

Transition Metals in Decomposing Macrophytes in a Wetland System

P.A. Azeez* and B. Anjan Kumar Prusty

Environmental Impact Assessment Division
Sálim Ali Centre for Ornithology and Natural History (SACON)
Anaikatty (PO), Coimbatore-641 108, India
✉ azeezpa@yahoo.co.uk

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Abstract: The present work provides the baseline information on concentrations of select transition metals (iron, manganese, copper, zinc, nickel, lead and chromium) in seven macrophytes and their changes in the course of their decomposition in the wetlands of Keoladeo National Park, Bharatpur, India. Litterbag experiments were carried out in nylon litterbags of two different mesh sizes (0.14 and 0.375 mm) in the field and in the laboratory water tanks. The macrophytes selected for the study were *Paspalum distichum*, *Paspalidium punctatum*, *Cyperus alopecuroides*, *Pseudoraphis spinescens*, *Ipomoea aquatica*, *Neptunia olearhiza* and *Hydrilla verticillata*, which dominate the aquatic vegetation of the wetland system. On the whole there was no notable influence of mesh size on the release of metals from the decomposing plant matter. In field condition the level of Cr, Ni and Pb in plant matter at the end increased while their levels decreased in water indicating the uptake and accumulation of metals in plants from the surrounding water column during decomposition.

Key words: Decomposition, litterbag, macrophytes, transition metals, wetland.

Introduction

Wetlands are one of the most productive ecosystems in the world (Whittaker, 1971; Gopal et al., 1982; Adamus and Stockwell, 1983; Herdendorf and Raphael, 1986; Maltby, 1986; Gopal et al., 1993; Mitsch and Gosselink, 2000; Prasad et al., 2002), and have been a receiver of wastewater and run off, and a filtering system. Metals are among important inorganic pollutants reaching the wetlands and affecting various trophic levels along the food chain in due course of time. Macrophytes that occupy an important position in the structure and functioning of aquatic ecosystems (Boston and Perkins, 1982) are one of the most exposed groups to elevated levels of pollutants in the system. The plants serve as a “polishing system” (Deng et al., 2004; Matagi et al., 1998)

in wetlands and help removal of the pollutants. However the availability and release/leaching of metals to and from the aquatic macrophytes depend on a variety of ambient environmental conditions such as pH, redox condition, substrate anoxia etc. (Davison and Woof, 1984; Granina et al., 2004). Sediment is an important repository (Achyuthan et al., 2002; Mathew et al., 2003; Belzile et al., 2004; Jonathan et al., 2004) of metals, and rooted macrophytes mine metals from the sediment. Hence, metals pollutants, in wetlands with macrophytes, follow a cyclic pattern along the vegetation-water interface; the elements absorbed by plants from water and sediment return after death and subsequent decomposition. The present work reports the findings of the study carried out on concentration of select metals in some macrophytes and surrounding water, rate of decomposition of select aquatic macrophytes, variation

*Corresponding Author

in metal concentration in due course of decomposition, and influence of decomposing macrophytes on water quality.

Study Area

The present investigation was carried out in Keoladeo National Park (Figure 1), Bharatpur, Rajasthan, India (Azeez and Vijayan 1995; Azeez et al., 2000; Vijayan, 1991). The area falls under semi-arid hot dry zone of India (Pal et al., 2000), with chilled winter and scorching summer, and temperature normally ranging from 1 to 49°C. The climate of the area cover four distinct seasons: summer/pre-monsoon (April to June), rainy/monsoon (July to Mid-September), post-monsoon (mid-September to mid-November) and winter (mid-November to March) (Prusty and Azeez, 2004).

Materials and Methods

Seven macrophyte species dominating the aquatic vegetation were selected for the study. The species, with their respective codes referred in the tables given in brackets, were *Paspalum distichum* (PLM), *Paspalidium punctatum* (PDM), *Cyperus alopecuroides* (CYP), *Psuedoraphis spiniscens* (PSU), *Ipomoea aquatica* (IPO), *Neptunia olearhiza* (NEP) and *Hydrilla verticillata* (HYD). The plants harvested at their peak growth just before flowering, were air-dried and cut into 3 to 4 cm long bits. Twenty-five grams of each plant were enclosed in nylon litterbags (20 × 30 cm) of two different mesh sizes (0.14 mm and 0.375 mm).

The study was conducted both in the field and in the laboratory. In the field, samples of each plant species enclosed in bags of both mesh sizes in duplicates were kept submerged in D and E blocks of the National Park. The D and E blocks remain inundated throughout the year. The seven species enclosed in different bags were attached to fixed poles with separate long plastic ropes. Six of such poles were set in the field. Of these one pole each was garnered on 10, 30, 60, 90, 120 and 150th day, taken to the laboratory and prepared for analysis. In the laboratory the study was conducted in cement tanks of size 70 × 50 × 50 cm. The thoroughly washed cement tanks were kept filled with water from the sanctuary for more than a month, with frequent change of water, to remove the leachable chemicals. To each tank of 80 L capacity, 60 L of freshly collected filtered park water was poured in. Six bags of 0.14 mm mesh size with one plant species were kept immersed in one tank and six bags of the second mesh size (0.375 mm) with the same species in separate one. The water in each tank was aerated for 5 to 6 hrs to prevent anaerobic conditions. The water level in each tank was maintained by adding required quantity of filtered sanctuary water, a sample of which was taken for laboratory analysis. One bag each was removed from every tank on 10, 30, 60, 90, 120 and 150th day and prepared for further analysis. Water samples were also collected from each tank along with the litterbags.

The litterbags collected from both the field and the laboratory tanks were drained of water and the wet weights were determined. A sample of decomposing plant

matter in each bag was taken to determine dry weight after oven drying at ~60° C for 24 hours. Other portion of the contents in each bag was divided into two unequal portions (of 75 and 25 percents), the first one for biological analysis and the second for chemical analysis. The portions meant for estimation of the transition metals (Fe, Mn, Zn, Cu, Ni, Cr, Pb and Cd) were oven dried, weighed, and analyzed using a Perkin Elmer Atomic Absorption Spectrophotometer (model AA 1100) after digestion with nitric-perchloric acids mixture (Allen, 1974). Water samples from both the field and the laboratory tanks were also analyzed for the metals. In addition, normal physicochemical characterization of

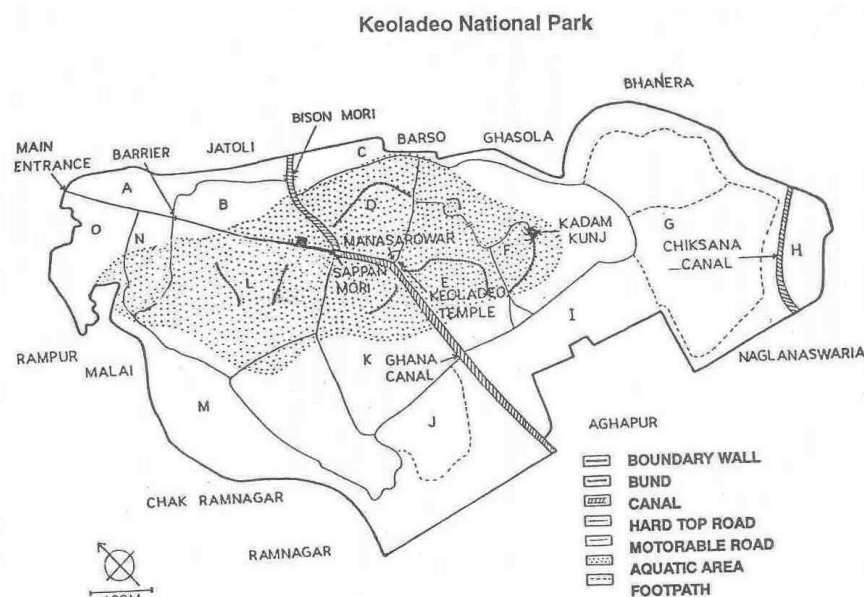


Figure 1: Study area map.

water samples was done following standard procedures (APHA/AWWA/WPCF, 1985).

Results

Laboratory Studies

The pH of the water use for study in the tanks varied between 7.0 and 8.8 with the average being 7.7 (Table 1). The phenolphthalein alkalinity varied from 0.0 mg to 19 mg l⁻¹ while the total alkalinity ranged between 218.5 mg l⁻¹ and 317.3 mg l⁻¹ with the average of 266.5 mg l⁻¹. The water was comparatively soft and had low chemical oxygen demands. The sulfate concentration varied widely and its highest concentration recorded was almost ten times of the highest chloride content. Highest and lowest phosphate concentration recorded was 3.5 mg l⁻¹ and 0.01 mg l⁻¹ respectively. Among alkali metals, Ca was found in high concentrations, Mg lowest and Na and K in the midrange among the four. Among the transition metals, Fe was seen in highest concentration. Fe and Mn was recorded in all the samples while Cr was recorded in least number of samples and in low concentration.

The concentrations of Fe, Mn, Zn, Cu, Cr, Ni and Pb in the plant samples are presented in Table 2. Among the

Table 1: Chemical properties of water used in the laboratory study

<i>Parameter</i>	<i>Maximum</i>	<i>Minimum</i>	<i>Average</i>
pH	8.8	7	7.7
Phenolphthalein alkalinity	19	0	8.9
Total alkalinity	317.3	218.5	266.5
Total hardness	226.2	116.7	182.4
Chloride	266	44.2	137.5
Chemical oxygen demand	294.6	16.3	62.2
PO ₄	3.5	0.1	1.3
SO ₄	2167.1	299.4	752.1
Ca	153.8	52.3	80.6
Mg	38.8	5.8	24.8
Na	88.49	28.51	58.78
K	97.1	3.5	53.97
Fe	11.89	0.54	3.97
Mn	0.17	0.02	0.08
Cr	0.02	0	0.01
Cu	0.02	0	0.01
Ni	0.04	0	0.02
Pb	0.08	0	0.02
Zn	0.2	0	0.03

All values, except pH, are in mg/L

Table 2: Transition metals in the decomposed plant matter in the tank after the experiment

<i>Metals</i>	<i>CYP</i>	<i>HYD*</i>	<i>IPO</i>	<i>NEP</i>	<i>PDM</i>	<i>PLM</i>	<i>PSU</i>
Fe Initial (ppm)	169.0	287.0	170.0	112.0	116.0	106.0	111.0
Fe Mesh1	54.3	23.1	54.0	23.4	51.8	45.8	44.4
Fe Mesh2	44.6	20.6	48.9	25.3	68.0	48.3	31.4
Mn Initial (ppm)	230.0	1277.0	370.0	1007.0	160.0	280.0	130.0
Mn Mesh1	73.0	65.4	58.8	11.4	62.3	31.7	91.9
Mn Mesh2	112.6	28.1	58.6	22.2	104.8	53.2	99.8
Zn Initial (ppm)	13.0	15.0	8.0	15.0	9.0	10.0	14.0
Zn Mesh1	88.3	72.2	72.3	59.5	85.9	81.5	90.0
Zn Mesh2	80.8	71.9	86.3	52.6	62.5	39.4	79.0
Cu Initial (ppm)	3.0	1.0	1.0	ND	ND	0.5	0.5
Cu Mesh1	44.9	107.4	74.5	ND	ND	86.2	84.0
Cu Mesh2	78.3	109.9	74.7	ND	ND	84.1	61.1
Pb Initial (ppm)	ND	0.02	ND	0.01	ND	ND	ND
Pb Mesh1	ND	ND	ND	ND	ND	ND	ND
Pb Mesh2	ND	ND	ND	ND	ND	ND	ND
Cr Initial (ppm)	0.3	0.2	0.1	ND	0.2	0.1	0.1
Cr Mesh1	43.5	99.4	119.6	32.9	116.4	119.5	81.7
Cr Mesh2	76.7	99.6	109.0	73.2	94.7	84.2	61.4
Ni Initial (ppm)	ND	0.2	0.1	0.1	ND	0.1	0.1
Ni Mesh1	129.6	99.4	94.1	79.8	89.9	129.6	76.1
Ni Mesh2	74.9	99.6	83.1	73.3	76.1	89.3	59.1

*In the case of *Hydrilla* after 60 days. Initial = Initial (on 0th day of experiment) concentration, Mesh1 = concentration in smaller mesh sized bag, Mesh2= concentration in bigger mesh sized bag; Mesh1 and 2 are percentage of the initial. For Ni the percentages at latter stages are calculated with respect to the concentration at 10th day of submergence.

metals, Mn was seen in highest concentrations in all the plants, followed by Fe whereas Cr, Ni and Pb were seen in very low concentrations or were undetectable. *Hydrilla* and *Neptunia* were found to have accumulated very high levels of Mn. Pb was not detected in most of the plant species, while Cr was detected in all species except *Neptunia*. Cu was not detected in *Neptunia* and *Paspalidium*. In general, metal concentration decreased in the decomposing plant matter. The decrease in Cu concentration was in the range of 55.1 percent (in *Cyperus* in small mesh bags) and -9.9 percent (in *Hydrilla* in large mesh bags). Only in *Hydrilla* and *Neptunia*, Pb was detected, in the former $0.02 \mu\text{g g}^{-1}$ and in the latter $0.01 \mu\text{g g}^{-1}$. Cr concentration ranged between 0.10 and $0.20 \mu\text{g g}^{-1}$ in other plants. Except in *Hydrilla*, *Paspalidium*, *Paspalum* and *Neptunia* in small-mesh bags and *Neptunia* in large-mesh bags, in all other cases Cr concentration decreased with decomposition. In the original plant matter before decomposition, Ni in detectable concentration was not recorded in *Cyperus* and *Paspalidium*. However, at later stages it was recorded in all the species. Nonetheless, the concentration towards the end of the experiment followed the same trend of other metals.

Iron showed fall in concentration in the course of decomposition. Thus by the end of 150 days of submergence the concentration of the metal decreased to at least half of the initial concentration. Mn found in highest concentration among the metals also mostly fell

in concentration as decomposition progressed. In the small mesh-bags, the general trend was a decrease in concentration of Mn after 150 days. Thus after the experiment Mn in the plant remaining in these bags was in the range of 11.4 (*Neptunia*) to 91.9 percent (*Pseudoraphis*) of the initial concentration. In the case of *Cyperus* and *Paspalidium* in large mesh bags a higher than original concentration of Mn was noted in plant remainings.

The pH of water in all the tanks, including the control, increased considerably from the starting day of the experiment towards the end. The pH in the control tank increased up to 9.08 by the 120th day. By the 10th day of the experiment, the pH showed a slight decrease both in the control and experimental tanks. The fall in pH was the highest in the tank with *Ipomoea* (pH 6.82). The pattern was same in both tanks with small and large mesh bags. During the study, however, the pH was not allowed to change widely because it may alter the decomposition processes. Frequently the tank water was supplemented by sanctuary water of lower pH to maintain the volume of water in the tank and to keep control over the pH changes.

Iron concentration in the tank water was 1.5 mg l^{-1} (Table 3). In control tank the Fe concentration decreased drastically towards the end of the experiment reaching down to 0.43 mg l^{-1} . Fe content decreased gradually in the water with decomposing vegetation also. By the end

Table 3: Transition metals in water in the tank during plant decomposition

Metals	BAGS	DAY	CON	CYP	HYD	IPO	NEP	PDM	PLM	PSU
Fe	Ini.	0	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Fe	Mesh1	150	28.2	59.7	50.5	36.9	14.0	24.3	14.1	14.1
Fe	Mesh 2	150	28.2	64.9	35.0	22.9	20.7	42.0	48.0	48.0
Mn	Ini.	0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Mn	Mesh1	150	77.5	187.5	153.5	162.5	212.5	230.5	194.5	125.0
Mn	Mesh 2	150	77.5	161.5	165.5	179.5	345.0	247.0	229.5	166.5
Cr	Ini.	0	ND	ND	ND	ND	ND	ND	ND	ND
Cr	Mesh 1	150	ND	ND	ND	ND	ND	ND	ND	ND
Cr	Mesh 2	150	ND	ND	ND	ND	ND	ND	ND	ND
Ni	Ini.	0	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Ni	Mesh 1	150	19.1	28.9	8.8	10.2	11.4	ND	2.8	10.3
Ni	Mesh 2	150	19.1	10.0	13.8	11.6	11.6	13.6	12.0	15.5
Pb	Ini.	0	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Pb	Mesh 1	150	9.5	19.1	36.1	21.5	8.7	17.3	5.8	20.9
Pb	Mesh 2	150	9.5	8.1	6.4	8.3	6.7	6.5	4.8	20.2
Zn	Ini.	0	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Zn	Mesh 1	150	60.0	40.0	20.0	45.0	43.3	30.0	66.7	55.0
Zn	Mesh 2	150	60.0	70.0	28.3	38.3	36.7	53.3	55.0	36.7

Mesh1 and Mesh2 = metals as percentage of the initial concentration, CON = water in the control tank, Ini = initial concentration in ppm, ND = not detected.

of the study Fe concentration was in the range of 14.0 to 64.9 percent of the initial. The lowest concentration was with *Neptunia* in small mesh bags and the highest with *Cyperus* in large mesh bags. 2.0 mg l^{-1} of Mn was recorded initially in the experimental water. In control tanks, Mn concentration decreased by 22.5 percent during 150 days. On the other hand, this pattern got reversed in the tanks with decomposing plants. In these tanks Mn content increased 1.5 to 3.5 times of the initial concentration. The highest Mn content was with *Neptunia* in large mesh bags where it increased up to 345 percent of the initial concentration and the lowest with *Pseudoraphis* in the small mesh bags where it increased to 125 percent. Chromium was not detected in the water in the tanks during the study even though the metal was recorded in the plants. In the tanks, initial concentration of Ni was 0.04 mg l^{-1} . The concentration of Ni drastically reduced in both control tank and the tanks with plants by the end of the experiment (Table 3). In the control tank on 150th day, Ni was only 0.008 mg l^{-1} . Initially, Pb content was only 0.08 mg l^{-1} and in the controls, it reduced to 9.5 percent in 150 days while in other tanks the reduction was in the range of 4.8 to 36.1 percent. At the start of the study, Zn content in the water was 0.6 mg l^{-1} . The reduction in controls was 60 percent on the 150th day. In the other tanks on the same day, the reduction was 30 to 70 percent.

Field Studies

Metals Fe, Zn, Cu, Ni and Cr increased in the decomposing plant after 150 days of submergence (Table 4). Mn increased in most of the plants except in *Hydrilla* and *Neptunia* where the trend was of decrease. In these two species the initial Mn content was very high compared to others. In most of the plants Pb was very low and below detectable limit. In case of *Hydrilla* after 150 days when the metal was recorded in large mesh bags the concentration increased, while in small mesh bags it remained roughly at same level as initial (about 99%). In *Neptunia* in large mesh bags, when the metal was in detectable concentration, the trend was of increase, i.e. 296.4% and 299.4% in small and large mesh bags respectively. Among the metals, those had a trend of increase at the end of the experiment (Fe, Zn, Cu, Ni and Cr), the level range from 105.8 to 1091.3% of their respective initial concentration.

The physicochemical characteristics of water at the sites where macrophytes were submerged for decomposition in blocks D and E are presented in Table 5. In D block pH at the start of the experiment was 7.50 (on 0th day). The lowest and highest values recorded were

7.50 and 9.21 on 0th and 120th day respectively. In the case of block E water, the initial concentration was 7.83 (0th day). In this case, the initial trend of increase was followed by a trend of decrease till 90th day, which was again followed by an increasing trend till the end of the experiment. The transition metals in water showed considerable variation throughout the study period (Table 6). Among the metals studied, Zn was seen in lowest concentration (0.03 mg l^{-1} on 10th day in the D block water), which was 37.5% of the initial concentration i.e. the concentration on the 0th day. The highest concentration in case of Zn recorded was 0.50 mg l^{-1} ; 625% and 5000% of the initial concentrations in D and E blocks respectively. In the case of Cr, the lowest and highest concentrations recorded were 0.01 mg l^{-1} and 0.03 mg l^{-1} on 60th day from E block and 10th and 60th day both from D block respectively. The lowest and highest concentrations were 25% and 75% of the respective initial concentrations. In the case of Ni, the lowest and highest concentrations recorded were 0.01 mg l^{-1} and 0.05 mg l^{-1} on 150th day from E block and 10th and 60th day both from D block respectively. The lowest and highest concentrations were 20% and 125% of the respective initial concentrations. In the case of Pb, the lowest and highest concentrations recorded were 0.01 mg l^{-1} and 0.07 mg l^{-1} on 60th day from D block and 30th day from E block respectively. The lowest and highest concentrations were 20% and 140% of the respective initial concentrations.

The variation of Fe was more in D than E block water. In D block, the lowest and highest concentrations recorded were 0.43 and 8.79 mg l^{-1} on 150th and 30th day respectively, which was 19.54% and 399.54% of the initial concentration. In E block the lowest and highest concentrations recorded were 1.45 and 2.36 mg l^{-1} on 90th and 150th day respectively, which was 96.7% and 157.3% of the initial concentration. In the case of Mn, the variation between D and E blocks was very less. The lowest and highest concentrations of Mn recorded were 0.55 and 2.00 mg l^{-1} on 150th from D block and 30th and 120th day from E block respectively, which was 183.3% and 666.7% of their respective initial concentrations.

Discussion

There is no notable difference in the level of metals in the macrophytes in different mesh bags. Except for certain cases, all metals had a trend of decrease towards the end of the experiment in the plant matter in laboratory tanks, which might be due to the release of soluble fraction of the metal initially located in the leaves as an abiotic

Table 4: Transition metal concentration (in percentage of the initial concentration) in the decomposed plant matter after the experiment in the field

METAL	BLK	MESH	DAY	CYP	HYD*	IPO	NEP	PDM	PLM	PSU
Mn	Ini #		0	230	1277	370	1008	160	280	130
Mn	D	1	150	108.7	29.29	103.89	72.42	109.13	114.29	176.92
Mn	D	2	150	119.57	30.85	143.51	66.87	154.38	113.93	192.31
Mn	E	1	150	227.39	33.28	188.38	81.35	202.5	115.71	324.62
Mn	E	2	150	313.48	31.09	243.24	69.35	402.5	273.57	497.69
Fe	Ini		0	169	287	170	112	116	106	111
Fe	D	1	150	118.82	316.13	182.26	132.87	155.96	236.31	185.48
Fe	D	2	150	128.71	251.61	394.28	183.15	186.05	264.3	157.52
Fe	E	1	150	350.13	282.62	548.75	467.96	613.75	901.11	648.14
Fe	E	2	150	451.55	368.14	454.76	625.89	530.9	550.68	553.1
Zn	Ini		0	13	15	8	15	9	10	14
Zn	D	1	150	114.7	210.39	217.18	105.82	233.33	294.7	245.1
Zn	D	2	150	136.28	205.84	425	166.67	227.86	270	250
Zn	E	1	150	508.27	192.84	375	186.67	365.21	338.65	290.53
Zn	E	2	150	275.27	198.41	487.5	219.56	484.05	415.02	341.49
Cu	Ini		0	0.6	0.2	0.2	ND	ND	0.1	0.1
Cu	D	1	150	166.67	447.5	790.5	253.81	442.93	680	759
Cu	D	2	150	236.17	595	297.5	477.66	644.95	713	870
Cu	E	1	150	166.67	149	590.5	558.38	946.46	670	830
Cu	E	2	150	160.83	149	250	597.97	796.46	781	845
Pb	Ini		0	ND	0.02	ND	0.01	ND	ND	ND
Pb	D	1	150	ND	99.6	ND	ND	ND	ND	ND
Pb	D	2	150	ND	147.6	ND	ND	ND	ND	ND
Pb	E	1	150	ND	99.4	ND	296.4	ND	ND	ND
Pb	E	2	150	ND	148.8	ND	299.4	ND	ND	ND
Ni	Ini		0	ND	0.2	0.1	0.1	ND	0.1	0.1
Ni	D	1	150	222.22	199	700	200	301.01	292	200
Ni	D	2	150	272.78	197	500	200	396.97	300	400
Ni	E	1	150	771.67	200	400	497	604.04	498	497
Ni	E	2	150	497.22	198.5	700	599	902.02	791	922
Cr	Ini		0	0.03	0.02	0.1	ND	0.02	0.1	0.1
Cr	D	1	150	170.65	170.32	788.95	304.2	446.43	493.1	300
Cr	D	2	150	265.08	198.81	694.44	701.38	442.04	891.09	500
Cr	E	1	150	233.33	150	597.61	907.16	400	795.23	591.72
Cr	E	2	150	265.08	198.41	795.23	798.43	1091.27	885.83	694.44

* *Hydrilla* after 60 days. Ini = initial concentration in ppm, BLK = block, Mesh1 and 2 are the bags of small size and large size meshes.

process (Boucher et al., 2005). Zinc is an essential element in plant growth and plays an important role in the biosynthesis of enzymes (Lepp, 1981; Aksoy and Öztürk, 1996). Generally, concentrations of Zn in plants are in the range of 15 to 100 $\mu\text{g g}^{-1}$ (Table 7) against the concentration of 8-14 $\mu\text{g g}^{-1}$ observed in the present study. The normal concentration range for other metals such as Fe, Mn and Cu are 40-500, 50-1000 and 2.5-25 $\mu\text{g g}^{-1}$ respectively against the reported concentration of 106-287, 16-1277 and up to 0.6 $\mu\text{g g}^{-1}$ respectively in the present study. The increase in the trace metal

concentration in decomposing plant matter in the field may be partly due to contamination from the soil materials settling on the surface of bags. It is already observed that a considerable amount of clay and silt is settling over the bags, which contributes a lot to the remainder weight. It may also be partly due to the fact that the concentration of the metals increases on percentage basis, as there is a loss of weight of plant matter. In contrast with the concentration in plant matter, in water the concentration of some metals (Cr, Ni and Pb in blocks D and E while Fe and Mn in block D) decrease whereas some of the

Table 5: Physicochemical characteristics of water at the sites where macrophytes were submerged for decomposition in blocks D and E

<i>BLK</i>	<i>DAY</i>	<i>pH</i>	<i>ALKp</i>	<i>ALKt</i>	<i>SO₄</i>	<i>Cl</i>	<i>PO₄</i>	<i>HARD</i>
D	0	7.5	0	157.5	173.91	5.07	0.57	118.47
D	10	7.52	4.5	165.15	146.09	2.58	0.25	-
D	30	8.42	9	150.3	135.65	8.3	0.09	112.85
D	60	8.41	0	169.2	143.06	18.43	0.16	129.32
D	90	8.35	9.5	214.7	218.73	53.1	0.14	160.59
D	120	9.21	23.75	230.85	275.56	72.16	0.64	165.64
D	150	8.28	19	285	245.48	98.57	0	184.7
E	0	7.83	4.5	142.65	143.82	4.15	0.034	89.36
E	10	-	-	-	-	-	-	-
E	30	8.59	9	143.1	135.65	9.68	0.13	86.34
E	60	8.23	0	337.5	180.65	14.93	0.14	107.43
E	90	7.73	28.5	327.75	356.72	64.02	0.61	168.67
E	120	8.06	19	318.25	195.56	75.14	0.52	179.17
E	150	8.43	19	359.1	153.42	-	0.38	150.9

BLK = block, ALKp and ALKt = Phenolphthalein alkalinity and total alkalinity in terms of CaCO₃, Cl = Chloride content, PO₄ = Phosphate content, HARD = total hardness in terms of mg l⁻¹ as CaCO₃. All values are in mg l⁻¹.

Table 6: Metals (mg l⁻¹) in water of blocks D and E during the study of in situ decomposition

<i>BLK</i>	<i>DAY</i>	<i>Fe</i>	<i>Mn</i>	<i>Zn</i>	<i>Cr</i>	<i>Ni</i>	<i>Pb</i>
D	0	2.2	-	0.08	0.04	0.04	-
D	10	7.72	1.4	0.03	0.03	0.05	0.06
D	30	8.79	0.7	0.19	-	0.04	0.06
D	60	1	1	0.5	0.03	0.05	0.01
D	90	0.55	1.5	0.15	-	-	-
D	120	0.75	1	0.15	-	-	-
D	150	0.43	0.55	0.3	-	-	-
E	0	1.5	0.3	0.01	0.04	0.05	0.05
E	10	-	-	-	-	-	-
E	30	1.99	2	0.5	0.02	0.03	0.07
E	60	1.65	1	0.22	0.01	0.02	0.02
E	90	1.45	1.4	0.25	-	-	-
E	120	1.55	2	0.1	-	-	-
E	150	2.36	1.75	0.5	-	0.01	-

Table 7: General concentration range for transition metals in plant materials vs. recorded concentration in the present study

<i>Metal element</i>	<i>Concentration range (μg g⁻¹)</i>	<i>Present observation (μg g⁻¹)</i>
Fe	40-500	106-287
Mn	50-1000	16-1277
Zn	15-100	8-14
Cu	2.5-25	ND-0.6
Pb*	6.3-9.9	ND-0.2

Source: Allen (1974), *Source: Outridge and Noller (1991)

metals (Fe, Mn and Zn in block E) increase towards the end of the experiment. The level of Cr, Ni and Pb in plant matter at the end increased indicating the uptake and accumulation from the surrounding water column. It seems that new binding sites for cations are formed during decomposition.

In the case of water in tank, metals except Mn showed a trend of decrease. The reported levels may be partly due to the binding of these metal ions to humic compounds, whose formation is stimulated at high pH (Kok et al., 1990). Rising in pH also may speed up precipitation of metals. In the field, pH showed a trend of rise. In the tanks maintained in the laboratory, rise in pH was curtailed by intermittent addition of sanctuary water as well as aeration. Another probable reason for the trend of decline of metals in water is their absorption onto calcium carbonate as the wetland soil is rich in calcium salts (Prusty & Azeez, 2003), which is either originating from limestone rock fragments in soils and sediments or precipitation from soil water in the soils of semi-arid and arid regions (KNP falls in this category). Clay minerals in soils and sediments are responsible for absorption and coprecipitation of V, Ni, Co, Cr, Zn, Cu, Pb, Ti, Mn and Fe. Aquatic plants and animals can also absorb metals in solution. There is no notable influence of mesh size on the release of metals from the decomposing plant matter. Although in most of the cases metals followed a decreasing trend in the plant matter, it does not add to the concentration in water, as the metals are likely to form complexes with the aquatic humic substances in the wetlands, specifically where the underlying soil is alkaline in nature, as in the case of KNP.

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