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# The Woodlouse *Porcellio scaber* as a 'Biological Indicator' of Zinc, Cadmium, Lead and Copper Pollution

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*ABSTRACT*

*The amounts of zinc, cadmium, lead and copper were determined in the hepatopancreas and whole body of the woodlouse* Porcellio scaber *(Crustacea, Isopoda) and soil and leaf litter collected from 89 sites in the counties of Avon and Somerset, south-west England. Maps were drawn to compare the regional distribution of concentrations of metals in the samples.*

*The main source of zinc, cadmium, lead and copper pollution was centred on Avonmouth to the north-west of Bristol, the site of a primary zinc, lead and cadmium smelting works. Concentrations of all four metals in the hepatopancreas, whole woodlice, soil and leaf litter were above background levels over a large area on all maps which, in the case of cadmium in the hepatopancreas, extended for 25 km to the east of the smelting works.*

*The correlation coefficients between the concentrations of each metal in woodlice and soil, and between woodlice and leaf litter, were positive and statistically significant ($P < 0{\cdot}001$) in all cases. At individual sites, however, particularly those associated with disused mining areas, rubbish tips or busy roads, the concentrations of zinc, cadmium, lead and copper in woodlice could not have been predicted accurately from the levels of metals in leaf litter or soil due to the large scatter of data points along the lines of 'best fit'.*



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*Future exercises in pollution monitoring should include analysis of at least one representative of the primary consumers of vegetation to enable the 'availability' of metals to the fauna to be reliably assessed.* Porcellio scaber *is probably the ideal 'indicator species' in the UK because it has a strong affinity for zinc, cadmium, lead and copper, is large enough to provide sufficient tissue for analysis, and is common in a wide range of rural and urban habitats.*

## INTRODUCTION

The amount of zinc, cadmium, lead and copper assimilated from vegetation by primary consumers depends as much on the form, as on the concentrations, of metals in their food. In aerially contaminated sites, most of the metals detected in vegetation are present as a blanket deposit of fine particles on leaf surfaces (Davies & Holmes, 1972; Little, 1973, 1977; Little & Wiffen, 1977, 1978; Cataldo *et al.*, 1981; Hosker & Lindberg, 1982) which are easily removed as the material passes through the guts of the animals. In contrast, metals in vegetation growing on contaminated soil (e.g. spoil tips of mining areas) are much less available as they have been taken up via the roots and are bound firmly within the plant tissues (Wieser, 1978, 1979). Other factors such as the type and pH of the soil (Herms & Bruemmer, 1980; Scokart *et al.*, 1983), bacteria and fungi on leaf surfaces (Coughtrey *et al.*, 1980), interspecific differences in metal uptake, interference between elements and restriction of leaf uptake due to tolerance (Coughtrey & Martin, 1977*b*, 1978*a*; Brown & Martin, 1981) all influence the form and concentrations of metals in plant material in different sites.

Further factors which complicate attempts to correlate concentrations of metals in leaf litter with those in primary consumers are introduced during sampling. In some sites, the dead leaves collected may not represent the food of the animals because the preferred components of the litter were consumed soon after falling on to the soil surface (Hassall & Rushton, 1984). Also, in sites where a thick layer of litter has built up, the concentrations of metals in the sample will depend on the depth from which the dead leaves are taken (Coughtrey *et al.*, 1979).

As a result of these problems, the suggestion has been made in numerous publications over the last decade that concentrations of metals in a single 'indicator' species of terrestrial invertebrate may provide a more accurate estimate of the 'biological availability' of metals to the fauna of contaminated ecosystems than that which could be predicted from levels in soil and vegetation (for a review of this topic see Martin & Coughtrey, 1982). Possible 'biological indicators' have included earthworms (Czarnowska & Jopkiewicz, 1978; Carter, 1983), fruit flies (Koirtyohann *et al.*, 1976), ants (Bengtsson & Rundgren, 1984), slugs and snails (Meincke & Schaller, 1974; Coughtrey & Martin, 1976, 1977*a*; Popham & d'Auria, 1980) and terrestrial isopods or woodlice (Wieser *et al.*, 1976; Coughtrey *et al.*, 1977). Of these, woodlice are probably the best candidates because they are able to store a range of metals to very high concentrations (Hopkin & Martin, 1982*a*,*b*, 1984*a*; Hopkin *et al.*, 1985*a*), are common in a diverse range of habitats in rural and urban areas (Sutton, 1980) and consume a wide variety of dead plant material (Hassall & Rushton, 1984).

In this paper we describe a practical example of biological monitoring in which the concentrations of zinc, cadmium, lead and copper have been determined in the hepatopancreas and whole body of *Porcellio scaber*, and samples of leaf litter and soil, collected from 89 sites in the counties of Avon and Somerset, south-west England. The region is largely unpolluted except for an area north-west of Bristol at Avonmouth, the site of one of the world's largest primary smelting works. The smelting works emits $6{\cdot}0\,\mathrm{kg\,h^{-1}}$ of zinc, $4{\cdot}0\,\mathrm{kg\,h^{-1}}$ of lead and $0{\cdot}4\,\mathrm{kg\,h^{-1}}$ of cadmium into the atmosphere (Coy, 1984), mostly as particles with a diameter of less than 1 $\mu$m (Harrison & Williams, 1983). These particles may be carried more than 20 km north-east of Avonmouth by the prevailing south-westerly winds (Burkitt *et al.*, 1972; Little & Martin, 1972, 1974; Gill *et al.*, 1975). There are also disused mine sites on the Mendip Hills near to the border between Avon and Somerset where the concentrations of zinc, lead and cadmium in the soils are among the highest in the world (Davies & Ginnever, 1979; Marples, 1979; Khan & Frankland, 1983).

The specific objective of the study was to determine how closely the concentrations of zinc, cadmium, lead and copper were correlated in soil, leaf litter, whole woodlice and the hepatopancreas, the organ within isopods which contains most of the metal in the animals (Hopkin & Martin, 1984*a*). If the ratios between the levels of zinc, cadmium, lead and copper in the samples were consistent over all the sites, then in future monitoring exercises it would not be necessary to collect woodlice since the levels within the isopods could be predicted from those in soil and leaf litter. If, however, the correlations were poor, it would confirm that monitoring programmes should include the regular sampling of woodlice as representatives of the primary consumers if the extent of transfer of metals into the fauna of contaminated ecosystems is to be reliably estimated.

## MATERIALS AND METHODS

The only four species of terrestrial isopods which are large enough to provide sufficient tissue for analysis and which occur throughout the UK are *Armadillidium vulgare*, *Oniscus asellus*, *Philoscia muscorum* and *Porcellio scaber* (Harding & Sutton, 1985). Of these, *Porcellio scaber* occurs in the most diverse range of rural and urban habitats and was therefore chosen for the study described in this paper.

### Collection and analysis of samples

About 30 specimens of *Porcellio scaber* and a representative sample of leaf litter (100 g) and surface soil to a depth of 2 cm (50 g) were collected from 89 sites in Avon and north Somerset during October and November 1983 (Fig. 1). *Porcellio scaber* was not present at three further sites to the north-east of the smelting works where only leaf litter and soil were collected (Table 1).

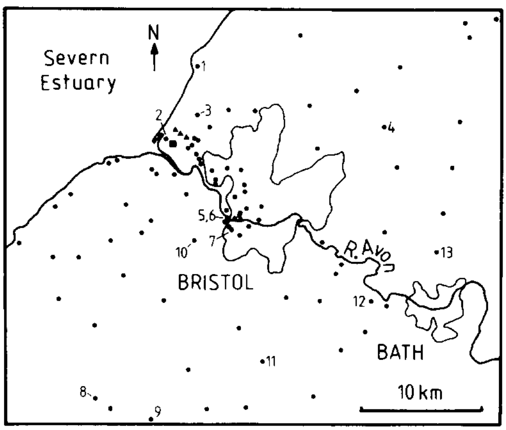


**Fig. 1.** Sites in Avon and north Somerset from which samples of *Porcellio scaber*, leaf litter and soil were collected (●). *Porcellio scaber* was abundant in all areas except for three sites (▲) to the north-east of a primary zinc, lead and cadmium smelting works at Avonmouth (■) where the concentrations of zinc, cadmium, lead and copper were exceptionally high in the leaf litter and soil (Table 1)

**TABLE 1**

Concentrations of Zinc, Cadmium, Lead and Copper in Soil (0–2 cm Horizon) and Leaf Litter from the Surface (Upper) and Soil/Litter Interface (Lower) ($\mu g\ g^{-1}$ dry weight) at 3 Sites on the Grass Verge of King's Weston Lane 1 km to the North-East of the Smelting Works (▲ in Fig. 1)

| *OSGR* | *Sample* | *Zn* | *Cd* | *Pb* | *Cu* |
|---|---|---|---|---|---|
| 524 797 | Litter (upper) | 13 300 | 208 | 7 850 | 1 250 |
| | Litter (lower) | 38 900 | 249 | 27 400 | 4 190 |
| | Soil | 111 000 | 82·6 | 14 600 | 4 160 |
| 528 795 | Litter (upper) | 15 700 | 106 | 13 200 | 1 350 |
| | Litter (lower) | 43 400 | 200 | 24 900 | 3 330 |
| | Soil | 31 900 | 124 | 11 300 | 1 200 |
| 532 792 | Litter (upper) | 20 300 | 232 | 17 700 | 2 200 |
| | Litter (lower) | 19 200 | 284 | 25 600 | 2 500 |
| | Soil | 19 600 | 346 | 10 500 | 525 |

The layer of undecomposed grass was 5–10 cm in depth. This area to the north-east of the smelting works was the only part of Avon in which *Porcellio scaber* could not be found. OSGR, Ordnance Survey Grid Reference.

Seven collecting trips were made during the study period. At the end of each day, woodlice were returned to the laboratory and retained overnight in the polythene bags in which they had been collected. The following day, 12 specimens of *Porcellio scaber* of about 10 mm in length were selected from each site population. Approximately equal numbers of male and female woodlice were included. The hepatopancreas was removed from each individual and placed on a small piece of Millipore filter paper which had been dried and weighed. These samples together with the rest of the body including the gut, and the leaf litter and soil from each site, were dried overnight at 70 °C.

The hepatopancreas and body of each woodlouse were weighed on a microbalance. The tissue fractions from each site were pooled in pairs of flasks and digested in 20 ml of boiling, concentrated Aristar grade nitric acid (BDH Chemicals, Poole, Dorset, UK). The digests were diluted to 50 ml with distilled deionised water. A sample of soil (1 g) and finely ground leaf litter (1 g) from each site were prepared in a similar manner. The digests were analysed for zinc, cadmium, lead and copper by flame (Varian AA775) or flameless (Varian GTA95) atomic absorption spectrophotometry (for further details see Hopkin & Martin, 1982*a*, 1983).

### Preparation of maps

Sixteen maps were prepared showing the regional distribution of concentrations of zinc (Fig. 2), cadmium (Fig. 3), lead (Fig. 4) and copper (Fig. 5) in (a) pooled samples of the hepatopancreas of *Porcellio scaber* (12 at each site), (b) pooled samples of 'whole' woodlice (12 at each site) calculated from the amounts of metals in the hepatopancreas and the body fraction combined, (c) soil and (d) leaf litter. Lines were drawn by eye which delimited five levels of contamination: (1) uncontaminated; (2) low contamination; (3) moderate contamination; (4) high contamination; (5) very high contamination. The ranges of concentrations of zinc, cadmium, lead and copper for each of these levels of contamination are shown in Figs 2–5.

### Preparation of graphs

A three-dimensional representation of the regional distribution of concentrations of cadmium in the hepatopancreas of *Porcellio scaber* (Fig. 6) was prepared by computer with the G3D SAS/GRAPH program (SAS Institute Inc., Cary, North Carolina, USA).

Parameters of regression equations of lines of best fit were calculated for concentrations of metals in whole woodlice against hepatopancreas, whole woodlice against leaf litter, and whole woodlice against soil (Table 2). Scatter diagrams of these relationships were also drawn. Those relating concentrations of zinc, cadmium, lead and copper in whole woodlice to leaf litter are shown in Fig. 7.

## RESULTS

The main source of zinc, cadmium, lead and copper pollution in Avon was to the north-west of Bristol at Avonmouth (Figs 2–5). Concentrations of these metals in *Porcellio scaber*, soil and leaf litter were above background levels over a large area on all maps, which in the case of cadmium in the hepatopancreas covered more than 500 km$^2$ (Figs 3(a), 6).

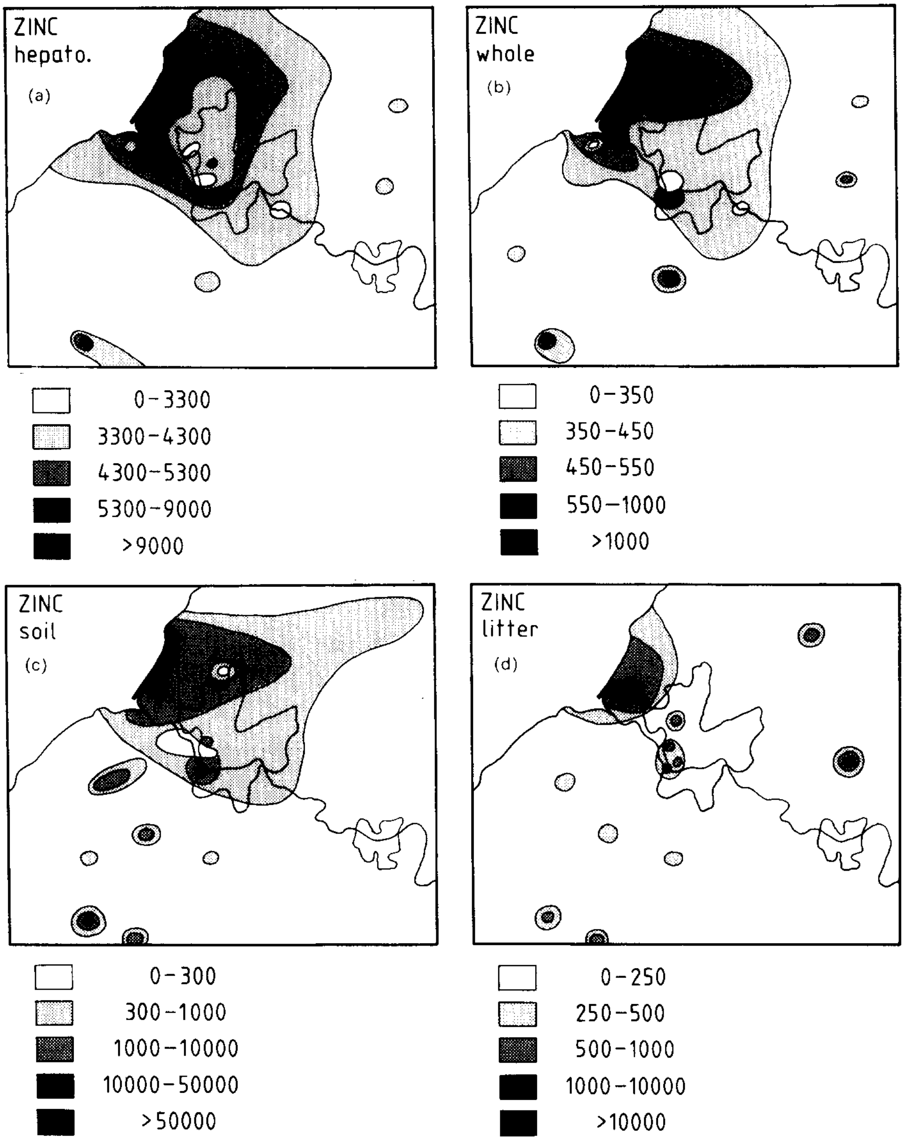


**Fig. 2**

**Figs 2–5.** Regional distribution of concentrations of zinc (Fig. 2), cadmium (Fig. 3), lead (Fig. 4) and copper (Fig. 5) in the hepatopancreas (a, hepato), whole specimens of *Porcellio scaber* (b, whole), soil (c) and leaf litter (d) in Avon and north Somerset, south-west England ($\mu g\, g^{-1}$ dry weight). The main area of zinc, cadmium, lead and copper pollution on all maps was north-west of Bristol at Avonmouth, the site of a primary zinc, lead and cadmium smelting works. Other isolated sites where samples contained higher than background levels of one or more metals were associated with disused mine sites, rubbish tips or busy roads.

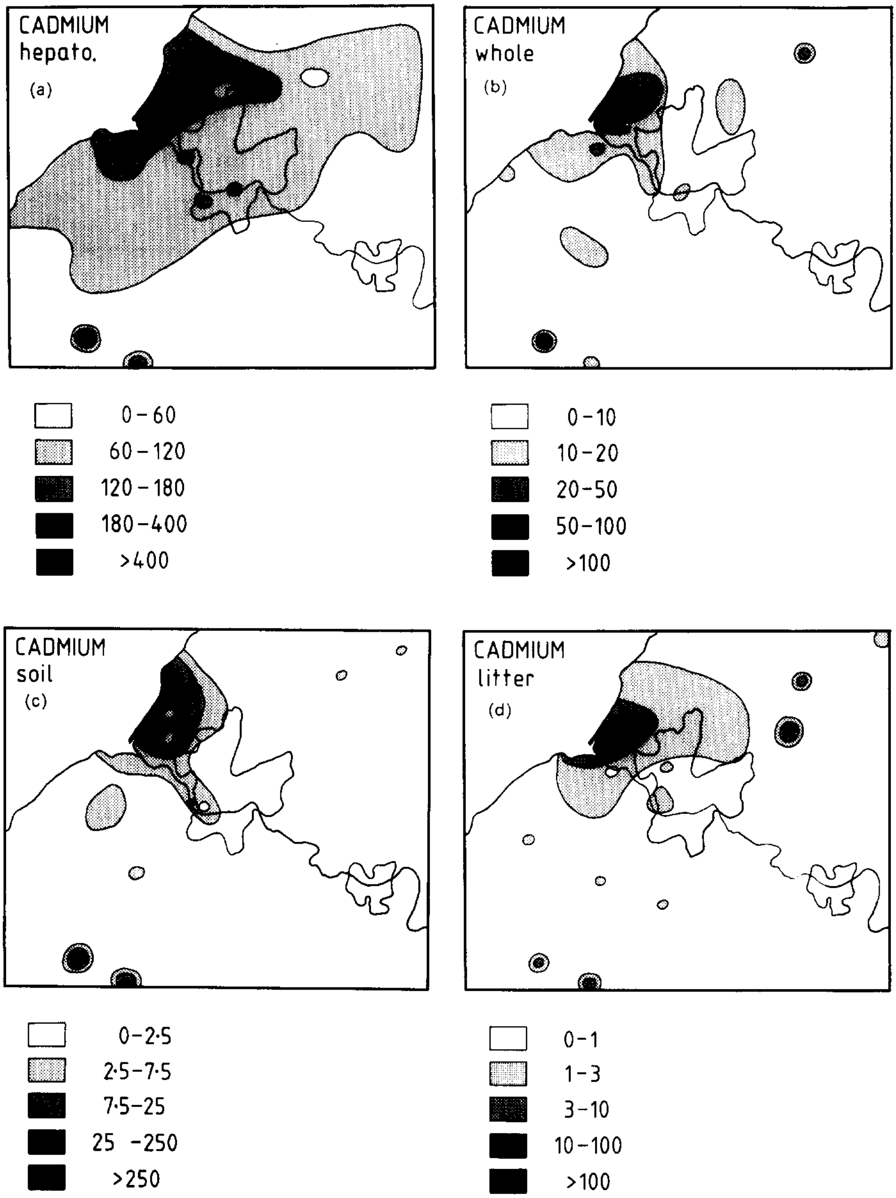
CADMIUM
hepato.
(a)
0 - 60
60 - 120
120 - 180
180 - 400
>400
CADMIUM
whole
(b)
0 - 10
10 - 20
20 - 50
50 - 100
>100
CADMIUM
soil
(c)
0 - 2·5
2·5 - 7·5
7·5 - 25
25 - 250
>250
CADMIUM
litter
(d)
0 - 1
1 - 3
3 - 10
10 - 100
>100

**Fig. 3**

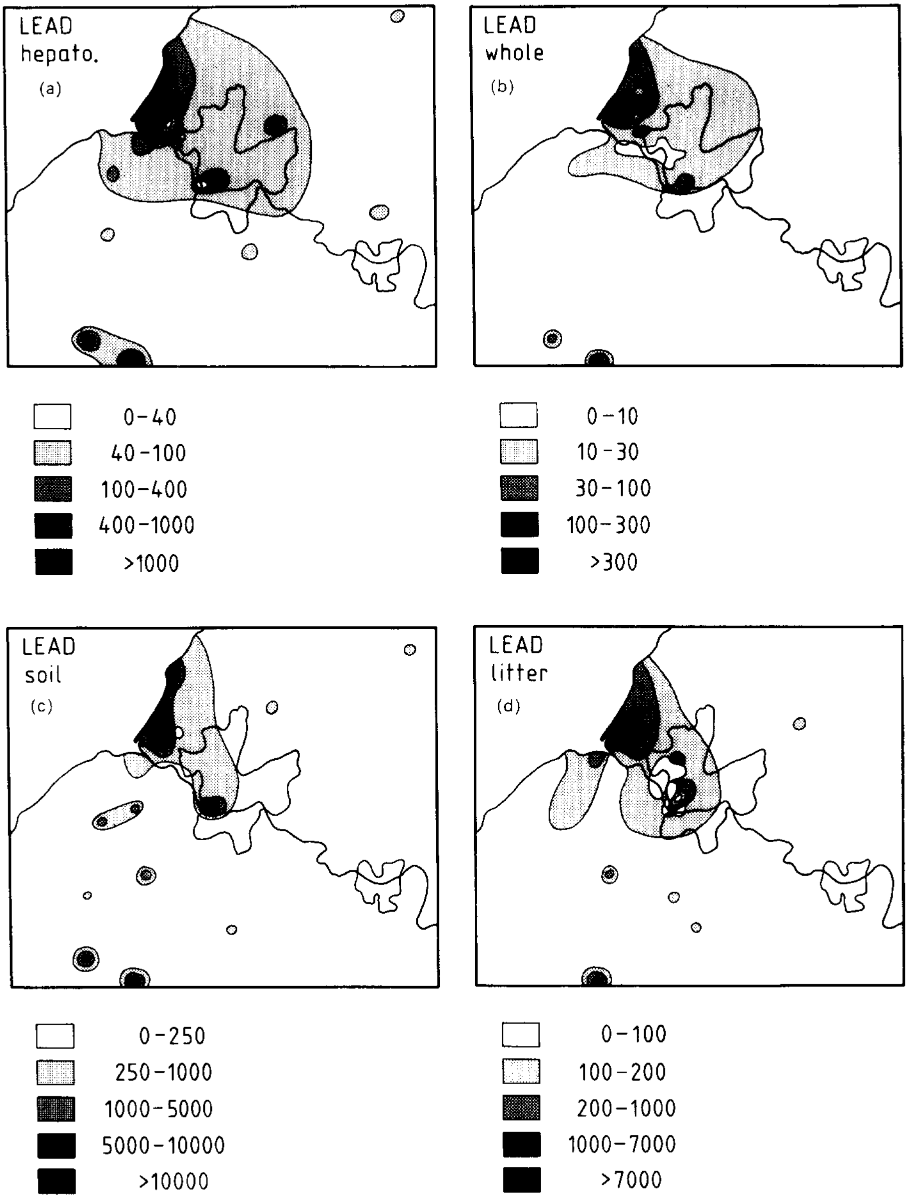
LEAD
hepato.
(a)
0-40
40-100
100-400
400-1000
>1000
LEAD
whole
(b)
0-10
10-30
30-100
100-300
>300
LEAD
soil
(c)
0-250
250-1000
1000-5000
5000-10000
>10000
LEAD
litter
(d)
0-100
100-200
200-1000
1000-7000
>7000

**Fig. 4**

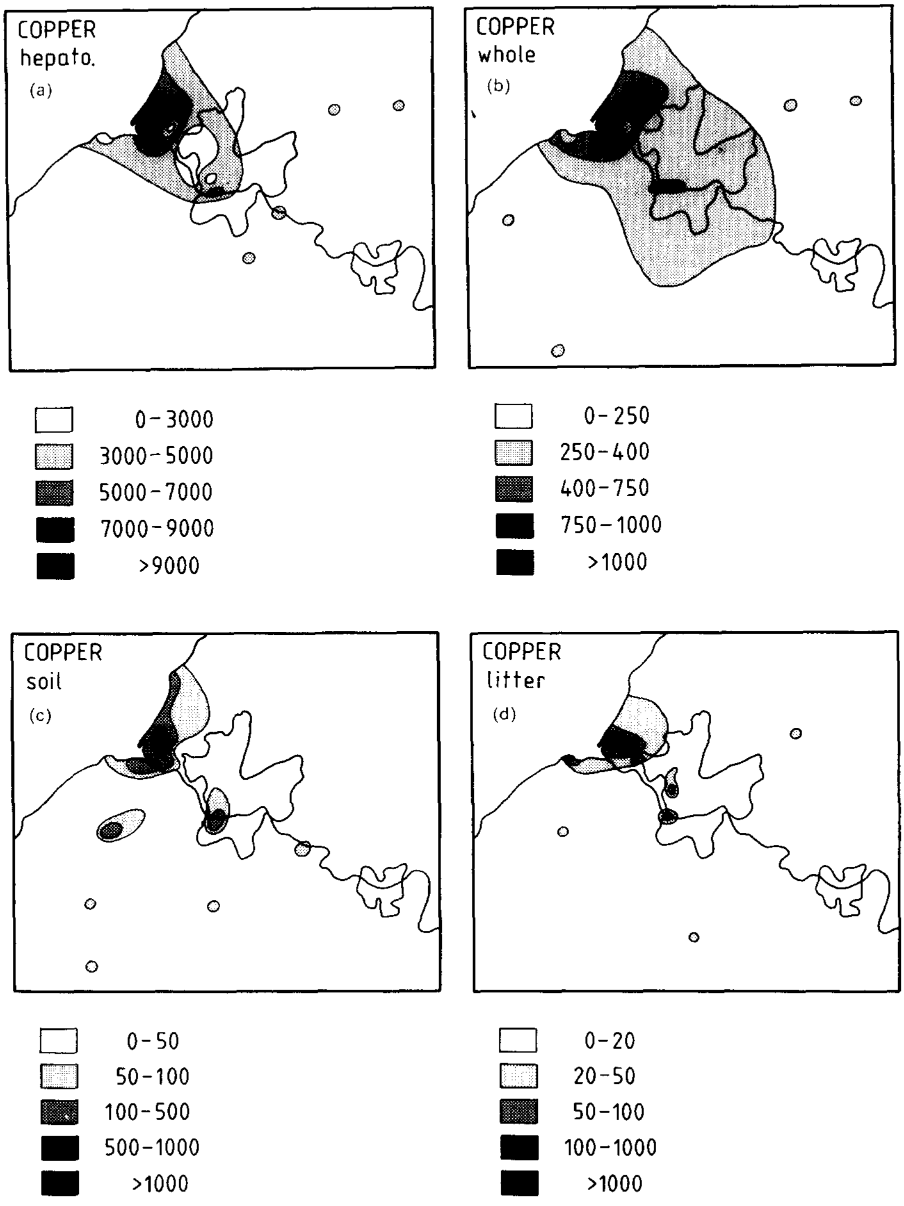
COPPER
hepato.
(a)
0-3000
3000-5000
5000-7000
7000-9000
>9000
COPPER
whole
(b)
0-250
250-400
400-750
750-1000
>1000
COPPER
soil
(c)
0-50
50-100
100-500
500-1000
>1000
COPPER
litter
(d)
0-20
20-50
50-100
100-1000
>1000

**Fig. 5**

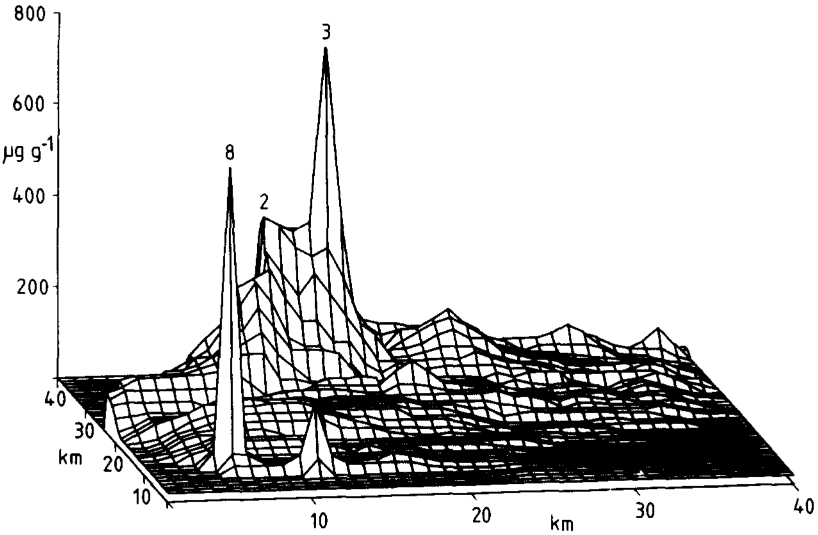


**Fig. 6.** Three-dimensional plot of concentrations of cadmium in the hepatopancreas of *Porcellio scaber* looking in a north-north-easterly direction (compare with the two-dimensional representation of these data in Fig. 3(a)). The highest concentrations of cadmium were in woodlice from St Andrews Rd (425 $\mu g\, g^{-1}$ dry weight, site 2) and Hallen Wood (797 $\mu g\, g^{-1}$ dry weight, site 3) near to the smelting works at Avonmouth, and at Shipham (699 $\mu g\, g^{-1}$ dry weight, site 8), a disused zinc mine which is heavily contaminated with cadmium. Concentrations of cadmium were above background levels over a wide area which extended for 25 km to the east of the smelting works.

There was little advantage in analysing the hepatopancreas of *Porcellio scaber* separately as the concentrations of zinc, cadmium, lead and copper in this organ were very closely correlated with the levels of metals in whole woodlice at all sites ($r > 0{\cdot}900$ for all metals, Table 2). The correlations between the levels of metals in woodlice and soil, and woodlice and leaf litter, were also statistically significant (Table 2). However, when these relationships were plotted as scatter diagrams (e.g. Fig. 7), it was clear that the concentrations of zinc, cadmium, lead or copper in woodlice could not be accurately predicted from the concentrations in soil or leaf litter due to the large range of possible concentration factors. For example, although the concentrations of zinc, cadmium, lead and copper in the hepatopancreas of *Porcellio scaber* from St Andrew's Rd (site 2) and Hallen Wood (site 3) were almost identical (Table 3), the levels of metals in soil and litter (dead grass) at the

**TABLE 2**
Parameters of Regression Equations of Lines of Best Fit of Concentrations of Metals in the Hepatopancreas and Whole Specimens of *Porcellio scaber*, Whole Woodlice and Leaf Litter (see also Fig. 7), and Whole Woodlice and Soil from 89 Sites in Avon and North Somerset

| *Hepatopancreas (x): Whole woodlice (y)* | | | |
|---|---|---|---|
| *Metal* | *a* | *b* | *r* |
| Zn | 8·89 | 223 | 0·939 |
| Cd | 8·70 | 14·0 | 0·917 |
| Pb | 6·71 | 21·0 | 0·901 |
| Cu | 9·49 | 33·5 | 0·929 |
| *Whole woodlice (x): Leaf litter (y)* | | | |
| *Metal* | *a* | *b* | *r* |
| Zn | 0·295 | 298 | 0·653 |
| Cd | 3·44 | 5·74 | 0·695 |
| Pb | 0·086 | 6·43 | 0·589 |
| Cu | 2·51 | 254 | 0·493 |
| *Whole woodlice (x): Soil (y)* | | | |
| *Metal* | *a* | *b* | *r* |
| Zn | 0·021 | 363 | 0·585 |
| Cd | 0·260 | 10·9 | 0·576 |
| Pb | 0·004 | 16·8 | 0·405 |
| Cu | 1·05 | 244 | 0·562 |

$y = ax + b$. All $r$ values are significant at $p < 0{\cdot}001$; $n = 89$.

two sites were very different. Consequently, there were large differences in the concentration factors between the two sites (Table 3).

Such discrepancies were even more apparent in sites contaminated with metals from other sources (Table 3). At Severn Beach (site 1), woodlice collected from the base of a derelict hut built from galvanised corrugated iron, where the soil contained nearly 3 % zinc, contained more than 1 % zinc in the hepatopancreas whereas litter from this site was only slightly contaminated. A similar result was obtained at Shipham (site 8) where the litter contained much lower concentrations of cadmium and lead than would be expected from the levels of these metals in woodlice and soil.

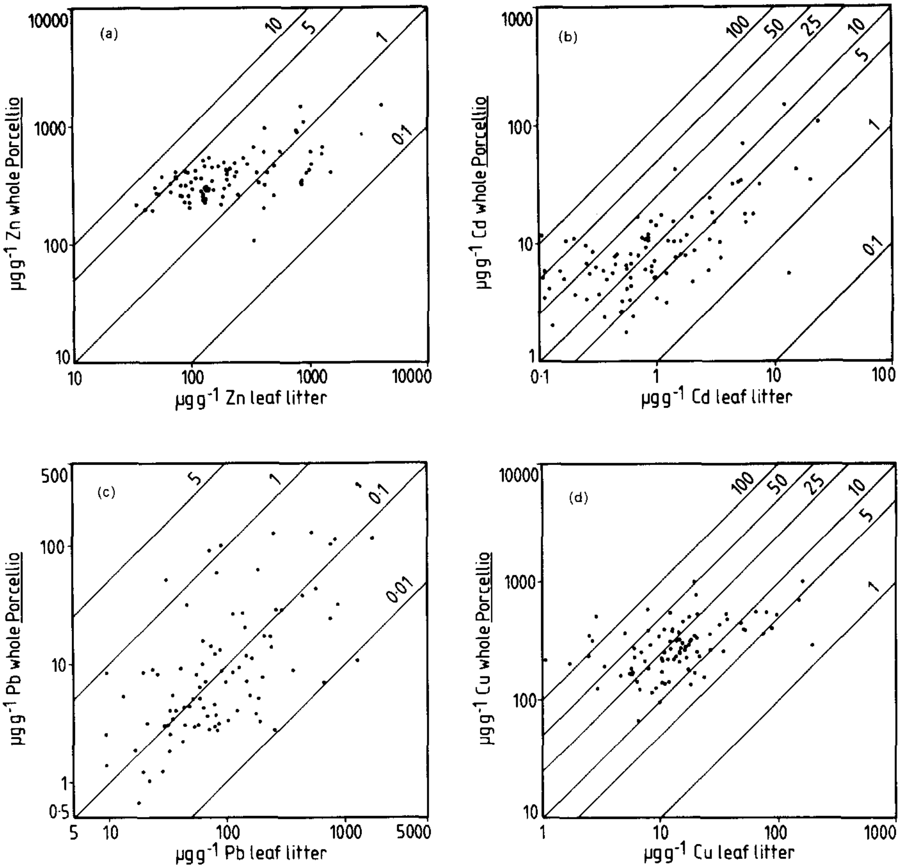


**Fig. 7.** Scatter diagrams relating concentrations of zinc (a), cadmium (b), lead (c) and copper (d) in whole woodlice with concentrations in leaf litter (dry weight). The lines on the graphs join points with the same concentration factor (concentration of metal in whole woodlice/concentration of metal in leaf litter). In general, cadmium and copper are accumulated by *Porcellio scaber* to a greater relative extent than zinc, and to a much greater relative extent than lead.

Conversely, woodlice and leaf litter from an unofficial city centre rubbish tip at Ashton (site 7) were uncontaminated with lead whereas the soil contained more than 1 % of this metal. At Westerleigh (site 4), woodlice and soil collected near to the base of a metal railway bridge contained low levels of cadmium. However, the litter sample from this site contained a higher concentration of cadmium than litter from Hallen Wood 3 km downwind of the smelting works (Table 3).

**TABLE 3**
Concentrations of Selected Metals in Pooled Samples of 12 Woodlice, and Soil and Leaf Litter ($\mu g\,g^{-1}$ dry weight), from Sites Mentioned in the Text

| *Site* | *OSGR* | *Metal* | *Hepato* | *Whole* | *Soil* | *Litter* | *CF* |
|---|---|---|---|---|---|---|---|
| Severn Beach (1) | 543 853 | Zn | 10 300 | 961 | 27 700 | 417 | 2·30 |
| St Andrew's Rd (2) | 518 793 | Zn | *13 500* | 1 500 | 6 170 | 4 150 | 0·36 |
| | | Cd | 425 | 106 | 103 | 24·8 | 4·27 |
| | | Pb | 489 | 328 | 4 480 | 1 290 | 0·25 |
| | | Cu | *9 480* | 1 000 | 257 | 168 | 5·95 |
| Hallen Wood (3) | 553 802 | Zn | 12 300 | 1 440 | 7 590 | 856 | 1·68 |
| | | Cd | *797* | 146 | 97·1 | 12·4 | 11·8 |
| | | Pb | 436 | 142 | 757 | 530 | 0·26 |
| | | Cu | 9 210 | 991 | 91·9 | 20·3 | 48·8 |
| Westerleigh (4) | 700 803 | Cd | 66·5 | 5·5 | 1·2 | 13·2 | 0·42 |
| Swing Bridge (5) | 567 724 | Pb | 517 | 101 | 1 790 | 92·5 | 1·09 |
| Swing Bridge (6) | 567 724 | Pb | 207 | 31·6 | 1 300 | 890 | 0·03 |
| Ashton (7) | 571 719 | Pb | 39·5 | 6·9 | 13 500 | 101 | 0·07 |
| Shipham (8) | 453 573 | Zn | 9 400 | 900 | 24 900 | 799 | 1·13 |
| | | Cd | 699 | 70·0 | 406 | 5·4 | 13·0 |
| | | Pb | 508 | 51·5 | 6 480 | 31·5 | 1·63 |
| | | Cu | 673 | 67·3 | 75·2 | 6·6 | 10·2 |
| Charterhouse (9) | 503 553 | Pb | *1 130* | 113 | 9 830 | 1 790 | 0·06 |
| Long Ashton (10) | 538 709 | Zn | *1 480* | 215 | 173 | 178 | 1·21 |
| Bishop Sutton (11) | 597 604 | Cd | *16·9* | 1·7 | 0·1 | 0·6 | 2·83 |
| Corston (12) | 688 655 | Pb | *2·5* | 0·7 | 54·3 | 18·7 | 0·04 |
| Langridge (13) | 744 696 | Cu | *640* | 124 | 16·1 | 9·1 | 13·6 |

Italicised figures are the highest and lowest mean concentrations of metals detected in the hepatopancreas of *Porcellio scaber*. The numbers in parentheses refer to the position of each site on Fig. 1. OSGR, Ordnance Survey Grid Reference; CF, concentration factor (concentration of metal in whole woodlice/concentration of metal in litter).

Samples collected from sites in close proximity to one another may not necessarily be contaminated to the same extent. Sites 5 and 6 were on opposite sides of a concrete wall which ran parallel to the A4 trunk road. The 'soil' from these sites, which consisted mainly of wind-blown material, was heavily contaminated to a similar degree with lead, derived presumably from car exhausts (Table 3). However, the litter from site 6, which consisted of *Buddleia* leaves from the base of a bush facing the road, contained 10 times more lead than dead grass from site 5 on the side of the wall which was sheltered from the traffic. Woodlice also exhibited differences in their lead content between the two sites, although surprisingly those from the exposed site 6 contained less of this metal than those from the sheltered site 5.

*Porcellio scaber* was abundant at all locations visited except for three sites on the grass verge of King's Weston Lane north-east of the smelting works, where a considerable number of wooden planks and cardboard boxes had been dumped (▲, Fig. 1). Woodlice and other cryptozoic invertebrates such as centipedes and millipedes are usually very common under such material, but at these sites the only invertebrates discovered after extensive searching were clubionid spiders. The soil and grass litter at these sites contained exceptionally high concentrations of metals, particularly zinc, which at one site comprised more than 10% of the dry weight of the soil (Table 1).

## DISCUSSION

This study has shown clearly that the determination of concentrations of zinc, cadmium, lead and copper in soil and leaf litter does not enable the concentrations of these metals in woodlice to be accurately predicted. At least one representative of the primary consumers must be analysed if the biological 'availability' of metals in contaminated terrestrial ecosystems is to be realistically assessed. *Porcellio scaber* is an ideal candidate for such a biological indicator species because of its size, abundance in a diverse range of habitats in the UK, and affinity for zinc, cadmium, lead and copper.

Once the concentrations of these metals are known in *Porcellio scaber*, it may be possible to predict the levels of zinc, cadmium, lead and copper in other invertebrates. Recent studies on the concentrations of metals in nine species of terrestrial isopods have indeed shown that the ratios of levels of metals between woodlice within sites are consistent over a range of uncontaminated and contaminated sites. Further studies are required to determine whether such ratios are consistent between other groups of animals in terrestrial ecosystems.

One of the most significant findings of this survey was the presence of considerable amounts of zinc and copper in the hepatopancreas of *Porcellio scaber* from uncontaminated sites. Such an accumulation of metals in the hepatopancreas has important implications for predators of *Porcellio scaber*, particularly those species which eat only the soft tissues and discard the exoskeleton. These include animals for which injured or moulting woodlice provide an occasional component of the diet, such as opilionids and lithobiid centipedes (Sunderland & Sutton, 1980; Hopkin & Martin, 1983, 1984*b*; Adams, 1984; Hopkin *et al*., 1985*b*) and spiders of the genus *Dysdera*, which are the only animals known to exist exclusively on a diet of terrestrial isopods (Hopkin & Martin, 1985). Levels of metals in the hepatopancreas of individual woodlice may be more than twice those of the mean for the population within a site (Hopkin & Martin, 1984*a*). Therefore, predators of *Porcellio scaber* in uncontaminated sites must possess mechanisms which can, on individual feeding occasions, cope with levels of zinc and copper in the hepatopancreas component of their diet in excess of 5000 $\mu g\ g^{-1}$ on a dry weight basis (Figs. 2 and 5). The ability to deal with very high concentrations of these essential elements must have been one of the main mechanisms that had to be evolved before these animals were able to predate on woodlice. In sites contaminated with zinc and copper where the hepatopancreas of individual *Porcellio scaber* may contain more than 5% of these metals combined on a dry weight basis (Hopkin & Martin, 1982*a*), possession of such an ability is probably the main factor which governs whether a predator of woodlice can survive.

## CONCLUSIONS

This study has clearly shown that the concentrations of zinc, cadmium, lead and copper in at least one representative of the primary consumers can not be predicted from the concentrations of these metals in soil and leaf litter. It is recommended that future exercises in pollution monitoring should include the analysis of at least one representative of the primary consumers of vegetation to enable the 'availability' of metals to the fauna to be reliably indicated. *Porcellio scaber* is probably the ideal 'indicator species' in the UK because it has a strong affinity for zinc, cadmium, lead and copper, is large enough to provide sufficient tissue for analysis, and is common in a wide range of rural and urban habitats.

## ACKNOWLEDGEMENTS

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