Original Research

Six Trace Metals in White-Tailed Eagle from Northwestern Poland

E. Kalisińska*, W. Salicki, A. Jackowski

Department of Zoology, Biotechnology and Animal Science Faculty, Agricultural University of Szczecin, ul. Doktora Judyma 20, 71-466 Szczecin, Poland

Received: September 19, 2005
Accepted: May 5, 2006

Abstract

Trace metal contents were determined in kidney, liver, breast muscle, and brain of 11 white-tailed eagles collected in 1995-2001 in northwestern Poland. Four essential metals (Fe, Zn, Cu, Mn) and two highly toxic ones (Pb and Cd) were assayed. Concentrations of lead in kidney, liver, and brain of one of the individuals were high enough to indicate lead poisoning; the concentrations in the second bird were sublethal and increased in the third. In the remaining birds the concentrations reflected the geochemical background levels. The cadmium level in the white-tailed eagles examined was low. Numerous significant and positive (except for three cases) correlations between the metals within individual organs (three each in the brain in liver, two each in the kidney and muscle) and between the organs (the highest number – 9 – of significant correlations was detected between metal contents in the brain and the kidney) were revealed. The brain lead concentration was found to be positively correlated with the metal's concentrations in the kidney and liver as well as in the two latter organs (r_s>0.88).

The results of this study as well as literature data allow us to conclude that the white-tailed eagle in the area of study and in its neighbourhood is clearly exposed to considerable lead poisoning.

Keywords: trace metals, liver, kidney, brain, muscle, white-tailed eagle

Introduction

Trace metal loads in diurnal raptors (order Falconiformes) have been, particularly during the recent two decades, a subject of numerous studies. Both European scientists and their US and Canadian colleagues have been focusing mainly on three highly toxic metals: lead, mercury, and cadmium [1-13]. Scientific literature dealing with other metals in various falconiforms is decidedly less copious [14-16]. Many workers have stressed synergistic or antagonistic interactions between trace metals within the body [17-22]. Numerous such interactions are reflected in correlations both between metals within an organ and between contents of a metal present in various organs [23-25]. There is a need to analyse relationships between a larger group of trace metals, including those essential for normal functioning of the body (e.g., iron, zinc, and copper) as well as those regarded as toxic.

Falconiforms, as top predators, are rare or extremely rare in ecosystems, although their ranges are usually extensive [8, 26, 27]. As numerous raptor species are endangered, various conservation measures are being applied to change that status. For example, the white-tailed eagle (*Haliaeetus albicilla,* Falconiformes), the species in the focus of this study, is protected by the Washington Convention (the Convention on Trade in Endangered Species of Wild Flora and Fauna, CITES). This eagle is classified as globally endangered (CITES: App. I: vulnerable). In many European countries, including Poland, falconiforms

*Corresponding author; e-mail: e.kalisinska@biot.ar.szczecin.

are granted strict protection, as stipulated by the Bern Convention (the Convention on the Conservation of European Wildlife and Natural Habitats), the Bonn Convention (the Convention on Migratory Species of Wild Animals), and the EU Bird Directive (applicable in the EU countries only) as well as by the national legislations. All the legal regulations mentioned prohibit collection (without appropriate permits) of dead individuals and/or recognizable parts thereof. Consequently, collection of ecotoxicological data on protected raptors has been made very difficult and tedious. The scientists concerned have usually access to a few, several, or seldom more individuals of a species from which tissues samples can be collected for chemical analyses. This is the reason why knowledge on predacious bird ecotoxicology progresses relatively slowly. On the other hand, for the protection and conservation of those species to be effective, the causes of the existing threats, including those resulting from anthropogenic environmental pollution, have to be thoroughly understood. It is necessary to collect possibly large data sets and to make various comparisons, e.g., between conspecific individuals inhabiting various areas of their natural range or between ecologically similar species that differ in their diets and ranges.

The white-tailed eagle is a rare palearctic species; its European populations are estimated at 2392-2450 individuals [27]. The Polish white-tailed eagle population is estimated at 430-500 breeding pairs, 142-180 of them occurring in Western Pomerania [28]. The Polish white-tailed eagles account for about 20% of the European population, a distinct increase in the Polish population size was observed during the past 25 years [29].

According to Hagemeijer and Blair [27] who classified the endangerment status of the avian species, the white-tailed eagle should be considered rare. In Poland, this species is listed in the "Red Data Book of Animals: Vertebrates" [30], and is entered under the "threatened category, lower risk; requiring the least concern" category.

The present study was aimed to determine the contents of 4 essential trace metals (iron, zinc, copper, and manganese) and those of two highly toxic ones (lead and cadmium) in tissues of the white-tailed eagle from northwestern Poland, and to compare the data obtained with those reported in the available scientific literature.

Materials and Methods

The study involved 11 individuals of white-tailed eagles (7 males: 5 adults and 2 immature ones, and 4 females: 2 adults and 2 immature), which died under various circumstances in Western Pomerania. One of the eagles died after falling to the ground after an airborne fight with another eagle; another bird died as a result of colliding with power lines; the remaining birds were found dead, but circumstances of their deaths are unknown. All the carcasses were in good condition. The birds were collected, according to the relevant Polish regulations, in 1995-2001 at sites shown in Fig. 1.

The birds' age was determined from the colour of beaks, head, and rectrices [8, 26], the gender being determined from gonads. Prior to autopsy, the birds were kept at –20°C. Assays were performed on samples of the brain, liver, kidney, and breast muscle. The analytical procedures were identical with those described by Kalisińska et al. [20]. The assays involved determinations of tissue per cent water content (by weight) and contents of 6 metals: iron, manganese, copper, zinc, lead, and cadmium. The metals were analyzed by induction-coupled plasma-atomic emission spectrometry (ICP AES) in a JOBIN YVON JY 24 apparatus at the Department of Toxicology, Agricultural University of Szczecin. To validate the analytical techniques used, reference samples (BCR 186 lyophilized pig kidney) of the Commission of the European Communities were assayed as well. The metal contents are expressed in g wet weight (w.w.). Because trace metal contents, as a rule, are not distributed normally, the non-parametric Mann-Whitney test [31] was used to compare metal contents in the immature and old individuals. In addition, cross-correlations between pairs of metals within an organ or a tissue and between tissues and organs were examined with Spearman's correlation coefficients.

Results

Results of metal analyses in the reference sample and the declared contents are compared in Table 1.

The water contents in the liver, kidney, brain, and breast muscle tissues were 74.7; 77.1; 81.4; and 73.4%, respectively.

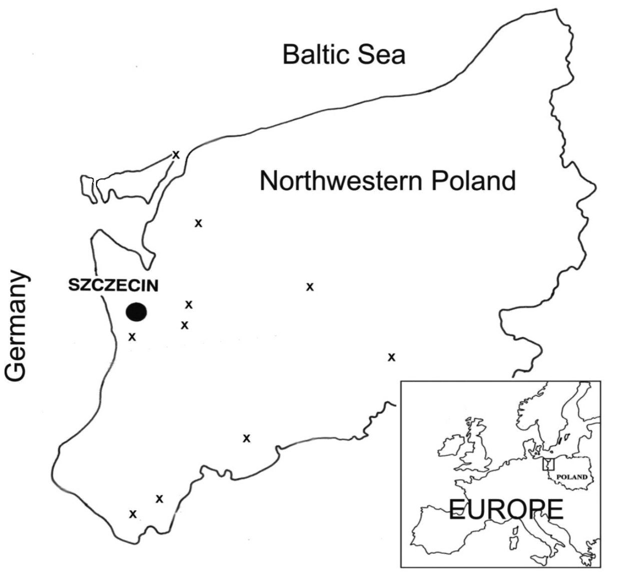

Fig. 1. Geographical location of the collection sites of the white-tailed eagles.

Table 1. Declared values (CR) and this study's results (OR) of trace metal contents in the certified reference material BCR No. 186 (lyophilised pig kidney) (data expressed as μg/g dry weight).

Value	Fe	Mn	Cu	Zn	Pb	Cd
CR	299 ± 10	8.5 ± 0.3	31.9 ± 0.4	128 ± 3	0.306 ± 0.011	2.71 ± 0.15
OR	327 ± 9	9.1 ± 0.1	34.0 ± 0.3	131 ± 2	0.412 ± 0.161	3.30 ± 0.06

Contents of the 6 metals assayed in various tissues of the adult and immature white eagle were in most cases similar, therefore, Table 2 summarises data across all the individuals. Significant age-dependent differences ($p \leq 0.05$) were revealed only for iron and cadmium. The two metals occurred at significantly higher concentrations (w.w.) in the adults (74.19 μgFe/g and 0.013 μgCd/g) than in the immature birds (53.01 μgFe/g and 0.005 μgCd/g).

Among the physiologically important trace metals, the highest contents were typical of iron; both the liver and kidney contained much higher iron contents (431 and about 160 μg/g w.w., respectively) than the breast muscle and the brain (63 and 26 μg/g w.w., respectively; Table 2). Zinc was another metal that occurred at substantial concentrations (almost 10 μg/g in the brain and more than twice as much in the kidneys, liver, and breast muscle). The copper contents were found to range within 2-4 μg/g. The lowest contents were those of manganese (not more than 0.55 μg/g in the brain and muscles as well as 1.6 and 2.8 μg/g in the kidneys and liver, respectively; Table 2).

Only one of the white-tailed eagle individuals revealed high toxic lead concentrations in the liver and kidney (15.58 and 10.03 μg/g w.w., respectively), another individual showing contents that can be regarded as sub-lethal (1.84 and 4.51 μg/g w.w., respectively). The brains of those individuals contained, respectively, 1.50 and 0.99 μgPb/g w.w. A third white-tailed eagle showed slightly elevated lead concentrations in its liver, kidney and brain (2.24, 1.95 and 0.68 μg/g w.w., respectively). The remaining white-tailed eagles had less than 1 μgPb/g w.w. in their livers and kidneys and less than 0.5 μg/g in their brains. Cadmium, the other toxic metal, occurred at low concentrations in the brain, muscle, and liver (less than 0.100 μg/g w.w., except for a single case of a higher content in liver), but clearly higher contents were present in kidneys: the mean kidney level was 0.190 μg/g, whereas contents 3-4 times as high were detected in three cases (0.514; 0.576; and 0.752 μg/g).

Although only a low number of white-tailed eagles could be examined, numerous important cross-correlations were revealed between metal contents in the brain, liver, kidneys, and muscle tissue and between those and other metals in different biological materials (Table 3). The highest number of significant correlations was found between the trace metals present in the brain and kidneys, all the correlations except one being positive.

Discussion

Comprehensive toxicological studies on trace metals in homoiotherm vertebrates are usually focused on the liver and kidneys (the organs most important in detoxification processes and in elimination of harmful substances from the body) as well as on the skeletal muscles (they account for about 50% of body weight). Studies that specifically target lead focus on bones which accumulate lead over the longest time. Research involving the brain is undertaken much less often, although irregularities in brain structure and function lead to altered behaviour and its often dramatic consequences [24, 32-35].

Various authors report trace metal contents relative to wet or dry weight. Information on the tissue (or organ) water content facilitates comparisons and conversions. Such information concerning the white-tailed eagle was given by Falandysz et al. [36] and Kenntner et al. [37]. Calculations involving data from this study and those reported by the authors quoted show the white-tailed eagle brain, kidney, and breast muscle to contain an average of 81, 71.8, 75, and 73.3% water, respectively. As shown by Kalisińska et al. [20], the same tissues and organs of the mallard had similar water contents (81.2, 74.4, 78, and 74% in the brain, liver, kidney, and breast muscle, respectively). For simplicity, the conversions made in this work assume 80 and 75% to be water contents of the brain and the remaining organs, respectively.

Table 4 contains data, extracted from relevant publications, on 6 trace metals (Fe, Zn, Cu, Mn, Pb, and Cd) assayed in the white-tailed eagle. Most studies reported dealt with the highly toxic metals (lead and cadmium); at the same time, the metals were assayed in the highest number of birds. Information on other metals, which may occur as macro-, micro-, and ultramicroelements, is scant; it can be found, for example, in papers describing materials collected in Poland [15, 36, 38-40].

Scientists often encounter difficulties when assigning contents of highly toxic metals (including lead and cadmium), found in tissues and organs, to one of the three categories: toxic, sub-lethal, or geochemical background. So far, most of the relevant studies published dealt with lead concentrations in the waterfowl and in avian predators. Mateo et al. [7] analyzed the falconiform threshold lead concentrations suggested by various authors. They subsequently suggested the following threshold levels for raptor birds: the liver content of

30 μgPb/g d.w. and/or the kidney content of 20 μgPb/g (corresponding to 7.5 and 5 μgPb/g w.w., respectively) signal acute lead intoxication; the liver content exceeding 6 μg/g d.w. and/or the kidney content of 8 μg/g d.w. (i.e..1.5 and 2 μgPb/g w.w., respectively) mean an elevated, sub-lethal level; and contents lower than those given above are considered as resulting from exposure to the normal geochemical background concentrations. The contents listed are close to those quoted by other authors [9, 10, 17, 42-44]. Lead concentration in anseriform brain that indicate a serious exposure begin at 1 μg/g w.w. [45].

Garcia-Fernandez et al. [46] studied ratios between lead contents in the liver (Pb_{liv}), kidneys (Pb_{kid}), and brain (Pb_{brain}) in falconiforms and showed the following ratios arranged in the following order: Pb_{liv}/Pb_{kid} 0.94 Pb_{liv}/Pb_{brain} 4.41, and Pb_{kid}/Pb_{brain} 4.71, respectively. Kenntner et al. [4] determined the ratio between the kidney to the liver lead contents in the white-tailed eagle (n=57) from Germany and Austria to vary from 0.161 to 17.234, with a median value at 1.124. It can be thus assumed that lead contents in soft tissues are at their highest in the kidneys, followed by those in the liver, the brain contents being the lowest. Positive correlations between lead contents

Table 2. Trace elements (in μg/g wet weight) in tissues and organs of white-tailed eagle *Haliaeetus albicilla* (GM, geometric mean; AM, arithmetic mean; SD, standard deviation).

Elements in biological material	n	GM	AM	SD	Range
Brain	9				
Fe		26.07	27.97	11.28	15.97-49.95
Zn		9.97	10.07	1.45	8.21-12.62
Cu		2.26	2.36	0.76	1.55-4.00
Mn		0.34	0.34	0.08	0.24-0.46
Pb		0.157	0.495	0.498	0.001-1.502
Cd		0.007	0.014	0.012	0.001-0.032
Liver	8				
Fe		431.5	559.0	471.5	197.1-1584
Zn		24.87	26.57	10.20	12.04-46.78
Cu		4.02	4.22	1.40	2.56-6.47
Mn		2.79	3.07	1.15	0.82-4.73
Pb		0.126	2.508	5.357	0.001-15.580
Cd		0.025	0.042	0.037	0.001-0.115
Kidney	8				
Fe		158. 9	174.5	86.7	103.2-350.3
Zn		19.58	20.04	4.57	14.44-25.63
Cu		4.07	4.37	1.87	2.58-8.2
Mn		1.60	1.75	0.95	1.15-4.03
Pb		0.143	2.128	3.557	0.001-10.03
Cd		0.190	0.346	0.259	0.012-0.752
Breast muscle	10				
Fe		62.78	66.30	21.74	29.9-102.7
Zn		23.91	25.55	9.88	13.07-39.9
Cu		2.64	2.86	1.19	1.48-5.33
Mn		0.52	0.55	0.16	0.25-0.81
Pb		0.013	0.158	0.321	0.001-1.044
Cd		0.008	0.017	0.021	0.001-0.07

in the liver and kidneys and occasionally between lead contents in the brain and those in the liver and kidneys were reported from falconiforms by various authors [17, 18, 22, 47, 48]. Such correlations were also proved for the Polish white-tailed eagle (Table 3). Thus, documenting and reporting such correlations is justified, also because they seem to provide an indirect means with which to assess lead loads in various organs when data on only one of them are available (usually with the exception of muscles). Effects of lead, a highly neurotoxic metal, on bird physiology, behaviour, mortality, and reproductive success were extensively reviewed by Burger [32].

The raptors which capture mainly the waterfowl and feed on carcasses (ducks and geese that were shot, small mammals, and viscera of large ungulates, discarded by hunters) are particularly exposed to toxic effects of lead. Their animal food contains lead pellets and bullets. In addition, the gizzards of waterfowl and other birds may contain shooting pellets, and the tissues may be lead-contaminated as well as a consequence of past toxicity exposures [3, 10, 16, 18, 43, 44, 49-53]. Not all the birds that have been shot die immediately: some manage to escape. U.S. estimates report that 15 to 25% of such birds can be injured but escape, or are killed but unretrieved [54]. According to Scheuhammer and Norris [55], 10-68% of free-living waterfowl contain embedded pellets. The sources of me-

Table 3. Statistically significant Spearman's rank correlation coefficients (r_S) calculated for metal vs. metal relationships in each type of white-tailed eagle biological material and between them.

Biological material	Correlated metals	r_S	Significance level of r_S
Brain (n=9)	Zn vs. Mn	0.833	0.01
	Zn vs. Pb	0.867	0.01
	Zn vs. Cd	0.763	0.05
Liver (n=8)	Fe vs. Mn	0.762	0.05
	Cu vs. Cd	0.714	0.05
	Pb vs. Cd	0.743	0.05
Kidneys (n=8)	Fe vs. Cd	0.762	0.05
	Pb vs. Cd	0.922	0.01
Muscle (n=10)	Zn vs. Mn	-0.721	0.05
	Fe vs. Cd	0.853	0.01
Brain vs. liver (n=8)	Pb vs. Pb	0.886	0.05
Brain vs. kidneys (n=6)	Fe vs. Cu	-0.943	0.01
	Fe vs. Mn	0.829	0.05
	Zn vs. Zn	0.829	0.05
	Zn vs. Pb	0.829	0.05
	Zn vs. Cd	0.829	0.05
	Mn vs. Mn	0.829	0.05
	Pb vs. Fe	0.886	0.01
	Pb vs. Pb	0.943	0.01
	Pb vs. Cd	0.943	0.01
Brain vs. muscle (n=8)	Mn vs. Zn	-0.738	0.05
	Mn vs. Mn	0.762	0.05
	Cd vs. Mn	0.708	0.05
Liver vs. kidneys (n=8)	Fe vs. Fe	0.738	0.05
	Fe vs. Cd	0.714	0.05
	Pb vs. Pb	0.922	0.01
	Pb vs. Cd	0.755	0.05

Table 4. Comparison of trace metal contents (µg/g wet weight) in white-tailed eagle from different countries (GM, geometric mean)

Metal	Liver			Kidney			Breast muscle			Brain			Country, collection time (source)
	n	GM	range	n	GM	range	n	GM	range	n	GM	range	
Fe	1		268	1		123	1		288				NW Poland, 1981 [39]
Zn			70.4			18.3			22.8				
Cu			0.618			1.98			1.29				
Mn			2.52			0.665			0.828				
Pb			0.123			0.329			0.117				
Cd			0.025			0.168			0.006				
Fe	1		240	1		40	1		100				NW Poland, 1982 [38]
Zn			77			8			32				
Cu			5.6			2.9			4.9				
Mn			2.1			0.78			0.27				
Pb			0.47			0.30			0.039				
Cd			0.072			0.60			0.021				
Fe	2		i320; a350	2		i140; a190	2		i44; a130	1		i16	NW Poland, 1984 [42]
Zn			i79; a38			i16; a26			i19; a37			i8.4	
Cu			i24; a2			i3; a4.4			i3.8; a3.4			i2.5	
Mn			i3; a1.2			i1; a0.92			i0.29; a0.70			i0.20	
Pb			i0.24; a0.13			i0.12; a0.23			i0.07; a0.63			i0.11	
Cd			i0.067; a0.09			i0.12; a1.2			i0.006; a0.024			i0.019	
Fe	4	694	320-1300	4	192	150-700	4	86	55-120	1		41	NW Poland, 1986-87, [36] *
Zn		62	38-100		42	35-60		53	42-80			20	
Cu		6.0	3.3-13.0		5.7	3.2-11.0		8.9	3.8-80			2.5	
Mn		3.1	1.8-4.5		1.44	0.98-2.40		0.62	0.47-0.84			0.48	
Pb		1.57	0.06-28.0		2.07	0.20-13.0		0.31	0.06-1.20			1.8	
Cd		0.044	0.017-0.850		0.65	0.47-0.76		0.019	0.009-0.058			0.034	

Table 4 continued

Fe	10	1200 ^{D,A}	440-5.100	10	1200 ^{D,A}	210-2.900	12	310 ^{D,A}	160-1.000				NW, W Poland, 1991-95, [15, 40]
Zn		170 ^{D,A}	93-320		140 ^{D,A}	59-360		12 ^{D,A}	61-220				
Cu		13 ^{D,A}	5.7-36		14 ^{D,A}	6.6-40		9.2 ^{D,A}	3.9-16				
Mn		8.5 ^{D,A}	1.8-16		4.6 ^{D,A}	2.5-7.2		1.6 ^{D,A}	0.6-5.9				
Pb		1.1 ^{D,A}	0.48-1.3*		0.92 ^{D,A}	0.19-1.9**		0.98 ^{D,A}	0.05-3.9**				
Cd		0.15 ^{D,A}	0.015-0.41		1.5 ^{D,A}	0.029-4.4		0.02 ^{D,A}	0.004-0.051				
Pb	57	0.619	0.014-61.974	57	0.680	0.011-17.133							Germany and Austria, 1993-2000, [4]
Cd		0.019	0.004-0.663		0.132	0.011-0.665							
Pb	44	0.577	0.042-54.295	41	0.525	0.064-16.979							Germany, 1979-98, [37]
Cd		0.023	0.004-0.261		0.142	0.004-0.809							
Pb	1		<0.1 ^{D}										Britain, 1980-90, [10]
Pb	11	0.354	0.027-36.281	12	0.284	0.026-14.906							Greenland, 1997-2000, [6]
Cd		0.317	0.084-0.555		1.754	0.447-5.577							
Pb	1		79 ^{D}	1		58 ^{D}							Japan, 1997 [68]
Cd			0.67 ^{D}			6.5 ^{D}							
Pb	3	110 ^{D,A}	77-174	2		58-141 ^{D}	1		9.3 ^{D}				Japan, 1997-98, [59]
Cd		0.397 ^{D,A}	0.26-0.67			2.3-6.5 ^{D}			0.015 ^{D}				

^{D}dry weight; ^{A}arithmetic mean; ^{M}median; i, immature; a, adult; * two samples (2.7 and 40 µg/g) excluded; ** two samples (2.6 and 48 µg/g) excluded value calculated from data of Falandysz et al. [40]; data for breast muscle in Falandysz et al. [44]; data for liver and kidney in Falandysz et al. [17]

tallic and non-metallic lead mentioned above are a threat mainly to the diurnal raptors, but also, albeit sporadically, to nocturnal predators. In the U.S. states of Minnesota and Wisconsin, the percentages of the eagles *Haliaeetus leucocephalus* and *Aquila chrysaetos* affected by lead poisoning (as assessed on the basis of blood samples from 654 individuals) were compared before and after the ban of lead shot (i.e., pre-1990). In Minnesota, the respective percentages were 25 and 42%, the corresponding values for Wisconsin being 42 and 32% [56]. Canadian studies [44], based on lead analyses of kidneys and liver of dead eagles *H. leucocephalus* and *A. chrysaetos* (n=127 in both species) revealed plumbism in 12% and elevated concentrations of lead in 4% of the individuals. Mateo et al. [51] contend that there is a clear relationship between the hunting season and the number of raptors affected by elevated blood Pb levels (>200 ng/ml). The birds so affected may, at the end of the hunting season, account for more than 80% of the population, to drop to about 23% later on. Bone assays of 34 globally threatened Spanish imperial eagles (*Aquila adalberti*) showed lead poisoning to have affected 12% of them [11]. The data reported for the white-tailed eagle from Europe, Greenland, and Asia show the species to be threatened by lead poisoning disease and revealed a large scale of the problem [4, 6, 37, 57, 58]. Studies carried out in Germany and Austria on 57 white-tailed eagles showed 16 of them (28%) to have liver Pb contents of 5-62 µg/g w.w.; according to the criteria adopted, those birds were classified as lead-poisoned [4]. The highest number of white-tailed eagles was collected in the German provinces bordering Poland, i.e., Mecklenburg-Vorpommern (n=19) and Brandenburg (n=24). Of the 43 birds examined, as many as 15 (33%) showed liver and/or kidney Pb contents in excess of 5 µg/g w.w. [4]. In their study focusing on Germany only, Kenntner et al. [37] reported 20% (9 out of 46) of the eagles examined to have been lead-poisoned. In the 1990s white-tailed eagles with more than 2 µgPb/g w.w. in their liver and/or kidneys were encountered during winter months, i.e.; during the winter waterfowl hunting season [37]. The northwestern region of Poland and the adjacent German provinces abound in water bodies, including a temporarily flooded area at the River Warta's confluence with the Odra. Such areas are favourite nesting, wintering, and rooking grounds of waterfowl during their migrations. Those areas have been used as human hunting grounds and lead-containing pellet shots present a serious threat for the birds [20, 45, 59]. At the same time, those areas are inhabited by a substantial part of the Polish white-eagle population (up to 180 breeding pairs) [28], with a further 100-127 pairs nesting in the neighbouring areas of Mecklenburg-Vorpommern [60, 61]. On the basis of this study (1994-2001) and data reported by other authors for 1981-95, it can be contended that, of the 26 white-tailed eagles collected at those periods of time, 4 (15.4%) were affected by plumbism, another two (7.7%) showing sub-lethal lead contents. The German and Polish studies show the white-tailed eagle in this part of Europe to be exposed to lead poisoning. Effects of sub-lethal and lethal poisoning of the eagle species discussed may be important for its population size and condition.

The mean cadmium contents in the white-tailed eagle (Tables 2 and 4) show the metal levels to be usually very low in the brain and muscles (0.006-0.058 µg/g w.w.), low in the liver (0.023-0.245 µg/g w.w.), and highest in the kidneys (0.190-1.754 µg/g w.w.). Among northwestern Poland's white-tailed eagles examined by Falandysz [41] and Falandysz et al. [15], two individuals showed their kidney cadmium level to slightly exceed 1 µg/g w.w. The kidneys of one of the two white-tailed eagles examined in Japan contained elevated (in excess of 6.5 µg/g d.w., i.e., about 1.6 µg/g w.w.) amounts of cadmium [57]. However, the highest kidney cadmium contents were those reported from the Greenland white-tailed eagle: more than 5.5 µg/g w.w. in some individuals, the geometric mean of the 11 Greenland individuals examined being 1.754 µg/g w.w. [6].

Homoiotherm vertebrates tend to accumulate cadmium with age; the highest concentrations are accumulated in kidneys and damage the kidney tubules. For this reason, cadmium is frequently termed nephrotoxic [2, 5, 17, 20, 46, 62, 63]. Scheuhammer [64] suggested that a cadmium level over 3 mg/kg d.w. in liver and over 8 mg/kg d.w. in kidney (0.75 and 2 µgCd/g w.w., respectively) might indicate an increased environmental exposure to that metal. In light of those criteria, only some Greenland white-tailed eagles showed kidney cadmium contents indicative of an elevated risk of exposure to cadmium.

Serious pathological changes brought about by high cadmium contents (taken up mainly with food and/or with water) involve primarily impairment of kidney tubules, calcium metabolism disorders (skeletal decalcification), and liver function impairment [19, 62, 63]. The changes accompany very high cadmium contents (above 100 µg/g w.w.) detected in avian kidneys [62]. It should be added that kidney cadmium contents are correlated with those in the liver, even if the contents themselves are low [17, 20, 46, 62]. As reported by Garcia-Fernandez et al. [46], a group of more than 100 individuals representing 32 avian species showed as much as 92% of the total amount of cadmium to be concentrated in the liver and kidneys (61% of which was found in the kidneys), 4% in the brain, 3.5% in bones, and as little as 0.5% in the blood. The authors quoted found a number of significant correlations, including those between the kidney cadmium contents and the contents in the liver and brain as well as between the liver contents and those in the brain. In addition, they calculated mean ratios between the liver (Cd_{liv}) and kidney (Cd_{kid}) and brain (Cd_{brain}) cadmium contents. In the multi-species bird group under study, the following ratios were obtained: Cd_{liv}/Cd_{kid} 0.51; Cd_{liv}/Cd_{brain} 7.6; and Cd_{kid}/Cd_{brain} 13.8; the ratios showed clear species-dependent differences. The largest differences in the Cd_{kid}/Cd_{brain} and Cd_{liv}/Cd_{brain} ratios were those between the swift *Apus apus* (n=13; 70 and 38, respectively) and the remaining 6 most abundant species, including the common kestrel *Falco tinnunculus* (n=14; 20 and 8, respectively). Of the 7 bird species analyzed by Garcia-Fernandez et al. [46] in detail, the swift typically shows the highest level of locomotor activity, for which reason its blood-brain barrier may function differently (it is tighter and less permeable for Cd) than in the remaining species. The Cd_{liv}/Cd_{kid}, Cd_{kid}/Cd_{brain}, and Cd_{liv}/Cd_{brain} ratios in the white-tailed eagle were 0.13; 27; and 3.6, respectively (were calculated from the GM values in Table 2). The white-tailed eagle Cd_{kid}/Cd_{liv} ratio (a reverse of the already presented one) was 7.841, as calculated by Kenntner et al. [4]. After conversion to Cd_{liv}/Cd_{kid}, the value is 0.16, i.e., very close to that obtained in this study.

Other studies, e.g. those involving the northern goshawk (*Accipiter gentilis)* showed, despite the usually narrow ranges of cadmium contents in the liver and kidneys (0.001-0.791 and 0.014-1.097 μg/g w.w., respectively), significant differences between individuals differing in their condition, i.e. between those in very poor and moderate condition and between those in very poor and good condition, higher residue levels being found in more emaciated birds [5]. The authors quoted stressed that, while in their natural environment, the birds are exposed to various xenobiotics (including other non-essential trace metals, organochlorine pesticides, and PCBs) which, acting in concert, may significantly worsen the birds' condition and reproductive success. This argument is additionally strengthened by results of studies on synergies between some trace metals and by significant correlations between them, e.g. between cadmium and lead and between lead and iron in the liver as well as between cadmium in the liver and lead in the brain [18, 20, 22] (cf Table 3 in this study). Moreover, trace metals such as lead and cadmium, when in low but persisting concentrations, may detrimentally affect an individual's humoral immune response [65], at least in the great tit (*Parus major*), a small songbird. It cannot be ruled out that the threat to birds posed by cadmium present in the natural environment has been underestimated by numerous researchers.

Conclusions

White-tailed eagles in northwestern Poland and in the neighbouring German areas have been exposed to lead poisoning. The scale of the problem is similar to that observed in the white-tailed eagle and in other eagle species in Europe, Asia, and North America.

Results of this study and data extracted from literature allow us to assess differences and similarities in contents of essential trace metals between individuals of the white-tailed eagle from various areas and to compare the two raptors with other avian species. Both the scientific and the conservation-related reasons necessitate analyses of a wider array of metals (not only the toxic ones) and more in-depth studies of the relationships between them.

Acknowledgements

We wish to thank Mr. Marek Kalisiński, the Regional Coordinator of the Eagle Conservation Committee, Poland, and the Regional State Forest Directorate in Szczecin for the assistance in procuring birds for analysis. We acknowledge the staff of the Department of Toxicology, Agricultural University of Szczecin, for performing chemical assays.

References

1. BAGLEY G.E., LOCKE L.N. The occurrence of lead in tissues of wild birds. Bull. Environ. Contam. Toxicol. **2**, 297, **1967**.
2. HONTELEZ L.C.M.P., VAN DEN DUNGEN H.M., BAARS A.J. Lead and cadmium in birds in the Netherlands: a preliminary survey. Arch. Environ. Contam. Toxicol. **23**, 453, **1992**.
3. JANSSEN D.L., OSTERHUIS J.E., ALLEN J.L., ANDERSON M.P., KELTS D.G., WIEMEYER S.N. Lead poisoning in free-ranging California condors. JAVMA, **189**, 1115, **1986**.
4. KENNTNER N., TATARUCH F., KRONE O. Heavy metals in soft tissue of white-tailed eagles fund dead or moribund in Germany and Austria from 1993 to 2000. Environ. Toxicol. Chem. **20**, 1831, **2001**.
5. KENNTNER N., KRONE O., ALTENKAMP R., TATARUCH F. Environmental contaminants in liver and kidney of free-ranging northern goshawks *(Accipiter gentilis)* from three regions of Germany. Arch. Environ. Contam. Toxicol. **45**, 128, **2003**.
6. KRONE O., WILLE F., KENNTNER N., BOERTMANN D., TATARUCH F. Mortality factors, environmental contaminants, and parasites of white-tailed sea eagles from Greenland. Avian Dis. **48**, 417, **2004**.
7. MATEO R., TAGGART M., MEHARG A.A. Lead and arsenic in bones of birds of prey from Spain. Environ. Pollut. **126**, 107, **2003**.
8. NEWTON I. Population Ecology of Raptors. T & A D Poyser, London, **1990**.
9. PAIN D.J., AMIRAD-TRIQUET C., BAVOUX C., BURNELEAU G., EON L., NICOLAU-GILLAUMET P. Lead poisoning in wild populations of marsh harriers *Circus aeruginosus* in the Camargue and Charente-Maritime, France. Ibis **135**, 379, **1993**.
10. PAIN D.J., SEARS J., NEWTON I. Lead concentrations in birds of prey in Britain. Environ. Pollut. **87**, 173, **1995**.
11. PAIN D.J., MEHARG A.A., FERRER M., TAGGART M., PENTERIANI V. Lead concentrations in bones and feathers of the globally threatened Spanish imperial eagle. Biol. Conserv. **121**, 603, **2005**.
12. SCHARENBERG W., STRUWE-JUHL B. Total mercury in feathers of white-tailed eagle (*Haliaeetus albicilla* L.) from northern Germany over 50 years. Bull. Environ. Contam. Toxicol. **64**, 686, **2000**.

13. WAYLAND M., MILLER M.J.R., BOLLINGER T., MCADIE M., LANGELIER K., KEATING J., FROESE M.W. Mortality, morbidity, and lead poisoning of eagles in western Canada, 1986-98. J. Raptor Res. **37**, 8, **2003**.
14. FALANDYSZ J., MIZERA T. Trace element concentrations in feathers of white-tailed sea eagles *Haliaeetus albicilla* collected recently in Poland. In: Meyburg B.-U. & Chancellor R.D. (Eds.), Raptor Conservation Today, pp. 717-723, **1994**.
15. FALANDYSZ J., ICHIHASHI H., SZYMCZYK K., JAMASAKI S., MIZERA T. Metallic elements and metal poisoning among white-tailed sea eagles from the Baltic south coast. Marine Pollut. Bull. **42**, 1190, **2001**.
16. HENNY C.J., BLUS L.J., HOFFMAN D.J., GROVE R. Lead in hawks, falcons and owls downstream from a mining site on the Coeur d´Alene River, Idaho, Environ. Monit. Asses. **29**, 267, **1994**.
17. BATTAGLIA A., GHIDINI S., CAMPANINI G., SPAGGIARI R. Heavy metal contamination in little owl *(Athene noctua)* and common buzzard *(Buteo buteo)* from northern Italy. Ecotoxicol. Environ. Safety **60**, 61, **2005**.
18. BEYER W.N., SPANN J.W., SILEO L., FRANSOM J.C. Lead poisoning in six captive avian species. Arch. Environ. Contam. Toxicol. **17**, 121, **1988**.
19. COOK J.A., MARCONI E.A., DI LUZIO N.R. Lead, cadmium, endotoxin interaction: effect on mortality and hepatic function. Toxicol. Appl. Pharm. **28**, 292, **1974**.
20. KALISIŃSKA E., SALICKI W., MYSŁEK P., KAVETSKA K.M., JACKOWSKI A. Using the mallard to biomonitor heavy metal contamination of wetlands in north-western Poland. Sci. Total Environ. **320**, 145, **2004**.
21. KENDALL R.J., VEIT H.P., SCANLON P.F. Histological effects and lead concentrations in tissues of adult male ringed turtle doves that ingested lead shot. J. Toxicol. Environ. Health **8**, 649, **1981**.
22. ZACCARONI A., AMORENA M., NASO B., CASTELLANI G., LUCISANO A., STRACCIARI G.L. Cadmium, chromium and lead contamination of *Athene noctua*, the little owl, of Bologna and Parma, Italy. Chemosphere **52**, 1251, **2003**.
23. COSSON R. P., AMIARD J. C., AMIARD-TRIQUET C. Trace element in little egrets and flamingos of Camargue, France. Ecotoxicol. Environ. Safety **15**, 107, **1988**.
24. BURGER J., RODGERS J. A., GOCHFELD M. Heavy metal and selenium levels in endangered wood storks *Mycetaria americana* from nestling colonies in Florida and Costa Rica. Arch. Environ. Contam. Toxicol. **24**, 417, **1995**.
25. LLACUNA S., GORRITZ A., SANPERA C., NADAL J. Metal accumulation in three species of passerine birds (*Emberiza cia*, *Parus major*, and *Turdus merula*) subjected to air pollution from a coal-fried power plant. Arch. Environ. Contam. Toxicol. **28**, 298, **1995**.
26. DEL HOYO J., ELLIOTT A., SARGATAL J. (Eds). Handbook of the Birds of the World. Vol. 2. New World Vultures to Guineafowl. Lynx Edicions, Barcelona **1994**.
27. HAGEMEIJER E.J.M., BLAIR M.J. (Eds). The EBCC Atlas of European Breeding Birds: Their Distribution and Abundance. T & A D Poyser, London **1997**.
28. ADAMSKI A., LONTKOWSKI J., MACIOROWSKI G., MIZERA T., RODZIEWICZ M., STAWARCZYK T., WACŁAWEK K. Distribution and numbers of rare birds of pray in Poland at the end of the 20th century (in Polish, English summary). Not. Ornit. **40**, 1, **1999**.
29. TOMIAŁOJĆ L., STAWARCZYK T. The Awifauna of Poland. Distribution, Numbers and Trends. PTPP pro Natura, Wrocław, Poland (in Polish, English summary) **2003**.
30. GŁOWACIŃSKI Z. (Eds.). Polish Red Data Book of Animals. Vertebrates. PWRiL, Warszawa, Poland, (in Polish, English summary) **2001**.
31. SOKAL R.R., ROHLF F.J. Biometry. The principles and practice of statistics in biological research. Third edition. W.H. Freeman and Company, New York **1995**.
32. BURGER J. A risk assessment for lead in birds. J. Toxicol. Environ. Health **45**, 369, **1995**.
33. BURGER J., GOCHFELD M. Behavior effects of lead exposure on different days for gull (*Larus argentatus*) chicks. Pharm. Bioch. Behavior **50**, 97, **1995**.
34. CHERN C.-M., PROCTOR S.P., FELDMAN R.G. Exposure assessment in clinical neurotoxicology: environmental monitoring and biologic markers. In: Chang L.W., Slikker W. (Eds.), Neurotoxicology Approches and Methods. Academic Press, San Diego **1995**.
35. DAVIS J.M., OTTO D.A., WEIL D.E., GRANT L.D. The comparative developmental neurotoxicity of lead in humans and animals. Neurotox. Terat. **12**, 215, **1990**.
36. FALANDYSZ J., JAKUCZUN B., MIZERA T. Metals and organochlorines in four female white-tailed eagles. Mar. Pollut. Bull. **19**, 521, **1988**.
37. KENNTNER N., OEHME G., HEIDECKE D., TATARUCH F. Retrospektive Untersuchung zur Bleiintoxikation und Exposition mit potenziell toxischen Schwermetallen von Seeadlern *Haliaeetus albicilla* in Deutschland. Vogelwelt **125**, 63, **2004**.
38. FALANDYSZ J. Metals and organochlorines in a female white-tailed eagle from Uznam island, southwestern Baltic Sea. Environ. Conserv. **11**, 262, **1984**.
39. FALANDYSZ J., SZEFER P. Metals and organochlorines in a specimen of white-tailed eagle. Environ. Conserv. **10**, 256, **1983**.
40. FALANDYSZ J., STRANDBERG L., MIZERA T., KALISIŃSKA E. The contamination of white-tailed sea eagles with organichlorines in Poland. Roczniki PZH **51**, 7, **2000**.
41. FALANDYSZ J. Metals and organochlorines in adult and immature males of white-tailed eagle. Environ. Conserv. **13**, 69, **1986**.
42. PATTEE O.H., WIEMEYER S.N., MULHERN B.M., SILEO L., CARPENTER J.W. Experimental lead poisoning in bald eagle. J. Wildl. Manage. **45**, 806, **1981**.
43. PAIN D.J., AMIRAD-TRIQUET C. Lead poisoning of raptors in France and elsewhere. Ecotoxicol. Environ. Safety **25**, 183, **1993**.
44. WAYLAND M., BOLLINGER T. Lead exposure and poisoning in bald eagles and golden eagles in the Canadian prairie provinces. Environ. Pollut. **104**, 341, **1999**.

45. KALISIŃSKA E. Lead and other heavy metals in the brain of geese hunted in the vicinity of Słońsk, Poland. Biol. Bull. Poznań **37**, 273, **2000**.
46. GARCIA-FERNÁNDEZ A.J., SANCHEZ-GARCIA J.A., GOMEZ-ZAPATA M., LUNA A. Distribution of cadmium in blood and tissues of wild birds. Arch. Environ. Contam. Toxicol. **30**, 252, **1996**.
47. CUSTER T.W., FRANSON J.C., PATTEE O.H. Tissue lead distribution and hematologic effects in american kestrels (*Falco sparverius* L.) fed biologically incorporated lead. J. Wildl. Dis. **20**, 39, **1984**.
48. GARCIA-FERNÁNDEZ A.J., MOTAS-GUZMÁN M., NAVAS I., MARIA-MOJICA P., LUNA A., SANCHEZ-GARCIA J.A. Environmental exposure and distribution of lead in four species of raptors in southeastern Spain. Arch. Environ. Contam. Toxicol. **33**, 76, **1997**.
49. LOCKE L.N., FRIEND M. Lead poisoning of avian species other than waterfowl. In: Pain D.J. (Eds.), Lead Poisoning in Waterfowl. Proceedings of an IWRB Workshop Brussels, Belgium 1991. IWRB Special Publication No. **16**, Slimbridge, UK. pp. 19-22, **1992**.
50. LOCKE L.N., THOMAS N.J. Lead poisoning of waterfowl and raptors. In: Fairbrother A., Locke L.N., Hoff G.L. (Eds.), Noninfectious Diseases of Wildlife. Manson Publishing The Veterinary Press, London, pp. 108-117, **1996**.
51. MATEO R., ESTRADA J., PAQUET J.-Y., RIERA X., DOMINGUEZ L., GUITART R., MARTINEZ-VILALTA A. Lead shot ingestion by marsh harriers *Circus aeruginosus* from the Ebro delta, Spain. Environ. Pollut. **104**, 435, **1999**.
52. PAIN D.J. Lead poisoning of waterfowl. In: Pain D.J. (Eds.), Lead Poisoning in Waterfowl. Proceedings of an IWRB Workshop Brussels, Belgium 1991. IWRB Special Publication No. **16**, Slimbridge, UK. pp. 7-13, **1992**.
53. WIEMEYER S.N., JUREK R.M., MOORE J.F. Environmental contaminants in surrogates, foods, and feathers of California condors (*Gmnogyps californianus*). Environ. Monit. Asses. **6**, 91, **1986**.
54. MOREHOUSE K. Crippling loss and shot-type: the United States experience. In: Pain D.J. (Eds.), Lead Poisoning in Waterfowl. Proceedings of an IWRB Workshop Brussels, Belgium 1991. IWRB Special Publication No. **16**, Slimbridge, UK. pp. 32-37, **1992**.
55. SCHEUHAMMER A.M., NORRIS S.L. The ecotoxicology of lead shot and lead fishing weights. Ecotoxicology **5**, 279, **1996**.
56. KRAMER J.L., REDIG P.T. Sixteen years of lead poisoning in eagles, 1980-95: an epizootiologic view. J. Raptor Res. **31**, 327, **1997**.
57. IWATA H., WATANABE M., KIM E-Y., GOTOM R., YASUNAGA G., TANABE S., MARUDA Y., FUJITA S. Contamination by chlorinated hydrocarbons and lead in Steller's sea eagle and white-tailed sea eagle from Hokkaido, Japan. First Symposium on Steller's and White-tailed Sea Eagles in East Asia. In: Ueta M., McGrady M.J. (Eds.), Wild Bird Society of Japan. Tokyo, Japan, pp. 91-106, **2000**.
58. KUROSAWA N. Lead poisoning in Steller's sea eagles and white-tailed sea eagles. In: Ueta M., McGrady M.J. (Eds.), First Symposium on Steller's Sea Eagles and White-tailed Sea Eagles in East Asia. Wild Bird Society of Japan, Tokyo Japan, pp. 107-109, **2000**.
59. KALISIŃSKA E., WYSOCKI R., DAŃCZAK A., KALISIŃSKI M.M., ENGEL J. Hunters' shot in the stomach of wild geese *Anser* taken in the area of Słońsk, Poland. Acta Ornith. **30**, 117, **1995**.
60. NICOLAI B. Atlas der Brutvögel Ostdeutchlands: Mecklenburg/Vorpommern, Brandenburg, Sachsen-Anhalt, Sachsen, Thüringen. Gustav Fischer Verlag Jena & Stuttgart. **1993**.
61. STRUWE-JUHL B. Brutbestand und Nahrungsökologie des Seeadlers *Haliaeetus albicilla* in Schleswig-Holstein mit Angaben zur Bestandsentwicklung in Deutschland. Vogewelt **117**, 341, **1996**.
62. LARISON J.R., LIKENS G.E., FITZPATRICK J.W., CROCK J.G. Cadmium toxicity among wildlife in the Colorado Rocky Mountains. Nature **406**, 181, **2000**.
63. WHITE D.H., FINLEY M.T., FERRELL J.F. Histopathologic effects of dietary cadmium on kidneys and testes of mallard ducks. J. Toxicol. Environ. Health **4**, 551, **1978**.
64. SCHEUHAMMER A.M. The chronic toxicity of aluminium, cadmium, mercury, and lead in birds: a review. Environ. Pollut. **46**, 263, **1987**.
65. SNOEIJS T., DAUWE T., PINXTEN R., VANDESANDE F., EENS M. Heavy metal exposure affects the humoral immune response in a free-living small songbird, the great tit (*Parus major*). Arch. Environ. Contam. Toxicol. **46**, 399, **2004**.
66. KIM E.-Y., GOTO R., IWATA H., MARUDA Y., TANABE S., FUJITA S. Preliminary survey of lead poisoning of Steller's sea eagle *(Haliaeetus pelagicus)* and white-tailed sea eagle *(Haliaeetus albicilla)* in Hokkaido, Japan. Environ. Toxicol. Chem. **18**, 448, **1999**.