PERGAMON

Chemosphere 52 (2003) 1251–1258

CHEMOSPHERE

www.elsevier.com/locate/chemosphere

Cadmium, chromium and lead contamination of *Athene noctua*, the little owl, of Bologna and Parma, Italy

A. Zaccaroni [a,*], M. Amorena [b], B. Naso [c], G. Castellani [d], A. Lucisano [e], G.L. Stracciari [a]

[a] Department of Veterinary Public Health and Animal Pathology, Bologna University, Via Tolara di Sopra 50, I-40064 Ozzano Emilia, Bologna, Italy
[b] Department of Veterinary and Agro-alimentary Sciences, Teramo University, Piano D'Accio, 64020 Nepezzano, Teramo, Italy
[c] Department of Veterinary Pharmacology and Toxicology, Italy
[d] Physics Department and DIMORFIPA, Bologna University, Via Tolara di Sopra 50, I-40064 Ozzano Emilia, Bologna, Italy
[e] Department of Animal Pathology and Health, Napoli University, Via Delpino 1, 80137 Napoli, Italy

Received 3 September 2001; received in revised form 12 December 2002; accepted 28 March 2003

Abstract

A study was conducted to determine cadmium, chromium and lead concentrations in liver and brain of 52 little owls (*Athene noctua*) from two provinces of Emilia Romagna region, with the aim of furnishing indirect information concerning contamination of their habitat, also considering possible environmental dispersion of the metals. Metal analysis was performed by atomic absorption spectrophotometry with graphite furnace.

Variance analysis with sampling area, gender and age shows that no statistical difference was found for gender, while a significant difference ($P < 0.05$) was found for cadmium and lead, but not for chromium, when sampling areas and age were of concern.

For all metals highest mean concentrations were found in liver (170 ppb for cadmium, 297 ppb for chromium and 312 ppb for lead). These levels can be considered as indicative of chronic exposure to low and "background" amounts of pollutants and they are of no toxicological concern, as they are always well below the toxic thresholds defined for each metal.

The present study can be considered as a starting point for further analyses, aimed to the definition of any possible subtle effect (e.g. effects on enzymes activity) and of any possible correlation between levels of pollutants and appearance of possible adverse effects. It also furnished useful data for diagnostic cases and potentially for monitoring local contamination.

Keywords: Heavy metals; Little owl; Environmental monitoring; Italy

1. Introduction

Due to their industrial use and the low chemical reactivity some heavy metals can be responsible for environmental contamination and available for biomagnification, through air, water and food and through food-chain steps.

Biomagnification is greatly evident in local environment through non-migrating predator species. These local, upper trophic level species play a very important role as environmental contamination indicators.

Little owl (*Athene noctua*) is a small raptor ranging in lowlands and hills inhabited by humans, which holds a

---

[*] Corresponding author. Tel.: +39-51792704; fax: +39-51799511.
E-mail address: azaccaroni@vet.unibo.it (A. Zaccaroni).

0045-6535/03/$ - see front matter © 2003 Elsevier Science Ltd. All rights reserved.
doi:10.1016/S0045-6535(03)00363-1

prominent position within the food chain. Although it mainly hunts in twilight and at night, it is active in part of the day, mainly during summer, feeding on the ground in open areas.

The diet of this owl is not restricted to any particular prey and is highly adaptable to local condition. Arthropods (principally insects) compose the highest percentage of the diet when the number of individuals is considered, while mammals represent the highest percentage when biomass is of concern (Zerunian et al., 1982).

Considering limited environmental contaminant data in little owl, we present cadmium, chromium and lead concentrations in two tissues of little owl (*Athene noctua*), originating from two provinces in the region Emilia Romagna. The purpose was to furnish indirect information concerning metal contamination of their prey and resultant exposure and possible variations in environmental contamination. Furthermore, data obtained, based on age and gender of the animals, could be compared to literature available on data concerning heavy metals presence in raptor tissues—and little owl in particular (Franson et al., 1983; Macdonald and Randall, 1983; Hoffman et al., 1985a,b; Janssen et al., 1986; Scheuhammer, 1987; Wiemeyer et al., 1987; Gènot et al., 1995; Garcia-Fernàndez et al., 1997).

2. Experimental

Fifty two little owls, from Bologna ($n = 41$) and Parma ($n = 11$) provinces, collected during 1998, were sampled for the study. The areas studied are similar in agricultural and wooded land (Figs. 1 and 2).

Athene noctua sampled died from natural causes or following trauma. These animals were collected at Veterinary Medicine Faculty of Bologna or at the Lega Italiana Protezione Uccelli (LIPU) recovery center of Parma.

A higher number of animals were collected from Bologna province ($n = 41$) with respect to Parma province ($n = 11$). This was due to the fact that Avian Pathology Section of Bologna University was the reference center for Bologna province, so that a great number of animals was available per year. On the other hand, the smallest amount of birds collected in Parma province depended on the tendency of wildlife centers existing in that province to send dead animals to Bologna University. Age cohorts of animals were defined starting from morphological characteristics of each animal (i.e. plumage aspects and moult status).

A different pattern in age cohorts distribution can be found in the two sampling areas, as shown in Table 1, while no difference can be seen when gender is considered.

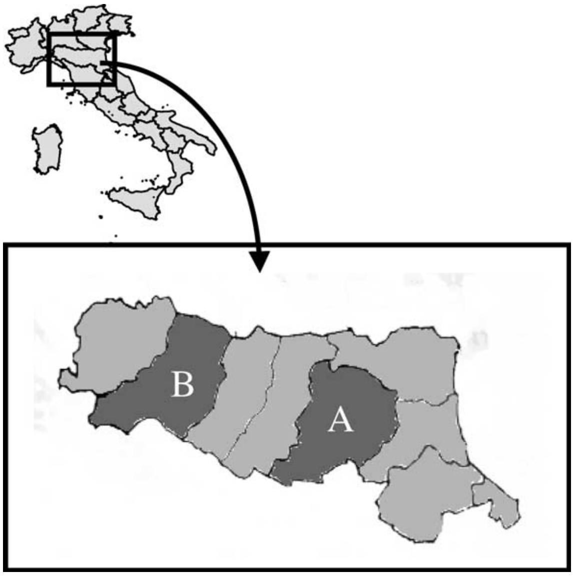

Fig. 1. Little owl sampling areas (dark zones): (A) Bologna province; (B) Parma province.

Analytical determinations were conducted on liver and brain tissue collected during necropsy and stored at −20 °C until analyses. Samples were freeze dried and 200 mg aliquots were subsequently mineralized following Angerer et al. (1988).

For the atomic absorption analysis of metals in tissues samples a Perkin Elmer Model 2380 equipped with a Perkin Elmer HGA 300 graphite furnace was used. The instrumental conditions for each metal are summarized in Table 2; deuterium background correction was used throughout the work.

All concentrations in tissues are expressed in ng/g (ppb) on a dry weight basis. Detection limit was 1 ppb for all metals. All specimens were run in batches that included blank, initial calibration standards and spiked specimens. The recovery yields ranged from 90% for cadmium to 98% for chromium, and the coefficients of variation were always below 10%.

Statistical analyses for age cohorts, gender and sampling area, were conducted using Mathematica® 3.0 Program (Wolfram Research Inc., Champaign, IL) and JMP 3.2.2 (SAS Institute, S. Francisco, CA), applying distribution analysis and description in order to characterize the metal concentrations data. We also computed the correlation matrix between tissues metals concentrations in order to point out commonalities between different metals and tissues. The confidence level for means was calculated by the relation ($m - t_c s$, $m + t_c s$), where m is the mean value, t_c is the cth quantile (corresponding to the 0.05 probability level) of the Student t distribution and s is the standard error of the mean (SEM). The age cohorts dependence of metals

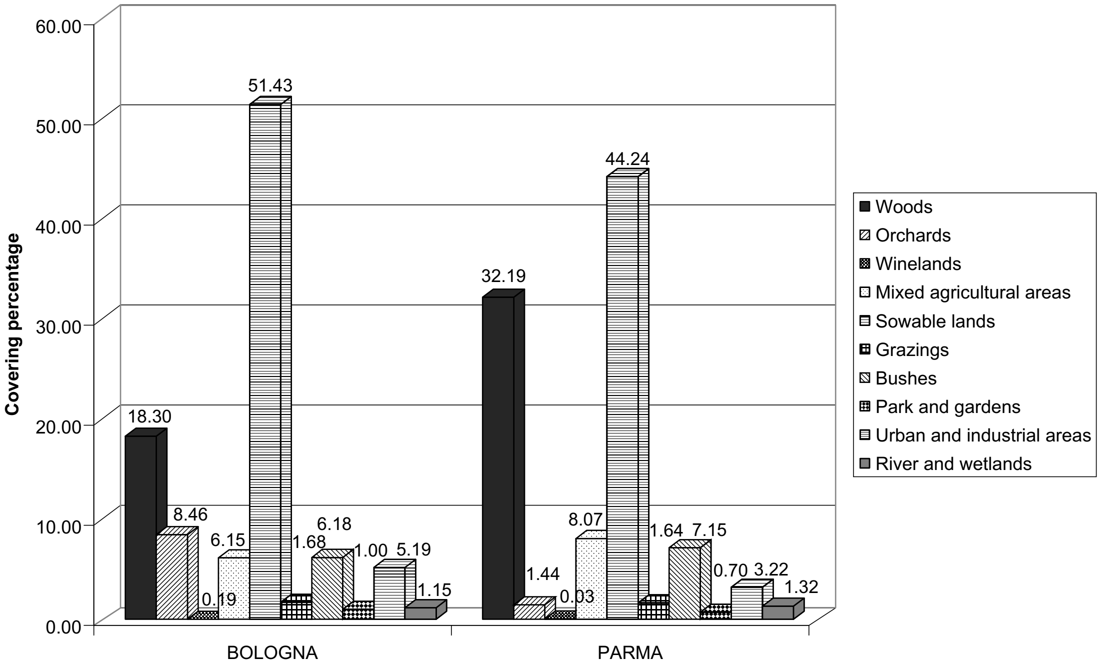

Fig. 2. Environmental characteristics and land use of studied areas.

Table 1
Age cohort and gender distribution of little owls, divided by sampling area (statistical analysis for gender and age cohorts was conducted on grouped data)

Area	Gender (%)		Age cohorts (%)		
	Males	Females	Fledglings	Juveniles	Adults
Bologna	20 (48.78)	21 (51.22)	4 (9.76)	27 (65.85)	9 (24.39)
Parma	8 (72.73)	3 (27.27)	5 (45.45)	1 (9.1)	5 (45.45)

Table 2
Instrumental conditions for metals measurement (data in different columns with the same letter refer to the same metal)

	Step						
	1	2	3	4	5	6	7
Thermal program							
Temp. (°C)	90	130	500[a] 1650[b] 700[c]	20	1500[a] 2500[b] 1700[c]	2500[a] 2800[b] 2500[c]	20
Ramp (s)	10	15	1	1	0	1	1
Hold (s)	20	20	25	15	5	5	10
Baseline (s)	/	/	/	5	/	/	/
Argon (ml/min)	300	300	300	300	0	300	300

[a] Cadmium: λ: 228.8 nm, slit width: 0.7 nm, maximum power: 24.
[b] Chromium: λ: 357.9 nm, slit width: 0.7 nm, maximum power: 17.
[c] Lead: λ: 283.3 nm, slit width: 0.7 nm, maximum power: 19.

concentration was analyzed by comparison of means with their standard errors. The effect of sampling area, gender and age cohorts on metal concentrations was analyzed by variance analysis (ANOVA).

3. Results

Cadmium, chromium and lead concentrations in hepatic and cerebral tissues of little owls are summarized in Table 3 by gender and sampling area and in Fig. 3 by age cohort.

Variance analysis (ANOVA) shows that there is statistical difference for cerebral cadmium, and cerebral and liver lead by location (Fig. 3). The difference in size between the Parma and Bologna sample could influence our statistics; but preliminary results based on comparisons of weighted means (data not shown) are in agreement with ANOVA (Kendall and Stuart, 1979).

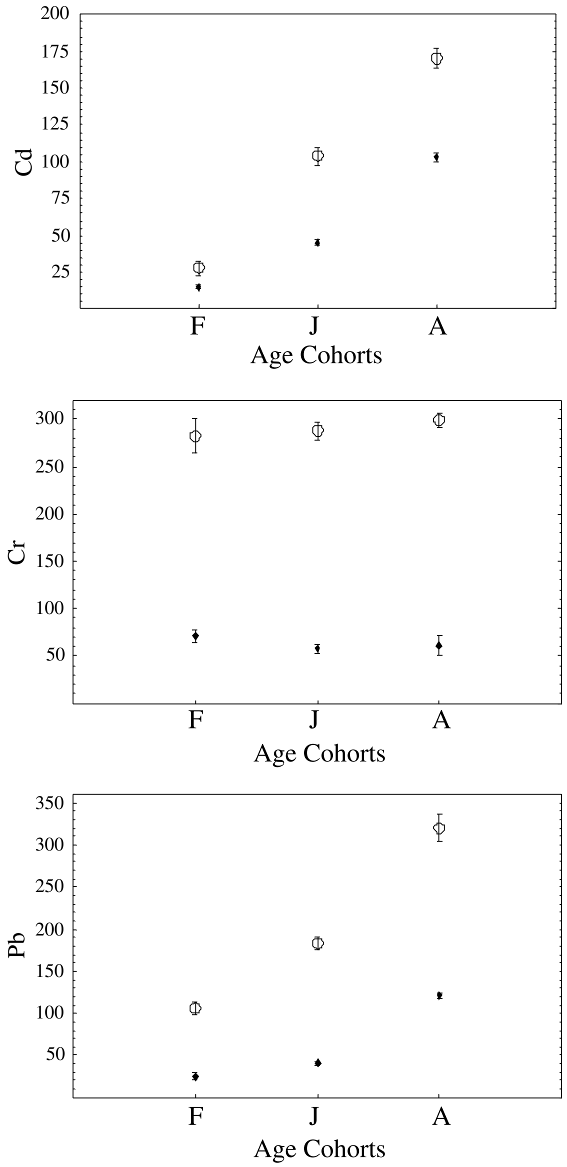

Fig. 3. Metals concentrations (ppb wet weight) as a function of age cohorts in little owl (mean ± s.e.m.) from both sites. Age cohorts: F = fledglings; J = juveniles; A = adults. In each graph, open spot (○): liver, filled triangles (▲): brain.

Despite the differences observed with respect to sampling area, being age the variable that explain the highest part of variability within the linear model, as resulting from ANOVA, the statistics for age cohort was centered on grouped data, age cohorts being considered as nominal values.

The age cohort dependence of metal concentrations is shown in Fig. 3. The relative extension of the error bars (SEM) shows that there is a significant trend ($P < 0.05$) in cadmium and lead concentrations both in liver and brain. Such a trend cannot be found for chromium.

Brain levels of the metals are always lower than those found in liver (Fig. 3). A statistical difference ($P < 0.05$) between liver and brain mean cadmium concentration was found in adults (170 ± 29 and 104 ± 14 ppb respectively), juveniles (105 ± 33 and 58 ± 29 ppb) and fledglings (28 ± 18 and 16 ± 6 ppb). The same is true for chromium (fledglings: 282 ± 18 and 71 ± 7 ppb; juveniles: 288 ± 10 and 58 ± 5 ppb; adults: 299 ± 7 and 61 ± 10 ppb respectively) and lead (fledglings: 106±8 and 25 ± 4 ppb; juveniles: 183 ± 7 and 41 ± 2 ppb; adults: 320 ± 16 and 121 ± 4 ppb respectively).

Linear correlation analysis (the classical Pearson correlation coefficient) for tissues metal concentrations shows that cadmium and lead in liver and brain are well correlated, ($R^2 = +0.80$, $P \ll 0.01$ and $R^2 = +0.79$, $P \ll 0.01$ respectively), while no correlation was found for chromium ($R^2 = -0.10$, $P = 0,4787$). A good correlation was found also between cadmium and lead hepatic and cerebral concentrations ($R^2 = +0.75, P \ll 0.01$ and $R^2 = +0.71$, $P \ll 0.01$ for hepatic cadmium to hepatic and cerebral lead respectively; $R^2 = +0.82$, $P \ll 0.01$ and $R^2 = +0.84$, $P \ll 0.01$ for cerebral cadmium to hepatic and cerebral lead respectively).

4. Discussion

Despite a good uniformity in sample by gender (28 males vs. 24 females) the predominance of juveniles (= 28) with respect to adults (= 14) and fledglings (= 9) can be explained originating from a lack of experience, which can bring them closer to roads, thus increasing the traumatic deaths. This creates a higher number available in “opportunistic” samplings, which makes this collection method to be not random. The age distribution can also explain the differences detected for cadmium between sampling areas. The highest percentage of adults in Parma sample (Table 2) can indeed influence the cerebral metal concentrations, as

Table 3
Heavy metals concentrations found in little owls' hepatic and cerebral tissue (ng/g, wet weight) by gender and sampling area (Statistical differences between sites are referred to the same tissue)

	N. animals	Mean ± s.e.m. range					
		Hepatic tissue			Cerebral tissue		
		Cadmium	Chromium	Lead	Cadmium	Chromium	Lead
Male	28	115 ± 10 18–216	290 ± 10 204–365	222 ± 18 49–416	62 ± 7 9–132	67 ± 6 5–131	69 ± 8 9–145
Female	24	102 ± 11 11–214	289 ± 9 201–487	188 ± 15 98–345	48 ± 6 8–123	54 ± 6 5–95	49 ± 7 12–108
Bologna	41	110 ± 7 18–216	288 ± 8 201–487	200 ± 11[a] 49–416	54 ± 5[b] 9–132	57 ± 5 5–117	57 ± 6[c] 12–136
Parma	11	105 ± 24 11–216	297 ± 13 214–361	232 ± 38[a] 98–416	61 ± 4[b] 8–132	76 ± 7 50–117	70 ± 16[c] 15–140

[a] $P = 0.0054$.
[b] $P = 0.0442$.
[c] $P = 0.0159$ (from ANOVA).

brain can be considered as a long term accumulation organ, in contrast to liver (Liao et al., 1997). Concerning lead, the highest percentage of industry and urban areas in Bologna province (Fig. 2), which imply a highest traffic load due to a higher number of people moving in that area, can be responsible for the differences observed in both tissues (Regione Emilia Romagna, 1994).

On the contrary the lack of statistical differences in cadmium, chromium and lead concentrations by gender for little owl is in agreement with the results from various authors which found no differences in pigeon (*Columba p. palumbus*), long tail duck (*Clangula hyemalis*), herons (*Ardea herodius*, *Nycticorax nycticorax*), egret (*Casmerodius albus*), cattle egret (*Bubulcus ibis*), gulls (*Larus atricilla*, *Larus-argentatus*), canvasback (*Aythya valisineria*), tern (*Sterna hirundo*), oystercatcher (*Haematopus ostralegus*), greater scaup (*A. marila*) and ducks (*Anas rubripes*, *A. platyrhyncos*). These authors stated that no physiologic difference exists between genders, and the same can be though for little owl (Peterson and Ellarson, 1976; Wanntorp et al., 1976; Hoffman and Curnow, 1979; Hulse et al., 1980; Fleming, 1981; Hutton, 1981; Parslow et al., 1982; Custer et al., 1986; Gochfeld and Burger, 1987).

The low ability of cadmium, chromium and lead of crossing the blood-brain barrier, if not during high acute intoxications, can be considered as one explanation of higher concentrations found in liver, as already observed in other wild species (Longcore et al., 1974; Dieter and Finley, 1979; Pattee et al., 1981; Anders et al., 1982; Hoffman et al., 1985a,b). Other factors which can influence this differences in distribution are the first pass metabolism by liver, the existence of binding proteins which can retain metals and the highest blood flow rate in liver. However, no data are available concerning heavy metals metabolism and kinetics in little owl, so that no assumption can be made on the main factors affecting metals accumulation.

Cadmium and lead increase with age, both in liver and brain; this can be partially due to tissue accumulation as toxicologically inactive complexes with metallothionein for cadmium, and to long half life for lead. In both cases it should be considered that age cohort differences play a role, in the little owl also, as already observed by Gochfeld et al. (1996) in gull, in determining a qualitative and/or quantitative difference in diet composition. These differences can induce a different pattern of metals intake, due to the different diet percent composition in arthropods, birds and little mammals between young and adult animals.

Concerning chromium, lack of any correlation can be partially explained with the physiological role exerted by the metal in the organism (e.g. glucose tolerance factor formation), which implies similar levels in all subjects, independently from age or gender. Following Gad (1989) and Witmer et al. (1989), homeostatic mechanisms prevent chromium uptake beyond that required for nutrition, thus creating similar levels in all subjects; an increase in chromium concentrations can be observed when these mechanism are saturated, being less effective in controlling metal uptake, as could be observed during chromium intoxication. In addition, one must consider low intestinal absorption, which can make tissue levels very low. This is confirmed by the observations of different authors which define how chromium concentrations in animal tissues can be equal, if not lower, to those found in soil and plants (Anthony and Kozlowski, 1982; Campa et al., 1986; Woodyard et al., 1986; Beyer et al., 1990).

When considering cadmium concentrations, it should be noted that highest mean concentrations obtained in liver (170 ± 8 ppb) are lower than those found in France for cadmium (382 ppb) by Gènot et al. (1995) in the same species. Following Burgat (1990), which defines values of 3–10 ppm as toxic threshold for this metal, Génot et al. (1990) consider the levels they found not sufficient for determining any alterations in animals, and the same can be stated for present data. Similarly, Feierabend and Myers (1984) consider that lead liver concentration below 6 ppm dry weight represents exposure to "background" levels. The mean concentrations found in the present work are well below the background value, so that such an exposure of that kind can be considered for our little owl.

Comparing obtained data with those available in literature concerning different avian species, it appears at first that detected concentrations are a consequence of repeated exposure to low environmental levels, with no adverse effect. This is confirmed by similar statements of Wiemeyer et al. (1987) concerning cadmium, chromium and lead levels in liver of osprey. Specifically, similar or slightly higher concentrations are considered by the authors as "normal" for the species and indicative of a low environmental contamination. Similar considerations arise when considering liver concentrations of the metals observed by various authors in non-raptor wild species like terns (*S. bergii*, *Thalasseus maximus*, *T. sandvicensis*), laughing gull (*L. atricilla*), storm petrels (*Oceanodroma leucorhoa*, *O. furcata*), auklets (*Cerorhinca monocerata*, *Ptychoramphus aleuticus*), murrelet (*Synthliboramphus antiquus*), greater scaup (*A. marila*), lesser snow geese (*Anser c. caerulescens*) always of the same magnitude of those found in Italian little owls, which are thought to have no toxic importance, when considering reproductive activity too (Howarth et al., 1981; Howarth et al., 1982; Maedgen et al., 1982; Szefer and Falandysz, 1987; Carpenè et al., 1996; Gochfeld et al., 1996; Elliott and Scheuhammer, 1997; Hui et al., 1998).

5. Conclusions

On the basis of existing literature, one can consider that data obtained concerning hepatic and cerebral levels of cadmium, chromium and lead in the little owl can be caused by a chronic exposure to low environmental levels. This exposure is of no toxicological concern, as concentrations detected are always well below the toxic thresholds defined for each metal. Thus no effect, not only on animals survival but also on reproduction, is expected.

The present study can be considered as a starting point for further analyses, aimed to the definition of any possible subtle effect (e.g. effects on enzymes activity) and of any possible correlation between levels of pollutants and appearance of possible adverse effects. It also furnished useful data for diagnostic cases and potentially for monitoring local contamination.

Acknowledgements

This work has been supported by Ministry of University and Scientific and Technological Research (M.U.R.S.T.) grants (MPI 60%).

We would like to thank the referees for their helpful comments in paper reviewing.

References

Anders, E., Dietz, D.D., Bagnell Jr., C.R., Gaynor, J., Krigman, M.R., Ross, D.W., Leander, J.D., Mushak, P., 1982. Morphological, pharmacokinetic, and hematological studies of lead-exposed pigeons. Environ. Res. 28, 344–363.

Angerer, J., Fleischer, M., Machata, G., Pilz, W., Stoeppler, M., Zorn, H., 1988. Digestion procedures for the determination of metals in biological material. In: Angerer, J., Schaller, K.H. (Eds.), Analyses of Hazardous Substances in Biological Materials—Methods for Biological Monitoring, vol. 2. VCH Verlagsgesellschaft, Weinheim, Germany, pp. 15–17.

Anthony, R.G., Kozlowski, R., 1982. Heavy metals in tissues of small animals inhabiting waste-water-irrigated habitats. J. Environ. Qual. 11, 20–22.

Beyer, W.N., Miller, G., Simmers, J.W., 1990. Trace elements in soil and biota in confined disposal facilities for dredged material. Environ. Pollut. 65, 19–32.

Burgat, V., 1990. Un micropolluant: le cadmium. Bull. O.N.C. 146, 40–42.

Campa III, H., Woodyard, D.K., Haufler, J.B., 1986. Deer and elk use of forages treated with municipal sewage sludge. In: Cole, D.W., Henry, C.L., Nutter, L. (Eds.), The Forest Alternative for Treatment and Utilization of Municipal and Industrial Wastes. University Of Washington Press, Seattle, Washington, pp. 188–198.

Carpenè, E., Isani, G., Catelli, E., Govoni, S., Delogu, M., 1996. Oligoelementi nei tessuti dell'avifauna. Obiettivi e documenti veterinari 7/8, 53–67.

Custer, T.W., Franson, J.C., Moore, J.F., Myers, J.E., 1986. Reproductive success and heavy metal contamination in Rhode Island Common Terns. Environ. Pollut. 41, 33–52.

Dieter, M.P., Finley, M.T., 1979. Delta aminolevulinic acid dehydratase enzyme activity in blood, brain, and liver of lead-dosed ducks. Environ. Res. 19, 127–135.

Elliott, J.E., Scheuhammer, A.M., 1997. Heavy metal and metallothionein concentrations in seabirds from the Pacific coast of Canada. Marine Pollut. Bull. 34 (10), 794–801.

Feierabend, J.S., Myers, O., 1984. A National Summary of Lead Poisoning in Bald Eagles and Waterfowl. National Wildlife Federation, Washington, DC.

Fleming, W.J., 1981. Environmental metal residues in tissues of canvasbacks. J. Wildl. Manage. 45, 508–511.

Franson, J.C., Silco, L., Pattee, O.H., Moore, J.F., 1983. Effects of chronic dietary lead in American kestrels (*Falco sparverius*). J. Wildl. Dis. 19, 110–113.

Gad, S.C., 1989. Acute and toxic systemic chromium toxicity. Sci. Total Environ. 86, 149–157.

Garcia-Fernàndez, A.J., Motas-Guzmàn, M., Maria-Mojica, P., Luna, A., Sànchez-Garcia, J.A., 1997. Environmental exposure and distribution of lead in four species of raptors in Southeastern Spain. Arch. Environ. Contam. Toxicol. 33, 76–82.

Gènot, J.C., Lecci, D., Bonnet, J., Keck, G., Venant, A., 1995. Quelques données sur la contamination chimique de la chouette chevêche, *Athene noctua*, et de ses oeufs en France. Alauda 63 (2), 105–110.

Gochfeld, M., Burger, J., 1987. Heavy metal concentrations in the liver of three duck species: influence of species and sex. Environ. Poll. 45, 1–15.

Gochfeld, M., Belant, J.L., Tara, Shukla, Benson, T., Burger, J., 1996. Heavy metals in laughing gulls: gender, age and tissue differences. Environ. Toxicol. Chem. 15 (12), 2275–2283.

Hoffman, R.D., Curnow, R.D., 1979. Mercury in herons, egrets and their foods. J. Wildl. Manage. 43, 85–93.

Hoffman, D.J., Franson, J.C., Pattee, O.H., Bunck, C.M., Anderson, A., 1985a. Survival, growth, and accumulation of ingested lead in nestling American kestrels (*Falco sparverius*). Arch. Environ. Contam. Toxicol. 14, 89–94.

Hoffman, D.J., Franson, J.C., Pattee, O.H., Bunck, C.M., Murray, H.C., 1985b. Biochemical and hematological effects of lead ingestion in nestling American kestrels (*Falco sparverius*). Comp. Biochem. Physiol. 80C, 431–439.

Howarth, D.M., Grant, T.R., Hulbert, A.J., 1981. A comparative study of heavy metal accumulation in tissue of the crested tern, *Sterna bergii*, breeding near industriali port before and after harbour dredging and ocean dumping. Aust. Wildl. Res. 9, 571–577.

Howarth, D.M., Hulbert, A.J., Horning, D., 1982. A comparative study of heavy metal accumulation in tissue of the crested tern, *Sterna bergii*, breeding near industrialised and non-industrialised areas. Aust. Wildl. Res. 8, 665–672.

Hui, A., Tekekawa, J.Y., Baranyuk, V.V., Litvin, K.V., 1998. Trace element concentrations in two subpopulations of lesser snow geese from Wrangel Island, Russia. Arch. Environ. Contam. Toxicol. 34, 197–203.

Hulse, M., Mahoney, J.S., Schroder, J.D., Hacker, C.S., Pier, S.M., 1980. Environmentally acquired lead, cadmium and manganese in Cattle Egret, *Bubulcus ibis*, and the Laughing Gulls, *Larus atricilla*. Arch. Environ. Contam. Toxicol. 9, 65–78.

Hutton, M., 1981. Accumulation of heavy metals and selenium in three seabird species from the United Kingdom. Environ. Pollut., Ser. A 26, 129–145.

Janssen, D.L., Oosterhuis, J.E., Allen, J.L., Anderson, M.P., Drew, G.K., Wiemeyer, S.N., 1986. Lead poisoning in free-ranging California condors. J.A.V.M.A. 189 (9), 1115–1117.

Kendall, M., Stuart, A., 1979. The Advanced Theory of Statistics, vols. 1–3. Griffin C. Ed., London, UK.

Liao, J.W., Tsai, S.F., Pang, F.V., Wang, S.C., 1997. Subchronic toxicity of cadmium via drinking water in rats. J. Chinese Soc. Veter. Sci. 23 (3), 283–292.

Longcore, J.R., Locke, L.N., Bagley, G.E., Andrews, R., 1974. Significance of Lead Residues in Mallard Tissues. US Fish Wildl- Serv. Spec. Sci. Rep.-Wildl., 182. 24pp.

Macdonald, J.W., Randall, C.J., 1983. Lead poisoning in captive birds of prey. Veter. Record 113, 65–66.

Maedgen, J.L., Hacker, C.S., Schroder, G.D., Weir, F.W., 1982. Bioaccumulation of lead and cadmium in the royal tern and sandwich tern. Arch. Environ. Contam. Toxicol. 11, 99–102.

Parslow, J.L.F., Thomas, G.J., Williams, T.D., 1982. Heavy metals in the livers waterfowl from the Ouse washes, England. Environ. Pollut., Ser. A 29, 217–327.

Pattee, O.H., Wiemeyer, S.N., Mulhern, B.M., Sileo, L., Carpenter, J.W., 1981. Experimental lead-shot poisoning in bald eagles. J. Wildl. Manage. 45, 806–810.

Peterson, S.R., Ellarson, R.S., 1976. Total mercury residues in liver and eggs of Oldsquaws. J. Wildl. Manage. 40, 704–709.

Regione Emilia Romagna, Servizio Cartografico Regionale, 1994. Carta regionale dell'uso del suolo.

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

Szefer, P., Falandysz, J., 1987. Trace metals in the soft tissues of scaup ducks (*Aythya marila* L.) wintering in Gdansk Bay, Baltic Sea. Sci. Total Environ. 65, 203–213.

Wanntorp, H., Borg, K., Hando, E., Ernie, K., 1976. Mercury residues in wood pigeons (*Columba p. palumbus* L.). Nord Veterinaermed. 19, 474–477.

Wiemeyer, S.N., Schmeling, S.K., Anderson, A., 1987. Environmental pollutant and necrospy data for ospreys from the eastern United States, 1975–1982. J. Wildl. Dis. 23 (2), 279–291.

Witmer, C.M., Park, H.S., Shupack, S.I., 1989. Mutagenicity and disposition of chromium. Sci. Total Environ. 86, 131–148.

Woodyard, D.K., Campa III, H., Haufler, J.B., 1986. The influence of forest application of sewage sludge on the concentrations of metals in vegetation and small mammals. In: Cole, D.W., Henry, C.L., Nutter, L. (Eds.), The Forest Alternative for Treatment and Utilization of Municipal and Industrial Wastes. University Of Washington Press, Seattle, Wash, pp. 213–218.

Zerunian, S., Franzini, G., Sciscione, L., 1982. Little owls and their prey in a Mediterranean habitat. Boll. Zool. 49, 195–206.

Annalisa Zaccaroni got her Degree in Biological Sciences in 1991, and her Specialization diploma in Toxicology in 1997. She got her PhD in Veterinary Pharmacology and Toxicology on February 24th 2001. Starting from November 2000 she is a researcher at Veterinary Faculty of Bologna University.

Michele Amorena got his Degree in Veterinary Medicine on 1985, and his PhD in Animal Breeding Science in 1989. Starting from 1990 until 1998 he was a researcher at Veterinary Faculty of Naples University. Starting from 1998 he is Associate Professor in Pharmacology and Toxicology at Veterinary Faculty of Teramo University.

Barbara Naso got her Degree in Veterinary Medicine on March 1998. Starting from 1999 she is having her PhD in

Veterinary Pharmacology and Toxicology; she is now at her last year.

Gastone Castellani obtained the Degrees in Biology and Physics in 1988 and 1992 respectively, and his PhD in Physics in 1995. Starting from 1997 he is a researcher at Veterinary Faculty of Bologna University.

Gian Luigi Stracciari obtained the Degree in Pharmacy on 1964. Starting from 1974 he is lecturer of Veterinary Toxicology, being confirmed on this teaching on 1979. At first as Associate Professor, subsequently ad Straordinary Professor and, starting from 1982, as Ordinary Professor he is in charge of the teaching of Veterinary Toxicology.