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Enrichment of Copper, Zinc, Manganese, and Iron in Five Species of Pondweeds (*Potamogeton* spp.)

Kai Aulio and Matti Salin

Department of Biology, University of Turku, SF-20500 Turku 50, Finland

Since SCULTHORPE's (1967) suggestion that the vascular aquatic plants could be useful indicator organisms for pollution monitoring, several studies have demonstrated the capacity of hydrophytes to accumulate heavy metals from the aquatic environment (e.g. ADAMS *et al.* 1973, RAY & WHITE 1976, ABO-RADY 1980, AULIO 1980, FRANZIN & McFARLANE 1980, LEDL *et al.* 1981). To be an applicable indicator species, an organism has to meet several requirements, e.g. in having a high tolerance to pollutants and a high enrichment capacity for these pollutants, as well as being representative and easy to handle (cf. the review by PHILLIPS 1977).

The present study was designed to obtain information on the heavy metal concentrations in plants from a single, rather uniform habitat. In this respect we determined the levels of the heavy metals copper, zinc, manganese and iron in five species of *Potamogeton*, collected from the heavily polluted estuary of the River Kokemäenjoki in western Finland. The accumulation capacity was studied in one particular habitat to ensure that the availability of metals is as uniform as possible for all the plants studied. Thus the differences between the species could be attributed to species-specific characteristics rather than to variations in environmental conditions.

MATERIAL AND METHODS

Plant samples for the heavy metal analyses were collected from the Kokemäenjoki River estuary in western Finland (61° 34' N, 21° 40' E) in August 1980. The study site is a shallow sedimentation basin, which is nearly thoroughly covered by rich and exceptionally productive macrophytic vegetation (cf. AULIO 1979). The estuarine water is principally fresh water carried by the River Kokemäenjoki. The river water is heavily polluted containing elevated levels of several heavy metals (cf. ISOTALO 1979).

The present study was concentrated in comparative analysis of the metal concentrations of five species of pondweeds (*Potamogeton* spp., Potamogetonaceae). Of the species included, *Potamogeton perfoliatus* L., *P. obtusifolius* Mert. & Koch and *P. praelongus* Wulf. represent submerged taxa, whereas *P. gramineus* L. has both

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submerged and floating leaves, and the mature individuals of *P. natans* L. have only floating leaves. For each species, six to 19 replicate samples were collected. Only shoot apices of about 5 cm long were taken for analyses. The determinations of the heavy metal concentrations were performed with conventional methods of atomic absorption spectrophotometry after dry ashing of 0.5 gram samples. The laboratory procedures are described in detail in a previous paper (AULIO 1980). All the results are presented as µg/g of dry weight. Differences in the analytical results of each species' elemental levels were tested by using the one-way analysis of variance.

RESULTS

The analytical results of the heavy metal concentrations in the five species of *Potamogeton* are given in Table 1. The differences in the metal concentrations between the taxa were tested by using the analysis of variance. Table 2 gives the F values of the ANOVA with the levels of statistical significance of the differences for all possible species-pairs.

The levels of copper in the individual samples varied between 19 µg/g (in *P. gramineus*) and 79 µg/g (in *P. praelongus*). The concentrations of Cu showed the least fluctuation in the present material with the coefficient of variation of 35 %. In general, the floating-leaved taxa (*P. natans* and *P. gramineus*) were poor in Cu as compared with the submerged species (Table 1). The interspecific differences were remarkable. Thus eight of the ten species-pairs showed highly significant ($P < 0.001$) differences in the analysis of variance (Table 2). No general ternd could be found, however, between the floating-leaved and submerged taxa (Table 2), but the enrichment of copper appeared to be species-specific.

The concentrations of zinc varied between 98 µg/g (in *P. gramineus*) and 775 µg/g (in *P. perfoliatus*). As in the levels of Cu, the concentrations of Zn were higher in the submerged than in the floating-leaved taxa (Table 1), although highly significant interspecific differences were found even within these ecological groups (Table 2). The actual concentrations of zinc were generally very high in the present material. Thus, except two samples, all the present values exceeded the Zn levels earlier reported for pondweeds (cf. RIEMER & TOTH 1969, DYKYJOVA 1979).

With the concentrations ranging from 1450 µg/g (in *P. natans*) to 12'100 µg/g (in *P. perfoliatus*) the levels of manganese showed more than eightfold interspecific differences. Of the individual species, *P. perfoliatus* appeared to be an accumulator of manganese, although even within this species the variability was rather great (mean = 8373 µg/g; range = 5600 - 12'100 µg/g). In the comparison between the taxa, five of the ten species-pairs showed highly significant differences in the levels of manganese (Table 2).

Table 1. The concentrations (µg/g dry weight) of copper, zinc, manganese and iron in the five species of *Potamogeton*, collected from the Kokemäenjoki River estuary in western Finland.

		Cu		Zn		Mn		Fe	
	n	$\bar{X}$	S.E.	$\bar{X}$	S.E.	$\bar{X}$	S.E.	$\bar{X}$	S.E.
P. perfoliatus	14	39.7	2.2	409.7	25.5	8372.9	588.3	3212.1	299.6
P. obtusifolius	19	44.5	1.8	190.8	11.0	3704.5	331.6	5943.9	941.6
P. natans	13	27.1	1.8	152.0	11.5	2643.5	276.9	1118.1	98.9
P. praelongus	10	61.3	3.2	228.9	10.4	4985.6	513.4	9930.0	849.9
P. gramineus	6	20.5	0.8	123.8	7.8	4820.0	93.6	3537.5	227.6
mean of all samples	62	39.8	1.8	243.9	15.6	4761.0	321.5	4639.9	483.6

n = number of samples

$\bar{X}$ = arithmetic mean

S.E. = standard error of the mean

Table 2. Comparison of the metal concentration of five species of *Potamogeton*. The F values of the one-way analysis of variance are given together with the significance of the differences.

Key to species: PER = *P. perfoliatus*, OBT = *P. obtusifolius*, NAT = *P. natans*, PRA = *P. praelongus*, GRA = *P. gramineus*

	PER vs. OBT	PER vs. NAT	PER vs. PRA	PER vs. GRA	OBT vs. NAT	OBT vs. PRA	OBT vs. GRA	NAT vs. PRA	NAT vs. GRA	PRA vs. GRA
Cu	-2.84	18.85***	-33.59***	30.59***	42.97***	-24.68***	53.90***	-99.91***	5.79*	104.67***
Zn	62.04***	67.26***	22.54***	38.21***	5.72*	-4.65*	10.84**	-21.18***	2.30	53.47***
Mn	54.13***	73.81***	16.10***	15.09**	5.26*	-4.60*	-3.44	-18.86***	-27.05***	0.07
Fe	-5.83*	41.36***	-75.96***	-0.45	17.70***	-7.10*	1.99	-154.27***	-132.59***	35.70***

Significance levels: * = P < 0.05; ** = P < 0.01; *** = P < 0.001.

The levels of iron showed the greatest interspecific differences in the present material (C.V. = 81 %). The concentrations of Fe of the individual samples ranged from 800 µg/g (in *P. natans*) to 14'050 µg/g (in *P. obtusifolius*). The remarkably low value for *P. natans* reflects a characteristically low enrichment capacity for Fe in this floating-leaved species (cf. LEDL *et al.* 1981). The comparison between the taxa showed six highly significant differences (Table 2), but no general trend could be found between the floating-leaved and submerged life forms. Of the individual species, *P. praelongus* appeared to be an efficient accumulator of iron (mean = 9930 µg/g; range = 8000 - 13'750 µg/g).

DISCUSSION

All the samples of *Potamogeton* from the Kokemäenjoki River estuary showed markedly high concentrations of copper, zinc, manganese and iron (Table 1) as compared with the previous values reported for pondweeds (cf. RIEMER & TOTH 1969, and the reviews by HUTCHINSON 1975 and by DYKYJOVA 1979) thus reflecting the highly elevated levels of metals in the study area (cf. ISOTALO 1979).

The enrichment of metals appeared to be species-specific. Thus, 25 of the 40 comparisons of the element levels resulted in highly significant ($P < 0.001$) interspecific differences (Table 2), and only six species-pairs showed non-significant differences in the metal concentrations. Assuming that the availability of the metals is uniform in the study site, it is evident that the differences are determined principally by the plant species.

The species-specific enrichment of elements may be a consequence of several factors, including differences in morphological characteristics (e.g. thickness of cuticular layers, or structures of vascular systems), and specific features in metal absorption through roots and/or shoots (cf. the review by DENNY 1980).

The present comparisons of the element levels did not reveal any trends according to the ecological life forms. In general, the submerged taxa were richer in metals than the floating-leaved species (Table 1).

In search for possible indicator organisms for pollution monitoring, the submerged species *Potamogeton perfoliatus* L. appeared to be the most promising. This species accumulated very high concentrations of both zinc and manganese, being rather poor in iron. Thus *P. perfoliatus* showed certain selectivity in the metal enrichment. In this respect *P. perfoliatus* meets the basic requirement of specificity in metal accumulation, an essential characteristics for a useful indicator organism (cf. PHILLIPS 1977). More analyses are still needed to test the constancy of the enrichment capacity in varying environmental conditions (AULIO & SALIN, in preparation).

The applicability of *Potamogeton perfoliatus* is strongly supported by the results of RAY & WHITE (1976) with a very near relative North American species *Potamogeton Richardsonii*.

The submerged species *Potamogeton praelongus* Wulf. showed marked enrichment capacity for iron (Table 1) with a high average concentration and relatively little intraspecific variation. The specific feature in Fe enrichment in *P. praelongus* was shown also by COWGILL (1974) whose record of 5.9 % iron clearly exceeds all the other values of Fe concentrations in pondweeds.

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