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Impact of Blast-furnace Plant Emissions in a Dune Ecosystem

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The effects and possible interactions of heavy metals within ecosystems have given considerable research on those metals that have known toxic effects. Many reports concern elemental concentrations in whole animals, tissues or organs, but very few represent the result of systematic sampling of the animals and their food on a comparable basis.

One of the industries with considerable heavy metal fallout, blast furnaces, expel large quantities of Fe-, Mn- and Zn-dust in their surroundings. These metals have an essential function in living systems, and are in general considered to be relatively harmless. As a result studies on the concentrations and effects of high levels of these metals on various biological components of terrestrial ecosystems have received little attention.

The present study describes the levels and patterns of distribution of Fe, Mn and Zn in a dune ecosystem, partly constituting a nature reserve in Holland. A blast-furnace plant complex is situated in the centre of the area. The availability of the metals to invertebrate fauna, and the accumulation of the metals through producer-herbivore systems was studied. In one of the insect species (*Thyria jacobaea* L.), the excretion mechanism for iron and manganese was studied in detail.

MATERIALS AND METHODS

Samples consisted of foliage of four species of dune plants, together with the principle insect species, two species of caterpillars, one aphid and a grass-hopper:

Senecio jacobaea L. ------ *Thyria jacobaea* L. (Lepidoptera)
Euonymus europaeus L. ---- *Yponomeuta evonymellus* L. (Lepidoptera)
Acer pseudoplatanus L. -- *Drepanosiphum* spec. (Aphididae)
grass, spec. div. -- *Stenobothrus* spec. (Acrididae)

Leaf samples were taken in June, September and November 1980 at distances of 1, 3, 4.5 and 7 km from the blast-furnaces downwind and 9 km windward in the Nature Reserve Kennemerduinen. One part of the leaf samples was rinsed in deionised water to remove adhering dust.

Experiments on excretion were made with *Thyria jacobaea* L. Eight groups of 14 caterpillars each were fed on cuttings of *Senecio jacobaea* L., placed in various solutions of $MnSO_4$ and $FeSO_4$. The resulting foliage concentrations are presented in Table IV. The caterpillars were grown on the cuttings for 14,

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and 10 days respectively. Faeces and exuviae were collected and the metal concentration determined.

All samples were dried at 60°C prior to weighing and digested in 7 parts nitric acid and 1 part perchloric acid. The animals were kept overnight at 5°C and dried in a freezer at -60°C. The diluted solutions were analysed using atomic absorption spectroscopy (Perkin Elmer SP 1900). All analyses are given on dry weight basis and result from duplicates.

RESULTS

Levels and patterns of distribution of Fe, Mn and Zn

Table I shows the concentrations of Fe, Mn and Zn found in the vegetation collected at 1 km distance from the blast-furnace and at 9 km in the nature reserve. In general the metal concentrations in the vegetation of the polluted area were found to be significantly higher than of the unpolluted site ($p<0.001$, ANOVA). A comparison with the concentrations found in leaves that were rinsed prior to destruction, revealed that a considerable proportion of the Fe and Mn contamination exists as superficial deposits. Surprisingly, the levels of Zn recorded from the nature reserve were relatively high. The leaves were found to contain 27% of the total zinc and 22% of the total manganese as superficial contamination. The concentration of metals varies between the various plant species, the ground vegetation (grass) being relatively high.

The spatial and temporal variation in concentrations of the metals is shown in Table II. An increase of the concentrations during the season is evident. From the measurements in November a decline can be noticed in the concentrations of all three metals with increasing distance from the source of pollution. The decline is steeper for Fe than for Mn and Zn. The distribution of Zn shows signs of a more widespread dispersal.

Table II Variation in total Fe, Mn and Zn concentrations in *Senecio jacobaea* L. during the season and along a transect in the line of the prevailing winds in a dune reserve north from the blast-furnace plant.

distance from plant	month	concentration (ppm ± SD) Fe	Mn	Zn
	June	660 ± 38	79 ± 1	83 ± 3
1 km	Sept.	3108 ± 706	212 ± 10	158 ± 21
	Nov.	5907 ± 875	250 ± 12	279 ± 8
3 km	Nov.	3656 ± 885	200 ± 31	366 ± 68
4.5 km	Nov.	1426 ± 667	117 ± 62	172 ± 22
7 km	Nov.	1413 ± 255	95 ± 6	136 ± 7

Heavy metals in the food chain

Table III shows the metal concentrations found in insect species and in their food leaves, and the concentration factors (CF) at an unpolluted and a polluted dune site. The concentration factors for Fe and Mn are lower than 1, and not different between the two sites, indicating regulation at a body level related to

Table I. Total heavy metal contamination in ppm (± S.D.) and % surface deposits in some component species of a dune ecosystem near a blast-furnace plant and of the Nature Reserve Kennemerduinen.

	Iron		Manganese		Zinc	
	nature res.	polluted area	nature res.	polluted area	nature res.	polluted area
S. jacobaea	252 ± 25	660 ± 17	27.6 ± 0.7	78.6 ± 0.8	61.2 ± 0.7	82.5 ± 3.0
E. europaeus	174 ± 1	656 ± 45	31.8 ± 0.8	60.1 ± 7.3	75.6 ± 6.8	53.0 ± 1.5
			± 4.2	73.2 ± 1.7	12.3 ± 1.8	45.9 ± 6.4
			± 4.2	85.2 ± 1.7	31.8 ± 0.8	56.4 ± 5.9
			22	32	27	11

Table III Metal concentrations in ppm (± S.D.), in food plants and principle insect species, and concentration factors (CF): insect/food plant, in an unpolluted and a polluted dune area.

plant species	Nature reserve			Blast-furnace plant		
	Fe	Mn	Zn	Fe	Mn	Zn
Senecio	225±25	27.6±0.7	61.2±0.7	660±17	78.6±0.8	82.5±3.0
Thyria	74± 3	23.1±0.4	124.8±4.2	341±32	39.6±3.4	127.8±1.7
CF	0.3	0.8	2.0	0.5	0.5	1.5
Euonymus	174± 1	31.8±0.8	75.6±6.8	656±45	60.1±7.3	53.0±1.5
Yponomeuta	45± 4	7.2±1.7	83.7±9.8	71± 4	8.4±1.7	73.2±1.7
CF	0.3	0.2	1.1	0.1	0.1	1.4
Acer	379±20	65.0±4.2	12.3±1.8	567±55	73.2±1.7	45.9±6.4
aphids	-	-	-	471±21	48.0±1.7	222.0±5.9
CF	-	-	-	0.8	0.7	4.8
Grass	381±13	76.2±4.2	31.8±0.8	1455±38	85.2±1.7	56.4±5.9
grass-hoppers	105± 4	16.2±5.9	258.6±6.8	183±30	10.8±0.7	230.1±5.5
CF	0.3	0.2	8.1	0.1	0.1	4.1

the environmental level. Zn is found to be concentrated (CF>1) by all species, up to a specific body concentration, independent of the environmental level. The level is particularly high for aphids and grass-hoppers, suggesting a higher Zn-need in these species.

Excretion of Mn and Fe by Thyria jacobaea L.

The body concentrations of *Thyria* caterpillars grown on *Senecio* cuttings with different Mn and Fe concentrations, are presented in Table IV.

Table IV Excretion of Mn and Fe by *Thyria jacobaea* L.

Senecio j. ppm	*Thyria j.* bodies	*T.j.* faeces ppm	*T.j.* faeces ug	*T.j.* exuviae ppm	*T.j.* exuviae ug	% excretion by exuviae
Mn-concentrations						
31± 5	31± 5	28± 1	31.9	353	2.1	6.6
148± 3	112± 1	207± 5	246.5	360	2.2	0.9
400± 34	137±16	502± 78	526.2	520	2.6	0.5
790±143	167±14	1005± 6	1264.0	1503	10.3	0.8
1155± 30	236±56	2013± 69	2997.8	2504	12.5	0.4
Fe-concentrations						
347± 26	30± 8	207± 50				
990±113	77± 6	679±128				
1810±255	124±38	1302± 12				
1681±235	129± 7	1779± 41				
4839±157	128±21	3059± 82				

Both Mn and Fe are found to increase slightly with the environmental level. The main proportion is excreted immediately via the faeces; the concentration in faeces and exuviae increases significantly with the environmental level. The proportion of Mn in the exuviae, however, is insignificant, since these products represent a very small biomass. Only the lowest food concentration resulted in a relatively high proportion of Mn in the exuviae, possibly associated with decomposing enzymes of the cuticle. The Fe-group produced too few exuviae to constitute a sample for destruction.

DISCUSSION

The cause of the differences in heavy metal concentrations in the foliage is complex and may be related to the permeability of the cuticle, to the cuticle structure and to the height of the vegetation. Particulates are strongly accumulated during the season by pubescent leaves, as found in *Senecio*. The uptake of metals from the soil is related to the depth of rooting (MARTIN et al. 1982). Ground vegetation, like grass which roots predominantly in the contaminated surface layers of the soil, showed higher concentrations than *Acer* foliage. Trees are deeper rooted where the soil is less contaminated.

Although high metal concentrations were found in the vegetation, no damage could be observed. LITTLE (1973) postulated that hardly any metal is likely to be present in the leaves in a form likely to induce metabolic toxicity.

An increased level of Zn was measured very remote from the pollution source. This suggests a different dispersal of the metals.

The reaction of the herbivores to Zn appeared to be different from that to Fe and Mn. In the reviews of HUGHES et al. (1980) and ERNST & JOOSSE (1983) it is summarized that several organisms concentrate Zn (CF>1). Fe and Mn are accumulated (CF<1). The largest quantity is immediately excreted by the faeces.

The absorbed metal may be stored in specific tissues and cells, before it leaves the body. Insects have special cells in the Malpighian tubules (JEANTET et al. 1977; SOHAL & LAMB 1978) and in the mid-gut (CRAIG 1960). In addition, holometabolic insects have the ability to get rid of toxic substances with the meconium, which is expelled by the freshly hatched adult insect (ERNST & JOOSSE 1983).

A comparison of the Mn and Fe concentrations from field and experimental animals showed a reasonable correspondence for Mn, but for Fe a significantly higher level was found in the field caterpillars. Apparently the field animals regulate the Fe on a higher level. In other evertebrate species similar physiological tolerance or genetic adaptations are found. JOOSSE et al. (1981) described physiological acclimation to Zn in woodlice. BROWN (1976, 1977) and FRASER (1980) found natural Cu- and Pb-tolerant isopod populations. It is not sure, however, whether the increased metal levels are harmless. JOOSSE & VAN VLIET (1983) found an increase of the metabolic rate in woodlice living in an Fe-contaminated area, indicating a higher energy utilisation.

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