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Accumulation and biological cycling of heavy metal elements in *Rhizophora stylosa* mangroves in Yingluo Bay, China

Zheng Wen-jiao[1], Chen Xiao-yong[2], Lin Peng[2]

[1]Environmental Science Research Center, [2]Department of Biology, Xiamen University, Xiamen 361005, People's Republic of China

ABSTRACT: Absorption, accumulation and dynamics of 7 heavy metal elements were studied in mature *Rhizophora stylosa* mangroves in Yingluo Bay, China. The concentrations of Cu, Pb, Zn, Cd, Cr, Ni and Mn in the sediments of the mangrove forest were determined to be 18.9, 10.0, 46.6, 0.077, 9.27, 14.6 and 89.5 µg g^{-1} dry wt, respectively. Evident differences of heavy metal concentrations have been observed in different parts of the plant, and the weighted means were 0.98, 0.86, 4.91, 0.11, 0.50, 1.06 and 14.60 µg g^{-1} dry wt for Cu, Pb, Zn, Cd, Cr, Ni and Mn respectively. In natural habitat conditions, the ability of *R. stylosa* to absorb each heavy metal except Cd was very low, and the weighted average accumulation indices of Cu, Pb, Zn, Cd, Cr, Ni and Mn in the plant to those in soil were only 0.05, 0.09, 0.11, 1.40, 0.05, 0.07 and 0.16, respectively. The heavy metal concentrations in residues on the floor were much higher than those in the plant and in litter falls. The total amounts of Cu, Pb, Zn, Cd, Cr, Ni and Mn in the standing crop of the forest were 28.73, 25.25, 143.68, 3.14, 14.61, 30.87 and 430.39 mg m^{-2}, among which about 90 to 96% of the total amounts was stored in the parts difficult to consume by the animals. The storages in residues on the floor were 271.7, 323.5, 1983.8, 8.2, 34.4, 63.0 and 1776.9 µg m^{-2}, respectively. With the development of leaves from young to old, Cu, Zn and Ni can be translocated and reused before defoliation, while amounts of other heavy metal elements increased in older leaves. In the biological cycle of 7 heavy metals in the forest the following was observed: (1) the annual uptakes of Cu, Pb, Zn, Cd, Cr, Ni and Mn by the forest were 1351.7, 1613.1, 8808.4, 240.7, 759.5, 1627.7 and 53692.0 µg m^{-2}; (2) annual retentions were 842.5, 806.9, 4694.2, 95.0, 464.9, 1054.0 and 14038.9 µg m^{-2}, respectively; (3) annual returns were 509.2, 806.2, 4114.3, 146.0, 294.6, 573.7 and 3965.3 µg m^{-2}, respectively. The estimated turnover periods were 56, 31, 35, 22, 50, 54 and 11 yr for Cu, Pb, Zn, Cd, Cr, Ni and Mn, respectively.

KEY WORDS: Mangroves · Heavy metal · Biological cycling · *Rhizophora stylosa*

INTRODUCTION

Mangroves are intertidal wetlands, common in tropical and subtropical coastal environments, especially in bays and estuaries. They support genetically diverse communities of terrestrial and aquatic organisms of direct and indirect socio-economic value. As the primary producer, mangroves supply food for marine animals. They also provide habitats for birds, insects, fishes, algae and bacteria. They consist of complex food chains or food webs (Teas 1979, Lin 1988). Due to the discharge of pollutants caused by the rapid development of cities along the coast and rivers, the environmental stresses on estuary mangrove ecosystems have increased.

Heavy metals are one of the most important pollutants and their effects on mangroves have been widely recognized (Walsh et al. 1979, Lin & Chen 1989, Mackey et al. 1992, Tam et al. 1995). Mangrove sediments are important sinks for land-derived contaminants, especially heavy metals. The urban and industrial activities in coastal areas and along rivers cause a significant increase in metal concentrations in solution and suspension in water, which converge to the estuary mangrove wetlands. The metals are trapped by the sediments, due to the sedimentation of suspended particles and various retention processes associated with surfaces of the sediment organic and inorganic matter The fates of nutrients and trace elements in sediments of mangrove swamps have been widely studied. But, few studies on the dynamics of heavy metals in the mangrove community have been reported. However, to quantify the relevance of the heavy metal accumulation process and the consequent segregation from the estuarine environment, a better knowledge of the capacity of the plant species involved in drawing the metals from sediments and releasing them as plant detritus to the estuarine food chains is needed (Lacerda & Abrao 1984).

The *Rhizophora stylosa* mangroves in Yingluo Bay, China, are one of the mangroves typical to China. Very little information is available on the characteristics of the mangroves, and most of the studies performed focused on community structure. Until now, no research data have been reported on heavy metals in sediments and plants and their dynamics in this mangrove ecosystem.

This paper deals with the absorption, accumulation and dynamics of 7 heavy metals in a *Rhizophora stylosa* forest. The aim is to reveal the actions of various heavy metals in *R. stylosa* mangroves.

MATERIALS AND METHODS

The research site is located in Shankou Mangrove Nature Reserve of Yingluo Bay (21° 28' N, 119° 43' E) in China, which is sited at the northeastern edge of Beibu Gulf, the mangroves occupying an area of about 730 ha. The dominant species is *Rhizophora stylosa*, although a total of 9 mangrove species occur in this forest (Lin & Hu 1983). This is the best conserved and largest area of *R. stylosa* forest in China. The research site was protected as a national class mangrove nature reserve in 1990 and hardly suffers disturbance. The waterway, with significant freshwater input, is the Lianjiang River, which flows into the northern portion of the bay. The river is clean, because the areas which the river flows through have very few industrial activities.

The studied community is a mature pure *Rhizophora stylosa* forest of some 87 hm^2 in mid-tidal zone. It is about 70 yr in age, 6 m in height, and 74 ind. per 100 m^2 in density. Trunk diameters at breast height are 5 to 11 cm. The plants have well-developed stilt roots and are rich in aerial roots. The leaf area index of the forest is 2.9, and the cover is 0.9. The forest is affected by tides occurring at regular intervals. Salinity of surface soil is 21.21‰, pH value 4.61 and organic matter content 13.4% (Lin et al. 1992).

The research was conducted in 1993. Five sample sites were selected in the forest. One was at the center of the forest, and the other 4 were about 50 m away from the center site on its 4 aspects. Each sample site was about 100 m^2 At each sample sites, fresh leaf, flower, fruit, twig, branch, trunk wood, trunk bark, aerial root, stilt root and underground root of *Rhizophora stylosa* were sampled randomly, 500 g of each component was collected. Residues in four 1 × 1 m^2 plots were all collected and 5 surface soil samples (0 to 30 cm in depth) were sampled randomly at each sites. All the samples from the 5 sites were mixed extensively according to the component. The plant samples and residue samples were taken to the laboratory immediately, washed with distilled water and dried at 60°C. Litter fall was collected continuously for 3 yr using 15 traps of 1 × 1 m^2 hung randomly among plants about 2 m above the ground (F. Z. Zheng et al. 1996).

In order to reveal the changes of heavy metal concentrations in a leaf during its development, leaves at 3 different stages of development were sampled from the same branch: young leaf (the first leaf pair), mature leaf (the third leaf pair), and yellow leaf (turning yellow for senescence).

All the samples were dried to constant weight at 60°C, ground, and then stored for analysis. The samples were digested by HNO_3-$HClO_3$. Concentrations of Cu, Pb, Zn, Cd, Cr, Ni and Mn were analyzed with atomic absorption spectrophotometers.

The standing crop and annual increment data were from Lin et al. (1992). Data on litter fall were from F. Z. Zheng et al. (1996). The amount of residues on the floor was measured seasonally.

The standing amount of heavy metals stored in the standing crop reflects the net accumulations of elements absorbed by the forest, which is calculated from the concentrations of heavy metals in each component sampled and the biomass of the forest. The potential amount of heavy metals in the residues on the floor is also calculated from the concentration of heavy metals in each fraction of the residues and the amounts of the residues.

The absorption ability of a plant for heavy metals in the soil is generally expressed by an accumulation coefficient. It can be calculated using the formula: $D_i = C_i/C_{soil\ i}$, where D_i is the accumulation coefficient for heavy metal i, C_i is the concentration of the heavy metal in the plant, and $C_{soil\ i}$ is the concentration of the heavy metal in the soil.

In an ecosystem, biological cycling means the cycling of materials among soil, plants and animals. This paper only deals with the cycling between plants and soil, which includes 3 processes: uptake, retention and return (Qu et al. 1983). Annual retention is the net accumulated amount of a heavy metal element in the forest in 1 yr, obtained from the annual increment of biomass of each fraction of the forest and the concentrations of the elements in each fraction (Zheng & Lin 1992). Annual return is the returned amount of a heavy metal in 1 yr, including the return by litter fall, dead root and that leached by rain, etc. Because it is difficult to measure the returns of an element via dead root, root secretion and rain leaching in a mangrove swamp, we only estimated the annual return via litter fall (Zheng & Lin 1992). So, the estimated values of return are underestimated slightly. The amount of uptake is equal to the total of retentions and returns.

The turnover period of an element in vegetation is the ratio of the total amount of the element in the standing crop to that in the annual litter fall. That is $P_i = S_i/R_i$, where the P_i is the turnover period of element i, S_i is the standing amount of the element, and the R_i is the annual return. The absorption coefficient, utilization coefficient and cycling coefficient can be used as another cycling index of an element between the forest and its habitats, and were calculated according to Chen & Lindley (1983).

RESULTS

Heavy metals in components of *Rhizophora stylosa* mangroves

Heavy metal concentrations in sediments

The concentrations of Cu, Pb, Zn, Cd, Cr, Ni and Mn in sediments (0 to 30 cm deep) in the *Rhizophora stylosa* forest of Yingluo Bay are shown in Table 1. The mean metal concentrations were found to decrease in the order Mn > Zn > Cu > Ni > Pb > Cr > Cd. This pattern is similar to the River Tees estuary, UK, sediments reported by Davies et al. (1991). All of them except Cr were lower than the concentrations of the corresponding elements in sediments in a *Kandelia candel* forest of Jiulong River Estuary (W. J. Zheng et al. 1996a, b) and in an *Avicennia marina* forest of Shenzhen Bay, China (Zheng & Lin 1996a, b). These values were similar to or lower than those in Sepetiba Bay of Brazil (Lacerda & Abrao 1984) and in mangrove sediments in the Brisbane river, Australia (Mackey et al. 1992).

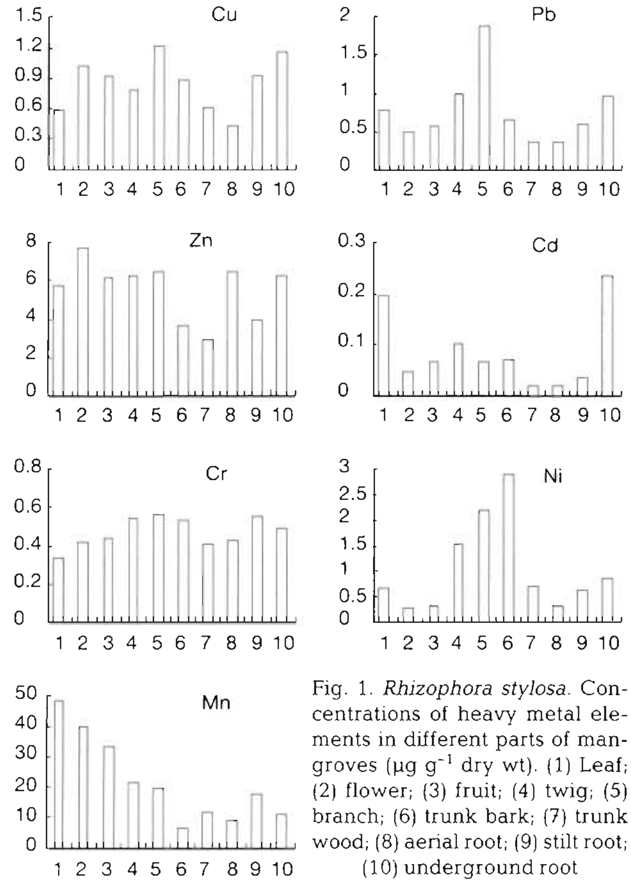

Fig. 1. *Rhizophora stylosa*. Concentrations of heavy metal elements in different parts of mangroves (µg g^{-1} dry wt). (1) Leaf; (2) flower; (3) fruit; (4) twig; (5) branch; (6) trunk bark; (7) trunk wood; (8) aerial root; (9) stilt root; (10) underground root

Heavy metal concentrations in different parts of *Rhizophora stylosa*

The concentrations of heavy metals in different parts of *Rhizophora stylosa* are shown in Fig. 1. Evident differences of concentrations of most heavy metals were observed in different parts of the mangroves, and weighted means were 0.98, 0.86, 4.91, 0.11, 0.50, 1.06 and 14.60 µg g^{-1} dry wt for Cu, Pb, Zn, Cd, Cr, Ni and Mn, respectively. The mean metal concentrations decreased in an order similar to that in the sediments. The highest concentrations of Cu, Pb and Cr were recorded in branches, and those of Zn, Cd, Ni and Mn were in flowers, underground roots, trunk bark and leaves, respectively. The lowest concentrations of Cu

Table 1. *Rhizophora stylosa*, *Kandelia candel* and *Avicennia marina*. Heavy metal concentrations in sediments (depth 0 to 30 cm) of 3 estuary mangroves in China (µg g^{-1} dry wt)

Mangroves	Cu	Pb	Zn	Cd	Cr	Ni	Mn
Rhizophora stylosa, Yingluo Bay	18.9	10.0	46.6	0.077	9.27	14.6	89.5
Kandelia candel, Jiulong River Estuary[a]	29.7	18.3	111.0	0.094	4.73	16.9	583.0
Avicennia marina, Shenzhen Bay[b]	38.3	28.7	114.0	0.136	7.97	25.0	537.0

[a]Data from W. J. Zheng et al. (1996a, b). [b]Data from Zheng & Lin (1996a, b)

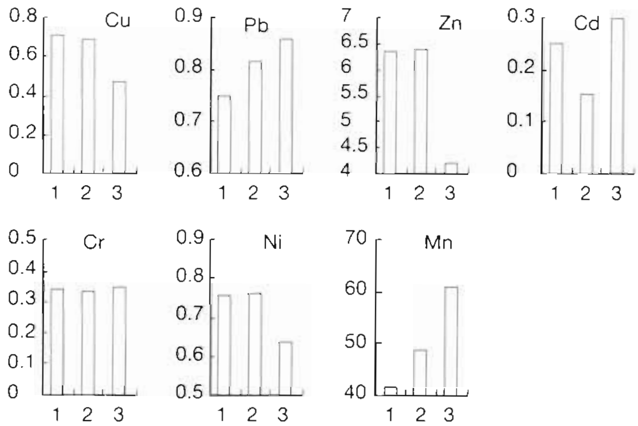

Fig. 2. *Rhizophora stylosa*. Changes of concentrations (µg g^{-1} dry wt) of heavy metal elements in leaves at different stages of development in mangroves. (1) Young leaf (first leaf pair); (2) mature leaf (third leaf pair); (3) yellow leaf (turning yellow for senescence)

and Ni were in aerial roots and flowers, and Pb, Zn and Cd were lowest in trunk wood, and Cr and Mn were lowest in leaves and trunk bark, respectively.

Heavy metal concentrations in leaves at different developmental stages were also determined. Different changes in heavy metal concentration were found in leaves as they developed (Fig. 2). Pb and Mn concentrations increased gradually with leaf development. Concentrations of Cu, Zn and Ni were similar in young and mature leaves, higher than those in yellow leaves. The change in Cr concentration was not evident.

Heavy metal concentrations in litter falls and residues on the floor

Table 2 shows the concentrations of heavy metals in different fractions of litter falls. The concentrations of Cu, Cr, Pb and Zn were highest in litter fall flowers or branches (1.31, 0.59, 2.48, 8.25 µg g^{-1} dry wt, respectively), and lowest in litter fall fruits and leaves (0.62, 0.36, 0.52, 5.00 µg g^{-1} dry wt, respectively). The highest concentrations of Cd and Mn were found in litter fall leaves, and the lowest in litter fall fruits. Concentrations of heavy metals in leaf residue were much higher than those in branch residue, especially of Zn and Pb. It is noteworthy that the concentrations of all the 7 heavy metals except Ni of each fraction in residues were higher than those in litter fall. The concentrations of heavy metals in leaf residue were 1.3 to 28.6 times of those in litter fall leaves, and in branch residue were 1.1 to 3.8 times of those in litter fall branches.

Ability of *Rhizophora stylosa* to absorb heavy metals in soil

The weighted average accumulation coefficients of *Rhizophora stylosa* for 7 elements in topsoil in Yingluo Bay were in the order Cd > Mn > Zn > Pb > Ni > Cu = Cr (Table 3). Most of them were lower than 0.2, but that of Cd was 1.395. The accumulation coefficients of Cu, Pb, Zn, Cr and Ni in each fraction were lower than 0.2, and those of Mn (except 0.535 for leaf) were lower than 0.5. However, the accumulation coefficients of Cd in leaf, twig and underground root were 1.3 to 3.0, and those in other fractions were lower than 1. The results showed that *R. stylosa* forest had different absorption and accumulation abilities for different heavy metals in natural habitat conditions. Among them, Cd was the easiest to be absorbed, next Mn, and Cr and Cu were the last.

Amounts and distributions of heavy metals in *Rhizophora stylosa* forest

The standing amounts of Cu, Pb, Zn, Cd, Cr, Ni and Mn in *Rhizophora stylosa* forest in Yingluo Bay were

Table 2. *Rhizophora stylosa*. Concentration of heavy metal elements in litter fall and residues on the floor in a mangrove community (µg g^{-1} dry wt)

Fraction		Cu	Pb	Zn	Cd	Cr	Ni	Mn
Litter fall	Leaf	0.62	1.06	5.00	0.224	0.36	0.76	59.6
	Flower	1.31	2.48	6.95	0.050	0.59	0.54	34.5
	Fruit	0.69	0.52	6.29	0.034	0.44	0.32	13.3
	Branch	1.09	1.84	8.25	0.064	0.59	2.08	19.1
Residue	Leaf	15.50	25.00	143.00	0.476	1.18	3.32	77.2
	Branch	4.13	1.94	16.60	0.120	0.80	1.08	38.0

Table 3. *Rhizophora stylosa*. Accumulation coefficient of mangroves from the soil

Fraction	Cu	Pb	Zn	Cd	Cr	Ni	Mn
Leaf	0.031	0.080	0.121	2.523	0.036	0.045	0.535
Flower	0.053	0.050	0.164	0.595	0.045	0.019	0.442
Fruit	0.048	0.058	0.132	0.854	0.047	0.022	0.366
Twig	0.042	0.099	0.134	1.307	0.059	0.104	0.237
Branch	0.064	0.188	0.139	0.867	0.061	0.149	0.220
Trunk bark	0.046	0.065	0.078	0.918	0.057	0.198	0.073
Trunk wood	0.032	0.037	0.063	0.259	0.044	0.048	0.127
Aerial root	0.023	0.037	0.138	0.259	0.045	0.022	0.103
Stilt root	0.049	0.059	0.084	0.453	0.060	0.044	0.198
Underground root	0.060	0.096	0.134	3.014	0.053	0.059	0.123
Weighted average	0.052	0.086	0.105	1.395	0.054	0.072	0.163

28.73, 25.25, 143.68, 3.14, 14.61, 30.87 and 430.39 mg m^{-2}, respectively (Table 4). Cd was higher in underground than in aboveground fractions and the others were converse. Compared with other mangroves (Zheng & Lin 1996a, b, W. J Zheng et al. 1996a, b), the amounts of Cu, Zn and Mn were only 53.5, 76.5 and 26.4% of those of corresponding elements in *Avicennia marina* forest, and 36.3, 42.8 and 5.4% in *Kandelia candel* forest, respectively, whereas the amounts of Cd, Cr and Ni were 4.4, 2.4 and 1.5 times those of corresponding elements in *A. marina* forest, and 2.7, 4.2 and 2.9 times those in *K. candel* forest, respectively.

The residues in *Rhizophora stylosa* forest in Yingluo Bay were only 35.36 g m^{-2}. The estimated potential amounts of the 7 heavy metals in the residues were 271.7, 323.5, 1983.8, 8.2, 32.4, 63.0 and 1776.9 µg m^{-2} for Cu, Pb, Zn, Cd, Cr, Ni and Mn, respectively, among which the amount in residue leaves made up 63.0, 85.4, 79.7, 64.3, 40.1, 58.3 and 48.0% of the total, respectively (Table 5). It showed that the amounts of the 7 heavy metals in residues were low though concentrations were high. The potential amounts of the 7 elements, except Pb, were also lower than those in the *Kandelia candel* forest (W. J. Zheng et al. 1996a, b) and those in the *Avicennia marina* forest (Zheng & Lin 1996a, b).

Biological cycles of heavy metals in *Rhizophora stylosa* forest

The annual retention of Cu, Pb, Zn, Cd, Cr, Ni and Mn in the *Rhizophora stylosa* forest in Yingluo Bay was 842.5, 806.9, 4694.2, 95.0, 464.9, 1054.0 and 14038.9 µg m^{-2}, respectively, which were in the order Mn > Zn > Ni > Cu > Pb > Cr > Cd (Table 6). The retention of Cu,

Table 4. *Rhizophora stylosa*. Total amount of heavy metal elements in the mangrove community (µg m^{-2})

Fraction	Biomass[a] (g m^{-2})	Cu	Pb	Zn	Cd	Cr	Ni	Mn ($\times 10^3$)
Leaf	685.1	405.6	540.5	3877.7	133.6	226.1	448.1	32.82
Flower and fruit	17.6	16.2	10.1	111.6	1.1	7.6	5.6	0.59
Twig	198.6	156.5	196.8	1239.3	20.1	108.2	301.9	4.21
Branch	4133.5	5501.5	7771.0	26826.4	276.9	2323.0	8969.7	81.43
Dead branch	188.2	436.6	297.4	1364.5	14.9	122.0	265.4	2.80
Trunk bark	1392.4	1208.6	906.5	5082.3	98.9	738.0	4024.0	9.13
Trunk wood	5547.7	3339.7	2047.1	16310.2	111.0	2280.1	3844.6	63.24
Aerial root	86.5	37.5	32.2	555.3	1.7	36.4	27.9	0.79
Stilt root	7371.6	6759.9	4334.6	28897.5	258.0	4069.2	4710.6	130.48
Underground root	9536.8	10872.0	9117.2	59414.3	2222.1	4701.6	8268.4	104.90
Total	29158.0	28734.1	25253.4	143679.1	3138.3	14612.2	30866.2	430.39

[a]Data from Lin et al. (1992)

Table 5. *Rhizophora stylosa*. Total amount of heavy metal elements in residues on the floor of mangroves (µg m^{-2})

Fraction	Residues[a] (g m^{-2})	Cu	Pb	Zn	Cd	Cr	Ni	Mn
Residue leaves	11.05	171.3	276.3	1580.2	5.26	13.0	36.7	853.1
Residue branches	24.31	100.4	47.2	403.6	2.92	19.4	26.3	923.8
Total	35.36	271.7	323.5	1983.8	8.18	32.4	63.0	1776.9

[a]Data from Lin et al. (1992)

Table 6. *Rhizophora stylosa*. Annual retentions of heavy metal elements in mangroves (µg m^{-2} yr^{-1})

Fraction	Annual increment[a] (g m^{-2})	Cu	Pb	Zn	Cd	Cr	Ni	Mn
Twig	198.65	156.5	196.9	1239.6	20.1	108.3	301.9	4211.4
Perennial branch	104.16	126.0	195.8	676.0	7.0	58.5	226.0	2052.0
Trunk bark	35.09	30.5	22.8	128.1	2.5	18.6	101.4	230.2
Trunk wood	139.80	84.2	51.6	411.0	2.8	57.5	96.9	1593.7
Aboveground root	187.94	171.3	110.0	742.2	6.6	103.5	119.4	3308.0
Underground root	240.33	274.0	229.8	497.3	56.0	118.5	208.4	2643.6
Total	905.97	842.5	806.9	4694.2	95.0	464.9	1054.0	14038.9

[a]Data from Lin et al. (1992)

Pb, Zn, Cd, Cr, Ni and Mn in the root accounted for 48.8, 42.1, 26.4, 65.9, 47.8, 31.1 and 42.4% of the total, respectively. The annual retention of Cu, Pb, Zn and Mn was only 20.7, 61.2, 28.7 and 13.0% of that of corresponding elements, respectively, by comparison with *Avicennia marina* mangroves (Zheng & Lin 1996a, b) and was 10.6, 22.3, 15.4 and 2.1% of corresponding elements by comparison with *Kandelia candel* mangroves (W. J. Zheng et al. 1996a, b).

Annual return of Cu, Pb, Zn, Cd, Cr, Ni and Mn in *Rhizophora stylosa* mangroves was 509.2, 806.2, 4114.3, 146.0, 294.6, 573.7 and 39653.1 μg m^{-2}, respectively, with the order Mn > Zn > Pb > Ni > Cu > Cr > Cd (Table 7). Litter fall leaves were the main route of return, and their return amounts of Cu, Pb, Zn, Cd, Cr, Ni and Mn were 75.8, 82.0, 75.8, 95.8, 75.8, 82.8 and 93.8% of the total, respectively.

The annual uptakes of Cu, Pb, Zn, Cd, Cr, Ni and Mn in *Rhizophora stylosa* mangroves were 1351.7, 1613.1, 8808.4, 240.7, 759.5, 1627.7 and 53692.0 μg m^{-2}, in which the retention ratios were 62.3, 50.0, 53.3, 39.4, 61.2, 64.8 and 26.1% of the total, and the return ratios were 37.7, 50.0, 46.7, 60.6, 38.8, 35.2 and 73.9% of the total for Cu, Pb, Zn, Cd, Cr, Ni and Mn, respectively. That is, retention > return for Cu, Zn, Cr and Ni; return > retention for Cd and Mn; and retention = return for Pb. Relations among annual uptakes, retentions and returns are summarized in Fig. 3.

The calculated turnover periods of Cu, Pb, Zn, Cd, Cr, Ni and Mn of *Rhizophora stylosa* mangroves in Yingluo Bay were 56, 31, 35, 22, 50, 54 and 11 yr, respectively. These indicated that the speeds of turnover were in the order Mn > Cd > Pb > Zn > Cr > Ni > Cu in *R. stylosa* mangroves. Compared with other elements in this forest, the turnover periods of Cu, Pb, Zn, Cd, Cr and Ni were longer than K, Na, Mg, Cl, indicating that the turnover ratios of heavy metals, except Mn, were rather low. The turnover periods of the 7 heavy metals except Pb in *R. stylosa* were much longer than those of corresponding elements in *Kandelia candel* (W J. Zheng et al. 1996a, b).

The absorption coefficient sequence of the 7 heavy metals was Cd > Mn > Pb = Zn > Ni > Cu = Cr (Table 8). The utilization coefficient sequence, however, was in the order Mn > Cd > Pb = Zn > Cr = Ni > Cu. The sequence of cycling coefficients was the same as the utilization coefficient which suggested that the flows of Mn and Cd were high, while those of Cu, Cr and Ni were low, coinciding with the conclusion of the turnover analysis.

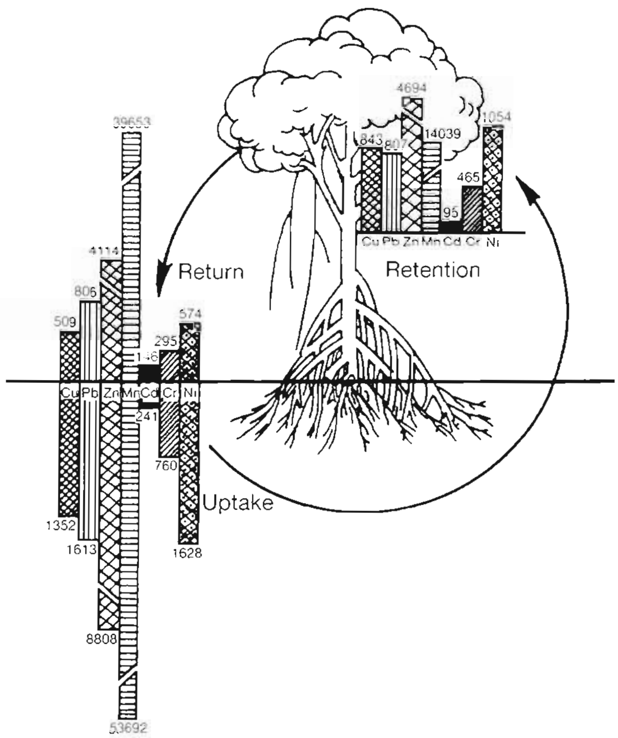

Fig. 3. *Rhizophora stylosa*. Biological cycling of heavy metal elements in the mangrove community (μg m^{-2} yr^{-1})

DISCUSSION

Mangrove wetlands are generally considered to be apt to trap heavy metals, because of their high organic material content and tiny sediment grain size. But the concentrations of Cu, Pb, Zn, Cd, Cr, Ni and Mn of sediments (0 to 30 cm deep) in the *Rhizophora stylosa* forest of Yingluo Bay were relatively low, especially Mn, Zn, Pb and Cd, compared with other mangrove estuar-

Table 7. *Rhizophora stylosa*. Annual return of heavy metal elements in mangrove community (μg m^{-2} yr^{-1})

Fraction	Annual amount[a] (g m^{-2})	Cu	Pb	Zn	Cd	Cr	Ni	Mn
Fall leaves	623.9	386.2	661.3	3119.5	139.8	223.4	474.8	37183.8
Fall flowers	16.2	21.2	40.2	112.5	0.8	9.6	8.8	558.6
Fall fruits	104.3	72.1	54.5	657.2	3.6	45.6	33.4	1389.7
Fall branches	27.3	29.7	50.2	225.1	1.8	16.0	56.7	521.0
Total	771.9	509.2	806.2	4114.3	146.0	294.6	573.7	39653.1

[a]Data from F Z. Zheng et al. (1996)

Table 8. *Rhizophora stylosa*. Absorption coefficient, utilization coefficient and cycle coefficient in the mangrove community

	Cu	Pb	Zn	Cd	Cr	Ni	Mn
Total amount (mg m^{-2})	28.73	25.25	143.68	3.14	14.61	30.87	430.39
Yearly uptake (µg m^{-2})	1351.7	1613.1	8808.4	241.7	759.5	1627.7	53692.0
Yearly return (µg m^{-2})	509.2	806.2	4114.3	146.0	294.6	573.7	39653.1
Soil (depth 0 to 30 cm) (mg m^{-2})	2664.9	1410.0	6570.6	10.9	1307.1	2058.6	12619.5
Absorption coefficient[a]	0.0005	0.0011	0.0013	0.0221	0.0006	0.0008	0.0043
Utilization coefficient[b]	0.047	0.064	0.061	0.077	0.052	0.053	0.125
Cycle coefficient[c]	0.377	0.500	0.467	0.606	0.388	0.352	0.739

[a]Absorption coefficient: Ratio of element absorption amount in unit time and unit area to total amount of that element in soil (depth 0 to 30 cm)
[b]Utilization coefficient: Ratio of element absorption amount in unit time and unit area to total amount of that element remaining in the forest
[c]Cycle coefficient: Ratio of the amount of element returned to environment to uptake amount of that element in unit time and unit area

ies. This suggests that the sediments of the *R. stylosa* forest were less polluted by heavy metals. It is true that the areas along the Lianjiang River and the coast were less developed than other areas of China and very few industrial activities had been carried out in these areas.

Concentrations of heavy metals were higher in residues than in litter falls of *Rhizophora stylosa* (Table 2). Similar results had also been observed in other mangrove wetlands (W. J. Zheng et al. 1996a, b). It might arise mainly from the adsorption by residues of heavy metals from the environment. The residues on the floor were the putrid leaves and branches that were litter fall remaining on the surface of the topsoil, most of which were decomposed or half-decomposed. This organic detritus directly came into contact with soil and sea-water, and adsorbed heavy metals. Lin & Chen (1989) also showed that the litter fall and residue leaves of *Kandelia candel* were evidently able to adsorb Hg. Mangrove litter falls are an important food and energy source for a variety of aquatic organisms and they have impacts on coastal productivity and quantity, including cultures of e.g. oysters, clams, crabs, shrimps, and fishes. The residues with high potential concentrations of heavy metals were unfavorable to the animals that fed on residues on the floor. Yet, the residues loaded heavily with contaminant such as heavy metals can often be shifted seawards with tidal flow, which would alleviate the accumulation and recycling of contaminants in mangrove zone in a way. It is true that there were only a few residues and low potential amounts of heavy metals on the floor (Table 5).

Our results showed that the absorption ability of *Rhizophora stylosa* for 7 heavy metals were different and the distributions of heavy metals in the plant were also different, revealing the distinguishing features of *R. stylosa*'s absorption and accumulation for various heavy metals under the complex environment. Concentrations of Cu, Zn and Mn in *R. stylosa* were lower than those in corresponding parts of the *Kandelia candel* forest at the Jiulong River estuary (W. J. Zheng et al. 1996a, b) and the *Avicennia marina* forest in Shenzhen Bay (Zheng & Lin 1996a, b), but the Cr concentration was converse. Accumulation coefficients of heavy metals, except Cd, were rather low, especially for Cu and Cr. These results indicated that the absorption and accumulation abilities of plants for heavy metals, except Cd, from the environment were very low, meaning that, as the primary producer, *R. stylosa* forest can provide clean food for consumers. Low accumulation coefficients also have been observed in *K. candel* and *A. marina* mangroves (Zheng & Lin 1996a, b, W. J. Zheng et al. 1996a, b). Low absorption ability of mangroves for heavy metals may relate to the low availability of heavy metal in the soil, because high concentrations of sulfur have been found in mangrove swamps and sulfur can combine with heavy metals to form a less-soluble complex.

The standing amount and distribution of heavy metals in a forest relate to the concentration of heavy metals in different parts as well as the biomass in different parts. In the *Rhizophora stylosa* forest, heavy metals were largely amassed in underground root, stilt root, trunk wood and branch. The amounts of Cu, Pb, Zn, Cd, Cr, Ni and Mn in the above 4 fractions were about 90 to 96 % of the total amounts in the forest. This indicated that a large quantity of the heavy metals absorbed by the forest was stored in the root, hard trunk and perennial branch, which were not easily eaten by animals, thus decreasing the transfer probability of heavy metals to secondary consumers. The estimated accumulation amounts of Cu, Pb, Zn, Cr, Ni and Mn in the *R. stylosa* community were only 1.1 to 3.4 % of the storage amounts of corresponding elements in surface soil, while Cd accumulation was 29 % of the storage amount, indicating that the amounts of heavy metals in the mangrove ecosystem were mainly stored in the sediments, and the amounts in the mangroves were small.

With the development of leaves from young to old, the changes in concentrations of heavy metals in leaves indicated that Pb, Cd and Mn were apt to be accumulated in older leaves, whereas Cu, Zn and Ni were not. Cu, Zn and Mn are essential elements of plants, and the decreasing of concentrations of Cu and Zn in old leaves may be because they were translocated and reused, but Mn was not. It has been reported that some essential elements were transferred and reutilized in many plant species before defoliation, while toxic materials were accumulated in older leaves and then removed via defoliation (Killingbeck 1985). The translocation efficiency of essential elements might be affected by the content level in plant and soil. High translocation happens when a plant lacks in the element, otherwise low or no translocation.

CONCLUSION

The concentrations of Cu, Pb, Zn, Cd, Cr, Ni and Mn of sediments (0 to 30 cm deep) in *Rhizophora stylosa* forest of Yingluo Bay were 18.9, 10.0, 46.6, 0.077, 9.27, 14.6 and 89.5 $\mu g\ g^{-1}$ dry wt, respectively. It is rather low compared with other mangrove zones, especially for Mn, Zn, Pb and Cd. This suggests that the sediments of the *R. stylosa* forest were clear and less polluted by heavy metals.

Evident differences were found in the concentration of heavy metals among different parts of the plant. The weighted means were 0.98, 0.86, 4.91, 0.11, 0.50, 1.06 and 14.60 $\mu g\ g^{-1}$ dry wt for Cu, Pb, Zn, Cr, Cd, Ni and Mn, respectively. The highest concentration of Cu was in branch and underground root; Pb in branch, Zn in flower, Cd in underground root and leaf, Cr in branch, bark, stilt root and twig, Ni in branch and bark, and Mn in leaf, flower and fruit.

The absorption abilities of *Rhizophora stylosa* for various heavy metals were different. Cd is the easiest to be absorbed and next was Mn. The absorption abilities for different elements decreased in the order Cd > Mn > Zn > Pb > Ni > Cu = Cr The accumulation ability of *R. stylosa* for the heavy metals, except Cd, were very low, and the weighted means of accumulation coefficients were lower than 0.2 (Cd, 1.4). It showed that *R. stylosa* mangroves, as the primary producer, can provide clean food for the consumers.

The standing amounts of Cu, Pb, Zn, Cd, Cr, Ni and Mn in *Rhizophora stylosa* mangroves were 28.73, 25.25, 143.68, 3.14, 14.61, 30.87 and 430.39 mg m^{-2}, among which about 90 to 96% was stored in the parts difficult to consume by animals. It would decrease the transfer probabilities of heavy metals to secondary consumers. The residues loaded heavily with contaminant can be shifted seawards with tidal flow, alleviating the accumulation and recycling of contaminants in a mangrove zone in a way.

Different changes of heavy metal concentration were found in the leaves as they developed. Pb, Cd and Mn were apt to be accumulated in older leaves, whereas Cu, Zn and Ni were not. Cu and Zn are essential elements for plants, and the decreasing of concentrations of Cu and Zn indicated that they were translocated and reused.

Annual absorbed amounts of heavy metals were in the order Mn > Zn > Ni > Pb > Cu > Cr > Cd, and were 53 692.0, 8808.4, 1627.7, 1613.1, 1351.7, 759.5 and 241.7 $\mu g\ m^{-2}\ yr^{-1}$ Annual retentions were 842.5, 806.9, 4694.2, 95.0, 464.9, 1054.0 and 14 038.9 $\mu g\ m^{-2}\ yr^{-1}$ for Cu, Pb, Zn, Cd, Cr, Ni and Mn, respectively. Annual returns were 509.2, 806.2, 4114.3, 146.0, 294.6, 573.7 and 39 653.1 $\mu g\ m^{-2}\ yr^{-1}$ for Cu, Pb, Zn, Cd, Cr, Ni and Mn, respectively. The turnover periods were in the order Cu > Ni > Cr > Zn > Pb > Cd > Mn, and were 56, 54, 50, 35, 31, 22 and 11 yr. All the turnover periods of heavy metals, except Mn, were longer than some nutrient elements, i.e. K, Na, Mg, Cl, showing that the heavy metals usually flow more slowly than nutrient elements.

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