---------------|-------------|-------------|-----------|-----------|
| North Bay       | 1364.93±15.33 | 78.98±1.87  | 74.20±1.00  | 8.25±1.18 | 1.25±0.20 |
| Aberdeen Jetty  | 467.76±20.72  | 0.72±0.11   | 11.04±0.43  | 2.99±0.05 | 0.00±0.00 |
| Fisheries Jetty | 3262.02±16.56 | 154.11±1.18 | 114.95±1.93 | 3.01±0.07 | 4.08±0.18 |
| Ross Island     | 1904.71±14.63 | 4.00±0.34   | 39.85±0.39  | 6.96±0.21 | 0.44±0.02 |
| Corbyn's Cove   | 675.21±5.32   | 59.27±1.70  | 34.26±1.59  | 6.84±0.60 | 0.94±0.08 |

Table 4—Bioconcentration factor values in *S. cucullata*

|                 | BCF <sub>mw</sub> |       |        |      |       | BCF <sub>ms</sub> |       |      |      |      |
|-----------------|-------------------|-------|--------|------|-------|-------------------|-------|------|------|------|
|                 | Zn                | Cu    | Fe     | Pb   | Ni    | Zn                | Cu    | Fe   | Pb   | Ni   |
| North Bay       | 1256.07           | 28.65 | 183.97 | 2.91 | 16.31 | 63.93             | 18.20 | 0.06 | 0.61 | 0.08 |
| Aberdeen Jetty  | 460.39            | 0.20  | 91.97  | 0.64 | 0.00  | 53.58             | 0.23  | 0.02 | 0.19 | 0.00 |
| Fisheries Jetty | 1223.26           | 11.85 | 251.71 | 0.71 | 27.28 | 200.37            | 7.97  | 0.03 | 0.17 | 0.11 |
| Ross Island     | 2474.72           | 1.63  | 449.43 | 1.71 | 3.16  | 641.96            | 0.40  | 0.08 | 0.20 | 0.02 |
| Corbyn's cove   | 762.67            | 7.47  | 308.08 | 0.51 | 13.77 | 24.60             | 9.86  | 0.02 | 0.55 | 0.04 |

Table 5. Comparison of trace metal levels of mollusc in reported works; nd, non-detectable level

| Sl. No. | Authors                                     | Source organism                                       | Zinc             | Copper        | Lead        | Iron           | Nickel      |
|---------|---|---|------------------|---------------|-------------|----------------|-------------|
| 1.      | Krishnakumari & Nair, 1992 <sup>22</sup>    | <i>Saccostrea cucullata</i><br><i>Cerethium rubus</i> | 4522<br>168.44   | 420<br>129    | x<br>x      | x<br>x         | x<br>x      |
| 2.      | Peerzada & Dickinson, 1989 <sup>24</sup>    | <i>Saccostrea cucullata</i>                           | 4.9 - 611        | 5.2 – 58.3    | nd          | 15 - 352       | 0.43 – 0.82 |
| 3.      | Sankaranarayanan et al., 1978 <sup>25</sup> | <i>Crassostrea madrasensis</i>                        | 2450-12500       | 70 - 205      | x           | 120-1600       | x           |
| 4.      | Greig et al., 1975 <sup>26</sup>            | <i>Crassostrea glomerata</i>                          | 97 - 900         | 4.4 - 380     | x           | x              | x           |
| 5.      | Bhat et al., 1968 <sup>27</sup>             | <i>Crassostrea gryphoides</i>                         | 171 - 403        | x             | x           | x              | x           |
| 6.      | Coombs, 1972 <sup>28</sup>                  | <i>Ostrea edulis</i>                                  | 1050 - 395       | 42 - 67       | x           | x              | x           |
| 7.      | Pringle et al., 1968 <sup>29</sup>          | <i>Crassostrea virginica</i>                          | 180 - 1420       | 7 - 517       | x           | x              | x           |
| 8.      | Mc Farren et al., 1961 <sup>30</sup>        | <i>Crassostrea virginica</i>                          | 360 - 4000       | x             | x           | x              | x           |
| 9.      | Wolfe, 1970 <sup>31</sup>                   | <i>Crassostrea virginica</i>                          | 132 - 368        | x             | x           | x              | x           |
| 10.     | Abdullah et al., 2007 <sup>32</sup>         | <i>Meretrix meretrix</i>                              | 50.3- 223.5      | 4.26 - 10.3   | 0.95-3.9    | x              | x           |
| 11.     | Brooks & Rumsby, 1965 <sup>33</sup>         | <i>Ostrea sinuata</i>                                 | 1674             | 37            | < 50        | 871            | < 32        |
| 12.     | Paez-Osuna et al. 2002 <sup>34</sup>        | <i>Crassostrea corteziensis</i>                       | 339 - 1595       | 12 - 216      | 2.3-7.6     | x              | x           |
| 13.     | Present Study                               | <i>Saccostria Cucullata</i>                           | 3262.02 - 467.76 | 0.72 - 154.11 | 2.99 – 8.35 | 11.04 – 114.95 | 0.44 – 4.08 |

concentrations in water and sediment, probably because the mollusc avoids absorption of the metal due to its toxicity.

The trace metal concentrations recorded during the present study were relatively low. Thangaradjou *et al.* (2010)<sup>38</sup> has made similar observations from seagrasses of Port Blair area. The low concentration of trace metals in water and sediment samples of Port Blair reported by Kaladharan *et al.*<sup>39</sup> further supports this observation. The trace metal (Zn, Cu, Fe, Pb, Ni) concentrations in *S. cucullata* from Andaman waters are within limits stipulated by CPCB, indicating that the island ecosystem is rather unaffected by anthropogenic inputs<sup>40</sup>. However, continuous monitoring using indigenous bioindicators like *S. cucullata* is highly desirable to help preserve this fragile and pristine ecosystem.

#### Acknowledgements

Authors thank Director, National Institute of Oceanography (NIO), Dona Paula, Goa, and the Scientist-in-Charge, NIO, Regional Centre, Kochi for facilities and encouragements. This is NIO contribution No. 5394.

#### References

- 1 Kucuksezgin F, Kontas A, Altay O, Uluturhan E & Darilmaz E, Assessment of marine pollution in Izmir Bay: Nutrient, heavy metal and total hydrocarbon concentrations, *Environ Int*, 32 (2006) 41–51.
- 2 Lafabrie C, Pergent G, Kantin R, Pergent-Martini C & Gonzalez J L, Trace metals assessment in water, sediment, mussel and seagrass species – Validation of the use of *Posidonia oceanica* as a metal biomonitor, *Chemosphere*, 68(2007) 2033–2039.
- 3 Wills J, A survey of offshore oil field drilling wastes and disposal techniques to reduce the ecological impact of sea dumping, *Sakhalin Environ Watch*, 13(2000) 23–29.
- 4 Alam M G M, Tanaka A & Allinson G, A comparison of trace element concentrations in cultured and wild carp (*Cyprinus carpio*) of Lake Kasumigaura, Japan. *Ecotoxicol Environ Saf*, 53(2002) 348–354.
- 5 Warren I D, Contamination of sediments by lead, cadmium, and zinc: a review, *Environ pollut*, 2(1981) 401–436.
- 6 Davison W & Zhang H, In situ speciation measurements of trace components in natural waters using thin-film gels, *Nature*, 367(1994) 546–548.
- 7 Stark J S, Johnstone G J, Palmer A S, Snape I, Larner B L, Riddle M J, Monitoring the remediation of a near shore waste disposal site in Antarctica using the amphipod *Paramoera walkeri* and diffusive gradients in thin films (DGTs), *Mar Pollut Bull*, 52(2006) 1595–1610.
- 8 Calmano W, Ahlf W & Forstner U, Sediment Quality Assessment: Chemical and Biological Approaches, in:

- Sediments and Toxic Substances*, edited by W Calmano & U Forstner, (Springer, Berlin) 1996, pp. 1–35.
- 9 Tankere-Muller S, Zhang H, Davison W, Finke N, Larsen O, Stahl H & Glud R N, Fine scale remobilization of Fe, Mn, Co, Ni, Cu and Cd in contaminated marine sediment, *Mar Chem*, 106 (2006) 192–207.
  - 10 Rainbow P S & Phillips D, Cosmopolitan biomonitors of trace metals. *Mar Pollut Bull*, 26 (1993) 593–601.
  - 11 Ferrat L, Pergent-Martini C & Rome´o M, Assessment of the use of biomarkers in aquatic plants for the evaluation of environmental quality: Application to seagrasses, *Aquat Toxicol*, 65 (2003), 187–204.
  - 12 Phillips D J H, The use of biological indicator organisms to monitor trace metal pollution in marine and estuarine environments, A review. *Environ Pollut*, 13 (1977) 281–317.
  - 13 Uysal H & Parlak H, The concentrations of some heavy metals in *Sphaeroma serratum* (Leach) collected from Izmir Bay, *J Faculty Sci Ege Univ*, 14 (1992) 1–5.
  - 14 Blackmore G, Interspecific variation in heavy metal body concentrations in Hong Kong marine invertebrates, *Environ Pollut*, 114 (2001) 303–311.
  - 15 ASTM, Guide for collection, storage, characterization and manipulation of sediments for toxicological testing. American Society for testing materials PH USAC, (1990), pp.1–971.
  - 16 Lau S, Mohamed M, Tan Chi Yen A & Suut S, Accumulation of heavy metals in freshwater molluscs, *Sci Total Environ*, 214 (1998) 113–121.
  - 17 Kureishy T W, Sanzgiry S & Braganca A M, Some heavy metals in fishes from the Andaman Sea, *Ind J Mar Sci*, 10 (1981) 303–307.
  - 18 Kureishy T W, Sanzgiry S, George M D & Braganca A M Mercury, cadmium and lead in different tissues of fishes from the Andaman Sea, *Ind J Mar Sci*, 12 (1983) 60–63.
  - 19 Braganca A & Sanzgiry S. Concentrations of few trace metals in some coastal and offshore regions of Bay of Bengal, *Ind J Mar Sci*, 9 (1980) 283–286.
  - 20 Talbot V, Seasonal variation of copper and zinc concentrations in the oysters *Saccostrea cucullata* from the Dampier Archipelago, Western Australia: Implications for pollution monitoring, *Sci Tot Environ*, 57 (1986) 217–230.
  - 21 Claisse D & Alzieu C, Copper contamination as a result of antifouling paint regulations?, *Mar Pollut Bull*, 26 (1993) 395–397.
  - 22 Krishna Kumari L & Nair V R, Uptake and bioconcentration of copper and zinc by the molluscs, *Saccostrea cucullata* (Born) and *Cerithium rubus* (Desh) from the coastal waters of Bombay, *Ind J Mar Sci*, 21 (1992) 74–76.
  - 23 Pequignat J E, Fowler S W & Small L F, Estimates of the zinc requirements of marine organisms, *J Fish Res Bd Can*, 26 (1969) 145–150.
  - 24 Peerzada N & Dickinson C, Heavy metal concentration in oysters from Darwin Harbour, *Mar Poll Bull*, 19 (1988) 182–184.
  - 25 Sankaranarayanan V N, Purushan K S & Rao T S S, Concentration of some heavy metals in the oyster, *Crassostrea madrasensis* (Preston), from the Cochin region, *Ind J Mar Sci*, 7 (1978) 130–131.
  - 26 Greig R A, Nelson B A & Nelson D A, Trace metal content of American Oyster, *Mar Poll Bull*, 6 (1975) 72–73.
  - 27 Bhat Y M, Sastry H, Shah S M & Krishnamurthy T M, Manganese and cobalt content of some marine bivalves from Bombay. Indian National Science Academy Proceeding, *Biology*, 34 (1968) 283–287.
  - 28 Coombs T L, The distribution of zinc in the oyster *Ostrea edulis* and its relation to enzymic activity and to other metals, *Mar Biol*, 12 (1972) 170–178.
  - 29 Pringle B H, Hissonge D E, Katz E L & Mulawka S T, Trace metal accumulation by estuarine mollusks, Proc Am Soc Civil Eng, *J. Sanitary Eng Div*, SA 3 (1968) 455–475.
  - 30 Mc Farren E F, Campbiel J E & Engle J B, The occurrence of copper and zinc in shellfish, Proc Shellfish Sanitation Workshop Nov. 28-30 (1961) 229–234.
  - 31 Wolfe D A, Zinc enzymes in *Crassostrea virginica*, *J Fish Res Bd Canada*, 27 (1970) 59–69.
  - 32 Abdullah M H, Sidi J & Aris A Z, Heavy Metals (Cd, Cu, Cr, Pb and Zn) in *Meretrix meretrix* Roding, Water and Sediments from Estuaries in Sabah, North Borneo, *Int J Environ & Sci Edu*, 2 (2007) 69–74.
  - 33 Brooks R R & Rumsby M G, The biogeochemistry of trace element uptake by some New Zealand bivalves, *Limnol Oceanogr*, 10 (1965) 521–527.
  - 34 Paez-Osuna F, Ruiz-Fernández A C, Botello A V, Ponce-Vélez G, Osuna-López J I, Frias-Espéricueta M, López-López G & Zazueta-Padilla H M, Concentrations of Selected Trace Metals (Cu,Pb,Zn), Organochlorines (PCBs, HCB) and Total PAHs in Mangrove Oysters from the Pacific Coast of Mexico: An Overview, *Mar Poll Bull*, 44 (2002) 1303–1308.
  - 35 De Astudillo L R, Yen I C & Bekele I, Heavy metals in sediments, mussels and oysters from Trinidad and Venezuela, *Rev Biol Trop*, 53 (2005) 41–53.
  - 36 D' Silva C & Qasim S Z, Bioaccumulation and elimination of copper in the rock oyster *Crassostrea cucullata*, *Mar Biol*, 52 (1979) 343–346.
  - 37 Hung T C & Han B C, Copper availability and assimilative capacity in sea water along the Charting coastal area, *Counc Agric Fishery Series*, 23 (1990) 221–229.
  - 38 Thangaradjou T, Nobi E P, Dilipan E, Sivakumar K & Susila S, Heavy metal enrichment in seagrasses of Andaman Islands and its implication to the health of the coastal ecosystem, *Ind J Mar Sci*, 39 (2010) 85–91.
  - 39 Kaladharan P, Nandakumar A & Valsala K K, Trace metals in the muscle tissue of nine marine fish species from Port Blair and Kochi, *J Mar Biol Ass India*, 48 (2006) 224–228.
  - 40 Pai I K, Ecology of Andaman Sea: past, present and future, *J Cell & Animal Biol*, 1 (2007) 011–014.