TERRESTRIAL SNAILS AS QUANTITATIVE INDICATORS OF ENVIRONMENTAL METAL POLLUTION

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Abstract. Concentrations of cadmium, lead, copper and zinc were measured in individuals of *Arianta arbustorum* from different urban sampling sites. In comparison to snails from a reference site, the animals collected in the city showed higher concentrations of cadmium, lead, and copper, indicating elevated levels of metal pollution. The most pronounced difference in tissue concentrations between control animals and contaminated snails was observed for lead. Within the city, metal levels in snails differed significantly, even between adjacent populations.

Arianta arbustorum is a suitable species for biomonitoring, because it is widespread, resident and easy to collect; it has a high capacity for metal accumulation and shows different concentrations depending on metal contamination of the sampling area. An interspecific comparison of metal concentrations in terrestrial gastropods was conducted to define background levels and classes of burden. Three pollution levels are distinguished on the basis of the snails' metal burden: no pollution (class 1: reference sites), moderate (class 2: traffic and other human activities in urban areas), and high pollution (class 3: mining and heavy industry).

1. Introduction

Because some species of molluscs accumulate high amounts of metals (Martin and Flegal, 1975; Howard and Simkiss, 1981; Russel *et al.*, 1981; Viarengo *et al.*, 1981; Ward, 1982; Dallinger and Wieser, 1984; Kurihara and Suzuki, 1987; Knutti *et al.*, 1988) and reflect the levels of bioavailable metals in their environment (Coughtrey and Martin, 1977; Bryan *et al.*, 1984; Talbot, 1985; Balogh, 1988; Czarnezki, 1987; Lyngby, 1987; Cossa, 1988) these animals are often used as quantitative indicators of metal pollution. Bivalve molluscs, in particular, combine several advantageous features for use in biomonitoring surveys (Goldberg, 1975; Philips, 1976; Talbot, 1986; Cossa, 1989) and they have been more frequently employed as biomonitors of metals in aquatic environments than have species of any other group of organisms (Philips, 1990). Marine mussels such as *Mytilus spp.* (Talbot, 1985; Lyngby, 1989; Cossa, 1988) and freshwater species such as *Lampsilis ventricosa* (Czarnezki, 1987), *Unio pictorum* (Balogh and Salanki, 1987; Balogh, 1988) and *Corbicula spp.* (Doherty, 1990) have been successfully used as monitor organisms. Gastropods have been less extensively studied as potential biomonitors than bivalve molluscs. Only few data, however, are available for terrestrial pulmonates. Several factors are known to influence metal concentrations in snails, for example body weight (Coughtrey and Martin, 1982), temperature (Meincke and Schaller, 1974), season (Williamson, 1979; Williamson, 1980), diet and microhabitat (Greville and Morgan, 1989), so that an accurate analysis of these factors is required.

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For individuals of a certain species to be useful as indicator organisms this species must meet a number of prerequisites (Butler *et al.*, 1971; Philips, 1980; Wren, 1986; Arndt *et al.*, 1987). In the present study the value of the terrestrial snail *Arianta arbustorum* as a quantitative indicator of metal pollution in an urban area was evaluated by means of a list of criteria, which can be summarized under the following headings:

- *Practical prerequisits*: distribution; abundance; ease of sampling, identification and handling; etc.
- *Metal accumulation and influencing factors*: dependence of rates of metal uptake and excretion on body size, age, season, weather, etc.; synergistic or antagonistic effects.
- *Incorporation of the results in a reference system*: definition of background concentrations and of different levels of burden to allow an assessment of the environmental situation of the study area.

2. Material and Methods

2.1. STUDY AREA AND SAMPLING OF THE SNAILS

Innsbruck (Tyrol, Austria), a city of approximately 120000 inhabitants, is situated in an alpine basin at a height of 560 m above sea level. Although there is no heavy industry, such as smelting and metal works, the city is an important traffic junction. Thus the main sources of metal pollution in Innsbruck are traffic exhausts, followed by emissions from heating systems and a few industrial plants (Dallinger *et al.*, 1989).

To ascertain whether the metal concentrations of *Arianta arbustorum* differ according to their habitat, the sampling sites were distributed over a large area and were selected to provide as wide a variety as possible. A wood eight kilometers to the east of the city and more than one kilometer from the next public road was defined as reference area (sampling site I). Sampling site II was a private garden in an old residential district now directly situated along a road of average traffic density. Another garden in the vicinity, separated from the road by a building, was designated as sampling site II*. Sampling site III was a hedge in the industrial zone in the west of Innsbruck and enclosing a printing office and a garage. The verge of an arterial road with dense traffic was chosen as sampling site IV. Sampling site V was a meadow with solitary bushes along a highway in the south of Innsbruck. At each of the sampling sites in the city of Innsbruck twelve snails with a body weight of about 0.3 g (dry weight without shell) were collected for determination of their metal concentrations (Table I). The following factors were examined:

- differences between the metal concentrations of *Arianta arbustorum* from sites listed in Table I, A;

TABLE I
Description of sampling sites, numbers (n) and body dry weights (means±standard deviations) of the snails.

site	description	distance from nearest road	body weight mean±SD [g]	n
(A) Inter-site differences				
I	wood (reference)	> 1 km	0.27±0.04	12
II	urban garden	2–5 m	0.29±0.06	12
III	industrial area	2–5 m	0.26±0.04	11
IV	main road	1–3 m	0.28±0.06	12
V	highway	10–20 m	0.30±0.08	12
(B) Differences between neighbouring habitats				
II	urban garden	2–5 m	0.24±0.06	12
II*	urban garden	20–30 m	0.26±0.06	12
(C) Seasonal pattern				
	season			
II	spring (05.05.87)		0.29±0.06	12
II	summer (31.07.87)		0.24±0.05	12
II	autumn (27.10.87)		0.29±0.06	12
III	spring (05.05.87)		0.26±0.04	11
III	summer (31.07.87)		0.22±0.04	12
III	autumn (27.10.87)		0.24±0.04	12

- metal burden in snails from two adjacent populations at sites II/II* (Table I, B);
- seasonal patterns of metal concentrations within one period of activity on sites II and III (Table I, C).

2.2. PREPARATION OF SAMPLES AND METAL ANALYSES

After removal of the shells, the tissues of the snails were put into screw-capped polypropylene tubes (Greiner, Austria), dried at 60°C for several days and weighed. The samples were digested with a mixture (1 : 1) of 1–2 ml of nitric acid (Suprapure, Merck) and distilled water in a heated aluminium block at 70°C. The concentrations of cadmium, lead, copper and zinc were measured by means of flame atomic absorption spectrophotometry (Perkin Elmer, model 2380) using an air-acetylene fuel mixture. Calibration was carried out using metal standard solutions (Titrisol, Merck) diluted with distilled water and nitric acid at the same ratio as the samples. The accuracy of the external calibration method was confirmed by the use of certified reference material (Lobster hepatopancreas, TORT 1, NRC). Metal concentrations were found to be within the accepted means for reproducibility.

3. Results

3.1. METAL CONCENTRATIONS OF *Arianta arbustorum* FROM DIFFERENT SAMPLING SITES

3.1.1. Cadmium

A concentration of 6.5 μg/g (dry wt.) was found in snails from sampling site I (controls), this concentration being significantly lower than that of snails collected in the urban region, with the exception of those from sampling site V (Figure 1a). As indicated in Figure 1a, statistically significant differences also exist within the cadmium concentrations of snails from the urban sites. On an average, snails living in an urban environment show a concentration of cadmium twice as high as that of the reference animals. The highest average concentration (14.46 μg/g) was found in snails from sampling site IV, which is situated directly beside a main road.

3.1.2. Lead

Compared to the other metals, concentrations of lead show the most pronounced intersite differences ranging from 4.8 μg/g at sampling site I to 22.8 μg/g at sampling site IV. The level of lead in animals from sampling site I is significantly lower by a factor of 3.5, 3, 5, and 3 for sites II, III, IV, and V respectively (Figure 1b). The mean level of lead in snails inhabiting urban areas is 3.5 times higher than the background values. Snails living near a main road (sampling site IV) have significantly higher concentrations of lead than snails from any of the other sampling sites (Figure 1b), thus indicating traffic exhausts as the main source of lead contamination in the vicinity of roads.

3.1.3. Copper

The copper concentration in control animals (sampling site I) is significantly lower than that found in snails from the other sampling sites (Figure 1c). The level of copper is elevated by a factor of between 2 and 4 in snails from the urban sites, reaching a maximum of 400 μg/g on sampling site II. The concentrations in snails from this site are significantly higher than from any other site.

3.1.4. Zinc

The lowest average concentration of zinc is 130 μg/g, and is found in control animals, the highest is 301 μg/g, measured in snails from V (Figure 1d). This means a difference of a factor of 2.5. But on an average, the zinc levels of urban snails (sampling sites II–V) are 1.5 times above the control level, which is lower than the factors found for cadmium, lead and copper.

In conclusion, the following picture can be drawn: individuals of *Arianta arbus-*

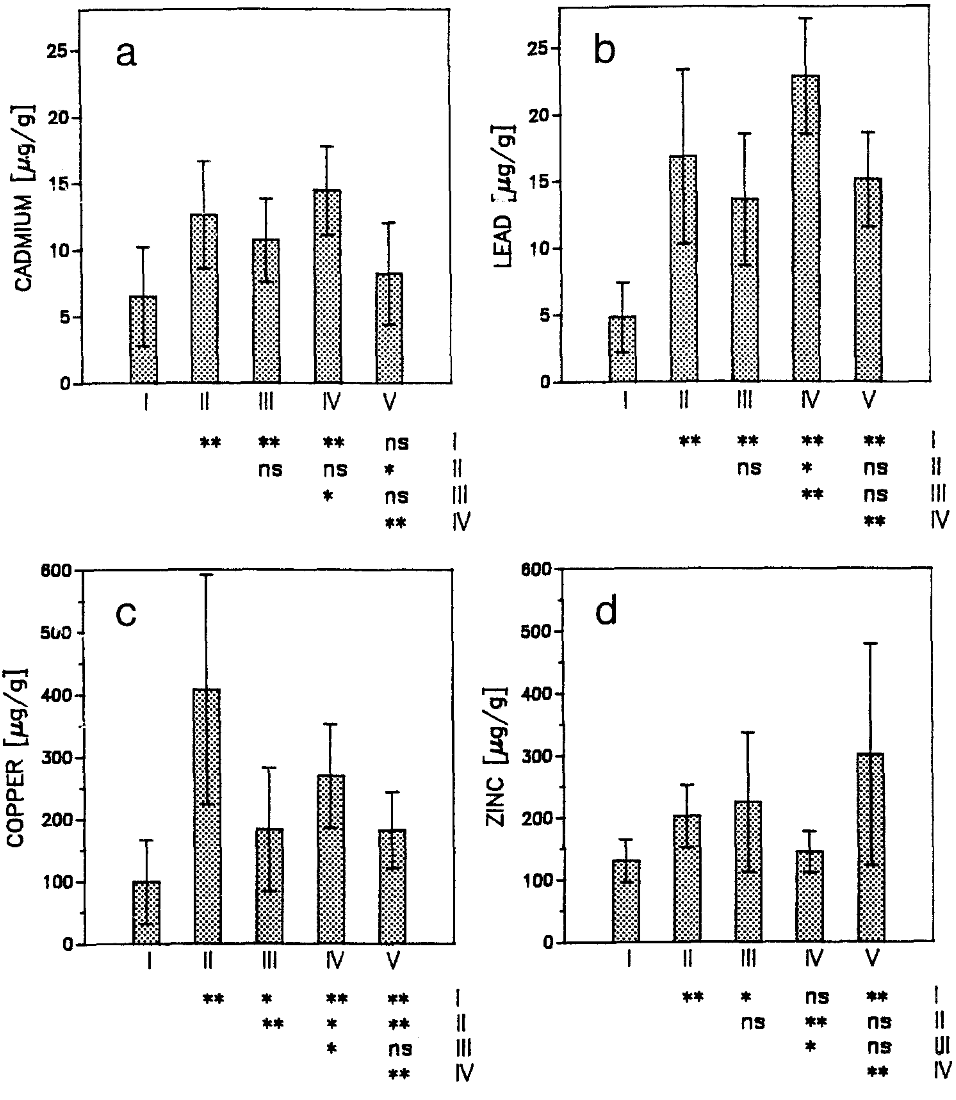

Fig. 1. Mean concentrations (± standard deviations) of (a) cadmium, (b) lead, (c) copper, and (d) zinc in specimens of *Arianta arbustorum* from sampling sites I–V in Innsbruck. Metal concentrations of different sites were compared by Student's t-test. The results of this test are shown below each diagram, levels of significance are indicated by symbols, as follows: ns...not significant ($p \geq 0.05$); *...$p \leq 0.05$; **...$p \leq 0.01$.

torum from the control area (sampling site I) show the lowest concentrations for all metals measured. Snails from urban sites invariably show significantly higher metal levels. This is most pronounced for lead, followed by copper, cadmium and zinc. Sampling site IV, close to a main road, is the most contaminated site with respect to lead and cadmium. The highest concentrations of copper were found on site II, and the highest zinc concentrations were measured on site V. A comparison of the urban sampling sites (II–V) often also shows significant differences in metal levels (Figure 1), which points to a sophisticated pattern of metal burden in this area.

3.2. DIFFERENCES BETWEEN TWO CLOSELY ADJACENT SNAIL POPULATIONS

Figure 2 shows the mean concentrations of cadmium (Figure 2a), lead (Figure 2b), copper (Figure 2c) and zinc (Figure 3d) in snails collected on sites II and II*. Apart from zinc, metal concentrations differ significantly between these two populations, which are separated only by a building. The concentration of copper is three times higher on site II than on site II*. Snails near the road (sampling site II) also carry higher amounts of cadmium and lead than those only 20 m away (sampling site II*).

3.3. SEASONAL VARIATIONS IN METAL CONCENTRATIONS

Figure 3 shows the patterns of metal concentrations during the year in snails from sites II and III. In snails from site II the only change found was in the concentration of zinc during one season, whereas in animals collected on site III the concentrations of cadmium, lead and zinc all showed significant seasonal variations. During the summer, when the concentration of cadmium showed a maximum, the concentrations of zinc and lead decreased continuously. No significant seasonal variations were found for copper.

4. Discussion

4.1. CRITERIA FOR THE SELECTION OF *Arianta arbustorum* AS INDICATOR SPECIES

A number of ecological and biological attributes of the helicid land snail *Arianta arbustorum* largely fulfill the preconditions of a suitable bioindicator: *Arianta arbustorum* is common in a variety of mostly moist habitats in north-western and central Europe (Kerney *et al.*, 1983), its range extends from the lowland up to an altitude of 2,700 m (Arter, 1990). Habitats resulting from human activities like gardens, parks, hedges, road verges, traffic islands and so on, are regularly inhabited by *Arianta arbustorum*, where up to 43 individuals/m^2 can be found (Baur and Baur, 1990). At the sampling sites in the city of Innsbruck numerous individuals of *Arianta arbustorum* were collected within a period of time. Because of its ubiquitous and wide distribution, *Arianta arbustorum* could be used for biomonitoring in many regions of Europe, especially in industrial and urban areas.

In order to be regarded as representative of the study area, an indicator organism should be sedentary or its activity range should be restricted (Butler *et al.*, 1971). Baur and Baur (1990) found that the average displacements of individuals of *Arianta arbustorum* ranged from 1.5 to 4.9 m within one season and that roads are barriers to the snails' dispersal. These results suggest that snail populations in towns dissected by paved roads may be isolated from each other. In this study

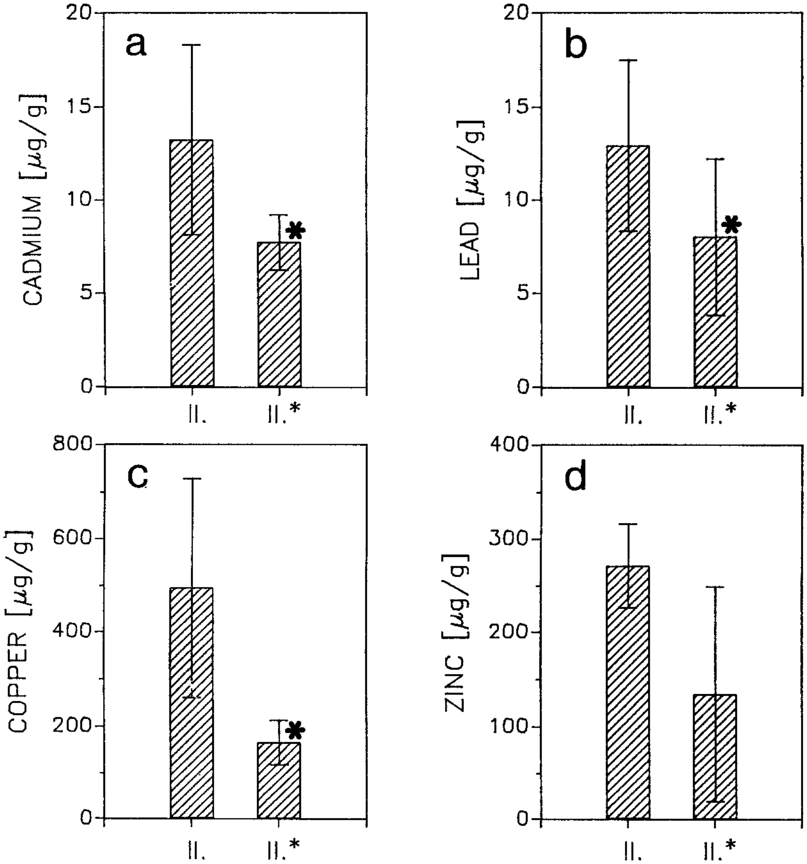

Fig. 2. Mean concentrations (± standard deviations) of (a) cadmium, (b) lead, (c) copper, and (d) zinc in specimens of *Arianta arbustorum* from sampling sites II and II*. Statistically different concentrations are indicated by an asterisk (Student's t-test; $p \leq 0.02$).

two populations of *Arianta arbustorum* separated by only one building differed in their metal contents, indicating different exposures of their habitats (Figure 2). For example, snails from the sampling site near the road (sampling site II) had higher lead concentrations than animals from site II*.

For biological monitoring, easily identifiable species are advantageous, in order to exclude errors arising from possible inter-specific differences. In the case of slugs, for example, very closely related species belonging to the same genus differ in their metal concentrations, probably attributable to differences in food preference, behaviour and alimentary physiology (Greville and Morgan, 1989). *Arianta arbustorum* are easily identifiable up to the species level (Kerney *et al.*, 1983), although there does exist a number of subspecies (Klemm, 1973; Nemeschkal and Kothbauer, 1988) showing conspicuous polymorphism, ranging from large snails

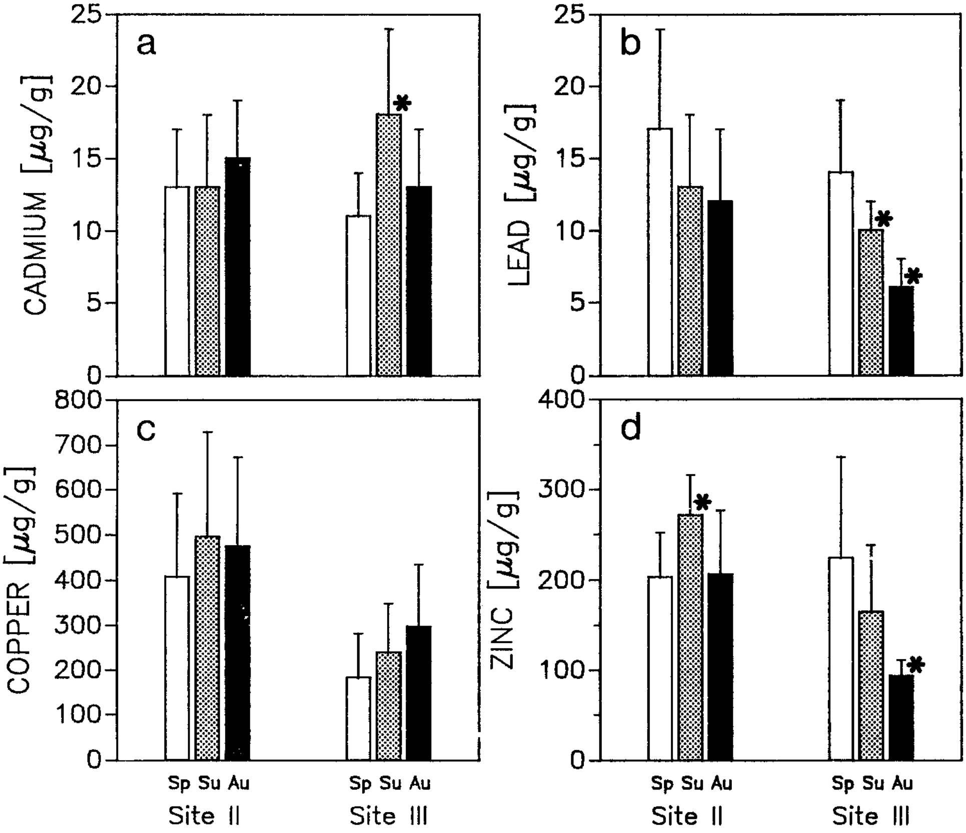

Fig. 3. Seasonal variation in (a) cadmium, (b) lead, (c) copper, and (d) zinc concentrations of *Arianta arbustorum* from sampling sites II and III. An asterisk indicates a significant change in metal concentration since the previous season (Student's *t*-test; $p \leq 0.01$). Abbreviations: Sp...spring; Su...summer; Au...autumn.

with brown shells in forests at lower altitudes, to smaller yellow individuals, found mainly in grasslands at higher altitudes (Arter, 1990). It is not known whether these subspecies differ with regard to metal accumulation.

The metal contents of *Arianta arbustorum* depend on the animals' size. The smaller animals have higher concentrations of cadmium, lead and zinc than larger individuals, but those heavier than 0.2 g (dry weight without shell) do not show this correlation (Berger and Dallinger, 1989; Berger, 1990). In order to avoid size-dependent interference, adult animals belonging to the weight class of 0.3 g were used in this study (Table I). This method also helps to avoid age-dependent effects, if the sampling sites are within an ecologically homogeneous area. Along an altitudinal gradient, size does not correlate with age (Baur and Raboud, 1988). In such a case an estimation of the age would be necessary.

Arianta arbustorum spend an average of 3–4 years as adults, but lifespans of up to 14 years have been recorded (Raboud, 1986; Baur and Raboud, 1988). Therefore, the bioaccumulation levels out short-term variations in the exposure and availability of a pollutant and represents the mean burden of the habitat.

Because of its convenient size, collection and handling of individuals of *Arianta arbustorum* are easily and quickly achieved. The animals can be kept under laboratory conditions and fed on artificial or homogeneous diet for long periods of time (Frömming, 1954), which allows experimental studies of the kinetics of metal accumulation and detoxification mechanisms of *Arianta arbustorum* and other pulmonate snails to be carried out. By using food enriched with cadmium, copper, lead or zinc, the routes and rates of metal accumulation have been quantified in *Helix aspersa* (Beeby, 1985), *Helix pomatia* (Berger *et al.*, 1991) and *Arianta arbustorum* (Berger and Dallinger, 1989). The metal concentrations achieved in these feeding experiments within a period of 10–30 days are similar to the highest values reported for snails under field conditions (Hopkin, 1989). Metal accumulation in terrestrial gastropods is efficient and occurs at fast rates, whereas elimination seems to be a slow process (Dallinger and Wieser, 1984; Berger and Dallinger, 1989). Their high capacity for the accumulation and storage of metals is attributed to the induction of metal-binding proteins belonging to the metallothioneins (Dallinger *et al.*, 1989). These proteins are probably responsible for the long half-life of cadmium in snails (Williamson, 1980). The low rate of elimination means that the metal concentrations present in the tissues are the sum of a long-term process of accumulation and are therefore indicative of the environmental level of this contaminant over a long period. Additionally, some short-term effects such as changes in feeding activity due to temperature, humidity and other meteorological variables could affect the amount of metals assimilated. Factors of this kind may account for the apparently irregular variations in metal concentrations in *Arianta arbustorum* collected from the same site within one activity period (Figure 3). For this reason the period of sampling should be as short as possible.

4.2. RANGES OF METAL CONCENTRATIONS IN TERRESTRIAL SNAILS: A REFERENCE SYSTEM TO DEFINE LEVELS OF BURDEN

To assess metal contaminations by means of biomonitoring it is important to know the whole range of concentrations possible for a monitor organism exposed to different levels of pollution. Since the information available about metal burdens of a given species of gastropods is insufficient for the establishment of such a scale, we have compared the cadmium, lead, copper and zinc concentrations of different terrestrial gastropod species from polluted and unpolluted regions to allow interpretation of the metal concentrations found in *Arianta arbustorum*. Data for 16 species (7 species of snails and 9 species of slugs) are summarized. A complete list of the species, metal concentrations, descriptions of the sampling sites and references are given in the Appendix.

The areas from which the gastropods of this inter-specific comparison were collected can be divided into three classes, according to the source of metal pollution:

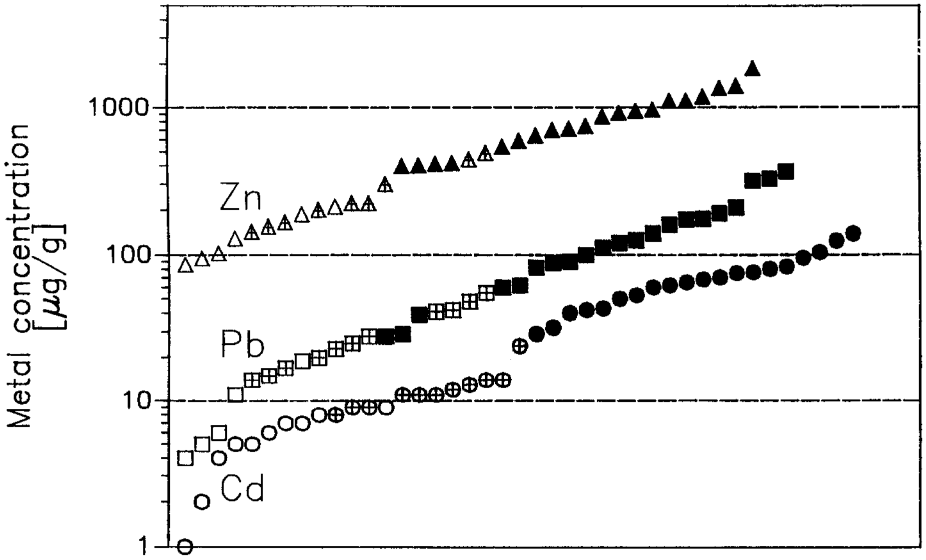

Fig. 4. Cadmium (circles), lead (squares) and zinc (triangles) concentrations reported from different species of terrestrial gastropods. The data are arranged in ascending order of concentration as listed in the Appendices A, B, and D. Three classes of sampling sites are distinguished (see text):
Class 1: reference areas;
Class 2: sampling sites near roads or within cities;
Class 3: mining areas or regions of metal-working industry.
Metal concentrations of animals from class 1 sites are indicated by open symbols, those of class 2 sites by crossed symbols and those of class 3 sites by closed symbols.

Class 1: reference areas;
Class 2: sampling sites near roads or within cities;
Class 3: mining areas and regions of metal-working industry.

If the metal concentrations of terrestrial gastropods give any information about the source and intensity of pollution of their habitats, this classification, derived only from a description of the sampling site, should correspond to the metal levels found in the animals. In Figure 4 the concentrations of cadmium, lead and zinc in terrestrial gastropods are shown in ascending order. The three categories of sampling sites, indicated by different symbols, are clearly distinguishable on the basis of the metal concentrations of the gastropods. Table II summarizes the ranges and mean concentrations of cadmium, lead, copper and zinc measured in gastropods from habitats belonging to classes 1, 2 or 3. The increase in metal burden for a specific class is shown by the ratio (*f*) of its mean metal concentration to the average background level (class 1).

The concentration of cadmium varies between 1 and 139 µg/g (Figure 4, Appendix A). The three classes of sampling sites are distinctly separated. Animals from class 1 habitats (controls) have a mean cadmium concentration of 5.4 μg/g, those from urban areas have an average of 12.7 μg/g. The wide range of concentrations in class 2 (8–24 μg/g) could be a result of the variable levels of exposure in cities, depending on traffic density and industrial activities. The highest and most variable concentrations are found in gastropods near mining areas and smelters. The mean concentration of 70 μg/g is 13 times above background, showing that this kind of human activity pollutes the environment much more than traffic and cities. The cadmium concentrations of gastropods indicate both highly polluted sites (class 3) as well as moderately polluted areas (class 2). This underlines the variety of possible uses of a bioindicator.

The cadmium concentration of *Arianta arbustorum* (see Appendix A) from sampling site I (7 μg/g) corresponds to the level of class 1 (Table II). The concentrations found on sampling sites II, III, and IV are as high as those measured in *Helix aspersa* and *Cepaea hortensis* from similar types of habitats (Williamson, 1980; Martin and Coughtrey, 1982). Although sampling site V is situated near a highway, cadmium concentrations in the snails are below the average of class 2 (Appendix A; Table II).

The range of lead concentration in terrestrial gastropods is 4–365 μg/g and can be divided into levels of burden corresponding to the three classes of sampling sites (Figure 4, Appendix B). The mean concentration of animals from class 1 sites is only a fifth and a sixteenth of those from class 2- and class 3-sites, respectively (Table II). In contrast to cadmium, the lead concentrations of class 2 and class 3 overlap to a much greater extent. This is because of the high variability of lead concentrations in gastropods from urban areas. Lead concentrations of snails collected near roads exceeded those of individuals living 3.2 km from a smelter (see Appendix B; Coughtrey and Martin, 1976; Williamson, 1980; Beeby and Richmond, 1987). This shows the importance of the contribution of traffic exhausts to total lead pollution. The variability of lead levels in urban gastropods can be attributed to the high dependence of environmental lead concentrations on distance from the road (Leonzio and Pisani, 1987; Yassoglou *et al.*, 1987; Kasperowski and Frank, 1989), on traffic density (Burguera *et al.*, 1989; Ho and Tai, 1988; Stary *et al.*, 1989; Dallinger *et al.*, 1991) and on exposure of the habitat (Dallinger *et al.*, 1989). This leads to a complex mosaic of different levels of pollution within a city, which can only be described by a narrow mesh of sampling points (Dallinger *et al.*, 1991).

On the basis of this interspecific comparison the concentrations of lead in *Arianta arbustorum* collected in Innsbruck are relatively low. The lead concentration in snails from sampling site I (5 μg/g) is below the average of class 1 (9 μg/g). The highest concentration of lead, measured in animals from site IV, was 23 μg/g, which is considerably less than the concentrations in most snails from class 2 sites. The distance of 10–20 m of sampling site V from the highway may be the reason for the low lead burden of its snails. Increasing distance from a road leads to expo-

TABLE II
Classification of metal concentrations in terrestrial gastropods according to the specific source of the pollutant.

		Class 1 controls	Class 2 traffic & cities	Class 3 smelters & mines
Cadmium				
Range	[μg/g]	1–9	8–24	29–139
Average	[μg/g]	5	13	70
	n	(10)	(10)	(20)
	f	1	2	14
Lead				
Range	[μg/g]	4–19	14–160	28–365
Average	[μg/g]	9	41	141
	n	(5)	(12)	(20)
	f	1	4.5	16
Copper				
Range	[μg/g]	46–104	30–408	45–228
Average	[μg/g]	84	188	84
	n	(4)	(7)	(9)
	f	1	2	1
Zinc				
Range	[μg/g]	86–212	144–748	400–1868
Average	[μg/g]	136	310	873
	n	(6)	(10)	(19)
	f	1	2	6.5

f = ratio of the mean metal concentration of a class to the mean concentration of class 1.

nentially decreasing metal concentrations in the soil, reaching background levels at approximately 50 m (Yassoglou *et al.*, 1987). Kasperowski and Frank (1989) found no elevation of lead 10 m away from a motorway. The lead concentration of the terrestrial snail *Cernuella virgata* decreases exponentially within a distance of 200 m from a road and is halved after the first 20 m (Leonzio and Pisani, 1987).

Copper concentrations of terrestrial gastropods range between 30 and 408 μg/g (Table II, Appendix C), but in this case the classification of sampling sites into different categories does not correspond with different levels of concentration (Table II). The following points should be considered in this context: (1) less information is available concerning copper in snails than for cadmium, lead or zinc.

(2) All sites summarized in class 3 relate to zinc or lead smelters or mines; no study deals with proper copper industries. (3) Investigations on marine molluscs show that the copper burden of these animals does not reflect environmental concentrations (Philips, 1976; Bryan *et al.*, 1983; Lyngby, 1987). Considering these points, more studies on the effect of copper pollution on the concentration of this metal in terrestrial gastropods are needed in order to assess their validity in biomonitoring surveys.

The zinc concentrations of terrestrial gastropods fit very well into the system of the three classes of sampling sites, although there are marked overlaps (Table II, Appendix D). The level of zinc in animals from control areas averages 136 μg/g. In gastropods from urban regions it is twice as high, and near zinc mines concentrations of more than 1000 μg/g were measured.

The zinc levels of individuals of *Arianta arbustorum* from sampling site I are typical for snails from sites belonging to class 1. The concentrations of zinc in snails from the other sampling sites seem to be below average.

On the basis of this inter-specific comparison it was shown that different sources and intensities of metal pollution are indicated by the level of the respective metal concentration in terrestrial gastropods. On the one hand, industry and mining activities cause extremely high concentrations of cadmium, lead and zinc in the snails tissues, and on the other hand cities and traffic are responsible for more moderate, yet significantly elevated levels of these elements.

Acknowledgements

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Appendices

Metal concentrations (A: cadmium; B: lead; C: copper; D: zinc) of terrestrial gastropods, expressed as μg/g (dry weight) and listed in ascending order. A short characterization of the sampling site as well as its class of burden is given (classes 1–3; see text). In some cases the distance (m or km) from the source of pollution is listed too. Sampling sites of this study are numbered according to Table I.

REFERENCES

(1) Coughtrey and Martin (1976); (2) Popham and D’Auria (1980); (3) Williamson (1980); (4) Martin and Coughtrey (1982); (5) Beeby and Richmond (1987); (6) Kratz *et al.* (1987); (7) Knutti *et al.* (1988); (8) Greville and Morgan (1990); (9) Hopkin (1989); (10) this study.

Appendix A: Cadmium concentrations

Species	Cd [μg/g]	Sampling site	Class	Ref.
Arion subfuscus	1	wood	1	7
Arion ater	2	wood	1	7
Helix pomatia	4	wood	1	7
Helix aspersa	5 ± 1	reference area	1	9
Helix aspersa	5 ± 1	reference area	1	5
Helix aspersa	6 ± 1	garden	1	1
Perforatella incanata	7	wood	1	7
Arianta arbustorum	7 ± 4	wood; I	1	10
Oxychilus sp.	8	wood	1	4
Arianta arbustorum	8 ± 4	highway; 10–20 m; V	2	10
Cepaea nemoralis	9	suburb	2	6
Helix aspersa	9 ± 1	car park	2	5
Helix aspersa	9	wood	1	4
Arianta arbustorum	11 ± 3	industrial area; III	2	10
Helix aspersa	11 ± 6	wood	2	4
Helix aspersa	11 ± 1	urban garden	2	4
Cepaea hortensis	12	roadside	2	4
Arianta arbustorum	13 ± 4	urban garden; II	2	10
Cepaea hortensis	14	roadside	2	3
Arianta arbustorum	14 ± 3	main road; IV	2	10
Helix aspersa	24 ± 4	wood	2	1
Arion fasciatus	29	smelter	3	4
Cepaea nemoralis	32 ± 7	zinc smelter	3	4
Arion hortensis	34 ± 4	Pb/Zn mine	3	8
Arion hortensis	42	smelter	3	4
Agriolimax reticulatus	43	smelter	3	4
Helix aspersa	50 ± 11	smelter; 1 km	3	9
Helix aspersa	53 ± 19	smelter; 3.2 km	3	4
Agriolimax reticulatus	60	smelter	3	4
Helix aspersa	62	smelter; 3.2 km	3	4
Deroceras reticulatum	64 ± 10	Pb/Zn mine	3	8
Helix aspersa	65 ± 8	smelter; 3.2 km	3	1
Cepaea nemoralis	68	smelter; 2 km	3	4
Milax budapestensis	70 ± 10	Pb/Zn mine	3	8
Clausilis bidentata	76	smelter; 2.8 km	3	4
Arion ater	76 ± 8	Pb/Zn mine	3	8
Agriolimax reticulatus	83	smelter	3	4
Arion subfuscus	93 ± 16	Pb/Zn mine	3	8
Agriolimax reticulatus	104	smelter	3	4
Deroceras caruanae	119 ± 16	Pb/Zn mine	3	8
Arion hortensis	139	smelter	3	4

Appendix B: Lead concentrations

Species	Pb [μg/g]	Sampling site	Class	Ref.
Helix aspersa	4 ± 1	reference area	1	5
Arianta arbustorum	5 ± 3	wood	1	10
Helix aspersa	6 ± 1	reference area	1	9
Helix aspersa	11	wood	1	4
Arianta arbustorum	14 ± 5	industrial area; III	2	10
Arianta arbustorum	15 ± 4	highway; 10–20 m; V	2	10
Arianta arbustorum	17 ± 7	urban garden; II	2	10
Helix aspersa	19 ± 8	garden	1	1
Arion ater	20 ± 2	highway; 40–80 m	2	2
Arianta arbustorum	23 ± 4	main road; IV	2	10
Helix aspersa	25 ± 14	wood	2	4
Helix aspersa	28 ± 4	wood	2	1
Helix aspersa	28	smelter; 3.2 km	3	4
Helix aspersa	29 ± 3	smelter; 3.2 km	3	1
Helix aspersa	39 ± 21	smelter; 3.2 km	3	4
Cepaea hortensis	41	road side	2	3
Helix aspersa	42 ± 6	urban garden	2	4
Helix aspersa	48 ± 5	car park	2	5
Cepaea hortensis	55	roadside	2	4
Arion hortensis	60	smelter	3	4
Agriolimax reticulatus	62	smelter	3	4
Arion hortensis	80 ± 9	Pb/Zn mine	3	8
Cepaea nemoralis	82	smelter; 2 km	3	4
Agriolimax reticulatus	88	smelter	3	4
Deroceras caruanae	98 ± 7	Pb/Zn mine	3	8
Arion fasciatus	112	smelter	3	4
Helix aspersa	121 ± 124	smelter; 1 km	3	9
Agriolimax reticulatus	126	smelter	3	4
Deroceras reticulatum	130 ± 15	Pb/Zn mine	3	8
Milax budapestensis	149 ± 18	Pb/Zn mine	3	8
Arion ater	160 ± 30	highway; 0–40 m	2	2
Agriolimax reticulatus	173	smelter	3	4
Arion ater	185 ± 25	Pb/Zn mine	3	8
Clausilis bidentata	208	smelter; 2.8 km	3	4
Arion subfuscus	307 ± 25	Pb/Zn mine	3	8
Arion hortensis	315	smelter	3	4
Cepaea nemoralis	365 ± 65	Zn smelter	3	4

Appendix C: Copper concentrations

Species	Cu [μg/g]	Sampling site	Class	Ref.
Helix aspersa	30 ± 15	moderately polluted	2	4
Helix aspersa	33 ± 8	moderately polluted	2	1
Helix aspersa	46 ± 4	garden	1	1
Milax budapestensis	68 ± 12	Pb/Zn mine	3	8
Arion ater	68 ± 3	Pb/Zn mine	3	8
Helix aspersa	68 ± 10	smelter; 3.2 km	3	1
Deroceras reticulatum	69 ± 16	Pb/Zn mine	3	8
Arion subfuscus	85 ± 7	Pb/Zn mine	3	8
Arion hortensis	85 ± 6	Pb/Zn mine	3	8
Helix aspersa	86 ± 15	control area	1	5
Helix aspersa	87 ± 25	smelter; 3.2 km	3	4
Arianta arbustorum	99 ± 67	wood; I	1	10
Helix aspersa	104 ± 28	control area	1	9
Deroceras caruanae	123 ± 14	Pb/Zn mine	3	8
Arianta arbustorum	182 ± 61	highway; 10–20 m; V	2	10
Arianta arbustorum	183 ± 99	industrial area; III	2	10
Helix aspersa	213 ± 23	car park	2	5
Helix aspersa	228 ± 43	smelter	3	9
Arianta arbustorum	269 ± 83	main road; IV	2	10
Arianta arbustorum	408 ± 184	urban garden; II	2	10

Appendix D: Zinc concentrations

Species	Zn [μg/g]	Sampling site	Class	Ref.
Helix aspersa	86	wood	1	4
Helix aspersa	95 ± 8	garden	1	1
Helix aspersa	103 ± 14	control area	1	9
Arianta arbustorum	130 ± 34	wood	1	10
Arianta arbustorum	144 ± 33	highway; 10–20 m; V	2	10
Helix aspersa	156 ± 55	wood	2	4
Helix aspersa	167 ± 9	wood	2	1
Oxychiclus sp.	189	wood	1	4
Arianta arbustorum	202 ± 50	urban garden; II	2	10
Helix aspersa	212 ± 22	control area	1	5
Helix aspersa	224 ± 32	urban garden	2	4
Arianta arbustorum	224 ± 112	industrial area; III	2	10
Arianta arbustorum	301 ± 178	main road; IV	2	10
Helix aspersa	400	smelter; 3.2 km	3	4
Helix aspersa	404 ± 151	smelter; 3.2 km	3	4
Helix aspersa	413 ± 46	smelter; 3.2 km	3	1
Helix aspersa	418 ± 71	smelter; 1 km	3	9
Cepaea hortensis	444	roadside	2	3
Cepaea hortensis	490	roadside	2	4
Arion hortensis	587 ± 69	Pb/Zn mine	3	8
Clausilis bidentata	592	smelter; 2.8 km	3	4
Cepaea nemoralis	644	smelter; 2 km	3	4
Agriolimax reticulatus	700	smelter	3	4
Cepaea nemoralis	714 ± 90	Zn mine	3	4
Helix aspersa	748 ± 146	carpark	2	5
Deroceras reticulatum	875 ± 122	Pb/Zn mine	3	8
Arion ater	923 ± 128	Pb/Zn mine	3	8
Agriolimax reticulatus	948	smelter	3	4
Deroceras caruanae	975 ± 72	Pb/Zn mine	3	8
Arion fasciatus	1111	smelter	3	4
Agriolimax reticulatus	1115	smelter	3	4
Arion subfuscus	1182 ± 103	Pb/Zn mine	3	8
Agriolimax reticulatus	1364	smelter	3	4
Arion hortensis	1413	smelter	3	4
Arion hortensis	1868	smelter	3	4

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