



Bioaccumulation and Detection of Trace Levels of Cadmium in Aquatic Systems by *Eichhornia crassipes*

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The water hyacinth (*Eichhornia crassipes*) may be used as a sensitive biological indicator for continuously monitoring trace quantities of toxic heavy metals in aquatic systems. A river water system polluted with cadmium was simulated while other factors of temperature, day-night cycle, water quality, and light intensity remained constant. When the water hyacinth is maintained in river water containing 0.001 mg/l. of cadmium chloride, the plant's root system will concentrate this element at an average rate of 0.9, 1.4, and 3.0 $\mu\text{g Cd/g}$ root dry weight after 24, 48, and 72 hr exposure periods, respectively. At a higher cadmium concentration of 0.01 mg/l., cadmium was concentrated in the roots much faster to levels of 6.8, 13.6, and 39.1 $\mu\text{g/g}$ root after 4, 8, and 24 hr exposure periods, respectively. At initial concentrations of 0.05 mg/l. cadmium, the roots contained 29.5, 48.8, and 156 $\mu\text{g/g}$ root following 4, 8, and 24 hr exposure periods, respectively. During these same time intervals, the water hyacinth sorbed 56.7, 153, and 281 $\mu\text{g/g}$ root when the initial cadmium concentration was increased to 0.10 mg/l.

The water hyacinth tops can also assist in the monitoring process when cadmium contamination levels are 0.10 mg/l. and greater. At this initial cadmium concentration, cadmium is translocated into the tops. After 8 hr, the tops averaged 1.1 $\mu\text{g/g}$ top. After 24 hr, this concentration was increased to 6.1 $\mu\text{g/g}$ top.

Introduction

Cadmium is a toxic, heavy metal which can present a serious threat to human health. Toxic effects from this heavy metal are well documented. Excess levels of cadmium can cause kidney and liver damage, pulmonary disease, and cancer in experimental animals (1-4). Chronic low levels of cadmium may contribute to hypertension, decreased growth, and alterations in blood cholesterol and trace element metabolism (5).

Heavy metals present a serious form of pollution in aquatic systems since they do not degrade as do most organics. Even trace quantities of toxic metals in water systems are serious potential health problems because of the ability of certain aquatic plants to concentrate heavy metals which are then consumed by fish that form a part of man's diet (6, 7).

Using biological indicators such as plants for monitoring both air and water pollution has been recognized and used to a limited extent over the

years. Mosses and lichens strongly sorb metal ions from the air and water and are useful for detecting atmospheric and aquatic lead and other metal contamination (8-10). Leaves and twigs of woody plants have also been used to indicate atmospheric pollution (11).

One of the most promising candidates for biological indicators of trace levels of heavy metals in aquatic systems is the water hyacinth (*Eichhornia crassipes*). In static laboratory experiments, this plant demonstrated an amazing ability to sorb and concentrate cadmium, as well as other metals such as mercury, lead, and nickel (12, 13). Water hyacinths have been used successfully by NASA at the National Space Technology Laboratories to remove organics and heavy metals from its chemical waste prior to discharge (14). In the course of this system's evaluation, water hyacinths were found to contain detectable levels of heavy metals, especially in the roots, although these same heavy metals in the waters were below normal detection limits by atomic absorption-flame spectrometry. The study presented in this paper is an outgrowth of this observed phenomenon. Water hyacinths are used to develop a rapid, biological monitoring system for

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establishing cadmium pollution in the aquatic environment.

Procedure

For each different cadmium concentration, twelve glass aquariums were filled with 15 liters of river water. Nine of the aquariums were polluted with sufficient 1000 mg Cd/l. standard solution to produce an approximate initial cadmium concentration of 0.1 mg/l. for run 1, 0.05 mg/l. for run 2, and 0.01 mg/l. for run 3. Three aquariums were left unpolluted. Four groups of nine water hyacinths were thoroughly washed and placed in three of the polluted containers and one of the unpolluted containers. After 4 hr, three plants from each aquarium were removed for analysis, and the remainder of the plants were transferred to four fresh aquariums. This procedure was repeated again after 8 hr. Each experiment was terminated after 24 hr.

For run 4, twelve glass aquariums were filled with 30 liters of river water. Nine containers were polluted to an approximate cadmium concentration of 0.001 mg/l. The experiment was conducted in the same manner as outlined above, except the plants were removed and transferred at 24, 48, and 72 hr intervals.

During each experiment, the plants were maintained with growth lights supplying approximately 500 FC to the plants during a 16 hr photoperiod and 8 hr nyctoperiod. The air temperature was $23 \pm 5^\circ\text{C}$. The initial unpolluted river water samples were analyzed according to *Standard Methods* (15) and found to contain the following average concentration: 0.25 mg/l. total Kjeldahl nitrogen; < 0.13 mg/l. phosphorus; 52 mg/l. dissolved solids; 9 mg/l. total organic carbon; pH 6.9. The initial cadmium concentration of 0.1 $\mu\text{g/l.}$ was determined with an IL 555 flameless atomizer and an IL 351 AA/AE spectrophotometer.

The roots and tops of the plants to be analyzed were separated, washed, dried at 60°C to a constant weight, ground, and homogenized in a Waring Blendor. A 0.500 g of each plant sample was weighed and transferred to a 75 ml volumetric digestion tube. The plant samples were charred at 400°C with 10 ml concentrated H_2SO_4 for 2 min and then digested for 20 min at 400°C with an additional 10 ml concentrated HNO_3 . The samples were allowed to cool, and then 2 ml 30% H_2O_2 was added. The tubes were again heated to 400°C for 10 min. Following the digestion process, the samples were diluted to volume with deionized, distilled water, and the cadmium content determined by flame spectrometry by using an IL 351 AA/AE spectrophotometer. A reagent blank was also digested in

the same manner, and any cadmium introduced into the plant samples from the reagents was subtracted from cadmium concentrations in the plants.

Discussion

The experiments for assessing the potential of using water hyacinths as biological indicators for estimating the level of cadmium pollution in aquatic systems were designed to simulate real conditions. A fresh volume of polluted river water was supplied to the plants at regular intervals. The cadmium concentrations were varied while other factors of temperature, day-night cycle, water quality, and light intensity remained constant. The data in Tables 1 and 2 are the results of this series of four experiments.

The first experiment conducted with 0.1 mg Cd/l. was a relatively high cadmium concentration for potable or recreational water systems. The water hyacinths were found to average 56.7 $\mu\text{g Cd/g root}$ (dry weight) after only 4 hr of exposure. The concentration in the roots continued to increase to an average of 153 $\mu\text{g/g root}$ after 8 hr and 281 $\mu\text{g/g root}$ after 24 hr. At this high cadmium level, cadmium was first detected in the leaves after only 8 hr of exposure.

The concentration in the second experiment was decreased to 0.05 mg Cd/l. The quantity of cadmium sorbed per gram dry root weight over the same time intervals was almost exactly half of the concentrations found at the 0.1 mg Cd/l. level. The cadmium was concentrated to average levels of 29.5, 48.8, and 156 $\mu\text{g/g root}$ after 4, 8, and 24 hr, respectively. No cadmium was detected in the leaves of these plants, nor was any cadmium detected in the leaves of any of the later experiments.

This same trend was also observed in the third experiment when the cadmium concentration was decreased to 0.01 mg/l. The cadmium concentrations in the roots averaged 6.8, 13.6, and 39.1 $\mu\text{g/g root}$ after 4, 8, and 24 hr, respectively.

The exposure time in the fourth experiment was increased in order for the water hyacinths to accumulate sufficient cadmium at the 0.001 mg/l. level to be detected by the procedure outlined above. This very low concentration of cadmium in the water had to be determined by atomic absorption using a flameless atomizer. The cadmium in the water could not be detected without concentrating it if the normal method of atomic absorption-flame spectrometry had been used. The first root samples analyzed after 24 hr exposure contained an average of 0.9 $\mu\text{g/g root}$. This concentration was far less than the expected value of one-tenth of the 39.1

Table 1. Average cadmium uptake within 24 hr."

Initial Cd concn in river water, mg/l.	Cd, $\mu\text{g/g}$ dry weight					
	After 4 hr		After 8 hr		After 24 hr	
	Tops	Roots	Tops	Roots	Tops	Roots
0.1	< 0.15	56.7 ± 16.9	1.1 ± 0.9	153 ± 14.0	6.1 ± 1.9	281 ± 9.0
0.05	< 0.15	29.5 ± 16.1	< 0.15	48.8 ± 17.1	< 0.15	156 ± 4.2
0.01	< 0.15	6.8 ± 1.9	< 0.15	13.6 ± 1.9	< 0.15	39.1 ± 5.6
0.001	—	—	—	—	< 0.15	0.09 ± 0.3

" Tops and roots of plant controls contained < 0.15 μg Cd/g dry weight after 24 and 72 hr.

Table 2. Average cadmium uptake in 0.001 mg Cd/l.

Exposure time, hr	Cd, $\mu\text{g/g}$ dry weight	
	Tops	Roots
24	< 0.15	0.9 ± 0.3
48	< 0.15	1.4 ± 0.2
72	< 0.15	3.0 ± 0.5

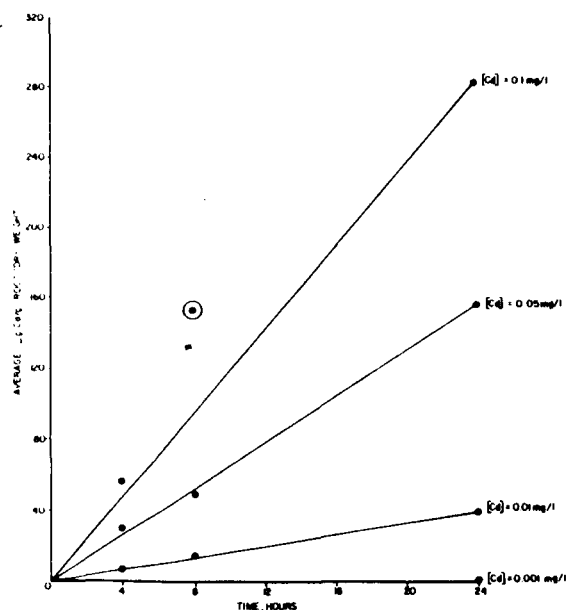


FIGURE 1. Average amount of Cd sorbed by the roots under different Cd concentrations and exposure times. (The circled point represents the amount of Cd sorbed after 8 hr when exposed to 0.1 mg/l. Cd and was not used in the least-squares analysis. The standard deviation for this point varied by 35%.)

$\mu\text{g/g}$ root found after 24 hr of exposure in 0.01 mg Cd/l. However, the 24, 48, and 72 hr samples demonstrated a fairly consistent linear relationship of μg Cd/g root (D.W.).

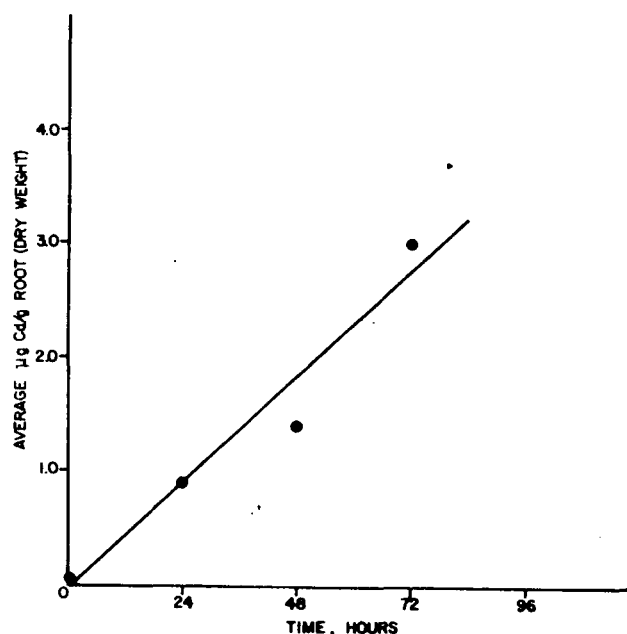


FIGURE 2. Average amount of Cd sorbed by water hyacinths vs. time on exposure to a Cd concentration of 0.001 mg/l. in river water.

Conclusions

The data from Table 1 were plotted in Figure 1, which demonstrates how a family of curves can be used to estimate low levels of cadmium in river water utilizing water hyacinths. At very low levels of cadmium this graph must be expanded as in Figure 2.

The leaves were found to be useful for estimating high cadmium concentrations. At the highest level of cadmium in this study, the leaves contained detectable levels of cadmium even after 8 hr of exposure.

The sorption rates of cadmium as well as other toxic heavy metals will vary from one system to another depending on environmental factors. However, the data necessary to obtain a family of curves such as Figure 1 for a particular aquatic system can be obtained without much difficulty.

REFERENCES

1. Leland, H. V. Heavy metals and other trace elements. *J. Water Pollut. Control Fed.* 47 (6): 1635 (1975).
2. Searle, C. E., Ed. *Chemical Carcinogens* (ACS Monograph 173), American Chemical Society, Washington, D. C., 1976, pp. 720-721.
3. Sax, I. N. *Industrial Pollution*. Van Nostrand Reinhold Co. New York, 1974, p. 594.
4. Doyle, J. J. Effects of low levels of dietary cadmium in animals—a review. *J. Environ. Qual.* 6: 111 (1977).
5. Schroeder, H. A. *The Trace Elements and Man*, Devin-Adair Co., Old Greenwich, Conn., 1973.
6. Jenkins, D. W. Flow of toxic metals in the environment. *International Conference on Environmental Sensing and Assessment*, Vol. 1, Institute of Electrical and Electronics Engineering, New York, 1976.
7. Tourbier, J., and Pierson, R. W., Jr., Eds. *Biological Control of Water Pollution*, Univ. Pennsylvania Press, Philadelphia, 1976.
8. Goodman, G. T., and Roberts, T. M. Plants and soils as indicators of metals in the air. *Nature* 231: 287 (1971).
9. McLean, R. O., and Jones, A. K. Studies of tolerance to heavy metals in the flora of the rivers, Ystwyth and Clarach, Wales. *Freshwater Biol.* 5: 431 (1975).
10. Tyler, G. Metal concentrations in moss, leaves and other indicators of metal exposure in the environment. *International Conference on Environmental Sensing and Assessment*, Vol. 1, Institute of Electrical and Electronics Engineering, New York, 1976.
11. Smith, W. H. Lead and mercury: burden of woody plants. *Science* 176: 1237 (1972).
12. Wolverton, B. C., Water hyacinths for removal of cadmium and nickel from polluted waters. *NASA Technical Memorandum TM-X-72721*, 1975.
13. Wolverton, B. C., and McDonald, R. C. Water hyacinths and alligator weeds for removal of lead and mercury from polluted waters. *NASA Technical Memorandum TM-X-72723*, 1975.
14. Wolverton, B. C., and McDonald, R. C. Wastewater treatment utilizing water hyacinths (*Eichhornia crassipes*). *Proceedings of the 1977 National Conference on Treatment and Disposal of Industrial Wastewaters and Residue*, Houston, Tex., April 26-29, 1977, Information Transfer Inc., Rockville, Md., 1977.
15. *Standard Methods for the Examination of Water and Wastewater*, M. C. Rand, A. E. Greenberg, and M. J. Taras, Eds., 14th ed. American Public Health Association, Washington, D. C., 1975.