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## Heavy Metal Levels in Two Biennial Pine Insects with Sap-Sucking and Gall-Forming Life-Styles

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### ABSTRACT

*The concentrations of cadmium, copper, nickel and lead were studied in two biennial pine insects in relation to the deposition of heavy metals in the environment around the industrialised town of Harjavalta in southwestern Finland. Sap-sucking pine bark bugs, *Aradus cinnamomeus* (Heteroptera, Aradidae), and gall-forming pine resin gall moths, *Petrova resinella* (Lepidoptera, Tortricidae) were collected on sample plots located at logarithmic distances along 9 km-long transects from the distinctive emission source. The responses of these insects representing different life-styles were compared. Heavy metal concentrations in *A. cinnamomeus* were highest (Cd  $17 \mu\text{g g}^{-1}$ , Cu  $1900 \mu\text{g g}^{-1}$ , Ni  $220 \mu\text{g g}^{-1}$ , Pb  $32 \mu\text{g g}^{-1}$ ) in the vicinity of the factor complex, and lowest in the outermost zones. This trend followed a linear regression model. The pattern was less clear in *P. resinella*, the concentrations being only one-tenth of those recorded in *A. cinnamomeus*. Correlations between metal levels in *A. cinnamomeus* and previously examined Sphagnum moss bags proved to be highly significant in every case.*

*The differences in the heavy metal concentrations of these two insect species, which occupy the same trophic position, would appear to be due to the differences in their feeding characteristics. Heavy metals accumulate in the posterior bulb of the midgut in the discontinuous alimentary system of A. cinnamomeus, while P. resinella is likely to secrete most of the metals into the walls of the galls. The almost total absence of these two insect species near the factory complex seems to be associated with the high concentrations of metals.*

## INTRODUCTION

Recent studies concerning the effects of heavy metals on forest ecosystems have generally demonstrated a reduction in the species number and an impoverishment of the community structure of ground-living invertebrates (Bengtsson & Rundgren, 1982, 1984; Bengtsson *et al.*, 1983; Beyer *et al.*, 1985). In addition to the direct effects of heavy metals on the mortality and fecundity of invertebrates, changes in vegetation also have an indirect influence on the fauna (Alstad *et al.*, 1982). Mosses and lichens that normally cover much of the forest floor are known to be especially sensitive to metal pollution (e.g. Laaksovirta, 1973; Laaksovirta & Silvola, 1975; Folkesson, 1984).

Vascular plants, such as trees, seem to be less threatened. The concentrations of metal pollutants in their biomass are usually much lower than in mosses or in litter (Roth, 1985), and their tissues are protected by an epiderm and a waxy surface layer. The uptake of metals mainly takes place via the roots (Tyler, 1984), although the emitted metal pollutants are directly deposited on needles and bark, where they can contaminate insects. The concentrations of heavy metals in arthropods collected from polluted areas have been investigated by several authors. It is widely held that heavy metals (Pb, Cd) concentrate along food-chains (Price *et al.*, 1974; Roberts & Johnson, 1978). However, van Straalen & van Wensem (1986) have pointed out that concentration of zinc and cadmium in forest floor arthropods seems to be connected to the physiological equipment of the species, rather than to body-size or trophic position.

The present study was conducted around an industrialised town where the deposition of heavy metals is remarkably high, even judging by international standards. There is much background information available about the deposition and effects of heavy metals and other pollutants on the environment (Hynninen, 1983, 1986; Hynninen & Lodenius, 1986; Arstila *et al.*, 1986; Kuokkanen, 1986; Sippola & Erviö, 1986).

Both of the forest insect species studied here, *Aradus cinnamomeus* Panzer (Het., Aradidae) and *Petrova resinella* (L.) (Lep., Tortricidae), have a 2-year

life-cycle and both were sampled during the second year of their life-cycle. Although these two species live mainly on Scots pine (*Pinus sylvestris* L.), they exploit it in different ways. *Aradus cinnamomeus*, the pine bark bug, lives under the bark slices and sucks sap from the trunk (Brammanis, 1975). The larva of *Petrova resinella*, the pine resin gall moth, lives in a resin gall formed at the top of the leader or branch (Eidmann, 1961). The population dynamics of both species have been investigated previously in the study area. It has been concluded that both species have benefitted from such pollution which has affected the physiological condition of the host trees. The changes in the environment have been especially favourable for the bug. However, both species seem to be almost completely absent in the immediate vicinity of the emission source (Helviövaara, 1986; Heliövaara & Väisänen, 1986*a,b*).

The aim of the present study is to analyse the concentrations of four heavy metals (Cd, Cu, Ni, Pb) in the two forest insect species along the industrial air pollutant gradient. Possible differences in the metal concentrations of the two species are studied in relation to their life-styles. Moreover, the effects of heavy metals on the abundance of these pests are discussed.

## MATERIALS AND METHODS

### Study area

The field work was carried out in May (*Aradus*) and August–September (*Petrova*), 1985, in the vicinity of the small industrialised town of Harjavalta in western Finland (61°20' N, 22°10' E). The study area lies on a wide, pine-dominated ridge running from south-east to north-west. Copper smelting, started in 1944, caused considerable damage to the vegetation in the area, and within a few years almost all the undergrowth in the neighbouring residential area had been destroyed (Karhu, 1982). Nowadays, the heavy pollution load imposed on the air of the town comes mainly from two factories, one producing copper and nickel and the other sulphuric acid and fertilisers. The effects of air pollutants on epiphytic lichens, coniferous trees and undergrowth have already been investigated in this study area by Laaksovirta (1973) and Laaksovirta & Silvola (1975). Lichens have been found to be absent within an area of 8.8 km<sup>2</sup> around the town.

### Sampling

The insects were collected in sample plots located along eight (*Aradus*) or five (*Petrova*) transects running from the factory complex to the main points of the compass. The transects were about 9 km long and each contained nine

sample plots spaced at logarithmic distances, except for one which had eight (see Heliövaara, 1986; Heliövaara & Väisänen, 1986a,b). Altogether 1800 *Aradus* adults and 65 *Petrova* larvae were collected in Harjavalta for the heavy metal analyses. The insects sampled on each plot were placed in a glass test tube. The samples from adjacent concentric zones were combined in a few cases owing to the small number of pine bark bugs collected. The galls of pine resin gall moths were removed before analysis. The moth larval material was combined and analysed in three concentric zones.

Both species were also sampled in Utti, eastern Finland (60°55' N, 26°55' E), in order to obtain independent control data. About 100 bugs and 40 moth larvae were collected in a young pine stand in an area where there are no factories in the vicinity. A nearby highway is the only source of pollutants of any significance in the area, apart from possible long-distance deposition of heavy metals.

### Heavy metal analyses

The cleaned, combined samples were dried at 105°C and weighed; *Aradus* 20–70 mg and *Petrova* 30–125 mg per sample. They were then digested in 1 ml of concentrated suprapur H<sub>2</sub>O<sub>2</sub>. The samples were filtered, diluted to 10 ml and stored at +4°C until analysis (maximum 2 weeks).

The samples were analysed in the ecological laboratory of the Department of Botany, University of Helsinki, using a Varian Techtron 1200 atomic absorption spectrophotometer combined with a CRA-90 graphite furnace and ASD-53 automatic sampler. Cadmium, copper, nickel and lead concentrations were determined using a sample volume of 10 µl.

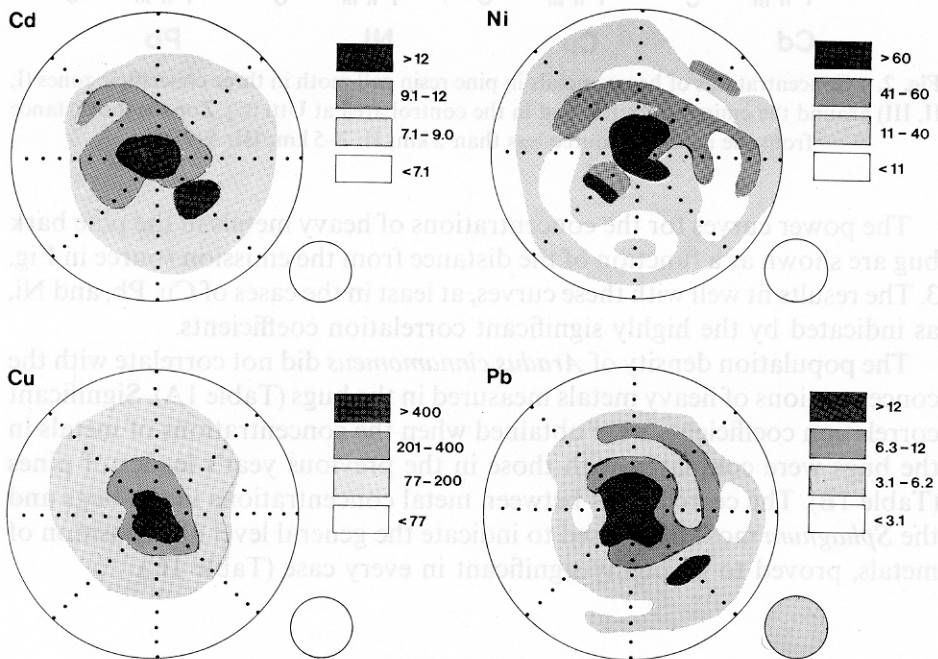
### Statistical analyses

Power curves were calculated to describe the concentrations of heavy metals in the pine bark bug as a function of the distance from the emission source. The data were fitted using a linear regression model and the statistical significance is indicated by the values of the correlation coefficients. Parametric correlation analysis was applied in comparing the contents of four heavy metals (Cd, Cu, Ni, Pb) in the bugs and the deposition of these metals around the town. The metal pollution level in each sample plot was derived from Hynninen (1983, 1986), who used *Sphagnum* moss bags and previous year's leaders of Scots pines as indicators of metal pollution. The deposition of heavy metals was given in µg g<sup>-1</sup> dry weight month<sup>-1</sup> for a 3-month period in summer 1981. The densities of the bugs used in the statistical analyses are based on results in Heliövaara & Väisänen (1986a).

## RESULTS

Cadmium, copper, nickel and lead were detected in all the *Aradus* and *Petrova* samples taken from around the factory complex. The concentration of different metals in *Aradus cinnamomeus* was usually lowest in the outermost zones, and highest in the vicinity of the factor complex. The concentration of cadmium varied the least, from 4.2 to 17  $\mu\text{g g}^{-1}$  in different zones. The highest levels were obtained for copper (41–1900  $\mu\text{g g}^{-1}$ ). The concentration of nickel varied from 2.3 to 220  $\mu\text{g g}^{-1}$ , and that of lead from 0.7 to 32  $\mu\text{g g}^{-1}$ . The lowest concentrations of Cd (2.4  $\mu\text{g g}^{-1}$ ) and Ni (below the detection limit) were recorded in the control area of Utti. The level of copper was also low (42  $\mu\text{g g}^{-1}$ ) there compared with the results for Harjavalta. The concentration of lead in the bugs was relatively high (6.4  $\mu\text{g g}^{-1}$ ) on the control plot. The results of the heavy metal concentrations in *A. cinnamomeus* are given in Fig. 1.

The pattern of the heavy metal concentrations in *Petrova resinella* was not



**Fig. 1.** The mean metal concentrations in pine bark bugs expressed using iso-lines (shades of grey) around the emission source connecting points with similar metal content ( $\mu\text{g g}^{-1}$ ) of the bugs. Lines of dots indicate eight 9-km radial transects containing sample plots spaced at logarithmic distances. Small circles on the right indicate metal concentrations in the control area at Utti.

as clear as that in *Aradus cinnamomeus* (Fig. 2). On average, the concentrations of metals were roughly only one-tenth of the values recorded in the pine bark bug. Only nickel showed a gradual decrease on moving away from the factories. The concentrations of all metals, except for nickel, in the three concentric zones were higher in the Harjavalta study area than in the Utti control area.

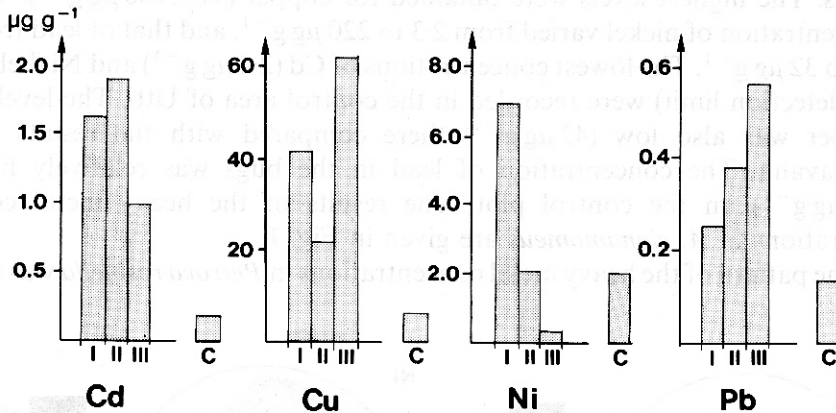


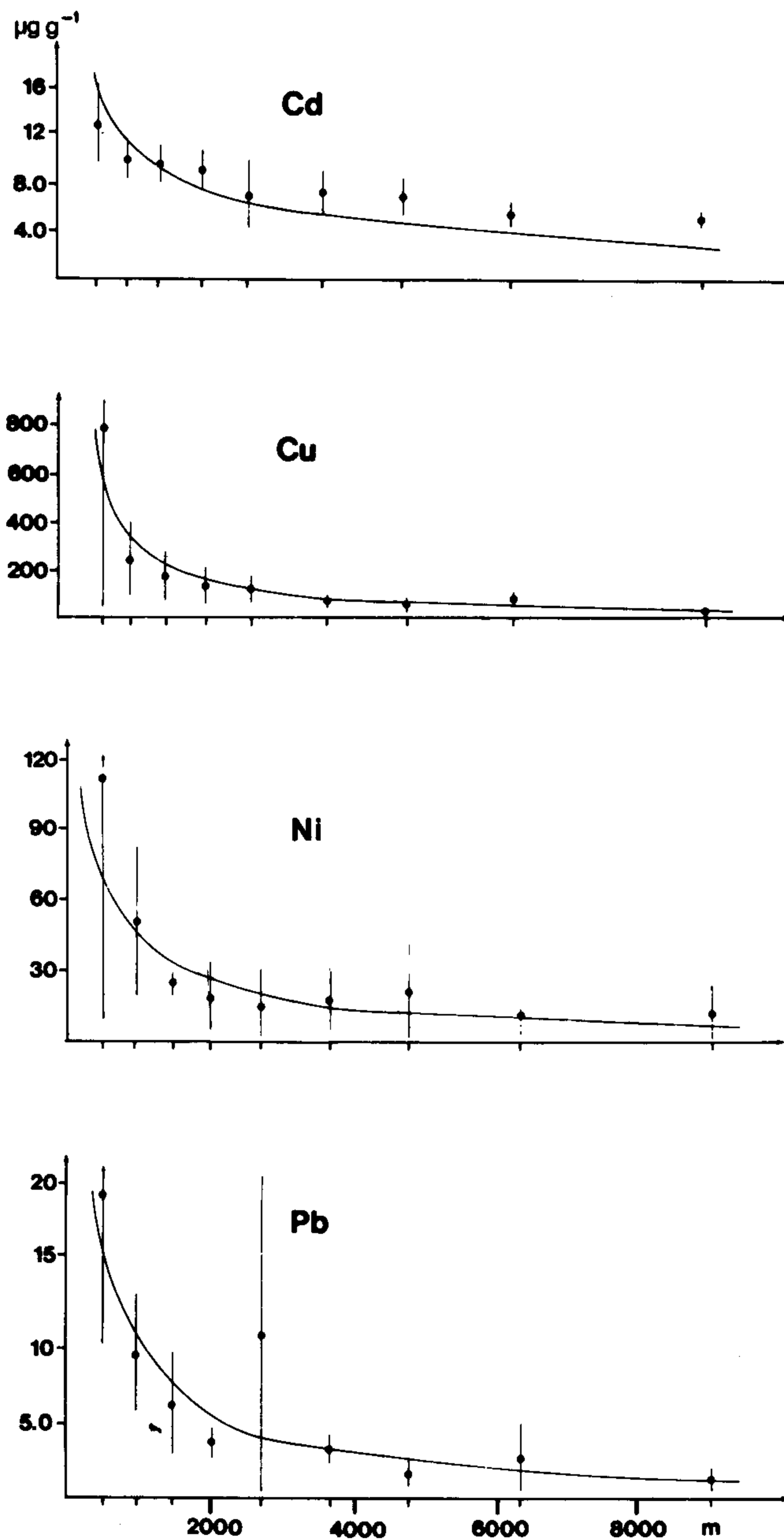
Fig. 2. Concentrations of heavy metals in pine resin gall moth in three concentric zones (I, II, III) around the emission source, and in the control area at Utti (C). Zone I: the distance from the emission source less than 2 km; II: 2–5 km; III: 5–9 km.

The power curves for the concentrations of heavy metals in the pine bark bug are shown as a function of the distance from the emission source in Fig. 3. The results fit well with these curves, at least in the cases of Cu, Pb, and Ni, as indicated by the highly significant correlation coefficients.

The population density of *Aradus cinnamomeus* did not correlate with the concentrations of heavy metals measured in the bugs (Table 1A). Significant correlation coefficients were obtained when the concentrations of metals in the bugs were compared with those in the previous year's leader of pines (Table 1B). The correlations between metal concentrations in the bugs and the *Sphagnum* moss bags, used to indicate the general level of deposition of metals, proved to be highly significant in every case (Table 1C).

## DISCUSSION

The results presented in this paper demonstrate that the two forest insect species living on Scots pine contain quite different amounts of heavy metals. This can be explained by the differences in their life style, although both



**Fig. 3.** Power curves for the concentrations of heavy metals in the pine bark bugs as a function of the distance from the emission source. Means of concentrations given for study plots in nine concentric zones. Vertical bars indicate standard deviations. Equations for the curves are as follows: Cd:  $y = 11.62x^{-0.57}$ ,  $r = -0.781$ ,  $P < 0.05$ ,  $df = 7$ ; Cu:  $y = 292.36x^{-0.96}$ ,  $r = -0.943$ ,  $P < 0.001$ ,  $df = 7$ ; Ni:  $y = 44.90x^{-0.72}$ ,  $r = -0.887$ ,  $P < 0.001$ ,  $df = 7$ ; Pb:  $y = 10.54x^{-0.91}$ ,  $r = -0.908$ ,  $P < 0.001$ ,  $df = 7$ .



**TABLE 1**  
 Correlations Between the Heavy Metal Concentrations in *Aradus* and Their Population Density in the Study Area (A), and Correlation Between Metal Concentrations in the Bugs and the Previous Year's Leaders of Pines (B) and *Sphagnum* Moss Bags (C)

	A				B				C						
	<i>Bug density</i>				<i>Previous year's leader</i>				<i>Sphagnum moss bags</i>						
	P	df	Cd	Pb	P	df	Cd	Pb	P	df	Cd	Ni	Pb	P	df
Cd	0.157	NS	52	0.589		26	0.569		0.01	26				0.001	62
Cu	0.132	NS	52	0.465		26		0.554	0.05	26				0.001	62
Ni	-0.071	NS	52		0.623	26			0.001	26		0.458		0.001	62
Pb	0.170	NS	52			26			0.01	26			0.502	0.001	62

species are herbivores and occupy the same trophic position. Since both species were sampled in the second year of their biennial life-cycle, the tenfold differences in their heavy metal contents cannot be explained by the different duration of exposure to contamination.

Van Straalen & van Wemsen (1986) found much higher concentrations of cadmium in a carabid beetle, *Notiophilus biguttatus*, compared with a linyphiid spider *Centromerus sylvaticus*, both of which are specialist feeders on collembolan prey. They explained this by the differences in the feeding characteristics of the species: spiders suck the internal contents of their prey and defecate only little, while carabids swallow their prey whole and produce significant amounts of faeces, thus decreasing the accumulation of heavy metals. Hopkin & Martin (1985) have observed that a spider *Dysdera crocata* has developed the ability to assimilate essential nutrients from the digested tissues of its prey, *Porcellio scaber*, without absorbing the toxic amounts of metals which they contain. This explanation could also be applied in the present case. The alimentary system of the pine bark bug is discontinuous, and the secretions accumulate in the posterior bulb of the midgut during the 2-year life cycle (Carayon, 1955; Goodchild, 1966). The larva of the pine resin gall moth secretes most of the pine-transported heavy metals into the walls of the galls which, unfortunately, were not studied. In addition, the moth larva living in its gall is better protected from direct contamination by heavy metals than the bug, which occasionally lives on the bark and is exposed to direct deposition. Contamination can be regarded as a source of error when comparing the bioaccumulation of metals in different species. The scattering of the observed values around the power curves may be partly due to this effect, and partly to habitat differences. From the predator's point of view, however, there is no difference (apart from chemical form) whether the heavy metals accumulate through nutrition or through direct contamination. Their effect in the food chain will be the same.

The results from the bug samples taken at different distances from the emission source show that metal concentrations near the emission source are 10–100 times higher than those at a distance of 9 km. In Sweden, the highest copper and lead levels of most ground-living invertebrate species have occurred in study sites lying closest to brass smelters (Bengtsson & Rundgren, 1984). In the present study, copper concentrations in the bugs are of the same magnitude as the highest levels previously recorded in soil invertebrates (Martin & Coughtrey, 1982; Bengtsson & Rundgren, 1984).

Beyer *et al.* (1985) have reported that various types of invertebrate (earthworms, slugs and millipedes) which feed on soil litter or soil organic matter are rare, or absent, near two zinc smelters in Pennsylvania, where the soil litter horizon was contaminated with Pb ( $2700 \mu\text{g g}^{-1}$ ), Zn ( $24\,000 \mu\text{g g}^{-1}$ ), Cd ( $710 \mu\text{g g}^{-1}$ ) and Cu ( $440 \mu\text{g g}^{-1}$ ). In Sweden, the

numbers of species and individuals per species of ground-living invertebrates have been observed to be significantly reduced within 650 m of a brass mill, where there was a concentration of  $2500 \mu\text{g g}^{-1}$  copper and  $3600 \mu\text{g g}^{-1}$  zinc in the litter layer (Bengtsson & Rundgren, 1984). This trend can also be seen in the present results. Both *A. cinnamomeus* and *P. resinella* are almost absent within 800 m of the factory complex (Heliövaara, 1986; Heliövaara & Väisänen 1986a), where the 3-month deposition of copper and zinc in the *Sphagnum* moss bags was 200–700 and 25–100  $\mu\text{g g}^{-1}$ , respectively (Hynninen, 1986). The results obtained in the present study agree with previous findings that high metal concentrations are associated with reductions in invertebrate numbers around the emission source.

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