Toxicity to Woodlice of Zinc and Lead Oxides Added to Soil Litter

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Report

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Previous studies have shown that high concentrations of metals in soil are associated with reductions in decomposer populations. We have here determined the relation between the concentrations of lead and zinc added as oxides to soil litter and the survival and reproduction of a decomposer population under controlled conditions. Laboratory populations of woodlice (*Porcellio scaber* Latr) were fed soil litter treated with lead or zinc at concentrations that ranged from 100 to 12,800 ppm. The survival of the adults, the maximum number of young alive, and the average number of young alive, were recorded over 64 weeks. Lead at 12,800 ppm and zinc at 1,600 ppm or more had statistically significant ($p < 0.05$) negative effects on the populations. These results agree with field observations suggesting that lead and zinc have reduced populations of decomposers in contaminated forest soil litter, and concentrations are similar to those reported to be associated with reductions in natural populations of decomposers. Poisoning of decomposers may disrupt nutrient cycling, reduce the numbers of invertebrates available to other wildlife for food, and contribute to the contamination of food chains.

The decomposition of organic matter in forest soil litter provides the nutrients required to keep a forest productive (1). When metals such as Pb and Zn are deposited from the air, the soil litter binds the metals tightly, and may accumulate high concentrations (1–3). Sites heavily contaminated with Pb, Zn and other metals have smaller populations of decomposer organisms such as fungi (4, 5), earthworms (6) and arthropods (7–10). Reducing the decomposition rate may disrupt nutrient cycling and result in an increase in the amount of soil litter present (8, 11–13). Determining which of several metals, if any, is present at toxic concentrations may be difficult in field studies, especially when there have been other chemical changes accompanying the contamination in the soils. To help interpret observations from contaminated sites we have used a woodlouse (*Porcellio scaber* Latr) as a bioassay, to determine the concentrations of Pb and Zn that are toxic under controlled conditions.

METHODS

Soil litter (01 and 02) was collected from an Othello silt loam (mesic Typic Ochraquult) on the Patuxent Wildlife Research Center in Maryland, U.S.A. The soil litter comprised about 50 percent *Acer rubrum* L, 20 percent *Quercus falcata* Michx, 20 percent *Liquidambar styraciflua* L, and 10 percent other hardwood species, by weight. Portions of the air-dried soil litter (about 10 percent moisture) were put in a dry food mixer and moistened with distilled water. Oxides of Pb (PbO) and Zn (ZnO) were added dry and mixed into the soil litter for two minutes. This process mixed in the metals and fragmented the soil litter, making it more homogeneous. About half of the soil litter, by weight, would pass through a 2-mm sieve. The treatment concentrations were 100, 200, 400, 800, 1,600, 3,200, 6,400 and 12,800 ppm Pb or Zn, dry weight. Five portions were left untreated, as controls. Initially 275 g of soil litter from each treatment was put into 12-liter polyethylene buckets, with a screen inserted in the top to allow air to circulate. An additional 47 g was added every eight weeks. Five samples of the control soil litter had a mean organic matter content of 84 percent, a pH (water) of 4.6, and contained a mean of 930 ppm Ca, 160 ppm Mg, 130 ppm K and 10 ppm P, as determined with a plasma spectrograph; and a mean of 15 ppm Pb, 8.9 ppm Cu, 56 ppm Zn, 0.61 ppm Cd and 1,000 ppm Fe, as determined with an atomic absorption spectrophotometer. Analytical procedures are described in Reference 11.

Woodlice (*Porcello scaber*) were collected from compost piles in Bowie, Maryland, and were acclimated to laboratory conditions. In March we added 60 woodlice, 30 of each sex, to each bucket. All were 7–9 mm long. Visibly gravid females were not included. Two clay flower-pot bottoms (9 cm diameter) were inverted in each bucket to provide shelter. The temperature of the laboratory fluctuated between 18°C and 24°C. Distilled water was added to the containers once a week. Woodlice were counted every 16 weeks for 64 weeks. A preliminary test had shown recovery rates of 97 percent for woodlice over 4 mm and 66 percent for woodlice less than 4 mm.

Three variables were determined for each bucket: 1) the average life span of the first generation of woodlice; 2) the observed maximum number of woodlice in the second generation; and 3) the average number of woodlice in the second generation that were alive at each count. The actual number of woodlice produced was probably greater than that observed, because the young may be cannibalized or die from other causes before they are counted. Means and standard deviations were calculated for each of the three variables for the control woodlice, and were used to locate the 95 percent prediction limits for a population unaffected by toxicants. It was assumed that the values of the variables were normally distributed and that additional members of this population would follow a t-distribution with a variance equal to the variance of the control population times $(1 + 1/n)$ (14). (The term $1/n$ is required because we do not know the true mean, but have only an estimate of it.) Because it seemed reasonable to assume that any effects would be most severe at the highest concentrations, the data on the treated woodlice were examined sequentially, starting with the highest treatment level, and continuing until a datum point for each variable was reached that was above the 95 percent prediction limit (Table). The probability of falsely concluding that a particular concentration of Zn or Pb was decreasing one of the three variables was 0.05. Note that the prediction limits are valid only for single points or points in the sequence, and are not valid for the simultaneous testing of the rest of the data.

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Table 1. Survival and reproduction of woodlice in control soil litter and in soil litter treated with Pb or Zn. Cultures initially contained 60 woodlice and were kept for 64 weeks. Values marked with an * are below the prediction limit for the control population ($p < 0.05$).

Treatment	Adult Survival (wks)[1]	Young (No)[2]	Survival of Young (No)[3]
Control 1	20.6	277	209
Control 2	20.5	228	183
Control 3	22.8	230	166
Control 4	20.2	271	192
Control 5	21.6	242	183
Pb 100	23.1	217	190
Pb 200	20.7	289	165
Pb 400	20.2	258	179
Pb 800	21.1	353	267
Pb 1600	20.7	237	186
Pb 3200	18.1	224	158
Pb 6400	20.1	305	159
Pb 12 800	15.3*	79*	30*
Zn 100	16.5	136	103
Zn 200	19.3	321	206
Zn 400	18.1	279	198
Zn 800	17.8	312	225
Zn 1600	20.5	194*	136*
Zn 3200	20.0	129*	63*
Zn 6400	14.7*	16*	9*
Zn 12 800	8.5*	0*	0*

[1] Average life span of first generation of woodlice.
[2] Maximum number of second generation of woodlice counted at any time during the study.
[3] Average number of second generation woodlice alive at four counts made at 16-week intervals.

RESULTS

The control woodlice had a mean adult life span of 21.1 weeks (prediction limit = 18.6 weeks), a mean number of 250 young produced (prediction limit = 196), and a mean number of 187 second-generation woodlice alive (prediction limit = 150). Zinc at 1,600 ppm or more reduced both the numbers of young woodlice produced and the mean number of second-generation woodlice alive to below the prediction limits established by the controls ($p < 0.05$) (Table 1). Zinc at 6,400 ppm or more reduced the life spans of the first-generation woodlice ($p < 0.05$). Lead at 12,800 ppm reduced the value of all three variables studied ($p < 0.05$). With the exception of the woodlice exposed to 100 ppm Zn, whose low survival rate we did not understand, the woodlice exposed to the concentrations of Zn and Pb below the effect levels survived and reproduced at rates comparable to those of the control woodlice.

By the end of the 64th week the control woodlice populations had grown less than we considered normal for this species, and had not yet produced a third generation. We concluded that the experimental conditions were adequate to maintain populations for several months, but that they were less than optimal for supporting the growth of populations for longer periods.

DISCUSSION

Laboratory populations of *Porcellio scaber* had a lower survival rate when fed soil litter contaminated by fallout from two zinc smelters than when fed uncontaminated soil litter (11). The effect was observed with soil litter collected as far as 19 km downwind from the smelters and containing as little as 1,800 ppm Zn. Natural populations of a wide variety of other arthropods were greatly reduced at two sites near the zinc smelters, where the 02 soil litter contained 15,000 or 26,000 ppm Zn (10). Numbers and species richness of ground-dwelling invertebrates were reduced at a site near a brass mill, where soil litter was contaminated with 3,600 ppm Zn and 2,500 ppm Cu (7). Our results showed that as little as 1,600 ppm Zn added as an oxide to soil litter reduced laboratory populations of woodlice. Oxides were chosen for this study because they are frequently emitted from industrial sources of metals, such as smelters. More soluble forms might have been more toxic.

Woodlice were less sensitive to Pb in soil litter than to Zn; only the highest concentration of Pb (12,800 ppm) was shown to be toxic. A study of contaminated sites containing up to 19,000 ppm Pb from mine wastes failed to find any effects on the populations of arthropods (15). However, populations of detrivorous arthropods were reduced at sites within 1.2 km of a lead smelter where the soil litter contained 12,000 ppm or more Pb (8). The Zn concentration in the soil litter at the 1.2 km site was 520 ppm, which was too low to account for the toxicity. Dietary concentrations of up to 16,500 ppm Pb had no effect on the number of young produced by gravid *Porcellio scaber* (16).

Poisoning the invertebrates living in soil litter has several ecological consequences. There is a reduction in the amount of food available to wildlife feeding on invertebrates in the soil litter. The decomposition rate may be reduced, since decomposers fragment soil litter and bring it into close contact with microorganisms, as well as digest some of it directly (1). A reduced decomposition rate may disrupt nutrient cycling (9, 11, 13). Finally, decomposers of soil litter tend to contain especially high concentrations of metals when compared to other groups of organisms in a contaminated ecosystem (2), and may be an important source of contaminants to food chains.

References and Notes

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