Bull. Environm. Contam. Toxicol. 22,021-027 (1979)

The Accumulation of Heavy Metals in the Submerged Plant *(Elodea nuttallii)*

M. Nakada, K. Fukaya, S. Takeshita, and Y. Wada
Department of Special Materials, Kanagawa Prefectural Environmental Center, Futamatagawa, Yokohama, Japan

Several species of submerged plants grow in flowing water of polluted urban rivers in Japan. The measurement of heavy metals content in the submerged plants are suitable for a criterion to estimate the average heavy metals concentration in water.

DIETZ (1972) reported enrichment of heavy metals in six submerged plants collected from the Ruhr river (Germany). He found that the enrichment was dependent primarily on the species of plant and specific selectivity, and that the microanalysis of plants might yield useful results in the calculation of the concentration of heavy metals in water, making use of enrichment factors (fe).

However, he did not describe the relationship between enrichment factors and concentration changes in water. We have investigated not only the relationship, but also changes of enrichment factor when heavy metals coexist with phosphoric acid ion. For this purpose, we chose Elodea nuttallii, because this aquatic plant is prolific in polluted urban rivers in Japan and accumulates heavy metals easily.

MATERIALS AND METHODS

Samples of Elodea nuttallii were collected from the unpolluted area in the Sagami river (Kanagawa Prefecture in Japan). They were cultivated in a large water tank (acrylic plastic, 150x150x50 cm) for 1-2 mo. All experiments were conducted in a greenhouse (25°C) during June to September.

In the first experiment, we prepared solutions containing a single heavy metal (Pb, Cd, Cu or Zn) with concentrations of 0.025, 0.05, 0.1 or 0.5 ppm. In the second experiment, we prepared solutions containing four heavy metals (Pb, Cd, Cu and Zn) with concentrations of 0.025, 0.05, 0.1 or 0.5 ppm as to each metal. In the first and second experiments, the adult bodies of E. nuttallii were used and they were cultivated separately in these solutions for 30 days. In the third experiment, we prepared solutions containing four metals (Pb, Cd, Zn and Fe) and phosphoric acid ion. Each solution had the same concentration of 0.1 or 1.0 ppm as to each metal, and had the concentration of 0.25 or 2.5 ppm as to phosphoric acid ion. In the third experiment, the

0007-4861/79/0022-0021 $01.40

buds (5-8 cm) of the plant collected from the large water tank were used and they were cultivated separately in these mixed solutions for 30 days.

After the cultivation, they were stirred electrically for 20 min after washing by hand and were immersed in clean water for one day. The samples without roots were dried at 100°C for 2 h and the dry weight determined. Heavy metals were determined generally by atomic absorption (DDTC-MIBK extract) after sulfuric acid - nitric acid dissolution. Three aliquots from each solution were analysed and means are given in Tables 1 through 4.

RESULTS

Table 1 gives the heavy metal contents in each part of bodies of Elodea nuttallii collected from the Sagami river. The content of heavy metals were generally rich in roots, but poor in leaves and stocks. In the case of leaves and stocks, the contents of Zn, Fe and Mn were comparatively rich, but poor of Pb, Cd and Cu. Considering the results, we used green parts of the plants without roots and chose four heavy metals (Pb, Cd, Cu and Zn) in the following two experiments.

TABLE 1

Heavy metal contents in each part of E. nuttallii collected from the Sagami river (mg/kg)

	Heavy metal					
Part	Pb	Cd	Cu	Zn	Fe	Mn
Leaf	12.2	0.9	10.8	111	856	393
Stock	17.4	0.3	7.8	160	628	165
Root	323	13.5	23.7	332	1800	895

In the first experiment, we studied the relationship between uptake of heavy metals and the concentration in water when E. nuttallii were cultivated separately in the solutions of one of four metals for 30 days (Table 2). The results indicated that the uptake of heavy metals in the plant increased with increase of the concentrations in water but the enrichment factor decreased. It is seen that the uptake of Pb was greater than that of Cd and Cu and high values of enrichment factors on Pb were confirmed at comparatively low concentration. Cadmium is known for high accumulation in rice in Japan. But, this element was not considered to be highly toxic to E. nuttallii. Values of enrichment factor at 0.5 ppm was the highest of the four elements. Copper is of physiological importance in the formation of chlorophyll. However, the enrichment of copper was relatively low in comparison with other elements and necrobiosis occurred at 0.5 ppm. These results indicate that the toxicity of copper may be more significant than that of other elements. Zinc is essential for the development of higher plants and is contained in abundance in the

TABLE 2

Uptake of heavy metals and the concentration in water when *E. nuttallii* was cultivated separately in the solutions containing single heavy metal (Pb, Cd, Cu or Zn) for 30 days

Heavy metal	Pb		Cd		Cu		Zn	
Concentration in water (mg/L)	Content of uptake (mg/kg)	fe*	Content of uptake (mg/kg)	fe*	Content of uptake (mg/kg)	fe*	Content of uptake (mg/kg)	fe*
0.025	156	6200	43.3	1730	35.4	1420	-	-
0.05	214	4300	56.7	1130	51.5	1030	-	-
0.1	281	2800	106	1060	60.8	610	303	3000
0.5	341	680	409	820	dead	-	357	710

$$^{*}\text{fe (Enrichment factor)} = \frac{\text{Concentration of heavy metals in plants (net weight) (ppm)}}{\text{Concentration of heavy metals in surface water (ppm)}}$$

plants. It is suggested that the enrichment of zinc is similar to that of lead.

In the second experiment, Table 3 gives the relationship between heavy metal concentration in water and their uptake when E. nuttallii was cultivated in the mixed solutions of heavy metals for 30 days. Values of enrichment factor in Table 3 were relatively low in comparison with that in Table 2, but the relative ranking of four elements showed same results. It is suggested that the marked decrease of values in Pb and Cd at 0.1 ppm may show synergistic action of these four elements.

In the third experiment, we studied the effects of phosphoric acid on the enrichment of heavy metals (Table 4). We used buds (5-8 cm) of E. nuttallii because it was suggested that a submerged plant may markedly take up heavy metals in budding period. The buds of the plant markedly took up heavy metals in comparison with adult bodies of E. nuttallii and the enrichment were increased further when heavy metals at 1.0 ppm coexisted with phosphoric acid at 2.5 ppm.

DISCUSSION

Regarding the significance of the enrichment factor (fe), DIETZ (1972) suggested that the enrichment of heavy metals in water plants is a useful criterion to calculate the average concentration of these elements in water and thus by means of a relatively small number of samples, it is readily possible to assess the trend of water pollution by metals.

We have investigated the basic problems on the enrichment factor, making use of Elodea nuttallii, and found that the fe values of heavy metals in the plant were decreased with increase of concentration in water and the fe values for E. nuttallii in the presence of a single heavy metal were relatively high in comparison with that of mixed heavy metals.

These results suggest that in estimating the average concentration of heavy metals in water it is possible to use the enrichment factor of the heavy metals such as Cd, Pb and Cu, which are comparatively poor in control plants.

MULLIGAN et al. (1969) reported that submerged plants such as E. nuttallii grow comparatively well in low concentration of phosphoric acid ion. NAKAMURA et al. (1969) found that the enrichment of Cd in the yeast run parallel with that of phosphorus. Based on these results, we examined the effect of phosphorus in water on the enrichment of heavy metals in submerged plants. Our data indicated that the enrichment of heavy metals in the buds of E. nuttallii markedly increased at 1.0 ppm solution of heavy metal with 2.5 ppm phosphoric acid ion, but the same result did not occur in the case of adult bodies of E. nuttallii. It is of physiological interest that the enrichment of heavy metals in

TABLE 3

Uptake of heavy metals and the concentration in water when *E. nuttallii* was cultivated separately in mix solutions containing all of four heavy metals (Pb, Cd, Cu and Zn) for 30 days

Heavy metal	Pb		Cd		Cu		Zn	
Concentration in water (mg/L)	Content of uptake (mg/kg)	fe	Content of uptake (mg/kg)	fe	Content of uptake (mg/kg)	fe	Content of uptake (mg/kg)	fe
0.025	114	4500	41.5	1660	34.1	1360	-	-
0.05	276	5500	47.3	950	44.8	900	-	-
0.1	47.7	480	37.5	380	54.2	540	257	2600
0.5	dead	-	dead	-	dead	-	dead	-

TABLE 4

Effects of phosphoric acid on the enrichment of heavy metals with the buds* of E. nuttallii were cultivated separately in the mixed solutions containing all of four metals (Pb, Cd, Zn and Fe) for 30 days

Concentration of heavy metal in water (mg/L)	Concentration of phosphoric acid in water (mg/L)	Pb		Cd		Zn		Fe	
		Content of uptake (mg/kg)	fe	Content of uptake (mg/kg)	fe	Content of uptake (mg/kg)	fe	Content of uptake (mg/kg)	fe
0.1	0.25	760	7600	620	6200	3500	35000	4500	45000
	2.5	580	5800	560	5600	3920	39000	4870	48700
1.0	0.25	7490	7500	3430	3400	6720	6700	5840	5840
	2.5	15900	15900	10200	10200	14500	14500	8090	8090

*The buds (5–8 cm) of E. nuttallii collected from the large water tank were used.

these buds markedly increased during budding period and phosphorus in water promote further the enrichment.

Making use of these results we are planning to estimate the average concentration of heavy metals in various river water in Japan.

ACKNOWLEDGEMENT

We wish to thank Prof. Hiroshi Fukushima of Yokohama City University for the suitable advices on the aquatic plants.

REFERENCES

DIETZ, F.: The report of 6th International Water Pollution Research, Session 2, Hall A-Monday, Paper No. 4, (1972).

MULLIGAN, H. F.: Verh. Internat. Verein. Limnol. 17, 802 (1969).

NAKAMURA, H. and J. ASHIDA: Mem, Coll. Sci., Univ. Kyoto, B, 26, 323 (1969).