Transfer of cadmium from ants to ant-lions

Pekka Nuorteva

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Ants have been found to bear exceptionally high loads of Cd and other metals, but are in general quite resistant to the toxic effects of Cd. Possible harmful effects caused to their predators by high Cd content have not been studied. Detection of a sparse population of ant-lions on a beach at Padva in Bromarv, offered the possibility to make some preliminary observations of such harmfull effects. AAS-analyses showed that free-living ant-lion larvae bear a Cd load of 4.5 ppm/dwt in young larvae, 8.5 ppm in old ones. This corresponded approximately to the level occurring in their most important food items in Padva (4.5 ppm mean for workers of *Formica rufibarbis* Fabricius and 6.1 ppm for foragers of *F. fusca* Linnaeus). The level of Cd in the single ant-lion imago caught (0.5 ppm) was clearly lower than in larvae. Among the Cd-antagonistic metals, Cu showed levels in ant-lions two- or three-fold those found in ants, whereas no parallel difference existed for Zn levels. During larval development the level of the essential Cu diminished to half whereas the level of Zn increased two-fold. The fate of surplus cadmium in the food chain was followed experimentally by feeding a forest-living colony of *Formica aquilonia* Yarrow with 0.5 kg honey containing 600 mg $CdCl_2$. This elevated the Cd content of surface workers up to a level 10-fold that considered normal, 90–100 ppm (n = 4), and of the inside workers up to 5-fold, 36–61 ppm (n = 6). When surface workers were fed to ant-lion larvae ad libidum, larval Cd content rose in one week to the level of the food (87 ppm). When the feeding of ant-lion larvae was continued by feeding them inside workers for additional 4 weeks, these larvae showed a Cd level (49 ppm), similar to that of their food; then when the feeding had continued for 8 weeks, the level, however, rose to 120 ppm. All ant-lion larvae, including those with the highest Cd content, were fully active and showed no symptoms of disease. Artificial Cd-feeding had no clear effect on the Cu-levels in ants or ant-lions, but Zn responded by an increase from the natural level of 501–603 ppm to 560–1 200 ppm.

Pekka Nuorteva, prof.emeritus, Environmental Protection/Helsinki University, Caloniuksenk. 6 C 64, FIN-00100 Helsinki, Finland

1. Introduction

Red wood ants have been found to bear an exceptionally high load of Cd and other metals (Bengtsson & Rundgren 1984, Fangmeier & Steubing 1986, Stary & Kubiznakova 1987, Hunter et al. 1987, Ylä-Mononen et al. 1989, Nuorteva 1990, Nuorteva et al. 1992, Oja 1992,

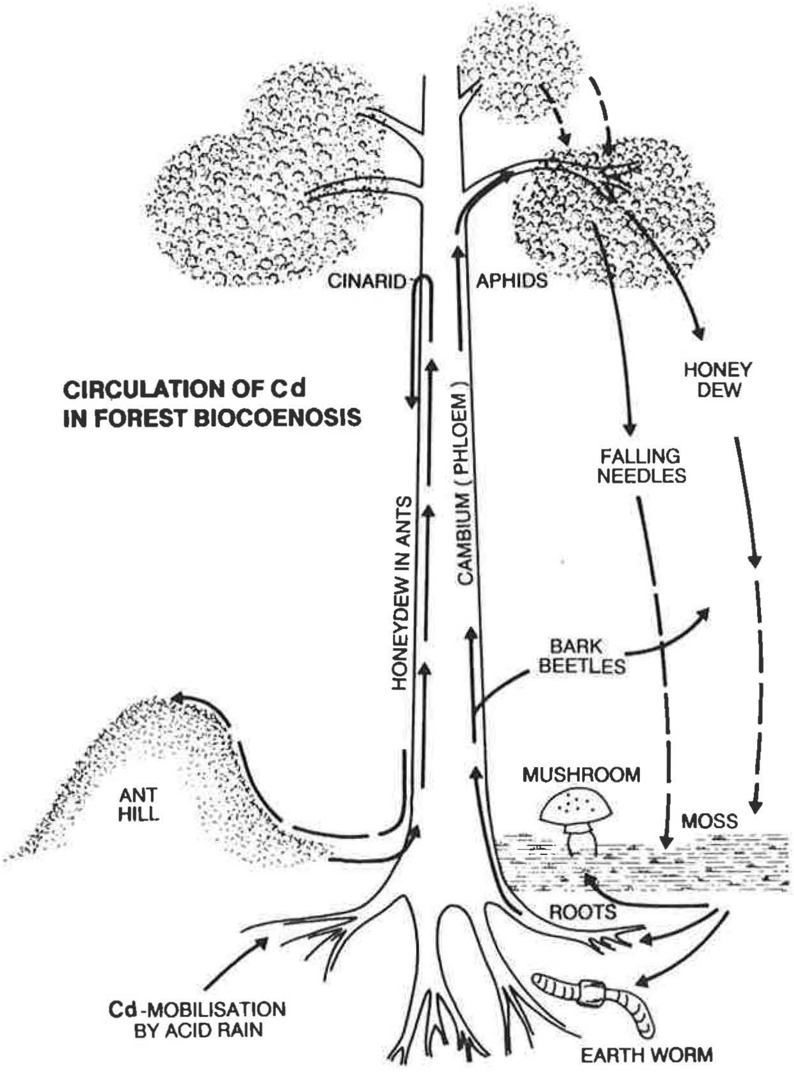

Fig.1. Circulation of Cd from detritus to ants (Nuorteva 1990)

Maavara et al. 1994). The ultimate source of metals for ants, is detritus. From that origin a fraction of the metals goes into the phloem of trees and from there enters phloem-feeding aphids (Nuorteva 1990, Maavara et al.1994). The aphids absorb from their intestines mainly amino acids, whereas sugars pass intact through their intestine to be excreted as honeydew. In a manner similar to that of sugars, aphids also excrete the metals from their food (Crawford et al. 1983, Stary & Kubiznakova 1987, Nuorteva 1990) (Fig.1). Because honeydew is the dominant food for red wood ants (Rosengren & Sundström 1991), it is clear that the high metal levels in ants can be attributed to their honeydew diet. Anthropogenic metal pollution, as well as experimental dietary metal contamination, can cause elevated metal levels in ants (Nuorteva et al. 1978, Stary & Kubiznakova 1987, Crawford et al. 1983, Nuorteva 1988, 1990, Nuorteva et al. 1992, Oja 1992, Maavara et al. 1994).

In ants the highest metal loads may cause disturbances in their secretion of metabolic and detoxification enzymes, a process which may then result in difficulties in hibernation (Migula et al. 1993, Maavara et al. 1994). In general, however, one may say that ants resist effects of the metals exceptionally well. Their resistance stems from the negative bioaccumulation occurring along the social food chain of the ant colony:

foragers – surface workers – inside workers – nurses – larvae – pupae -hibernating reserve workers and reproductive ants (Oja 1992, Maavara et al. 1994).

Theoretically, there exists a possibility, however, that a high Cd level in ants may be dangerous for their predators, but nothing is known as yet about this possibility.

Detection of a sparse ant-lion colony in our study area offered the possibility of carrying out preliminary analyses and pilot type tests on these curious ant predators.

2. Material and methods

2.1. Materials from nature

The sparse colony of ant-lion larvae was observed on the Padva sand beach of the Baltic in the parish of Bromarv, SW-Finland. The ant-lion larvae lived in the sand at a distance of 3–20 m from the border of a pine forest. Long furrows in the surface sand led away from the cone-shaped pitfalls of the ant-lions.

No keys exists for separating the larvae of the two Finnish species of ant-lions, *Myrmeleon formicarius* Linnaeus and *M. bore* Tjeder. We were able to catch only one adult from the Padva area. It was a female collected on 28 June, 1994 and belonged to the species *M. formicarius* (length of the anterior wing 37 mm). A female of the same species was collected and pinned by Mrs S.-L. Nuorteva 3 July, 1956 in a pine forest in Wättlaxvik, Bromarv, about ten km from Padva beach. We have thus direct evidence only for the occurrence of *M. formicarius* in our study area. The habitat of the larvae on the beach was, however, more typical for *M. bore*, because *M. formicarius* seems to prefer sandy sites in pine forests (Tjeder 1949, Meinander 1962). The two available adult specimens were analysed separately.

2.2. Experimental elevation of the Cd-levels

In order to test preliminarily the resistance of ant lion larvae to cadmium, some specimens were dug out of the beach and were transferred to sand terrarium where they were fed on such workers of *Formica aquilonia* whose Cd levels had been artificially elevated far above natural levels. This elevation was initiated 29 May, 1992 by feeding 0.5 kg of honey containing 600 mg Cd to an *F. aquilonia* colony (= nest no. 18 in our ant experiments) in Tenala, Lindö, Vesterkulla. Only two-thirds of the honey offered was, however, consumed.

Workers from this nest served as food for the ant-lion larvae. During the first week the larvae were fed with surface workers. For practical reasons, it was later necessary to feed to them only inside workers, which had been taken from the nest together with nest material. These inside workers, nest material and a supply of sugar and water were placed in a container, from which the ants were readily available as ant-lion food in the laboratory. The Cd-loaded ants were transferred to the terrarium of ant-lion larvae at rate ensuring that living food was continuously available to the larvae. Ant lion larvae were killed for analysis when they had consumed Cd loaded worker ants for 0, 7, 35 and 55 days.

2.3. Metal analyses

Metal analyses were performed for Cd as well as for its antagonists Zn and Cu by means of atomic absorption spectrophotometry (AAS), as described earlier in detail (Nuorteva 1990). All results are given on a dry-weight basis.

3. Results

3.1 Natural levels

For the results of AAS analyses of free-living ant-lions of some ant species in the locally unpolluted Bromarv-Tenala area see Table 1. These ant-lion larvae bore a Cd load varying from 4.5 ppm in young larvae to 8.5 ppm in older ones. The Cd-level in the adult caught in Padva was clearly lower (0.5 ppm), indicating Cd excretion during metamorphosis, which seems to be a rule in holometabolous insects. The pinned specimen from Wättlaxvik had higher Cd-level (3.0 ppm), but this level also was only about a third of the level in old larvae.

The Cd-levels of ant-lion larvae were lower than those of the most common ants of the area, *Formica aquilonia* and *F. sanguinea* Latr., but roughly the same as those existing in the complex of ants living on the sand beach in Padva (= the latter being a mixture of the obviously most important prey, *Formica fusca* L., and the numerally dominant but small-sized *F. rufibarbis* F; mean Cd-contents for those were 6.1 and 4.5 ppm respectively). Thus no clear evidence existed for bioaccumulation from prey to predator.

Of the Cd-antagonistic metals Cu showed clearly higher levels in ant-lion larvae (32–70 ppm) than in worker ants of any species (11–18 ppm). This kind of difference did not appear for Zn. During larval development the content of Cu diminished until the half, whereas the content of Zn doubled.

3.2. Experimentally elevated Cd-levels

In the pilot test in which the *F. aquilonia* colony in Tenala was fed on honey bearing a strong Cd-load (600 mg), the Cd-level of the surface workers rose to 90–100 ppm (= ten times normal values, surface workers generally being used as a standard for an ant-colony metal level) (Table 2).

The Cd feeding had thus elevated the normal Cd-level for ants in Finland to levels similar to those occurring in polluted environments in central Europe (Stary & Kubiznakova 1987). Because of negative bioaccumulation in the social food chain, however, the Cd-content of inside workers, those used after the first week of the present experiment, rose only to 36–61 ppm.

During the first week of the ant-lion feeding experiment, the food consisted of surface workers loaded with 90–100 ppm Cd. This food elevated the mean Cd-level in ant lion larvae during that one week from 6.2 ppm to 87 ppm. When the feeding continued with the inside worker ants bearing a Cd load of 36–61 ppm, the metal level in ant-lion larvae declined; by the 35th day it fell to 49 ppm, corresponding to the level in the food. During further continuation of the feeding, the ant-lions' ability to stabilize their Cd content collapsed, and on the 55th day Cd reached 120 ppm (Table 2).

Table 1. Mean background levels of Cd, Zn and Cu (ppm/dwt) in ant-lions and in their food (= outside workers of *Formica* species; of the other species of ants data was available only of inside workers) in the unpolluted Bromarv-Tenala area in SW Finland. n = number of analyzed ant samples containing 50–100 specimens each.

	Cd	Zn	Cu
Ant-lions			
16 larvae, 3–5 mm long	4.5	315	70
18 larvae, 5–7 mm long	5.6	501	50
9 larvae, 7–10 mm long	8.5	603	32
1 adult female from Padva	0.5	150	20
1 pinned female from Wättlaxvik (1956)	3.0	190	33
Ants			
Camponotus herculeanus Linnaeus, n = 4	4.1	298	18
Formica aquilonia Yarrow, n = 8	9.1	671	16
F. sanguinea Latreille, n = 3	7.0	430	13
F. rufibarbis Fabricius, n = 9	4.5	300	13
F. fusca Linnaeus, outside workers, n = 2	6.1	275	13
F. fusca Linnaeus, inside workers, n = 6	2.6	219	15
Lasius niger Linnaeus, n = 3	3.1	279	12
L. flavus Fabricius, n = 6	3.4	250	12
Myrmica laevinodis Nylander, n = 3	0.1	193	19
M. ruginodis Nylander, n = 4	0.2	170	13

The artificial Cd-feeding had no clear effect on the Cu-levels in the ants or ant-lions. The content of Zn, in contrast, was clearly elevated and showed positive correlation with Cd-level. in ant-lion larvae. The situation can be understood thus: Cu is the normal Cd-antagonist, but in abnormally difficult situations Zn plays a supportive role in Cd-antagonism..

After feeding is completed the ant-lion larvae return the empty skins (exoskeletons) of ants to the surface of the sand. Analysis of exoskeletons showed metal levels similar to those of whole undamaged ants, indicating that the metal level of ant exoskeleton is about the same as that of its soft tissue.

4. Discussion

The Cd-level in young free-living ant-lion larvae was similar to that of their main food: the outside workers of ants of the species *Formica rufibarbis* and *F. fusca* (Table 1). This indicates that young ant-lion larvae excrete Cd at the same rate as it is ingested in the food. The Cd level only of the oldest larvae is a bit higher than the level in their food. Possibly the diminished reservoir of the antagonistically working Cu is responsible for the elevation of Cd (Table 1). Possibly the doubling of the level of the other antagonist, Zn, is not fully able to compensate for the decrease in Cu.

In the two imagines analyzed the Cd level was drastically lower than in full-grown larvae. In studies of our institute similar situation has been demonstrated in holometabolous insects like blowflies, bark beetles and moths (Nuorteva et Nuorteva 1982, Reijonen 1988, Nuorteva 1990, Nuorteva et al. 1992).

The experimental loading of ants with Cd caused a corresponding increase of Cd in their ant-lion predators. The resistance of ant-lions against the acute toxic effects of Cd is excellent. It would, however, be naive to think that acute toxicity could be the only or the most important means by which environmental toxins affect population dynamics. For example retarded activity, reduced growth rates and increased age at pupation have been noted as ecologically important expressions of Cd- and Hg-toxicity in insects (Nuorteva & Nuorteva 1982, Schütt & Nuorteva 1983, Simkiss et al. 1993)

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Table 2. Mean levels of Cd, Zn and Cu (ppm/dwt) in *Formica aquilonia* colony in Tenala fed in May with 0.5 kg honey containing 1200 ppm CdCl2 and in ant-lions fed ad libidum with Cd-fed workers of *F. aquilonia*. n = number of analyzed ant samples containing 50–100 specimens each.

	Cd	Zn	Cu
Formica aquilonia workers			
normal background, surface workers, n = 1	11	750	17
Cd-fed, surface workers, n = 4	96	798	20
Cd-fed, inside workers, n = 6	44	558	11
Cd-fed, workers, eaten by ant-lions (n = 2)	51	600	11
Great ant-lion larvae			
9 larvae from the beach = control	8	603	32
2 larvae fed with surface workers in 7 days	87	1100	33
2 larvae fed with inside workers in 35 days	49	560	32
1 larva fed with inside workers in 55 days	120	1200	33

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