Ornis Fennica 76:25–32. 1999

Metal levels of feathers in birds of various food chains in southern Finland

Tapio Solonen, Martin Lodenius & Esa Tulisalo

Solonen, T., Dept. of Ecology and Systematics, Div. of Population Biology, P.O. Box 17, FIN-00014 University of Helsinki, Finland; present address: Luontotutkimus Solonen Oy, Neitsytsaarentie 7 b B 147, FIN-00960 Helsinki, Finland. E-mail: tapio.solonen@pp.inet.fi
Lodenius, M., Dept. of Limnology and Environmental Protection, P.O. Box 27, FIN-00014 University of Helsinki, Finland
Tulisalo, E., Dept. of Limnology and Environmental Protection, P.O. Box 27, FIN-00014 University of Helsinki, Finland

Received 25 March 1998, accepted 24 november 1998

We examined levels of five metals (Al, Cu, Zn, Cd, Pb) in feathers of six species of birds of various food chains. In the primary consumers (*Columba livia*), the variability of the levels of all the metals studied was relatively high. Among the secondary (and higher-level) consumers, the variation was highest in the vole-eaters *(Strix aluco, Buteo buteo)*, intermediate in the bird-eaters *(Accipiter gentilis, A. nisus)*, and low in the fish-eaters (*Pandion haliaëtus*). Metal levels were relatively high, on the one hand, in *C. livia* (urban environment), and, on the other hand, in *P. haliaëtus* (aquatic habitat). Cu and Pb levels were at their highest in samples near urban areas, Al and Cd in samples of aquatic food chains. The metal levels indicated that there were food web related differences in metal accumulation between species. However, a consistent tendency that levels were higher in the species of higher trophic levels than in those of the lower ones was not found.

1. Introduction

Atmospheric emissions of harmful heavy metals have increased along with the growth of industry, energy production, and traffic (Boutron & Delmas 1980, Rühling 1994). Leaching of aluminium and other metals from soil have also increased as a result of acidification caused by acid deposition of atmospheric emissions of sulphur and nitrogen oxides (see, e.g., Vanstraalen & Bergema 1995). Recently, some declining trends have been demonstrated (e.g., Wahlström et al. 1996, Neste 1997), but monitoring of the metal levels in the environment is still necessary (e.g., Esselink et al. 1995). A suitable method for monitoring might be to study the accumulated levels in feathers of birds (Solonen & Lodenius 1990, Denneman & Douben 1993).

Metal levels in feathers reflect the levels in food during the feather growth, i.e. during the growth of young birds, or during the moult period of fully grown birds (e.g., Westermark et al. 1975, Solonen & Lodenius 1990). They can, therefore, be supposed to indicate metal contamination of food chains of the species concerned. Birds of different food chains probably are locally subjected to different metal concentrations. It has been expected that the accumulation of metals increases with higher trophic level of the species, i.e. from herbivores to carnivores (see, e.g., Furness 1987, Esselink et al. 1995), while an alternative hypothesis suggests that such a biomagnification is nonexistent (e.g., Laskowski 1991). Biomagnification is not considered, in general, responsible for toxic effects of metals in terrestrial carnivores (Nuorteva 1990, Laskowski 1991).

We examined levels of five metals (Al, Cu, Zn, Cd, Pb) in feathers of six species of birds of different habitats and food chains in southern Finland. The species included a herbi/omnivorous pigeon, an owl and a buzzard which feed largely on herbivorous voles, two mainly bird-eating hawks, and a fish-eating raptor. We studied variations and correlations between the levels of different metals in each species, in order to investigate whether there were a few common or many local sources of metals in the study area. Our aim was also to find out if there were differences in metal levels that can be attributed to differences in habitat or the general food composition of birds.

2. Material and methods

Feather samples were collected from nestling Goshawks *Accipiter gentilis* (21 broods), Sparrowhawks *A. nisus* (20), Common Buzzards *Buteo buteo* (21), Ospreys *Pandion haliaëtus* (17), and Tawny Owls *Strix aluco* (33) mainly within a radius of 50 km from the city of Helsinki in Uusimaa, southern Finland, in 1988–1989, and from fully grown Feral Pigeons *Columba livia domestica* (26 ind.) in Helsinki in February 1989. Pigeons included both young and adult individuals. Feral Pigeons represented solely an urban environment, Tawny Owls urban and rural habitats, hawks suburban, rural and wilderness areas, buzzards rural and wilderness areas, and Ospreys aquatic foraging habitats. Each sample included a few secondary coverts needed for metal analyses (see Solonen & Lodenius 1990). Levels of aluminium (Al), copper (Cu), zinc (Zn), cadmium (Cd), and lead (Pb) were analysed as described below.

All samples were first dried and then stored at room temperature in plastic tubes. Before the chemical analysis, samples were dried overnight at 105°C. The samples weighed 0.5 g or less and were placed in glass test tubes and heated in 5 ml of concentrated HNO_3 (BDH, Aristar) for 2 h at 50°C, and after that for 16–18 h at 110°C. Five millilitres of H_2O_2 (Merck, p.a.) was added, and the samples were heated for an additional 6 h. The samples were filtered (filter paper Schleicher & Schüll 5892) and diluted with distilled water to 25 ml. Finally, the sample solutions were analysed for their heavy metal concentrations by a flame (Al, Cu, Zn) atomic absorption spectrophotometer (AAS) (Varian SpectrAA 400) or by graphite furnace (Cd, Pb) AAS (Varian SpectrAA 400 equipped with GTA-96). For the determination of aluminium, NaCl was added to the sample solutions to make a concentration of at least 500 g/ml of Na+ and the samples were analysed by flame AAS (Perkin-Elmer 360).

All the results were reported as concentrations of the dry weight in µg/g (Table 1). In calculations, the values below the determination limit were adjusted by half of the limit value. Statistical procedures followed the general standards (Sokal & Rohlf 1981). In multiple significance tests, the Bonferroni correction (e.g., Bland 1995) was applied.

Table 1. Certified and obtained values (µg/g dry wt) for the BCR standard reference material "Cod muscle" CRM-422 (Cu, Zn, Cd, Pb) and "Pine needles" NBS/SRM 1575 (Al) and determination limits for the metals analysed. No HF was used in digestion which means that silicate bound Al is not extracted.

	Certified value mean ± 95% CI	Obtained value mean ± SD; n = 6	Our determination limit
Cu	1.05 ± 0.07	2.0 ± 1.0	1.0
Zn	19.6 ± 0.5	20.9 ± 1.5	1.0
Cd	0.017 ± 0.002	0.018 ± 0.003	0.005
Pb	0.085 ± 0.015	< 0.5	0.1
Al	545 ± 30	440 ± 18	10

3. Results

Metal levels of feathers varied considerably both within and between species (Tables 2 and 3). Variation was minor (species-specific CVs averaging 11–34%) in the zinc and copper levels, whereas concentrations of aluminium, cadmium and lead varied considerably (CVs averaging 102–131%) (Table 3). In the birds of prey, in general, the variation of metal levels in feathers was highest in the vole-eaters (Tawny Owl, Common Buzzard), intermediate in the bird-eaters (hawks), and low in the fish-eaters (Osprey), but the variability of the levels of different metals varied considerably between species. In the Feral Pigeon, again, the variability of the levels of all the metals studied was relatively high (even though all the samples were from a single restricted locality). There were no significant associations between the levels of different metals in each bird species (Spearman rank correlation, Bonferroni correction).

The distribution of metal levels deviated significantly ($P < 0.05$) from normality in the Tawny Owl for aluminium, zinc, cadmium and lead, in the Pigeon for cadmium and lead, and in the Goshawk and Buzzard for aluminium (Kolmogorov-Smirnov test), largely due to some exceptionally pronounced peaks in contamination levels. Of the highest metal levels recorded (250 µg/g for Al, 46 µg/g for Cu, 200 µg/g for Zn, 1.7 µg/g for Cd, and 240 µg/g for Pb), cadmium was recorded in a Tawny Owl brood, the others were found in Feral Pigeons. In general, metal concentrations were relatively high, on the one hand, in the Feral Pigeon (urban environment), and, on the other hand, in the Osprey (aquatic habitat) (Table 2). Copper and lead levels were at their highest in birds of urban food chains, aluminium and cadmium in those of aquatic food chains.

In those species sampled along a gradient from urban to rural habitat, the highest values of metals (Al, Cd, Pb) were, in general, found near the most urban areas (Helsinki region) (Fig. 1). However, the relationships between the distance from the city of Helsinki and metal levels were not significant (Spearman rank correlation). The single peak values clearly reflect the vicinity of some local pollution sources (garbage dump, metal factory, oil refinery). In the Tawny Owl and Goshawk, the highest local concentrations of several metals (Al, Cu, Cd, Pb) were found in the most urban samples. The highest single cadmium levels of the owls were found near a garbage dump (1.7 µg/g) and a metal factory (0.33 µg/g). The levels of zinc and lead in feathers of the Tawny Owl (the only species of adequate sample size for analysis) declined significantly with a greater distance from a local oil refinery ($r_S = -0.355$ and

Table 2. Levels (median and range) (µg/g) of aluminium (Al), copper (Cu), zinc (Zn), cadmium (Cd), and lead (Pb) in feathers of *Columba livia, Strix aluco, Buteo buteo, Accipiter nisus, A. gentilis*, and *Pandion haliaëtus* in southern Finland. The species are arranged according to their approximate level in the food web from lower to higher. For determination limits, see Table 1.

Species	n	Metal levels (median and range) (µg/g)				
		Al	Cu	Zn	Cd	Pb
Columba livia	26	35	14.0	130	0.08	24.5
		5–250	8.4–46	96–200	0.03–1.30	6.6–240
Strix aluco	33	28	4.4	120	0.05	0.2
		5–200	2.7–14	110–150	0.02–1.70	0.1–4.2
Buteo buteo	21	5	6.1	140	0.15	1.3
		5–90	0.5–13	120–170	0.03–0.72	0.1–21
Accipiter nisus	20	18	7.9	130	0.17	0.3
		5–94	5.6–14	120–150	0.06–0.57	0.1–1.1
Accipiter gentilis	21	24	5.8	130	0.19	0.1
		5–140	3.1–11	100–150	0.00–1.60	0.1–3.5
Pandion haliaëtus	17	58	6.8	110	0.26	0.8
		33–110	5.6–8.6	98–140	0.04–1.10	0.6–2.7

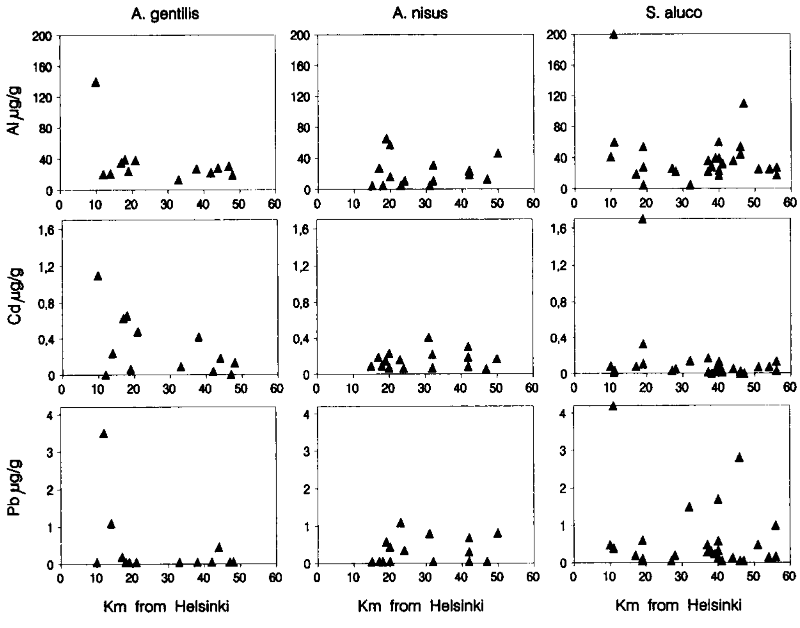

Fig. 1. Metal levels (Al, Cd, and Pb) (µg/g) of feathers in three species of birds (*A. gentilis, A. nisus, S. aluco*) sampled along a gradient from urban (Helsinki) to rural habitats.

$r_S = -0.392$, respectively, $n = 27$, $P < 0.05$).

There was no noticeable trend that the metal levels were higher in the species of higher trophic level than in those of the lower ones (Table 2). The result was largely similar when considering the samples from urban food chains alone (Table 4). However, the median levels of aluminium, cadmium, and lead differed significantly between species ($P < 0.001$, Kruskal-Wallis test). In the rural environment, the median levels of cadmium in the four species studied differed significantly ($P < 0.01$), and those of aluminium nearly significantly ($P < 0.10$, Kruskal-Wallis test) (Table 5). The data gave some clues that metal levels were higher in higher trophic levels. Significant differences were found between buzzards and hawks in aluminium, and between owls and diurnal birds of prey in cadmium ($P < 0.05$, Mann-Whitney U-test). In the Tawny Owl, the metal levels were generally low (except that of Al), as compared with those raptors whose diets mainly consist of secondary consumers such as insectivorous birds. This is in contrast to the Buzzard, where the level of aluminium was very low, while the lead concentration especially was unexpectedly high.

Table 3. Relative variation (CV %) of metal levels in feathers of the species of birds studied (cf. Table 2).

Species	Coefficients of variation (%) of metal levels					
	Al	Cu	Zn	Cd	Pb	Average
Columba livia	109	51	20	163	137	96
Strix aluco	97	46	7	251	148	110
Buteo buteo	170	42	11	90	131	89
Accipiter nisus	97	23	6	72	93	58
Accipiter gentilis	100	26	11	122	146	81
Pandion haliaëtus	39	15	9	88	57	42
Average	102	34	11	131	119	

4. Discussion

4.1. Local variation in metal levels

The number of samples in each species was small for proper detailed analyses of local variation in metal levels. Thus, we mainly examined the distribution of single peak values in common species along a gradient from urban to rural habitats. The present results suggest that there were considerable local variations in the metal levels of the environment and/or in the diet of the species studied. Minor variations in the zinc and copper levels suggest a few general sources of these metals in the study area, whereas concentrations of aluminium, cadmium and lead varied considerably, suggesting the existence of many local sources. The lack of significant connections between the levels of different metals in each bird species also suggest that metals largely originated from many different local sources.

Not unexpectedly, the metal levels were generally highest in the feathers of the Feral Pigeon of the urban environment. As the birds sampled were fully grown, the possibility of external contamination cannot be excluded (cf., e.g., Scheuhammer 1987). At the same time, the nestlings of the most urban pairs of birds of prey (Goshawk, Tawny Owl) also had heavy loads of metals. Their diets often included Feral Pigeons (T. Solonen, unpubl.).

High levels of metals could, in general, be explained by urban pollution sources, industry, or traffic. The high concentrations of lead were easily explained by traffic emissions (cf., e.g., Kendall & Scanlon 1982). The high values of lead in the Common Buzzard were untraceable, but they might result because Buzzards commonly forage near roads (T. Solonen, personal observation). In some raptors, one possible source of lead is also the shot ingested from the prey (Pain et al. 1995).

4.2. Trophic differences

There were various difficulties in examining the trophic differences in metal levels in this study. The division of the samples between terrestrial habitats was not easy because the gradient from urban to rural habitats is gradual, not sharp-cut, for most of the species studied. Within urban habitats, the comparison between trophic levels was not fully possible because the habitat of the Feral Pigeon was restricted to the most urban environment while that of the other species covered larger and more variable areas, being more suburban. In addition, their sample sizes were small. Some local peak pollution sources and the uneven and locally varied distribution of samples in different species probably also largely hampered the detection of food web-related differences in metal levels between species.

Our results suggest that the bird species studied were not similarly affected by local pollution sources and by traffic emissions. However, the present results do not unambiguously suggest biomagnification of metals along the food chains. They rather suggest, in accordance with some recent papers, that differences in behaviour of metals in food chains, together with the large interspecific variation in metal levels in species, imply that metal biomagnification is not a rule and that various patterns of metal transfer are possible (e.g., Grodzinska et al. 1987, Laskowski 1991). In any case, interspecific differences between the accumulation patterns of pollutants have been observed as a result of the different trophic levels of the analysed birds (e.g., Honda et al. 1986, Braune

Table 4. Metal levels (median and range) (µg/g) of feathers in birds sampled from urban habitats. Only those metals whose levels varied considerably (Table 3) were included.

Species	n	Aluminium		Cadmium		Lead	
Columba livia	26	35	5–250	0.08	0.03–1.30	24.5	6.6–240
Strix aluco	4	51	34–200	0.03	0.02–0.09	1.4	0.4–4.2
Accipiter gentilis	6	27	5–140	0.31	0.00–1.10	0.7	0.1–3.5

1987, Wenzel & Gabrielsen 1995).

We found that the aluminium and cadmium concentrations were highest in the Osprey of the aquatic food chains, resembling the situation of mercury (cf. Scheuhammer 1987). The mercury levels of feathers in birds of prey of the present study area were higher in aquatic environments than in terrestrial ones, and at the higher trophic levels (Solonen & Lodenius 1990). In species which prey mainly upon terrestrial vertebrates, e.g., the vole-eaters, including species of owls, the mercury levels were generally low, while the levels were quite high in the bird-eating hawks, especially in the Sparrowhawk (cf. Solonen & Lodenius 1984). Cadmium is also known for its ability to bioaccumulate in some terrestrial food chains (Lodenius 1990). In feathers of birds of prey, the levels of aluminium, cadmium, and lead were clearly lower, and those of copper and zinc were similar or somewhat higher, than the levels in mosses in the same general area (Lidman & Mäkinen 1992, Lidman 1996). There were, however, differences in the scale of the studies concerned, which can make the proper comparison of the results difficult.

4.3. Toxic relevance of metals in tissues

Metal levels in feathers are stable, reflecting the levels in food and blood during the feather growth (e.g., Westermark et al. 1975), while those in soft tissues such as liver and kidney vary for various reasons (see, e.g., Esselink et al. 1995, Jager et al. 1996). By using ratios between metal levels in feathers and in other tissues in the same individual birds reported elsewhere (e.g., Swiergosz 1991, Denneman & Douben 1993, Wenzel & Gabrielsen 1995), it is possible, however, to estimate roughly the metal levels in other tissues on the basis of metal levels in feathers. Such estimates suggest that the metal levels of the present study were, in general, relatively low with no indications of harmful effects. Some peak levels in feathers (for instance those of Cd and Pb, 1.7 and 240 μg/g, respectively) reported in this study, however, probably indicate harmful levels in essential organs (cf., e.g., Scheuhammer 1987, Esselink et al. 1995). High concentrations of some metals studied (Al, Cd, Pb) may also cause negative effects on the reproduction of birds (e.g., Scheuhammer 1987, 1988, Eeva & Lehikoinen 1996).

4.4. Conclusions

The scarcity of associations between metal levels probably was partly due to the small number and relatively large geographical cover of the samples analysed. A larger number and denser, evenly distributed coverage of samples would probably improve the resolution and reinforce the indicative power of the method. The sampling should rather be done in a nested way, three or more sample areas distantly apart, and a reasonable number of samples per site. When we have detailed information on the distribution of metals in different tissues of various species of birds, the value of feathers as indicators of metal levels of their body and the environment in which they live is greatly increased (cf., e.g., Furness et al. 1986, Solonen & Lodenius 1990).

The present results suggest that especially the Tawny Owl was a quite suitable species for monitoring the metal levels of the environment in southern Finland (cf., Ellenberg 1981, Weiss 1981, Solonen & Lodenius 1990, Esselink et al. 1995). It is relatively large, abundant, and stationary, and

Table 5. Metal levels (median and range) (μg/g) of feathers in birds sampled from rural habitats. Only those metals whose levels varied considerably (Table 3) were included.

Species	n	Aluminium		Cadmium		Lead	
Strix aluco	29	26	5–110	0.05	0.03–1.70	0.2	0.1–2.8
Buteo buteo	21	5	5–90	0.15	0.03–0.72	1.3	0.1–21.3
Accipiter nisus	19	16	5–94	0.16	0.06–0.57	0.3	0.1–1.1
Accipiter gentilis	15	24	5–38	0.18	0.03–1.60	0.1	0.1–1.5

it breeds in a wide range of habitats. In addition, the occurrence and density of the species can be manipulated by providing nestboxes (e.g., Solonen 1993).

In monitoring of metal levels of the environment, the feather method used here has some advantages over the commonly used moss technique (e.g., Rühling 1994). The period of time of exposure of each sample can be accurately estimated in the limits of a few weeks as compared with years. Each feather sample represents an area of a few square kilometres rather than a single point susceptible to many local disturbances. In addition, feathers give clues to the distribution of metals in various food chains.

Acknowledgements: Mikko Mönkkönen and anonymous referees made useful comments on earlier drafts of the manuscript. The Department of Limnology and Environmental Protection, University of Helsinki, provided working facilities for the metal analyses.

Selostus: **Lintujen höyhenten metallipitoisuuksien vaihtelu ravintoverkon eri tasoilla Etelä-Suomessa**

Tutkimme viiden metallin (alumiini, kupari, sinkki, kadmium ja lyijy) esiintymistä kuuden lintulajin (kanahaukka, varpushaukka, hiirihaukka, sääksi, lehtopöllö ja kesykyyhky) höyhenissä. Näytteet kerättiin vuosina 1988–1989 pääosin Uudeltamaalta ja ne otettiin kesykyyhkyä lukuunottamatta pesäpoikasilta. Kyyhkyt olivat täysikasvuisia, ensimmäisellä ikävuodellaan olevia tai vanhempia, talvehtivia lintuja. Kasvinsyöjillä (kesykyyhky) höyhenten metallipitoisuus vaihteli suuresti. Petolinnuista vaihtelu oli suurinta myyränsyöjillä, kohtalaista lintuja ravintonaan käyttävillä lajeilla ja vähäisintä kalansyöjillä. Metallipitoisuudet olivat suhteellisen korkeita toisaalta kesykyyhkyissä (kaupunkiympäristö), toisaalta sääksissä (vesiympäristö). Kupari- ja lyijypitoisuudet olivat korkeimmillaan kaupunkilinnuissa, alumiini- ja kadmiumpitoisuudet taas kalansyöjissä. Metallipitoisuudet erosivat usein huomattavasti eri lintulajien välillä, mutta ne eivät olleet yhtäpitävästi suurempia ravintoverkossa korkeammalla tasolla olevilla kuin muilla lajeilla. Höyhenet näyttivät kertovan varsin hyvin lintujen elinympäristön metallikuormituksesta ja sopivat siten hyvin ympäristön metallipitoisuuksien seurantaan.

References

Bland, M. 1995: An introduction to medical statistics. — Oxford Univ. Press, Oxford.

Boutron, C. & Delmas, R. 1980: Historical record of global atmospheric pollution revealed in polar ice sheets. — Ambio 9(5): 210–215.

Braune, B. M. 1987: Comparison of total mercury levels in relation to diet and molt for nine species of marine birds. — Arch. Environ. Contam. Toxicol. 16: 217–224.

Denneman, W. D. & Douben, P. E. T. 1993: Trace metals in primary feathers of the Barn Owl (Tyto alba guttata) in the Netherlands. — Environ. Pollut. 82: 301–310.

Eeva, T. & Lehikoinen, E. 1996: Growth and mortality of nestling great tits (Parus major) and pied flycatchers (Ficedula hypoleuca) in a heavy metal pollution gradient. — Oecologia 108: 631–639.

Ellenberg, H. 1981: Was ist ein Bioindikator? — Sind Greifvögel Bioindikatoren? — Ökol. Vögel (Ecol. Birds) 3, Sonderheft 1981: 83–99.

Esselink, H., van der Geld, F. M., Jager, L. P., Posthuma-Trumpie, G. A., Zoun, P. E. F. & Baars, A. J. 1995: Biomonitoring heavy metals using the Barn Owl (Tyto alba guttata): sources of variation especially relating to body condition. — Arch. Environ. Contam. Toxicol. 28: 471–486.

Furness, R. W., Muirhead, S. J. & Woodburn, M. 1986: Using bird feathers to measure mercury in the environment: relationships between mercury content and molt. — Mar. Pollut. Bull. 17: 27–30.

Grodzinska, K., Godzik, B., Darowska, E. & Pawlowska, B. 1987: Concentration of heavy metals in trophic chains of Niepolomice Forest, S. Poland. — Ekol. Pol. 35: 327–344.

Honda, K., Min, B. Y. & Tatsukawa, R. 1986: Distribution of heavy metals and their age-related changes in the Eastern Great White Egret, Egretta alba modesta, in Korea. — Arch. Environ. Contam. Toxicol. 15: 185–197.

Jager, L., Rijnierse, F., Esselink, H. & Baars, A. 1996: Biomonitoring the Buzzard Buteo buteo in the Netherlands: Heavy metals and sources of variation. — J. Ornithol. 137: 295–318.

Kendall, R. J. & Scanlon, P. F. 1982: Tissue lead concentrations and blood characteristics of Rock Doves from an urban setting in Virginia. — Arch. Environ. Contam. Toxicol. 11: 265–268.

Laskowski, R. 1991: Are the top carnivores endangered by heavy metal biomagnification? — Oikos 60: 387–390.

Lidman, H. 1996: Raskasmetalleja ja eräitä keveämpiä alkuaineita Sköldvikin teollisuusalueen ympäristön seinäsammalissa 1995. — Research report, Dept. Ecology and Systematics, Univ. Helsinki. (In Finnish.)

Lidman, H. & Mäkinen, A. 1992: Raskasmetallikartoitus Neste Oy:n Porvoon tuotantolaitosten ympäristössä seinäsammalen avulla kesällä 1991. — Research report, Dept. Botany, Univ. Helsinki. (In Finnish.)

Lodenius, M. 1990: Environmental mobilization of mercury and cadmium. — Publ. Dept. Environ. Conserv. Univ. Helsinki No. 13. Univ. Press, Helsinki.

Neste 1997: Corporate environmental report. Progress in 1996. — Neste, Espoo.

Nuorteva, P. 1990: Metal distribution patterns and forest decline. Seeking Achilles' heels for metals in Finnish forest biocoenoses. — Publ. Dept. Environ. Conserv. Univ. Helsinki No. 11. Univ. Press, Helsinki.

Pain, D. J., Sears, J. & Newton, I. 1995: Lead concentrations in birds of prey in Britain. — Environ. Pollut. 87: 173–180.

Rühling, Å. (ed.) 1994: Atmospheric heavy metal deposition in Europe — estimation based on moss analysis. — Nord 1994(9): 1–53.

Scheuhammer, A. M. 1987: The chronic toxicity of aluminium, cadmium, mercury, and lead in birds: a review. — Environ. Pollut. 46: 263–295.

Scheuhammer, A. M. 1988: Chronic dietary toxicity of methylmercury in the Zebra Finch, Poephila guttata. — Bull. Environ. Contam. Toxicol. 40: 123–130.

Sokal, R. R. & Rohlf, F. J. 1981: Biometry. — Freeman, New York.

Solonen, T. 1993: Spacing of birds of prey in southern Finland. — Ornis Fennica 70: 129–143.

Solonen, T. & Lodenius, M. 1984: Mercury in Finnish Sparrowhawks Accipiter nisus. — Ornis Fennica 61: 58–63.

Solonen, T. & Lodenius, M. 1990: Feathers of birds of prey as indicators of mercury contamination in southern Finland. — Holarct. Ecol. 13: 229–237.

Swiergosz, R. 1991: Cadmium, lead, zinc and iron levels in the tissues of pheasant (Phasianus colchicus) from southern Poland. — In: Bobek, B., Perzanowski, K. & Regelin, W. (eds.), Global trends in wildlife management. Trans. 8th IUGB Congress, Krakow 1987: 433–438. Swiat Press, Krakow-Warszawa.

Vanstraalen, N. M. & Bergema, W. F. 1995: Ecological risks of increased bioavailability of metals under soil acidification. — Pedobiologia 39: 1–9.

Wahlström, E., Hallanaro, E.-L. & Manninen, S. 1996: Suomen ympäristön tulevaisuus. — Edita, Suomen ympäristökeskus, Helsinki. (In Finnish.)

Weiss, J. 1981: Die Eignung des Waldkauzes (Strix aluco L.) als möglicher Umweltgütezeiger. — Ökol. Vögel (Ecol. Birds) 3, Sonderheft 1981: 101–110.

Wenzel, C. & Gabrielsen, G. W. 1995: Trace element accumulation in three seabird species from Hornøya, Norway. — Arch. Environ. Contam. Toxicol. 29: 198–206.

Westermark, T., Odsjö, T. & Johnels, A. G. 1975: Mercury content of bird feathers before and after Swedish ban on alkyl mercury in agriculture. — Ambio 4: 87–92.