

BIOLOGICAL CYCLING OF MICRO-NUTRIENTS (Cu, Fe AND Zn) IN *BRUGUIERA PARVIFLORA* DOMINATED MANGROVE FOREST AT KUALA SELANGOR NATURE PARK, MALAYSIA

MAHMOOD HOSSAIN^{1*}, SABERI OTHMAN³, MISRI KUSNAN²
and JAPAR SIDIK BUJANG²

¹*Forestry and Wood Technology Discipline
Khulna University, Khulna -9208, Bangladesh
Tel: 880-41-721791 Ext: 228 Fax: 880-41-731244
E-mail: mahmoodhossain@hotmail.com*

²*Faculty of Science, University Putra Malaysia, Malaysia*

³*Faculty of Science and Technology
University Pendidikan Sultan Idris, Malaysia*

ABSTRACT

The biological cycling of micro-nutrients (Cu, Fe and Zn) was studied at the Kuala Selangor Nature Park mangrove forest, Malaysia. The total stock of Cu, Fe and Zn in standing biomass of *Bruguiera parviflora* saplings and trees was 1195.38 g ha⁻¹, 87962.30 g ha⁻¹ and 2295.02 g ha⁻¹, respectively. The annual accumulation of Cu, Fe and Zn in plant components was 125.44 g ha⁻¹, 10073.63 g ha⁻¹ and 238.55 g ha⁻¹, and the annual return was 79.80 g ha⁻¹, 790.29 g ha⁻¹ and 178.15 g ha⁻¹. The calculated turnover period and absorption coefficients of Cu Fe and Zn were 15 yr, 111 yr and 13 yr; and 0.006, 0.001 and 0.003, respectively. The sequences of absorption coefficient and utilization coefficient were Cu>Zn>Fe and Zn>Cu>Fe, respectively.

Key words: Biomass, litter production, micro-nutrients, mangroves, nutrient cycling

INTRODUCTION

Estimation of standing biomass, annual biomass increment, litter production and litter standing crop are the approaches for estimating the productivity and functioning of a mangrove forest (Ong *et al.*, 1985; Gong and Ong, 1990). Measurement of within stand nutrient cycling could be another useful approach for estimating the same. Plants uptake nutrients from soil and translocate them to different parts to perform physiological functions (such as respiration, transpiration and photosynthesis), normal growth or to complete the life cycle (Jones *et al.*, 1991; Marschner, 1995). During the physiological functions, a portion of the absorbed nutrients is accumulated in plant biomass and remainder are released as litter fall and dead root, which is rapidly taken up by the plants and retained within the system (Duvigneaud and Smet, 1970; Binkley, 1986).

Micro-nutrient (e.g. Cu, Fe and Zn) content in plant is influenced by metabolic requirements (Baker and Walker, 1990), fluctuation of climatic condition, soil physiochemical characteristics and content of other nutrients in soil (Walbridge, 1991; Jones, 1998). The uptake, return and cycling of macro-nutrients in *Avicennia marina*, *Rhizophora apiculata*, *Aegiceras corniculatum* and *Kandelia candel* dominated stands at different mangroves have been studied (Clough and Attiwill, 1975; Aksornkoae and Khemnark, 1984; Gong and Ong, 1990; Li, 1997). But, within stand cycling of micro-nutrient in the tropical mangroves is yet to be investigated.

Bruguiera parviflora is distributed throughout Southeast Asia to tropical Australia and least studied among the mangrove communities. Present study synthesized the previous and new data and estimates the biological cycling of micro-nutrients (Cu, Fe and Zn) in *B. parviflora* dominated tropical mangroves.

* To whom correspondence should be addressed.

MATERIALS AND METHODS

The study area includes 100 ha of *B. parviflora* dominated mangrove forest in the Kuala Selangor Nature Park, Kuala Selangor, Malaysia (Latitude 3°20'N and Longitude 101°14'E), which belongs to Watson's (1928) tidal inundation class 4. The mean annual rainfall is about 1790 mm. Wet season (September to December) contributes 46% of the rainfall, intermediate season (January to April) contributes 31% and dry season (May to August) contributes 23% of the annual rainfall. Mean minimum and maximum temperature are 24° and 32°C, respectively.

Mahmood *et al.* (2004) estimated the standing biomass of *B. parviflora* saplings and trees in the area (Table 1). Annual biomass increment in different components (leaves, branches, stems, bark and roots) of *B. parviflora* saplings and trees were measured from nine saplings and eighteen trees selected randomly. Selected saplings and trees were tagged and Diameter at Breast Height (DBH) was measured in September 2001 and DBH of these tagged saplings and trees were again measured at yearly interval for successive two years. The biomass of each tagged sapling and tree was estimated by using allometric equations of Mahmood *et al.* (2004). The biomass accumulation in different components of each tagged sapling and tree was computed by subtracting the initial biomass from the final biomass. Finally, biomass accumulation was expressed in t ha^{-1} and calculated from the saplings and trees having mid DBH of respective DBH classes as derived by Mahmood *et al.* (2004).

Six saplings (DBH 1 to <4 cm) were randomly selected and uprooted by using low-pressure water jet and portable winch. Uprooted saplings were then separated into different components (leaves, buds, branches, bark, stems and roots) and sub-samples (about 100 g) of each component were taken randomly from each sapling. Six trees (DBH 4 to 16 cm) were selected randomly and sub-samples of leaves, buds, and small branches (diameter < 2 cm) were collected randomly by using sharp knife attached on a long pole. A harp knife and a screw borer were used to collect bark and stem samples respectively. One buttress root was selected randomly from each tree and roots were excavated followed by the buttress root by using high-pressure water jet and portable winch. Sub-samples (about 100 g) of leaves, buds, small branches (diameter < 2 cm), bark, stems and roots (homogenous sub-sample of smaller and bigger roots of diameter < 1 cm and diameter > 1 cm, respectively) collected from each trees. All sub-samples of plant components were oven-dried at 80 °C until constant weight. Eighteen litter traps (1 x

1 m) were suspended under the tree canopy by nylon rope at a height of 1.5 m above the ground (beyond the reach of high tides). The trapped litter was collected at monthly interval for 20 months (December 2001 to July 2003). The content of individual litter trap was sorted into leaves, small branches, bracts, flowers and propagules and oven dried at 80°C until constant weight. Micro-nutrient contents in different components of *B. parviflora* saplings, trees and litter were analysed during the intermediate season (March 2002 and 03), dry season (July 2002 and 03) and wet season (November 2002).

Nine samples of topsoil (up to 10 cm depth) were collected randomly from the study area during the wet season (November 2001 and 02), intermediate season (March 2002 and 03), dry season (July 2002 and 03), by using core sampler of 5 cm diameter. Soil texture and bulk density was measured according to Black (1965). The different samples of saplings, trees, litter components and soil were processed and acid digested according to Allen (1974) for the determination of total Cu, Fe and Zn in samples extraction by using Atomic Absorption Spectrophotometer (AAS PERKIN ELMER 4100, USA).

Nutrient stock in different components of saplings and trees was calculated from the individual nutrient content in each components multiplied by their dry weight. Annual accumulation of nutrients was calculated from the annual biomass increment in each component of saplings and trees multiplying with the individual nutrient content. Annual return of nutrient includes nutrients returned through litter fall, dead root and leaching by rain, etc. This study estimated the annual return of nutrients only through litter fall. Therefore, the estimated values of nutrient return could be slightly underestimated. The amount of nutrient uptake, turnover rate (yr), absorption coefficient, utilization coefficient and cycling coefficient were calculated from the following equations:

1. Uptake = Return + Accumulation (Duvigneaud and Smet, 1970)
2. Turnover rate (yr) = Nutrient stock in biomass / Return of nutrients (Duvigneaud and Smet, 1970)
3. Absorption coefficient = Uptake of the nutrient / Nutrient in soil pool (Zheng *et al.*, 1997)
4. Utilization coefficient = Uptake amount of nutrient / Stock of nutrient (Zheng *et al.*, 1997)
5. Cycling coefficient = Return of nutrient / Uptake of nutrient (Zheng *et al.*, 1997)

RESULTS AND DISCUSSION

Biomass increment in selected saplings and trees was not significantly (t -test, $p > 0.05$) different in two successive years and yearly average biomass increment in saplings and trees was 0.58 t ha^{-1} and 16.51 t ha^{-1} , respectively (Table 1). The amount of total litter production, leaf litter, small branches, bracts, flowers and propagules was $10.35 \text{ t ha}^{-1}\text{yr}^{-1}$, $7.06 \text{ t ha}^{-1}\text{yr}^{-1}$, $0.77 \text{ t ha}^{-1}\text{yr}^{-1}$, $1.03 \text{ t ha}^{-1}\text{yr}^{-1}$, $0.19 \text{ t ha}^{-1}\text{yr}^{-1}$ and $1.30 \text{ t ha}^{-1}\text{yr}^{-1}$, respectively. The rate of biomass increment and litter production are highly variable, both locally and regionally

Table 1: Standing biomass (after Mahmood *et al.*, 2004) and annual biomass increment in different components of *Bruguiera parviflora* saplings and trees

Plant components	Standing biomass (t ha^{-1})	Biomass increment ($\text{t ha}^{-1}\text{yr}^{-1}$)
Saplings		
Leaves	0.08	0.04
Buds (kg ha^{-1})	5.01	—
Branches	0.12	0.06
Stems	0.61	0.38
Bark	0.08	0.05
Roots	0.14	0.05
Trees	—	—
Leaves	10.91	1.11
Buds	0.50	0.05
Flowers	0.40	—
Branches	38.23	4.11
Stems	81.28	7.99
Bark	11.11	1.09
Roots	18.93	2.16
Total	162.42	17.09

(Clough, 1992; Woodroffe, 1984), and species to species (Sasekumar and Loi, 1983; Day *et al.*, 1996). Environmental parameters (rainfall, and temperature) and stand characteristics have significant influence on biomass increment and litter production (Lopez-Portillo and Ezcurra, 1985; Saenger and Snedaker, 1993). Moreover, biomass increment of a species in a particular site is varies with growth stage (Hutchings and Saenger, 1987). Soil texture was clay and the bulk density was 0.63 g cm^{-3} and the weighted mean contents of Cu, Fe and Zn were $17.92 \pm 1.23 \text{ } \mu\text{g g}^{-1}$, $9278.16 \pm 1004.33 \text{ } \mu\text{g g}^{-1}$ and $81.12 \pm 4.58 \text{ } \mu\text{g g}^{-1}$ respectively.

The total stock and annual accumulation of Cu, Fe and Zn in standing biomass were $1195.38 \text{ g ha}^{-1}$ and $125.44 \text{ g ha}^{-1}\text{y}^{-1}$; $87962.30 \text{ g ha}^{-1}$ and $10073.63 \text{ g ha}^{-1} \text{y}^{-1}$; and $2295.02 \text{ g ha}^{-1}$ and $238.55 \text{ g ha}^{-1} \text{y}^{-1}$, respectively. Narrow range of Cu (5.42 ± 0.62 to $10.47 \pm 1.14 \text{ } \mu\text{g g}^{-1}$) and Zn (6.50 ± 0.98 to $21.80 \pm 2.40 \text{ } \mu\text{g g}^{-1}$) content in different components (Table 2) and higher proportion of biomass in above-ground components (88% of total biomass) (Table 1) together contributed higher accumulation and stock of Cu and Zn in the above-ground components of saplings and trees. The narrow range of Cu and Zn content indicates the mobility and uniform distribution throughout the plant components (Kabata-Pendias and Pendias, 1984). On the contrary, very high content of Fe in roots (3906.63 ± 507.85 to $58281 \pm 410.08 \text{ } \mu\text{g g}^{-1}$) (Table 2) leads to increase higher proportion of Fe accumulation and stock in roots. Roots of mangroves found to accumulate and store higher amount of Fe compared to other components (Golley *et al.*, 1975; Silva *et al.*, 1990). Iron is

Table 2: Mean ($\pm$ SE) content and stock of micro-nutrients of micro-nutrients in different components of *Bruguiera parviflora* saplings and trees

Plant components	Nutrients content (mg g^{-1})			Amount of nutrients (g ha^{-1})		
	Cu	Fe	Zn	Cu	Fe	Zn
Saplings						
Leaves	7.43 ± 1.13	125.50 ± 4.87	11.41 ± 1.25	0.59	10.04	0.91
Buds	8.22 ± 1.31	60.11 ± 6.86	13.92 ± 1.54	0.04	0.30	0.07
Branches	8.55 ± 2.29	76.25 ± 12.97	9.33 ± 1.42	1.03	9.15	1.12
Stems	5.42 ± 0.62	54.80 ± 6.35	8.11 ± 1.18	3.30	33.43	4.95
Bark	6.44 ± 0.98	110.28 ± 9.46	15.67 ± 2.12	0.52	8.82	1.25
Roots	7.07 ± 1.01	5281.20 ± 410.08	18.74 ± 3.98	0.99	739.37	2.62
Trees	—	—	—	—	—	—
Leaves	7.65 ± 1.12	237.66 ± 43.73	15.13 ± 2.95	83.46	2592.85	165.09
Buds	9.07 ± 1.12	68.08 ± 10.28	19.06 ± 2.75	4.71	35.33	9.89
Flowers	10.47 ± 1.14	107.29 ± 6.01	21.80 ± 2.40	4.32	44.27	9.00
Branches	9.09 ± 0.96	102.62 ± 8.62	11.42 ± 1.22	347.36	3923.24	436.59
Stems	6.54 ± 1.16	59.93 ± 2.41	14.82 ± 2.54	531.73	4871.27	1204.73
Bark	5.69 ± 0.84	156.78 ± 14.45	10.02 ± 2.19	63.24	1741.80	111.32
Roots	8.14 ± 0.66	3906.63 ± 507.85	18.36 ± 2.98	154.09	73952.43	347.48

Table 3: Annual accumulation of micro-nutrients in different components of *Bruguiera parviflora* saplings and trees

Plant components	Nutrients accumulated (g ha ⁻¹)		
	Cu	Fe	Zn
Saplings			
Leaves	0.30	5.02	0.46
Branches	0.51	4.57	0.56
Stems	2.06	20.82	3.08
Bark	0.32	5.51	0.78
Roots	0.35	264.06	0.94
Trees	—	—	—
Leaves	8.49	263.80	16.80
Branches	37.34	421.78	46.94
Stems	52.27	478.86	118.43
Bark	6.20	170.89	10.92
Roots	17.58	8438.31	39.65

important in chlorophyll formation, protein synthesis and root tip meristem growth (Meyer *et al.*, 1973; Jones *et al.*, 1998), and hence higher Fe content is expected in plant roots. In addition, formation of Fe plaques on root surfaces is common in the mangrove environment (Lacerda, 1998), which could lead to higher Fe content in the roots.

The annual return of Cu, Fe and Zn in the form of litter fall was 79.80 g ha⁻¹, 790.29 g ha⁻¹ and 178.15 g ha⁻¹, respectively. Leaf fall is the main and quick source of nutrients return to soil and contributed to 65%, 75% and 78% of the total annual return of Cu, Fe and Zn, respectively (Table 4). The annual uptake of Cu, Fe and Zn was 205.24 g ha⁻¹, 10863.92 g ha⁻¹ and 416.69 g ha⁻¹, respectively (Table 5). Present study showed comparatively higher stock, accumulation, return and uptake of Cu and Zn than *Rhizophora stylosa* dominated stand in Nature Reserve of Yingluo Bay, China (Zheng *et al.*, 1997). Nutrients stock, accumulation, return and uptake in mangroves vary with standing biomass, annual biomass increment, litter production, plant species, age of stand, element characteristics, nutrients content in different components of plants, nutrient pool and

Table 5: Micro-nutrients uptake, return/accumulation ratio, turnover period, soil nutrients pool, absorption coefficient, utilization coefficient and cycling coefficient of *Bruguiera parviflora* dominated mangrove forest

	Cu	Fe	Zn
Uptake (g ha ⁻¹)	205.24	10863.92	416.69
Return/Accumulation ratios	0.64	0.08	0.75
Stock (g ha ⁻¹)	1195.38	87962.30	2295.02
Turnover period (yr)	15	111	13
Soil (0-30 cm depth) (kg ha ⁻¹)	33.87	17535.72	153.32
Absorption coefficient	0.006	0.001	0.003
Utilization coefficient	0.17	0.12	0.18
Cycling coefficient	0.39	0.07	0.43

soil physical and chemical characteristics (Jordan, 1985; Gong and Ong, 1990; Li, 1997; Zheng *et al.*, 1997).

Accumulation was higher than return for Cu, Fe and Zn and their turnover periods were calculated to be 15 yr, 111 yr and 13 yr, respectively (Table 5). Higher amount of Fe accumulation and stock in plants roots and lower amount (790.29 g ha⁻¹) of Fe in litter components (Table 4) resulted in low return/accumulation ratio and longer turnover period (Table 5). The sequences of absorption coefficient and utilization coefficient were Cu>Zn>Fe and Zn>Cu>Fe, respectively (Table 5). The sequence of cycling coefficient was similar with utilization coefficient and suggested that the flow of Zn was higher and lower flow was associated with Fe, which coincided with the turnover period (Table 5).

CONCLUSION

Nutrients in any forest ecosystem are cycled in a variety of chemical forms and the description of nutrient cycling is the part of the story. Nutrient cycling is never completely efficient. Nutrients are

Table 4: Mean ($\pm$ SE) content and annual return of micro-nutrients through litter fall

Litter components	Nutrients content (mg g ⁻¹)			Amount of nutrients (g ha ⁻¹)		
	Cu	Fe	Zn	Cu	Fe	Zn
Leaves	7.36 $\pm$ 1.38	84.33 $\pm$ 5.61	19.67 $\pm$ 3.17	51.99	595.40	138.84
Branches	10.31 $\pm$ 2.05	72.15 $\pm$ 6.55	12.27 $\pm$ 1.75	7.94	55.56	9.45
Bracts	6.65 $\pm$ 1.02	80.85 $\pm$ 14.74	17.53 $\pm$ 3.47	6.85	83.27	18.06
Flowers	9.20 $\pm$ 0.78	85.22 $\pm$ 22.26	17.61 $\pm$ 5.41	1.75	16.19	3.35
Propagules	8.67 $\pm$ 1.23	30.67 $\pm$ 2.43	6.50 $\pm$ 0.98	11.27	39.87	8.45

released from trees through leaching process and litter fall. Microbes decompose the litter and a portion of the litter is exported to the aquatic ecosystem in the form of litter and detritus export. The general observation suggested that forest stores large amount of nutrients in the woody plant components (stem, branches and roots), which move slowly through the system. But, stored nutrients in leaves, other green parts cycle rapidly between the soil and plants.

ACKNOWLEDGEMENTS

The authors wish to thank the Department of Biology, Universiti Putra Malaysia and Malaysian Natural Society for their financial and logistic support throughout the study period.

REFERENCES

- Aksornkoe, S. & Khemnark, C. 1984. Nutrient cycling in mangrove forest of Thailand. In: *Proceedings of the Asian Symposium on Mangrove Environment Research and management*. E. Soepadmo, A.N. Rao and D.J. Macintosh (Eds.). University of Malaya, Kuala Lumpur. 545-557 pp.
- Allen, S.E. 1974. *Chemical Analysis of Ecological Materials*. Blackwell Scientific publication, Oxford, UK. 565 pp.
- Baker, A.J. & Walker, P.I. 1990. Ecophysiology of metal uptake by tolerant plants. In: *Heavy metal tolerance in plants; evolutionary aspects*. A.J. Shaw (Eds.). Florida, CRC Press. 155-178 pp.
- Binkley, D. 1986. *Forest Nutrition Management*. John Wiley & Sons, New York. 290 pp.
- Black, C.A. 1965. *Method of Soil Analysis*, Part 1, Madison, Wis, American Society of Agronomy. John Wiley & Sons, New York. 769 pp.
- Clough, B.F. 1992. Primary productivity and growth of mangrove forests. In: *Tropical Mangrove Ecosystem, Coastal and Estuarine Studies 41*. A.I. Robertson and D.M. (Eds.). American Geophysical Union, Washington DC. 225-250 pp.
- Clough, B.F. & Attiwill, P.M. 1975. Nutrient cycling in a community of *Avicennia marina* in a temperate region of Australia. In: *Proceedings of International Symposium on Biology and Management of Mangrove*. G.E. Walsh, S.C. Snedaker and H.J. Teas (Eds.). University of Florida, Florida. 137-146 pp.
- Day, J.W. Jr., Coronado-Molina, C., Vera-Herera, F.R., Twilley, R., Rivera-Monroy, V., Alvarez-Guillen, H., Day, R. & Conner, W. 1996. A 7 year record of above-ground net primary production in a southeastern Mexican mangrove forest. *Aquatic Botany* **55**: 39-60.
- Duvigneaud, P. & Denaever-de Smet, S. 1970. Biological cycling of minerals in temperate deciduous forest. In: *Analysis of Temperate Ecosystems*. D.E. Reichle (Eds.). New York. Springer-Hague. 199-225 pp.
- Golley B.F., Mc Ginnis T.J., Clements, G.R., Child, I.G. & Duever, J.M. 1975. *Mineral Cycling in a Tropical Moist Forest Ecosystem*, University of Georgia Press, Athens. 248 pp.
- Gong, K.W. & Ong, E.J. 1990. Plant biomass and nutrient Flux in a Managed mangrove Forest in Malaysia. *Estuarine Coastal and Shelf Science* **31**: 519-530.
- Hutchings, P. & Saenger, P. 1987. *The Ecology of Mangroves*. University of Queensland Press. Australia. 388 pp.
- Jones, Jr. J.B. 1998. *Plant Nutrition Manual*. CRC Press, New York. 149 pp.
- Jones, Jr. J.B., Wolf, B. & Mills, H.A. 1991. *Plant Analysis Hand Book: A practical sampling, preparation, analysis and interpretation guide*. Micro-Macro Publishing, New York. 197 pp.
- Jordan, C.F. 1985. *Nutrient Cycling in Tropical Forest Ecosystems*. John Wiley & Sons, New York. 190 pp.
- Kabata-Pendias, A. & Pendias, H. 1984. *Trace Elements in Soils and Plants*. CRC Press, Florida. 478 pp.
- Lacerda, L.D. 1998. Trace metals in mangrove plants: why such low concentrations? In: *Mangrove ecosystem studies in Latin America and Africa*. L.D. Lacerda and H.S. Diop (Eds.) South America. UNESCO. 171-178 pp.
- Li, M.S. 1997. Nutrient Dynamics of a Futian Mangrove Forest in Shenzhen, South China. *Estuarine, Coastal and Shelf Science* **45**: 463-472.
- Lopez-Portillo, J. & Ezcurra, E. 1985. Litter fall of *Avicennia germinans* L. in a One-year Cycle in a Mudflat at the Laguna de Mecoacan, Tabasco, Mexico. *Biotropica* **17**(3): 186-190.
- Mahmood, H., Saberi, O., Japar Sidik, B., Misri, K. & Rajagopal, S. 2004. Allometric relationships for estimating above and below-ground biomass of saplings and trees of *Bruguiera parviflora* (Wight and Arnold). *Malaysian Applied Biology* **33**(1): 37-45.
- Marschner, H. 1995. *Mineral Nutrition of Higher Plants*. Academic Press, New York. 567 pp.

- Meyer, B.S., Anderson, D.B., Bohning, R.H. & Fratiane, D.G. 1973. Introduction to plant physiology. D. Van Nostrand Company, New York. 412 pp.
- Ong, J.E., Gong, W.K. & Wong, C.H. 1985. Seven Years of Productivity Studies in a Malaysian Managed Mangrove Forest, then What?. In: *Coastal and Tidal Wetlands of the Australian Monsoon Region*. K.N. Bardsley, J.D.S. Davie and C.D. Woodroffe (Eds.). Australian National University, Australia. 213-223 pp.
- Saenger, P. & Snedaker, S.C. 1993. Pantropical trends in mangrove above-ground biomass and annual litterfall. *Oecologia* **96**: 293-299.
- Sasekumar, A. & Loi, J.J. 1983. Litter production in three mangrove forest zone in the Malay Peninsula. *Aquatic Botany* **17**: 283-290.
- Silva, C.A.R., Lacerda, L.D. & Rezende, C.E. 1990. Metals Reservoir in a Red Mangrove Forest. *Biotropica* **22(4)**: 339-345.
- Walbridge, M.R. 1991. Phosphorus availability in acid or-ganic soils of the lower north Carolina coastal plain. *Ecology* **72**: 2083-2100.
- Watson, G.J. 1928. *Malayan forest Record 6: Mangrove Forests of the Malay Peninsula*. Fraser and Neave Ltd., Singapore. 456 pp.
- Woodroffe, C.D. 1984. Litter fall beneath *Rhizophora stylosa* Griff., vaitupu, Tuvalu, South Pacific. *Aquatic Botany* **18**: 249-255.
- Zheng, J.W., Yong, C.X. & Peng, L. 1997. Accumulation and biological cycling of heavy metal elements in *Rhizophora stylosa* mangroves in Yingluo Bay, china. *Marine Ecology Progress Series* **159**: 293-301.