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Sex, Age, and Tissue Specific Accumulation of Eight Metals, Arsenic, and Selenium in the European Hedgehog (*Erinaceus europaeus*)

Anni Rautio · Mervi Kunnasranta · Anu Valtonen · Mirva Ikonen · Heikki Hyvärinen · Ismo J. Holopainen · Jussi V. K. Kukkonen

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Abstract Many insectivores have been shown to be sensitive to heavy metals and therefore suitable for biomonitoring purposes. In Finland, the hibernation period of the European hedgehog (*Erinaceus europaeus*) is long, and during hibernation the stress caused by environmental toxins may be crucial. Concentrations of cadmium (Cd), copper (Cu), iron (Fe), magnesium (Mg), manganese (Mn), molybdenum (Mo), nickel (Ni), lead (Pb), arsenic (As), and selenium (Se) were measured in a population of hedgehogs in the town of Joensuu in eastern Finland during the summers of 2004 and 2005. The analyzed tissues were kidney, liver, hair, and spine. The sampled hedgehogs ($n = 65$) were mainly road-killed animals. As expected, the concentrations of heavy metals were low because the hedgehogs were living in a comparatively unpolluted area. Significant increases with age were found in Cd concentrations (kidney, liver, and spine) and some essential elements (Se in spine, kidney, and liver; Mo in kidney and liver; Cu in spine; Fe in liver; and Mn in spine). Age accumulation and correlations between Se and Cd and between Mo and Cd may indicate the protective roles of Se and Mo against Cd toxicity in hedgehogs, in which Cd is already at comparatively low concentrations. Sex had no significant effect on concentrations of the elements studied. In conclusion, age is an important parameter to be taken into account when studying heavy-metal concentrations in hedgehogs and other insectivores.

A. Rautio (✉) · A. Valtonen · M. Ikonen · H. Hyvärinen · I. J. Holopainen · J. V. K. Kukkonen
Department of Biology, University of Eastern Finland, 80101 Joensuu, Finland
e-mail: anni.rautio@uef.fi

M. Kunnasranta
Turku Game and Fisheries Research, Finnish Game and Fisheries Research Institute, 20520 Turku, Finland

Many species of wildlife face the challenges of urbanization. Dense housing construction, traffic, and environmental pollution in urban areas decrease the availability of suitable habitats and cause deterioration of the living conditions for many animals. Among small mammals, insectivores are more easily exposed to environmental toxins than herbivorous species (Hunter and Johnson 1982; Hunter et al. 1987, 1989; Ma 1989; Pankakoski et al. 1994; Alleva et al. 2006). Furthermore, it is commonly considered that the main exposure is through dietary intake (e.g., Talmage and Walton 1991). The invertebrate preys of insectivores, notably earthworms (Lumbricidae), contain relatively high levels of heavy metals, such as lead (Pb) and cadmium (Cd) (Ma et al. 1991). Direct exposure of insectivores by their grooming and burrowing behaviour, and by ingestion of soil, is also a possible cause (Talmage and Walton 1991).

Heavy metals, such as Cd, Pb, and the metalloid arsenic (As), have no biologic function and are highly toxic, even at relatively low concentrations. Cd is known to cause environmental pollution. It is released by the refinement and use of Cd and in fuel combustion (Ma and Talmage 2001). This heavy metal occurs widely; it is toxic and has good mobility through the food chain. Insectivores are exposed to Cd mainly through their diet. However, even when earthworms, which are rich in Cd, are consumed, only <5% of the ingested Cd is absorbed (Cooke and Johnson 1996). In mammals, Cd is stored mainly in kidney and liver, and it tends to accumulate with age (e.g., Hunter et al. 1989; Komarnicki 2000). Pb is a ubiquitous toxic metal in the environment (Ma and Talmage 2001). In vertebrates, ingested Pb is mainly transferred to bones (Johnson et al. 1978; Ma 1989; Talmage and Walton 1991). Pb concentrations in soft tissues reflect current exposure because the half-life of Pb is only 3–4 weeks (Shore and Douben 1994a; Cooke and Johnson 1996).

Concentrations of essential elements are normally homeostatically regulated and maintained at certain physiologic levels (e.g., Ma and Talmage 2001). Copper (Cu), zinc (Zn), and molybdenum (Mo), especially, can interact with each other or with some heavy metals, and these interactions can affect their concentrations, especially in liver and kidney (Underwood and Suttle 1999). In animal nutrition, selenium (Se) can serve either as a natural toxicant or an essential micronutrient (Wlodarczyk et al. 1995). It is an important antioxidant (Smith and Picciano 1986), and a moderate supply of Se may have beneficial effects on reproduction (Käkelä et al. 1999). Se is found in many different chemical forms and may interact with some environmental contaminants (Heinz 1996).

European hedgehogs (*Erinaceus europaeus*) can be used as biomonitors for environmental pollution (D'Havé et al. 2005a, b, 2006a, b, 2007; Alleva et al. 2006; Vermeulen et al. 2009). Traditionally, the hedgehog species lives near humans and can be found in parks and gardens, even in city centres, and thus is easily exposed to pollutants in the urban environment. Their relatively long life expectancy, low migration rate, small home range, and wide distribution range (Reeve 1994) are also relevant criteria their use as biomonitors. Hedgehog populations are reputed to have decreased significantly in the last few decades in Britain, and poisoning by industrial chemicals may have been an important factor (Battersby 2005). Heavy metals in hedgehog tissues have recently been studied in western and southern Europe (D'Havé et al. 2005a, 2006b; Alleva et al. 2006; Vermeulen et al. 2009). However, to the best of our knowledge, there have been no studies on age-specific accumulation of heavy metals, nor on age- or sex-dependant concentration differences in the essential elements in hedgehogs. In addition, studies on populations in northern Europe are lacking. In Finland, hedgehogs live in the northernmost parts of their distribution range (Kristoffersson et al. 1977). Physiologic adaptation of mammals to harsh winters is made up of the deposition and use of fat reserves (Batzli 1981). Hedgehogs, in particular, rely heavily on fat deposits as an energy source during their 7-month hibernation period (e.g., Konttinen et al. 1964). In Finland, weight loss during hibernation is on average 40% of the hedgehog's autumn weight (Kristoffersson and Suomalainen 1964). Any additional stress resulting from a contaminant body burden may increase winter mortality or lower body condition at emergence.

Consequently, the main objective of the present study was to investigate the age- and sex-specific concentrations and interactions of As, Cd, Cu, iron (Fe), magnesium (Mg), manganese (Mn), Mo, nickel (Ni), Pb, Se, and Zn in liver, kidney, hair, and spine of an urban hedgehog population in eastern Finland.

Materials and Methods

Sample Collection

Hedgehog tissue samples (kidney, liver, hair, and spine) were collected from 2004 to 2005 in the town of Joensuu (63°N 29°E). The study area is a medium-sized town in eastern Finland with a population of >57,000 people. The studied hedgehogs were mainly road-killed animals, but the group included 14 young hedgehogs that had starved to death during their first summer. Starved, first-year young could be distinguished on the basis of their body weight and length. The material consisted of 14 young female, 17 adult female, 16 young male, and 18 adult male hedgehogs. Road-killed animals were collected from a regular monitoring route that contained streets in the town centre and roads in the suburban areas. The hedgehogs were weighed, and their length and circumference were measured. Measurements were made only when the carcasses were undamaged. The carcasses were stored at −20°C until further treatment.

Age Determination

Age was determined from lower jaw sections (see Reeve 1994). A transverse section of the lower jaw was made from the region of the last molar. The jaw was fixed in 4% neutral formalin for 48 h, decalcified for 1 week in 6% HNO_3, dehydrated, and embedded in paraffin. The jaw was then cut into 10-µm thick sections with a Leica RM2165 microtome (Leica Instruments, Nussloch, Germany) and stained with Mayer's hematoxylin and eosin. The age of the individuals was shown by the periosteal growth lines of the bone, with each line representing 1 year.

Metal Analyses

The hedgehogs were dissected with stainless steel instruments, strictly avoiding the exposure of tissues to any contamination. The liver and kidney samples were wet weighed and then dried at 105°C to a constant weight. To remove external contamination, the hair and spine samples were washed with detergent and rinsed three times with ionised water and once with Milli-Q (Millipore) water. Hair and spine samples were dried at 60°C to a constant weight. All dried samples (liver, kidney, hair, and spine) were weighed and digested at room temperature for 10 min by adding 6 ml 65% HNO_3 and 1 ml H_2O_2. Digestion was completed in a microwave oven using the routine 3051 of the Environmental Protection Agency (CEM, Mars). Concentrations of As, Cd, Cu, Fe, Mg, Mn, Mo, Ni, Pb, Se, and Zn were analyzed by inductively coupled plasma-optical emission spectrometer (IRIS Intrepid II XSP; Thermo Electron Corporation). For quality assurance, reference material (spruce powder validated with certified peach leaves [SRM 1547; Pineco Trading] and human hair) and blanks were included in the element-determination procedure. The results were expressed as μg g^{-1} dry weight. The analyses were accepted when recoveries ranged between 90% and 110% of the certified values. Average element detection limits were as follows: 0.004 μg/g (Mg), 0.014 μg/g (Mn), 0.034 μg/g (Fe), 0.020 μg/g (Zn), 0.005 μg/g (Cu), 0.011 μg/g (As), 0.0004 μg/g (Cd), 0.003 μg/g (Mo), 0.002 μg/g (Ni), 0.015 μg/g (Se), and 0.009 μg/g (Pb) for kidney, liver, hair, and spine.

Statistical Analysis

Multivariate analyses of variance (MANOVA; $n = 4$) were performed to investigate the effect of age and sex and their interactions with metal, As, and Se concentrations in the studied tissues. When necessary, the dependent variables were [$\log_{10}(x + 1)$ or $1/(x + 1)$] transformed to meet the normality assumption. Equality of variances was checked with Levene's test. There were strong correlations among some of the elements. Removing elements from the analyses so that no strong correlations remained did not have any effect on the results. Therefore, all metals, As, and Se were included in the final MANOVA analyses. However, all dependent variables did not meet the normality assumption, even after transformations (hair: Mn, Ni, and Se; liver: Ni). These variables were excluded from MANOVA and, instead, nonparametric Mann–Whitney *U* tests were conducted. Inspection of the residuals did show slight deficiencies in one variable (Mn), but no large values of Cook's distance were observed. After MANOVAs were performed, linear regressions were performed separately for each metal to investigate their relations with age.

Nonparametric, repeated-measures analyses of variance (Friedman's test) were performed to compare the concentration of each metal, Se, and As among tissues. Wilcoxon's signed-rank tests were conducted for each pair of tissues to evaluate which ones differed from each other in their concentration of metals, As, and Se. Spearman's rank correlations were calculated to study the relations between metals, As, and Se, and the p values were corrected with the Bonferroni adjustment. All nondetectable values were treated as zero values when calculating mean ± SE values and in the statistical analysis. Statistical significance was set at $p < 0.05$. SPSS 16.0 for Windows (SPSS Inc., USA) was used for the statistical analysis.

Results

Our measurements were as follows: (1) body size [weight (g)]: female 506 ± 48 ($n = 31$) and male 529 ± 52 ($n = 32$); (2) nose to tail (cm): female 21 ± 0.6 ($n = 23$) and male 22 ± 0.5 ($n = 22$); and circumference (cm): female 27 ± 1.3 ($n = 20$) and male 28 ± 1.4 ($n = 21$). These measurements are in accordance with those of the average European hedgehog (Reeve 1994). In addition, the age distribution in our data are in line with earlier studies and life span estimates for hedgehogs (Fig. 1) (Kristoffersson 1971; Kristiansson 1981). Whole-age distribution was represented in our data (Fig. 1). The average age in the whole data was 1.5 ± 0.3 years for female and 1.7 ± 0.4 years for male hedgehogs (mean ± SE), respectively. The oldest studied female hedgehog was 5 years old, and the oldest male hedgehog was 7 years old. Young individuals who starved to death were compared with road-killed young individuals, but there were no significant differences in mean concentrations of metals, As and, Se between these groups (data not shown).

Mean concentrations of the measured metals, As, and Se in different hedgehog tissues are listed in Table 1. According to Friedman test, As, Cd, and Se concentrations were highest in kidney, whereas Fe, Mg, Mn, Mo, Pb, and Zn were predominantly highest in liver, and Cu and Ni were highest in hair. All of the elements quantified in this study were detected in all samples, with one exception: Mo was not detected in hair and spine.

MANOVAs showed that age was the only important parameter explaining the variation in concentrations when all measured elements were taken together (Table 2). Sex and age–sex interaction were insignificant in explaining differences for any tissue. Therefore, they were excluded from further analyses. The effects of age and sex on concentrations of those metals that were excluded from the

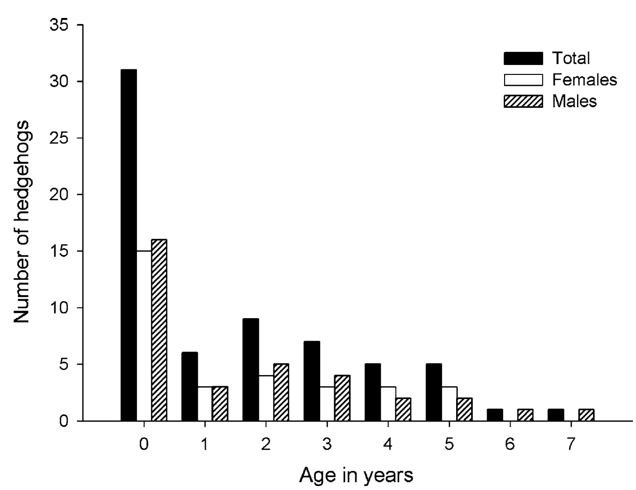

Fig. 1 Age and sex distribution of studied hedgehogs

Table 1 Metal, As, and Se concentrations in tissues (μg/g dry weight) of hedgehogs

Element	Hair ($n = 65$)	Spines ($n = 63$)	Kidney ($n = 64$)	Liver ($n = 58$)
As				
Mean ± SE	0.46[a] ± 0.05	0.42[a] ± 0.03	0.47[a] ± 0.02	0.45[a] ± 0.02
Min–max	<LD–1.62	0.16 –1.56	0.13–1.10	0.27–1.06
Cd				
Mean ± SE	0.04[a] ± 0.004	0.04[a] ± 0.002	5.74[b] ± 0.61	1.81[c] ± 0.20
Min–max	<LD–0.16	<LD–0.08	0.71–21.35	0.26–7.68
Cu				
Mean ± SE	24.38[b] ± 1.15	11.13[c] ± 0.50	17.17[a] ± 0.65	18.53[a] ± 0.88
Min–max	13.39–55.98	7.58–33.78	8.84–38.07	9.80–48.65
Fe				
Mean ± SE	25.30[a] ± 12.61	22.94[b] ± 1.67	294.43[c] ± 13.19	1023.69[d] ± 65.60
Min–max	<LD–827.46	4.69–79.14	126.96–768.57	361.77–2849.76
Mg				
Mean ± SE	144.88[a] ± 10.36	358.39[b] ± 10.63	600.36[c] ± 15.77	731.04[d] ± 15.07
Min–max	46.33–460.47	247.83–686.15	360.58–938.21	519.22–1086.24
Mn				
Mean ± SE	2.21[a] ± 0.52	1.85[a] ± 0.26	2.38[a,b] ± 0.14	6.33[c] ± 0.12
Min–max	<LD–31.11	<LD–9.48	0.90–5.44	1.69–19.18
Mo				
Mean ± SE	<LD	<LD	0.78[a] ± 0.04	2.55[b] ± 0.12
Min–max			0.29–1.96	1.47–5.12
Ni				
Mean ± SE	0.49[a] ± 0.14	0.14[b,d] ± 0.01	0.17[c,d] ± 0.05	0.07[c] ± 0.02
Min–max	<LD–8.82	<LD–0.69	<LD–2.11	<LD–0.83
Pb				
Mean ± SE	0.98[a] ± 0.19	0.54[a,b] ± 0.12	0.95[a,c] ± 0.10	1.03[a,c] ± 0.10
Min–max	<LD–7.10	<LD–7.02	<LD–4.50	<LD–3.90
Se				
Mean ± SE	0.18[a] ± 0.03	0.69[b] ± 0.03	4.63[c] ± 0.23	2.40[d] ± 0.07
Min–max	<LD–1.02	0.05–1.65	2.05–11.36	1.22–3.89
Zn				
Mean ± SE	167.85[a] ± 2.28	90.93[b] ± 0.79	103.22[c] ± 2.81	228.97[a,d] ± 17.16
Min–max	134.28–217.50	80.59–108.90	52.15–161.57	79.96–586.88

Min minimum, *max* maximum, *LD* limit of detection

Mean ± SE shown as minimum and maximum values

[a,b,c,d] Friedman tests (performed for all tissues) yielded <0.001 [except for As ($p = 0.157$)] for metals and Se. Mean concentrations followed by the same letter did not differ significantly from each other (Wilcoxon). Concentrations of Ni and Pb were lower than the LD in kidney for 16 and 2 individuals, respectively, and in liver for 32 and 2 individuals, respectively. Levels of As, Cd, Fe, Mn, Ni, Pb, and Se in hair were lower than the LD for 12, 14, 7, 13, 6, 14, and 37 individuals, respectively. One, 13, 2, and 1 individual(s) showed spine concentrations lower than the LD for Cd, Mn, Ni, and Pb, respectively. All individuals showed spine and hair concentrations lower then the LD for Mo

MANOVAs [because they did not fulfill the normality assumptions (hair: Mn, Ni, and Se; liver: Ni)] were tested with nonparametric Mann–Whitney *U* test, but no significant differences were found.

Linear regressions showed that there was a strong tendency for Cd, Se, and Mo to accumulate with age in hedgehog tissues (Figs. 2, 3, 4, 5). Cu (spine), Fe (liver), and Mn (spine) also accumulated with increasing age. By contrast, Cu (kidney), Mg (hair, spine, kidney, and liver), Mn (kidney and liver), and Zn (hair, kidney and liver) concentrations decreased with increasing age (Figs. 2, 3, 4, 5). In kidney and liver, the concentrations of Mg and Mn, in particular, decreased clearly with increasing age. There were also strong positive correlations between Cd and Se and between Cd and Mo in these tissues (Fig. 6). Significant correlation coefficients after Bonferroni adjustment

Table 2 Results of MANOVA describing how age, sex, and age × sex interaction explain the variation in concentrations of all metals, As, and Se for hair, spine, kidney, and liver

	F	*P*
Hair		
Age	7.740	<0.001
Sex	0.543	0.851
Interaction	0.736	0.687
Kidney		
Age	21.323	<0.001
Sex	0.570	0.831
Interaction	1.409	0.203
Spine		
Age	10.102	<0.001
Sex	1.196	0.320
Interaction	0.729	0.649
Liver		
Age	25.037	<0.001
Sex	0.674	0.742
Interaction	1.056	0.415

between metals, As, and Se in liver, kidney, hair, and spine of hedgehogs are listed in Table 3 and Fig. 6.

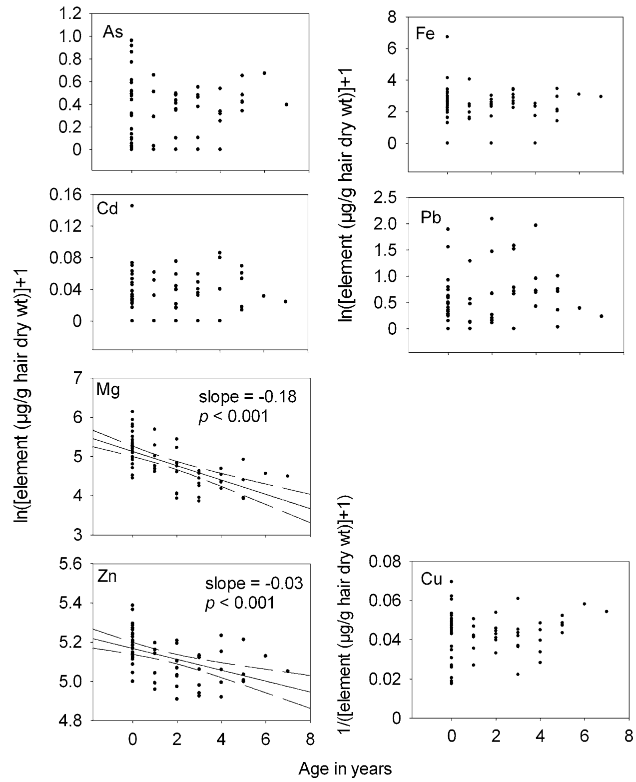

Fig. 2 Relations between age and metals and As concentrations in hair of hedgehogs. Linear regressions with 95% confidence limits (*long dash lines*) were performed separately for each element. Only results of significant regressions are shown. Slope and significance level are indicated in the figure

Discussion

Concentrations of Measured Elements

Concentrations of the measured metals, As, and Se were mainly in the same range as found in studies on other insectivores in nonpolluted reference areas in Finland (Pankakoski et al. 1994), but they were lower compared with studies made in more polluted areas (e.g., D'Havé et al. 2005a, 2006b; Hunter and Johnson 1982; Hunter et al. 1989; Komarnicki 2000; Pankakoski et al. 1993). The most toxic heavy metals (Cd and Pb) were recorded in low values in kidney and liver of hedgehogs. These concentrations represent only 20% of the values found in a more polluted area in Belgium (D'Havé et al. 2005a, 2006b) and only 2% of the values that may cause toxic effects in small mammals (Cooke and Johnson 1996; Ma 1996). In addition, the concentrations of Pb in both liver and kidney were higher in other insectivores compared with the present study (Andrews et al. 1989; Komarnicki 2000; Ma 1989; Ma et al. 1991; Pankakoski et al. 1994), but some exceptions existed (Chmiel and Harrison 1981).

In this study, the distribution of metals, As, and Se in tissues was similar to that reported by some earlier studies (e.g., D'Havé et al. 2005b). Ni was mainly stored in the hair, and thus hair loss may be an important way to eliminate this often nonessential element. As expected, the highest Cd concentrations were found in kidney and liver. Compared with adults, the young hedgehogs had higher Zn and Cu concentrations in liver. In many mammals, Zn and Cu concentrations are fairly high in the livers of newborn and just recently weaned young, which is probably caused by placental transfer and storage before birth (Moss et al. 1974; Hyvärinen and Nygren 1993). In addition, Cu and Zn reserves are probably associated with metalloproteins (Webb and Cain 1982) and stored until required during neonatal development.

Age-Related Accumulation and Interactions Between the Measured Elements

Hedgehogs also accumulate heavy metals in comparatively unpolluted areas. A clear accumulation of Cd with increasing age was observed in kidney, liver, and spine of hedgehogs. Kidney and liver, in addition to intestinal mucosa, have been shown to be the main sites for Cd accumulation (Bremner 1979); consequently, toxic symptoms are typically seen first in kidney (Travis and Haddock 1980; Shore and Douben 1994b; Komarnicki 2000). This

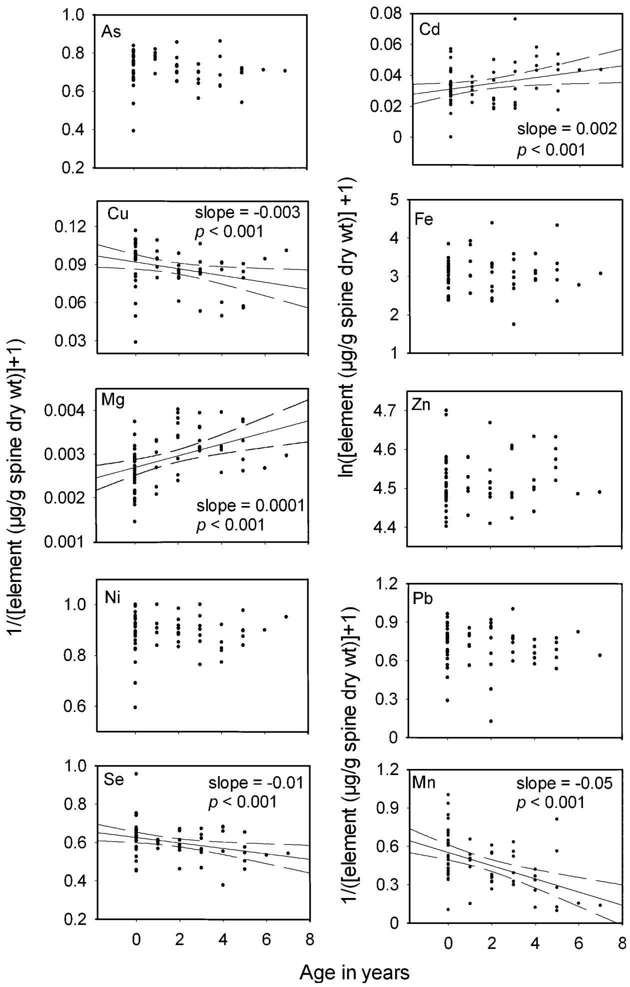

Fig. 3 Relations between age and metals, As and Se concentrations in spine of hedgehogs. Linear regressions with 95% confidence limits (*long dash lines*) were performed separately for each element. Only results of significant regressions are shown. Slope and significance level are indicated in the figure

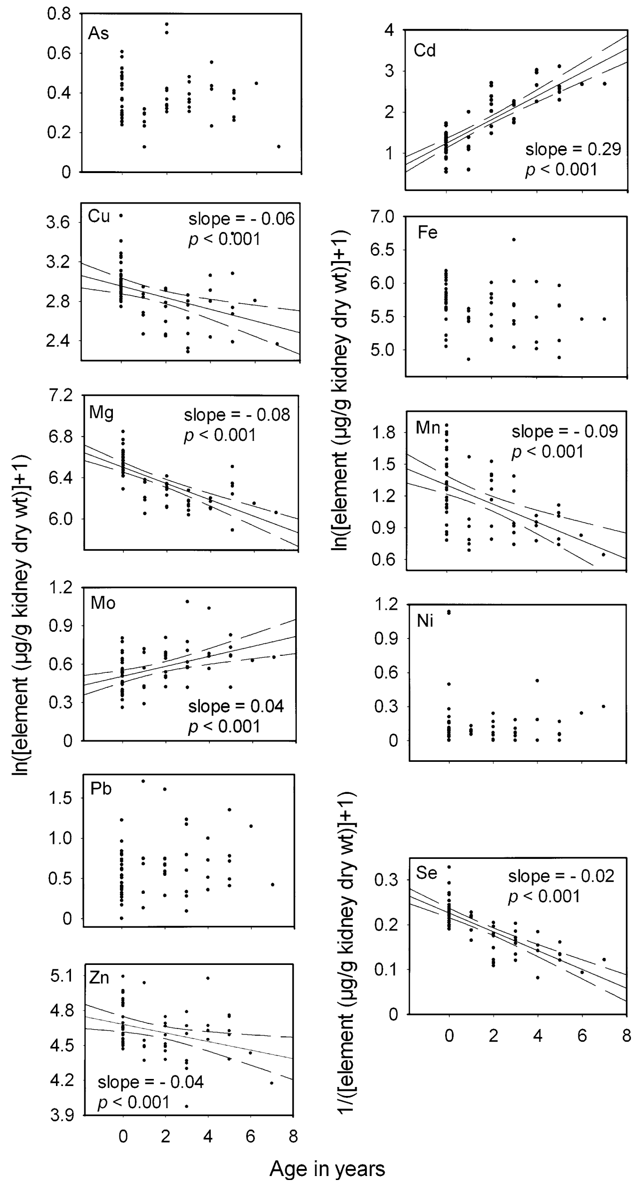

Fig. 4 Relations between age and metals, As and Se concentrations in kidney of hedgehogs. Linear regressions with 95% confidence limits (*long dash lines*) were performed separately for each element. Only results of significant regressions are shown. Slope and significance level are indicated in the figure

study comprised a fairly unpolluted area, but in strongly contaminated areas the concentrations of Cd may reach much higher levels in insectivores (Ma and Talmage 2001). This study shows that a relatively long-living hedgehog can accumulate heavy metals and that this may have negative effects on survival in polluted areas. Weight loss and even mortality is high during the hibernation, and in polluted areas stress caused by contaminant body burden may be increased. In contrast, hibernation also protects hedgehogs against toxic heavy metals. Cd is bound in proteins (e.g., Underwood and Suttle 1999), and during the winter fast its body burden is not increased. Actively wintering small mammals are forced to increase their food intake in cold, and therefore their heavy metal exposure may increase during the winter. Any further stress caused by contaminant body burden might be drastic to northern hedgehog populations because hedgehogs must gain more weight to survive the hibernation period than those living in more southern latitudes. Age-related Cd accumulation has been reported in some insectivores (e.g., Pankakoski et al. 1993; Shore and Douben 1994b; Komarnicki 2000) and also in other small mammals (e.g., McKinnon et al. 1976; Wren 1986; Hillis and Parker 1993), but not in hedgehogs. In overwintered adult moles (*Talpa europaea*), the average concentrations of Cd can be 3 and 15 times higher in the liver and kidney tissues, respectively, compared with juvenile moles (Pankakoski et al. 1993).

In all the analyzed tissues, Se concentration increased significantly with increasing age. Although the highest

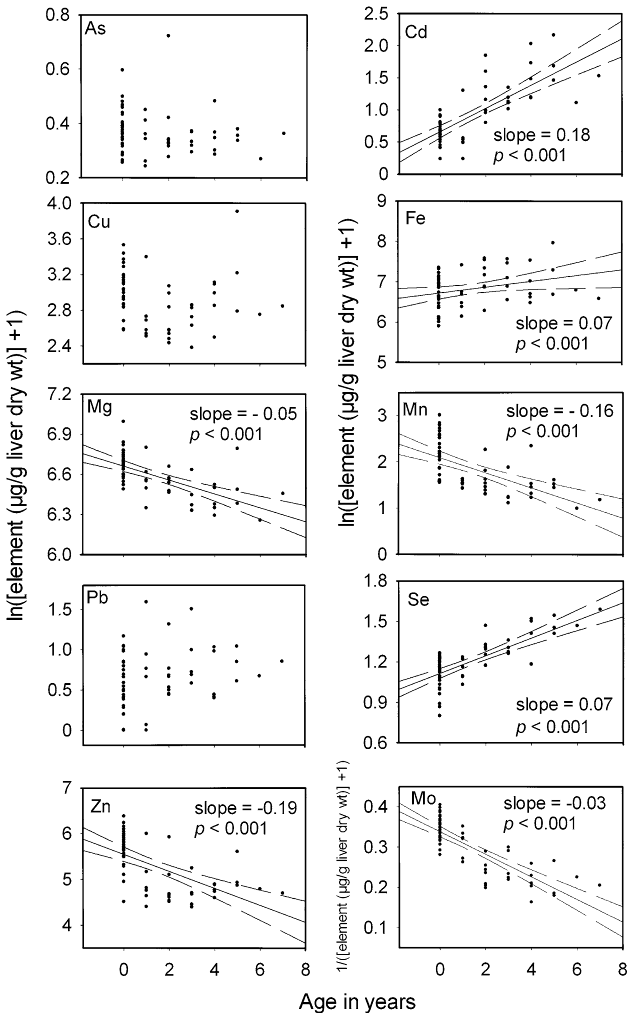

Fig. 5 Relations between age and metals, As and Se concentrations in liver of hedgehogs. Linear regressions with 95% confidence limits (*long dash lines*) were performed separately for each element. Only results of significant regressions are shown. Slope and significance level are indicated in the figure

average levels (<5 µg/g) in the studied hedgehogs were only 5% of the concentrations in small mammals in some polluted areas in California (Clark 1987), the concentrations were higher than the values found in an unpolluted site (1.56 µg/g) (Clark et al. 1992). In Finland, the concentration of Se in soil is naturally low, and thus Se has been added to agricultural fertilizers since the 1980s (Arthur 2003). In mammals, Se has a protective effect against increased heavy-metal concentrations. It tends to counteract, for example, the toxic effects of Cd (Wlodarczyk et al. 1995). The elimination of Hg toxicity is also well known (Koeman et al. 1973), and Se supplements have been shown to improve the reproduction performance of Ni-exposed rats (Käkelä et al. 1999). Similar increases of Se and Cd concentrations with increasing age in liver and kidney and strong positive correlations between these elements indicate that there is an interaction between these elements. Thus, Se may also have a protective role against Cd toxicity in hedgehogs.

The concentration of Mo had a tendency to increase with increasing age in hedgehog tissues. This has been shown also in greater white-toothed shrews (*Crocidura russula*) (Sánchez-Chardi et al. 2007). Especially liver, but also in kidney, Mo concentrations correlated positively with Cd concentrations (Fig. 6). Like Se, Mo might provide protection against the effects of increased heavy-metal concentrations. It has been suggested that sodium molybdate (Na_2MoO_4) is able to alleviate the acute toxicity of cadmium chloride ($CdCl_2$) in rat, and the protective mechanism of the metal is partly related to the enhancement of liver Cd–metallothionein induction (Yamane et al. 1990). Increased dietary levels of Mo and sulfur (S) decreased accumulation of Cd in tissues of sheep (Smith and White 1997). We assume that hedgehogs have been at comparatively high risk for heavy-metal toxicity due to their diet, even before humans caused pollution. Therefore, the detoxification mechanisms of hedgehog against heavy metals might be better developed during evolution than in most other terrestrial mammals. The observed increases of Mo and Se concentrations in liver and kidney, already after comparatively low Cd accumulation, may be connected with this. More studies are required to confirm the possible protective role of Se and Mo against any increased heavy-metal concentrations in hedgehogs.

Conclusion

The results of the present study demonstrate the considerable influence of age on heavy-metal contents in hedgehogs. We also showed that male and female hedgehogs do not differ in their metal, As, and Se tissue contents. Cd concentrations accumulated strongly with increasing age in the liver and kidney. The essential elements, such as Se (all tissues) and Mo (kidney and liver), also increased greatly with increasing age. In this study, heavy-metal concentrations were low, but results clearly indicate the possible risk of age-related accumulation. Hedgehogs are long-living insectivores that yearly go through a long hibernation period. Additional studies are needed to demonstrate the effects of increased heavy-metal concentrations in more polluted areas. In addition, the protective role of Se and Mo against Cd must be studied more. Age-specific accumulation of heavy metals and other environmental toxins might be an important factor to be considered when assessing the reasons for local extinctions or population declines of small mammals. Our results from a comparatively unpolluted area represent valuable background levels for comparison with more polluted sites in the future.

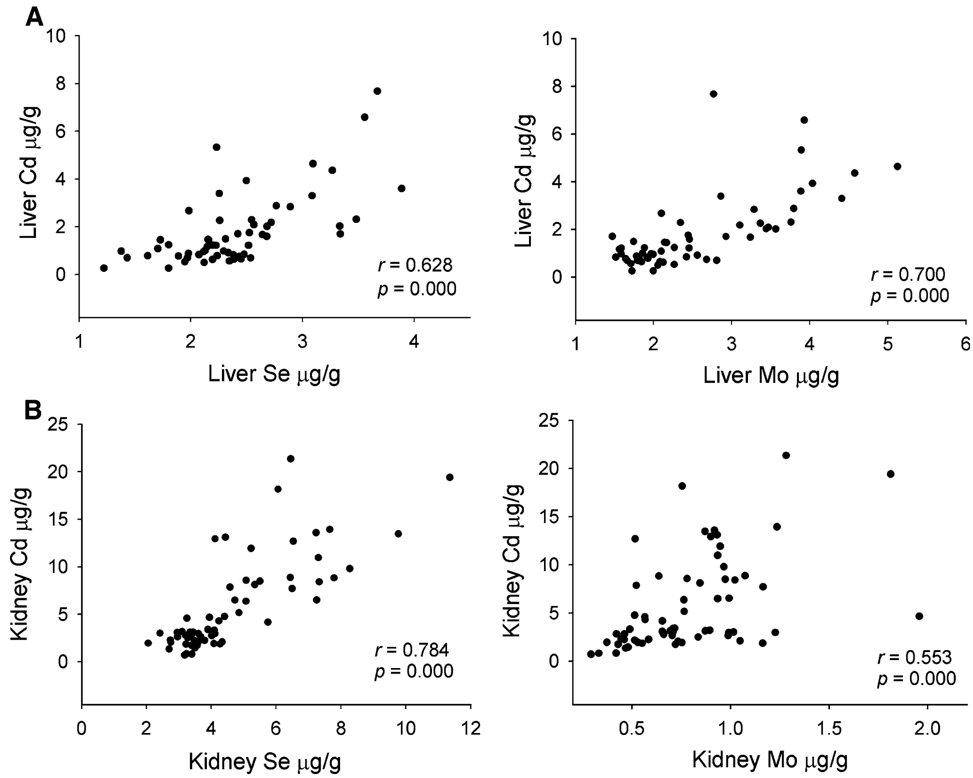

Fig. 6 Correlations between **a** Cd and Se and Cd and Mo in liver and **b** between Cd and Se and Cd and Mo in kidney. Spearman's rank correlation coefficients (*r*) and their *p* values are shown (see also Table 3)

Table 3 Spearman's rank correlation coefficients and *p* between metals, As, and Se in liver, kidney, hair, and spine of hedgehogs

Element	Liver			Kidney			Hair			Spines	
	r	*p*		*r*	*p*		*r*	*p*		*r*	*p*
Cd/Mo	0.700	<0.001	Cd/Mg	−0.614	<0.001	Mg/Se	−0.552	<0.001	Cd/Mn	0.618	<0.001
Cd/Se	0.628	<0.001	Cd/Mn	−0.396	0.001	Mg/Zn	−0.494	<0.001	Cd/Pb	0.540	<0.001
Cu/Mn	0.466	<0.001	Cd/Mo	0.553	<0.001				Cu/Mg	−0.479	<0.001
Cu/Zn	0.475	<0.001	Cd/Se	0.784	<0.001						
Mg/Mn	0.619	<0.001	Cu/Mg	0.545	<0.001						
Mg/Mo	−0.595	<0.001	Cu/Mn	0.521	<0.001						
Mg/Se	−0.428	0.001	Cu/Se	−0.394	0.001						
Mg/Zn	0.514	<0.001	Cu/Zn	0.489	<0.001						
Mn/Mo	−0.534	<0.001	Fe/Mg	0.446	<0.001						
Mn/Se	−0.435	0.001	Mg/Mn	0.485	<0.001						
Mn/Zn	0.637	<0.001	Mg/Se	−0.675	<0.001						
Mo/Se	0.635	<0.001	Mg/Zn	0.441	<0.001						
Mo/Zn	−0.501	<0.001	Mo/Se	0.546	<0.001						

Only *p* values significant after Bonferroni correction are shown

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