Bull Environ Contam Toxicol (2010) 85:486–491
DOI 10.1007/s00128-010-0146-2

Concentrations of Trace Elements in Tissues of Red Fox (*Vulpes vulpes*) and Stone Marten (*Martes foina*) from Suburban and Rural Areas in Croatia

Nina Bilandžić · Danko Dežđek · Marija Sedak · Maja Đokić · Božica Solomun · Ivana Varenina · Zorka Knežević · Alen Slavica

Received: 12 July 2010 / Accepted: 29 October 2010 / Published online: 11 November 2010

Abstract Trace elements concentrations (As, Cd, Cu, Pb and Hg) were determined in the liver, kidney and muscle of 28 red fox (*Vulpes vulpes*) and 16 stone marten (*Martes foina*) from suburban and rural habitats from Croatia. Rural and suburban habitats affected Cd and Hg levels in the muscle, liver and kidney of red fox. Significant differences in metal concentrations in the muscle, liver and kidney were detected among species. Suburban stone marten accumulated the highest levels of trace elements (mg/kg w.w.): in muscle 0.019 for Hg; in liver 0.161 for Cd, 36.1 for Cu and 0.349 for Pb; in kidney 1.34 for Cd and 0.318 for Pb. Values observed were higher than those found in suburban red fox and therefore, may represent an important bioindicator for the accumulation of toxic metals in urbanized habitats.

Keywords Red fox · Rural habitat · Stone marten · Suburban habitat · Toxic metals

N. Bilandžić (✉) · M. Sedak · M. Đokić · B. Solomun · I. Varenina · Z. Knežević
Department of Veterinary Public Health, Laboratory for Residue Control, Croatian Veterinary Institute, Savska cesta 143, HR-10000 Zagreb, Croatia
e-mail: bilandzic@veinst.hr

D. Dežđek
Laboratory for General Pathology, Department of Pathological Morphology, Croatian Veterinary Institute, Savska cesta 143, HR-10000 Zagreb, Croatia

A. Slavica
Department of Game Biology, Pathology and Breeding, Faculty of Veterinary Medicine, University of Zagreb, Heinzelova 55, 10000 Zagreb, Croatia

In highly industrialised areas with metallurgy, petrochemical and fertilizer industries, high levels of arsenic (As), copper (Cu) and lead (Pb) have been determined in the air (Sánchez de la Campa et al. 2007). Various anthropogenic emission activities are also a major cause of increased environmental concentrations of cadmium (Cd), mercury (Hg) and Pb. Since there is no effective mechanism for toxic element elimination due to their potential toxicity and accumulation in various compartments, chronic lower level intakes have damaging effects on both human and animals (Ikeda et al. 2000).

Although it is an essential metal required in the diet, Cu may produce toxic effect such as liver cirrhosis, dermatitis and neurological disorders (Storelli et al. 2007). Lead is one of the most widespread metal pollutants in the environment, even in rural areas. Mercury levels are biomagnified within terrestrial food chains and among carnivorous species, but are generally highest in fish-eating animals (Millán et al. 2008). The toxicological impacts of accumulated methylated forms of Hg were recorded in the American mink (*Mustela vison*) (Osowski et al. 1995). Risk of heavy metal exposure for carnivores may exist due to abandoned mines that have undergone little or no post-operational remediation (Reglero et al. 2008). Genotoxic damage in several species of terrestrial vertebrates, caused by pollution near mine sites, was reported in Spain (Millán et al. 2008). Determination of heavy metals in carnivorous mammals is important, given the fact that these animals are at the top of the food web and may therefore, be very sensitive to any ongoing biomagnification processes.

There are no mining activities in Croatia. Industrial production is centred in large cities such as Zagreb, Sisak or Rijeka. Pollution from sources causing the accumulation of Cd, Pb and Hg in tissues of free-living animals has been recorded (Reglero et al. 2008). Wild animal species, such as red deer, reindeer, roe deer or wild boar have been used in biomonitoring studies of contamination in free-migrating animal animals related to very large territories (Bilandžić et al. 2009). Some carnivores, such as red fox (*Vulpes vulpes*) and stone marten (*Martes foina*), settle in small territories and often adapt to urbanized areas. Because of the increased utilization of urbanized habitats, red fox and stone marten are suitable for monitoring the presence of anthropogenic pollutants in cities or suburbs (Dip et al. 2001). Both species are widely distributed across continental Croatia and represent an important ecological component of environments as a carnivore and scavenger.

The present biomonitoring study observed differences in metal levels as environmental contaminants (As, Cd, Cu, Pb and Hg) in tissues of red fox (*Vulpes vulpes*) and stone marten (*Martes foina*) that have invaded suburban and rural habitats in Croatia.

Materials and Methods

Muscle, liver and kidney tissues of 28 (16 from rural and 12 from suburban areas) red foxes (*Vulpes vulpes*) and 16 (8 from rural and 8 from suburban areas) stone martens (*Martes foina*) were collected during 2008 and 2009. All specimens were collected by quick-kill techniques (i.e. shooting, quick-kill traps), with the exception of five red foxes and four stone martens, which were road-killed. Red foxes and stone martens were hunted and collected in suburban areas of the cities Zagreb and Varaždin and from rural areas (villages, marshes and woods near villages) in the Hrvatsko Zagorje region in continental Croatia. Age was estimated by tooth wear. All animals sampled were adults. Upon collection, all muscle, liver and kidney samples were placed into labelled plastic bags and stored at −18°C to avoid tissue degradation prior to laboratory analyses. All tissue samples were homogenized prior to analysis.

All reagents were of analytical reagent grade, HNO_3, H_2O_2 and HCl (Analytical Grade, Kemika, Croatia). Double deionised water (Milli-Q Millipore, 18.2 MΩ/cm resistivity) was used for all dilutions. Plastic and glassware were cleaned by soaking in diluted HNO_3 (1/9, v/v) and rinsed with distilled water prior to use. Calibrations were prepared with element standard solutions of 1 g/l of each element supplied by Perkin Elmer. Stock solution was diluted in HNO_3 (0.2%). As matrix modifiers in each atomization for Pb and Cd, 0.005 mg $Pd(NO_3)_2$ and 0.003 mg $Mg(NO_3)_2$ (Perkin Elmer, USA) were used.

Sample tissues (2 g) were digested with 5 ml of HNO_3 (65% v/v), 1 ml of H_2O_2 (30% v/v) with a microwave oven. A blank digest was carried out in the same way. The Multiwave 3,000 microwave closed system (Anton Paar, Germany) was used for sample digestion. The digestion program began at a potency of 1,200 W and was then ramped for 10 min, after which samples were held at 1,200 W for 10 min. Digested samples were diluted to a final volume of 50 ml with double deionised water.

Analyses of As, Cd, Cu and Pb concentrations were conducted by graphite furnace-atomic absorption spectroscopy using an AAnalyst 800 atomic absorption spectrometer (Perkin Elmer, USA) equipped with an AS 800 autosampler (Perkin Elmer, USA). For graphite furnace measurements, argon was used as the inert gas. Pyrolytic-coated graphite tubes with a platform were used. The atomic absorption signal was measured in peak area mode against a calibration curve. Mercury in tissues samples were quantified without acid digestion using the AMA-254 (Advanced Mercury Analyzer, Leco, Poland), which employs direct combustion of the sample in an oxygen-rich atmosphere.

Randomly selected samples were analyzed in duplicate to estimate the precision of the results generated by GFAAS and Mercury Analyzer analysis. The wet weight (w.w.) limits of detection for the metals studied (LODs, mg/kg) and analyzed by GFAAS were: in kidney As 0.01, Cd 0.004, Cu 0.005 and Pb 0.005; in liver As 0.01, Cd 0.0004, Cu 0.0005 and Pb 0.0005; in muscle As 0.01, Cd 0.0004, Cu 0.0005 and Pb 0.005. For Hg analyzed by AMA-254 LODs were: Hg 0.00004 in kidney, Hg 0.0001 in liver and Hg 0.0005 in muscle. All specimens were run in batches that included blanks, a standard calibration curve, two spiked specimens, and one duplicate.

The quality of data was checked by the analysis of recovery rate using certified reference materials: bovine liver (BCR 185R, IRMM, Belgium) and muscle tissue (ERM-CE278, IRMM, Belgium). A reference sample of bovine liver (BCR 185R, IRMM, Belgium) was analyzed ($n = 5$) and the recovery (mean % recovery ± SE) was 93.9 ± 5.7% for As, 98.3 ± 2.5% for Cd, 98.2 ± 3.6% for Cu, and 97.1 ± 4.2% for Pb (no Hg certified value is available). A reference sample of muscle tissue (ERM-CE278, IRMM, Belgium) was analyzed ($n = 5$) and the recovery was 96.6 ± 6.3% for As, 97.9 ± 5.5% for Cd, 99.3 ± 4.6% for Cu, 96.4 ± 3.6% for Hg and 97.5 ± 4.1% for Pb.

Statistical analysis was performed using the Statistica® 6.1 (StatSoft® Inc., Tulsa, USA). To calculate mean metal concentrations in different tissues, non-detectable concentrations were assigned a value of half the quantification limit. Data were grouped according to species, tissue and sampling area. Concentrations were expressed as mean ± standard error, minimum and maximum values. Analysis of variance (general linear model) was used to evaluate the influence of habitat (rural or urban) on toxic metal concentrations in tissues. Differences between metal content in the muscle, liver and kidney were tested using the Student's t test. All statements of significance were based on the 0.05 level of probability.

Results and Discussion

According to the literature, this is the first study to determine the accumulation of heavy metals in red fox (*Vulpes vulpes*) and stone marten (*Martes foina*) as wild carnivores in rural and suburban areas in Croatia. Very few studies have been carried out to investigate metal exposure in stone marten and also to compare metal exposure between wild carnivores from rural and suburban habitats.

Concentrations of As, Cd, Cu, Hg and Pb in muscle, liver and kidney tissues of red foxes and stone marten are presented in Tables 1, 2 and 3. The highest Cd levels were found in liver and kidney of stone marten. A habitat influenced Cd accumulation in tissues of red fox: muscle, liver and kidney Cd concentrations in red fox from suburban areas were higher than those in red fox from rural areas. Muscle Cd levels detected were similar to those reported in red fox and also to the Egyptian mongoose, Iberian lynx and common genet from Andalusia, Spain (Millán et al. 2008). Mean Cd concentrations in liver reported in various carnivores ranged from 0.10 to 0.30 mg/kg (Hoekstra et al. 2003; Millán et al. 2008). In the present study, mean Cd liver and kidney levels observed in suburban red fox were 7 to 15-fold lower than levels found in red fox from suburban areas in Switzerland (0.94 and 1.82 mg/kg; Dip et al. 2001). Also, Cd levels in kidney of red fox were 4 to 20-fold lower than Arctic fox from Canada (1.08 mg/kg; Hoekstra et al. 2003). Hepatic Cd observed in rural red fox in this survey were 5 to 26-fold lower than those found in red fox from Andalusia, Spain (0.113 mg/kg; Millán et al. 2008), Italy (0.62 and 0.1 mg/kg; Corsolini et al. 1999; Alleva et al. 2006) and Arctic fox from Canada (0.21 mg/kg; Hoekstra et al. 2003). It is well known that Cd biomagnifies through the food chain and the toxicodynamics of Cd within organisms has shown that the main body stores of Cd are the liver and kidney (Burger 2008).

In this study, differences in Cd levels in tissues between species were detected. Measured hepatic Cd levels in rural and suburban stone marten were 6-fold lower than in stone marten (*Martes foina*) from Urbino-Pesaro Province, Italy (0.96 mg/kg; Alleva et al. 2006). Cadmium liver levels reported were similar when compared with levels described in the liver of Iberian lynx, red fox and Egyptian mongoose from Andalusia, Spain (Millán et al. 2008). Cadmium kidney concentrations detected in all three species were much lower than the suggested injury thresholds of Cd in the renal cortex (200 mg/kg) related to chronic intoxication (Beyer 2000).

In the present study, the highest Pb concentrations among species were detected in liver and kidney tissues of suburban stone marten. Lead levels detected in kidney were affected by environmental condition which is demonstrated with higher levels in suburban than in rural red fox. However, lead liver levels observed in suburban and rural red fox were lower than levels found in suburban (0.47 mg/kg) and rural red fox (0.37 mg/kg) from Switzerland (Dip et al. 2001) and also lower than those found in red fox from Andalusia, Spain (0.257 mg/kg; Millán et al. 2008), Italy (0.64 and 0.37 mg/kg; Corsolini et al. 1999; Alleva et al. 2006) and in Arctic fox from Canada (0.53 mg/kg; Hoekstra et al. 2003). In muscle tissue, Pb levels detected were

Table 1 Trace elements concentrations (mean ± SE and range; mg/kg, w.w.) in muscle of red fox and stone marten from Croatia

	As	Cd	Cu	Hg	Pb
Red fox suburban ($n = 12$)					
Mean ± SE	0.02 ± 0.004	$0.002 \pm 0.0005^{**,a,b}$	$3.57 \pm 0.575^{a,b}$	$0.007 \pm 0.002^{a,c}$	0.053 ± 0.024
Range	0.002 – 0.040	0.0003 – 0.006	1.55 – 8.12	0.0008 – 0.020	0.005 – 0.299
Red fox rural ($n = 16$)					
Mean ± SE	0.014 ± 0.002	$0.0006 \pm 0.0001^{**,a,d}$	$3.04 \pm 0.249^{b,c}$	$0.004 \pm 0.0007^{b,c,d}$	$0.040 \pm 0.025^{a,b}$
Range	0.002 – 0.029	0.0002 – 0.001	1.90 – 5.31	0.0006 – 0.011	0.005 – 0.410
Stone marten suburban ($n = 8$)					
Mean ± SE	0.11 ± 0.001	$0.004 \pm 0.001^{a,d}$	3.11 ± 0.735^{a}	$0.019 \pm 0.006^{a,c}$	0.028 ± 0.011^{a}
Range	0.005 – 0.020	0.001 – 0.009	1.92 – 8.16	0.005 – 0.059	0.003 – 0.092
Stone marten rural ($n = 8$)					
Mean ± SE	0.019 ± 0.005	$0.006 \pm 0.001^{b,d}$	$1.92 \pm 0.358^{a,b}$	$0.018 \pm 0.004^{c,d}$	0.029 ± 0.078^{b}
Range	0.005 – 0.051	0.001 – 0.013	0.01 – 3.02	0.001 – 0.033	0.003 – 0.056

Superscript letters indicate significant differences among species: [a] $p < 0.05$; [b] $p < 0.01$; [c] $p < 0.001$; [d] $p < 0.0001$

Asterisks indicate significant differences between rural and suburban groups: * $p < 0.05$; ** $p < 0.01$

Where no superscript letters and asterisks are presented, no significant differences were detected

Table 2 Trace elements concentrations (mean ± SE and range; mg/kg, w.w.) in liver of red foxes and stone martens from Croatia

	As	Cd	Cu	Hg	Pb
Red fox suburban ($n = 12$)					
Mean ± SE	0.014 ± 0.003	0.125 ± 0.051*	27.3 ± 8.12	0.025 ± 0.008**	0.131 ± 0.046[a]
Range	0.005 – 0.036	0.0002 – 0.553	5.80 – 86.8	0.003 – 0.080	0.024 – 0.584
Red fox rural ($n = 16$)					
Mean ± SE	0.013 ± 0.002	0.024 ± 0.009*[,b,c]	15.6 ± 3.83	0.009 ± 0.002**[,a,b]	0.058 ± 0.009[a,b]
Range	0.004 – 0.030	0.0002 – 0.099	2.79 – 56.7	0.0004 – 0.027	0.018 – 0.128
Stone marten suburban ($n = 8$)					
Mean ± SE	0.014 ± 0.003	0.161 ± 0.034[c]	36.1 ± 9.62	0.021 ± 0.004[b]	0.349 ± 0.197
Range	0.005 – 0.036	0.051 – 0.325	8.59 – 77.4	0.005 – 0.035	0.021 – 1.71
Stone marten rural ($n = 8$)					
Mean ± SE	0.017 ± 0.003	0.155 ± 0.059[b]	20.6 ± 11.2	0.029 ± 0.009[b]	0.130 ± 0.032[b]
Range	0.01 – 0.030	0.001 – 0.489	2.06 – 97.5	0.010 – 0.078	0.006 – 0.259

Superscript letters indicate significant differences among species: [a] $p < 0.05$; [b] $p < 0.01$; [c] $p < 0.0001$

Asterisks indicate significant differences between rural and suburban group: * $p < 0.05$; ** $p < 0.01$

Where no superscript letters and asterisks are presented, no significant differences were detected

Table 3 Trace elements concentrations (mean ± SE and range; mg/kg, w.w.) in kidney of red fox and stone marten from Croatia

	As	Cd	Cu	Hg	Pb
Red fox suburban ($n = 12$)					
Mean ± SE	0.015 ± 0.003	0.232 ± 0.088*[,a,b]	18.7 ± 7.37	0.064 ± 0.017*	0.189 ± 0.042*
Range	0.005 – 0.036	0.005 – 0.985	3.26 – 81.9	0.007 – 0.164	0.032 – 0.462
Red fox rural ($n = 16$)					
Mean ± SE	0.011 ± 0.002[a]	0.054 ± 0.028*[,b,c,d]	17.1 ± 8.07	0.032 ± 0.005*	0.098 ± 0.020*[,a,b]
Range	0.004 – 0.025	0.001 – 0.428	3.67 – 136.9	0.001 – 0.078	0.021 – 0.316
Stone marten suburban ($n = 8$)					
Mean ± SE	0.011 ± 0.001	1.34 ± 0.470[b,c]	9.02 ± 0.814	0.060 ± 0.009[b]	0.318 ± 0.138[a]
Range	0.005 – 0.018	0.069 – 3.78	6.10 – 12.3	0.020 – 0.105	0.046 – 1.24
Stone marten rural ($n = 8$)					
Mean ± SE	0.019 ± 0.004[a]	0.606 ± 0.136[a,d]	3.19 ± 1.09	0.069 ± 0.015[b]	0.216 ± 0.044[b]
Range	0.005 – 0.032	0.203 – 1.13	0.009 – 7.02	0.018 – 0.128	0.035 – 0.124

Superscript letters indicate significant differences among species: [a] $p < 0.05$; [b] $p < 0.01$; [c] $p < 0.001$; [d] $p < 0.0001$

Asterisks indicate significant differences between rural and suburban group: * $p < 0.05$; ** $p < 0.01$

Where no superscript letters and asterisks are presented, no significant differences were detected

similar to those reported in red fox from Andalusia, Spain (0.053 mg/kg) and to other species observed in Spain (Millán et al. 2008). Mean liver Pb levels observed in stone marten from rural areas (0.130 mg/kg) were lower, while concentrations from suburban areas (0.349 mg/kg) were similar to those found (0.33 mg/kg) in stone marten from Urbino-Pesaro Province, Italy (Alleva et al. 2006). Lead liver and kidney concentrations in all three species observed were below levels related to Pb toxicosis in mammals (10–25 mg/kg; Ma 1996).

The presented results indicate that habitat had no influence on Cu concentrations in red fox or stone marten. Liver tissues had the higher Cu concentrations in all four groups of carnivores. The highest mean Cu levels were observed in liver of suburban stone marten. Copper liver levels found in red fox were 2 to 5-fold lower than Cu levels (72 m/kg d.w.) reported in red fox from Spain (Millán et al. 2008) and 2 to 5-fold higher than those (5.5 and 7.1 m/kg) in Arctic fox from Canada (Hoekstra et al. 2003). Previous investigations have shown that Cu concentrations in liver vary widely among species: 18.2 and 35.4 mg/kg in Iberian lynx, 16.9 mg/kg in Egyptian mongoose, 89.5 mg/kg in Eurasian badger (Millán et al. 2008), 30 mg/kg in polar bear (Woshner et al. 2001) and 47.3–55.9 mg/kg in red deer (Reglero et al. 2008).

In the present study, Cu level differences in muscle and liver tissue among species were observed. The presented muscle Cu levels in red fox were similar to polar bear levels from Alaska (2.97 mg/kg; Woshner et al. 2001) and common genet from Spain (3.71 mg/kg; Millán et al. 2008). However, mean muscle Cu levels were less than half the values measured in red fox from Spain (8.64 mg/kg; Millán et al. 2008). The similar Cu concentrations found in liver in red fox and stone marten from suburban and rural areas suggested that these animals may use the same diet source.

In this study, habitat had significant effects on Hg accumulation in the liver and kidney: mean liver and kidney Hg levels in suburban red fox were higher than in rural red fox. Similar liver Hg levels observed in suburban red fox (0.025 mg/kg) were found in Urbino-Pesaro Province, Italy (0.03 mg/kg; Alleva et al. 2006). However, the hepatic Hg concentrations found were 6 to 18-fold lower than levels (0.16 mg/kg) reported in red fox in Italy (Corsolini et al. 1999), 16 to 43-fold lower (0.393 mg/kg) than in red fox in Spain (Millán et al. 2008) and 85-fold lower (0.77 and 0.85 mg/kg) than in arctic fox in Canadian Arctic (Hoekstra et al. 2003). Muscle Hg levels observed in red fox from rural and suburban areas were 23 to 40-fold lower than levels found in red fox in Spain (0.161 mg/kg; Millán et al. 2008) and in general to other species (Woshner et al. 2001; Millán et al. 2008).

Rural and suburban habitats in the present study had no influence on Hg tissue differences in stone marten. However, differences in Hg tissue concentrations among species were detected. Mean liver Hg levels observed in both stone marten groups were 3.7–5.5 lower than concentrations in stone marten from Urbino-Pesaro Province, Italy (0.11 mg/kg; Alleva et al. 2006) and more than 100-fold lower than levels (1.16–3.30 mg/kg) detected in wild mink in the Northwest Territories, Canada (Poole et al. 1995). Mercury concentrations in liver and kidney tissues of red fox and stone marten in the present study are below levels associated with Hg intoxication for non-marine mammals (20–30 mg/kg w.w.; Thompson 1996). As previously concluded, Hg accumulation is related to local contamination and natural background variability and also to the age of animal and duration of exposure (Hoekstra et al. 2003; Millán et al. 2008).

Arsenic levels measured in suburban and rural red fox and stone marten were not affected by habitat conditions. Significant differences in As levels were detected only in kidney tissue between rural stone marten and rural red fox. Muscle As concentrations were 2.4 to 4.3-fold lower than concentrations (0.047 mg/kg) and 21 to 38-fold lower (0.416 mg/kg) than those observed in red fox from Spain (Millán et al. 2008). Similar hepatic As levels were found in Egyptian mongoose (0.019 mg/kg; Millán et al. 2008). However, observed hepatic As levels were generally lower than in other species: 0.041 mg/kg in Iberian lynx (Millán et al. 2008), 0.044–0.061 mg/kg in red deer (Reglero et al. 2008) and 0.09 mg/kg in polar bear (Woshner et al. 2001).

In general, there are few reports on essential and non-essential metals in stone marten populations and is difficult to provide a comprehensive comparison of the accumulation of these metals to stone marten populations in other countries. The accumulation of elements depends on the physiological requirements in carnivore species and on the elemental level variability in the areas observed (Hoekstra et al. 2003). Differences in metal levels in tissues between the observed species reflect the different feeding selection and behaviour of animals, and the utilization of urban and rural habitat locations. Red foxes feed on a variety of animals, mostly rodent species, often mice and other small animals (amphibians, birds and eggs, reptiles, fish) and carrion. However, in urbanised habitats, red foxes adapt and often prey on rabbits, poultry, rats and carrion (Sidorovich et al. 2010). Stone marten have a similar diet composition and prey by night, mostly on rabbits and mice, different birds and small mammals living in trees (Sidorovich et al. 2010) and also adapt to habitat compartments. In conclusion, the present study shows that stone martens accumulate higher level of metals in tissues than red foxes related to the urbanized environmental compartments, thus suggesting that stone marten may represent an important bioindicator for the accumulation of toxic elements in urbanized habitats.

Acknowledgments The authors are thankful to all those having contributed to the study. Special thanks go to Marijana Fluka and Mirjana Hren for assistance in sample preparation. The study was supported with a grant from the Croatian Veterinary Institute, Zagreb, Croatia.

References

Alleva E, Francia N, Pandolfi N, De Marinis AM, Chiarotti F, Santucci D (2006) Organochlorine and heavy-metal contaminants in wild mammals and birds of Urbino-Pesaro Province, Italy: an analytical overview for potential bioindicators. Arch Environ Contam Toxicol 51:123–134

Beyer WN (2000) Hazards to wildlife from soil-borne cadmium reconsidered. J Environ Qual 29:1380–1384

Bilandžić N, Sedak M, Vratarić D, Perić T, Šimić B (2009) Lead and cadmium in red deer and wild boar from different hunting grounds in Croatia. Sci Total Environ 407:4243–4247

Burger J (2008) Assessment and management of risk to wildlife from cadmium. Sci Total Environ 389:37–45

Corsolini S, Focardi S, Leonzio C, Lovari S, Monaci F, Romeo G (1999) Heavy metals and chlorinated hydrocarbon concentrations in the red fox in relation to some biological parameters. Environ Monit Assess 54:87–100

Dip R, Stieger C, Deplazes P, Hegglin D, Mueller U, Dafflon O, Koch H, Naegeli H (2001) Comparison of heavy metal concentrations in tissues of red foxes from adjacent urban, suburban, and rural areas. Arch Environ Contam Toxicol 40:551–556

Hoekstra PF, Braune BM, Elkin B, Armstrong FA, Muir DC (2003) Concentrations of selected essential and non-essential elements in arctic fox (*Alopex lagopus*) and wolverines (*Gulo gulo*) from the Canadian Arctic. Sci Total Environ 309:81–92

Ikeda M, Zhang Z-W, Shimbo S, Watanabe T, Nakatsuka H, Moon C-S, Matsuda-Inoguchi N, Higashikawa K (2000) Urban population exposure to lead and cadmium in east and south-east Asia. Sci Total Environ 249:373–384

Ma WC (1996) Lead in mammals. In: Beyer WN, Heinz GH, Redmon-Norwood AW (eds) Environmental contaminants in wildlife: interpreting tissue concentrations. CRC Press, Boca Raton, pp 281–296

Millán J, Mateo R, Taggart MA, López-Bao JV, Viota M, Monsalve L, Camarero PR, Blázquez E, Jiménez B (2008) Levels of heavy metals and metalloids in critically endangered Iberian lynx and other wild carnivores from Southern Spain. Sci Total Environ 399:193–201

Osowski SL, Brewer LW, Baker OE, Cobb GP (1995) The decline of mink in Georgia, North Carolina, and South Carolina: the role of contaminants. Arch Environ Contam Toxicol 29:418–423

Poole KG, Elkin BT, Bethke RW (1995) Environmental contaminants in wild mink in the Northwest Territories, Canada. Sci Total Environ 160–161:473–486

Reglero MM, Monsalve-González L, Taggart MA, Mateo R (2008) Transfer of metals to plants and red deer in an old lead mining area in Spain. Sci Total Environ 406:287–297

Sánchez de la Campa AM, De la Rosa J, Querol X, Alastuey A, Mantilla E (2007) Geochemistry and origin of PM10 in the Huelva region, Southwestern Spain. Environ Res 103:305–316

Sidorovich VE, Sidorovich AA, Krasko DA (2010) Effect of felling on red fox (*Vulpes vulpes*) and pine marten (*Martes martes*) diets in transitional mixed forest in Belarus. Mamm Biol 75:399–411

Storelli M, Barone M, Garofalo G, Marcotrigiano GO (2007) Metals and organochlorine compounds in eel (*Anguilla anguilla*) from the Lesina lagoon, Adriatic Sea (Italy). Food Chem 100: 1337–1341

Thompson DR (1996) Mercury in birds and terrestrial mammals. In: Beyer WN, Heinz GH, Redmon-Norwood AW (eds) Environmental contaminants in wildlife: interpreting tissue concentrations. CRC Press, Boca Raton, pp 341–356

Woshner VM, O'Hara TM, Bratton GR, Beasley VR (2001) Concentrations and interactions of selected essential and non-essential elements in ringed seals and polar bears of arctic Alaska. J Wildl Dis 37:711–721