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Total mercury concentration in the kidneys of birds from Poland

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Abstract: A study was conducted on mercury renal concentration in 154 individuals of 28 species of birds with various habitat and trophic preferences. The highest geometric mean concentrations of Hg were found in large piscivorous birds such as Cormorant and Grey Heron. The maximum mercury levels were noted for individuals of White-tailed Eagle and Great Crested Grebe. Significant differences in renal mercury concentration between Sparrowhawk individuals were found in winter and in spring. Male Sparrowhawks generally accumulated rather more mercury in their kidneys than the females. Statistically significant differences in renal mercury concentration between males and females were also found for Goshawks. In gulls, differences in the level of mercury accumulation were dependent on the preferred food.

Key words: Mercury, biomonitoring, birds, kidney

1. Introduction

In Poland, due to the economic transformation and strongly advanced deindustrialization that occurred mainly in the last decade of the past century and in the first decade of the present century, mercury emissions decreased by more than half. Unfortunately, among European countries, Poland is still a prominent emitter of this toxic element into the environment (European Environment Agency, 2013). This is strongly related to the high use of coal for energy production (Hlawiczka and Cenowski, 2013; http://www.eoearth.org/view/article/153018/). Other sources of mercury in the environment, such as products and wastes of the electric/electronics industry, should be pointed out, especially those related to the manufacturing of light sources (e.g., fluorescent lamps) and measuring instruments. In addition, the production of certain paints and chemicals is connected with mercury emission (Hlawiczka and Cenowski, 2013). In agriculture, a high risk is related to the usage of mercury-containing pesticides and seed dressing (Boening, 2000). Owing to the cross-border character of mercury emission, the possibility of illegal transportation of mercury-containing wastes, and the complicated processes of migration and accumulation of this element in the environment, the continuous (short- and long-term) monitoring of this element is required (Boening, 2000; Bustnes et al., 2013). The use of birds as bioindicators of mercury levels provides an essential tool for studying the environmental quality of different ecosystems (Stankovic and Stankovic, 2013; Stankovic et al., 2014). As they play an important role in food chains, have wide geographical distribution, and are often sedentary species, birds are good biomonitors of heavy metals (Furnes et al., 1997; Ayaş, 2007; Ayaş et al., 2008; Castro et al., 2011; Bustnes et al., 2013; Stankovic and Stankovic, 2013). The above characteristics of these avian species and the analysis of contamination levels in key organs in spatiotemporal dimensions allow us to understand the mechanisms of transport and accumulation of mercury in different ecosystems. Current studies show that the concentration of Hg in the key organs of birds can reflect the concentration level of this element in their diet, which can be strictly related to the contamination degree of habitats or ecosystems used by the monitored birds (Monteiro et al., 1998; Falandysz, 2001; Kenntner et al., 2003; Bustnes et al., 2013). The especially high bioindicative value can be attributed to data derived from the analysis of key organs from sedentary top predators (Castro et al., 2011; Bustnes et al., 2013) and species with a very large home range (Krone et al., 2006; Misztal-Szkudlinska et al. 2011; Kitowski et al., 2012). The aim of the present study was to determine the mercury levels in kidneys from a high

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number of specimens (n = 154) from 28 species of birds inhabiting the eastern part of Poland, and also to discuss the factors influencing the elevated concentrations of this element.

2. Materials and methods

The kidneys used in our studies were taken from wounded birds delivered to veterinary clinics or rehabilitation centers close to the birds' nesting places between 2010 and 2011. The birds either died despite having received intensive treatment, or, due to being untreatable upon delivery, were euthanized with lethal injection by veterinary doctors to spare them suffering. The birds' overall 'stay' in the clinics/rehabilitation centers did not exceed 10 days. A significant number of specimens were found during fieldwork on roads under high-voltage power lines. Half of the collected Rooks originated from a communal roost found on a frosty night. A total of 154 specimens representing 28 species of birds were studied. The majority of the studied birds originated from farmland, aquatic, and forest habitats of eastern and southern Poland (Bialystok, Lublin, Rzeszow, and Warsaw regions). A significant share of the analyzed specimens, representing Hooded Crow *Corvus cornix*, Jackdaw *Corvus monedula*, Rook *Corvus frugilegus*, Mallard *Anas platyrhynchos*, Jay *Garrulus glandarius*, and Common Kestrel *Falco tinnunculus*, were birds from the urban environment of Warsaw. After extraction from the birds' bodies, kidneys were stored in freezers until the analysis was performed, and were finally freeze-dried. The kidneys of one bird were considered as one analyzed sample (no distinction between the kidneys was made).

Mercury contents in samples were determined by using a nonflame atomic spectrometry absorption technique (mercury analyzer: AMA 254, Altec, Czech Republic). For analysis with the AMA, 254 kidney samples were predried at 120 °C in the internal oven of the analyzer and burned in oxygen (of 99.999% purity) at 550 °C. The decomposition products were further carried by oxygen flow to an Au-amalgamator for selective mercury trapping. A short heat-up of the amalgamator caused the mercury to be released and measured by the cold vapor AAS technique at 253.65 nm in a dual path length (long and short) cuvette. Hence, the same quantity of mercury was measured twice with variable sensitivity, which enabled mercury determination over a wide range (from 0.05 to 600 ng) in a single measurement (according to EPA procedure CAS 7439-97-6, 2010). The detection limit was 10^{-5} mg/kg. The calibration values provided by the producer were controlled regularly with the calibration standard mercury solution (AccuTrace single element standard; AccuStandard Inc., New Haven, CT, USA). The studied birds were divided into 7 trophic guilds due to their food preferences (Alleva et al., 2006), namely piscivorous (fish-eating), herbivorous (plant-eating), small mammal-eating, omnivorous and terrestrial invertebrate-eating, and bird-eating (divided into 2 subguilds; Table 1). The results are presented as mean ± SD in mg/kg dw (dry weight).

3. Results

In all samples, the mercury level was found to be above the detection limit of the apparatus. Among the birds studied, the highest mean Hg concentrations were noted in specimens of those species for which fish constitute the food base, such as Cormorant *Phalacrocorax carbo* and Grey Heron *Ardea cinerea* (Table 1). The maximum mercury concentration levels of the abovementioned bird species were almost the same; however, the mean values (geometric) differed markedly: Cormorant revealed a two times higher concentration than Grey Heron (see Table 1). Elevated or very high mean concentrations of mercury were also noted in individual specimens belonging to the above food guild that we had at our disposal, such as Great Crested Grebe *Podiceps cristatus*, Goosander *Mergus merganser*, Black-throated Diver *Gavia arctica*, and Black Stork (Table 1). Noteworthy was also the White-tailed Eagle *Haliaeetus albicilla*, in which the median Hg concentration was relatively low (1.108 mg/kg dw), in spite of the fact that one specimen of that species revealed the highest (among all analyzed samples) mercury concentration (Table 1).

Kidneys of three gull species of various trophic preferences were also analyzed (Table 1). Among these species, the highest mean concentrations of mercury were found in Herring Gull *Larus argentatus*. The mean renal mercury concentrations assayed for Common Gull *Larus canus* and Black Headed Gull *Chroicocephalus ridibundus* were lower, though very similar (Table 1). The differences among the species studied are well illustrated by the comparison of median concentrations, the values for the particular gull species mentioned above being 0.856 mg/kg dw, 0.646 mg/kg dw, and 0.535 mg/kg dw, respectively (see Table 1). Also worth noting is the fact that the two highest mercury concentrations (1.235 mg/kg dw and 1.553 mg/kg dw) were discovered in specimens of Black Headed Gulls that were recovered in the Warsaw area (capital of Poland, population of 2.5 million) and brought to the bird rehabilitation center of the Warsaw Zoo. The examination of renal mercury concentration in the remaining specimens from eastern Poland revealed that it fell within the range of 0.439–0.545 mg/kg dw.

Specimens of Sparrowhawks were considered as two groups with respect to the season in which they were brought to clinics and/or found dead in the field. The analyses revealed significant differences in median concentrations ($Z = 2.88$, $n_1 = 6$, $n_2 = 6$, $P = 0.0039$) between birds that died in summer (0.663 mg/kg dw, range: 0.341–0.797 mg/kg dw) and those that died in winter (2.252 mg/

Table 1. Total concentration of mercury in kidneys [mg/kg dry weight (dw)] of individuals of birds. N – number of samples. SD – standard deviation. Food (trophic guilds): P – piscivorous, Bl – large bird-eating, Bs – small bird-eating, H – herbivorous, O – omnivorous, S – small mammal-eating, T – terrestrial invertebrate-eating. Min. – minimum value. Max. – maximum value.

Species	N	Food	Mean	SD	Geometric mean	Median	Min.	Max.
Ardea cinerea	8	P	4.424	3.497	3.107	3.902	0.847	10.197
Ciconia nigra	1	P	3.671	-	-	-	-	-
Gavia arctica	1	P	2.988	-	-	-	-	-
Haliaeetus albicilla	5	P	4.111	5.864	2.078	1.108	0.715	14.447
Larus argentatus	2	P	0.856	-	-	-	0.276	1.437
Larus canus	7	P	0.689	0.310	0.619	0.646	0.233	1.084
Mergus merganser	1	P	10.460	-	-	-	-	-
Phalacrocorax carbo	3	P	8.954	1.229	8.901	8.254	8.237	10.373
Podiceps cristatus	1	P	11.650	-	-	-	-	-
Anas platyrhynchos	8	O	1.352	2.049	0.604	0.324	0.214	6.166
Chroicocephalus ridibundus	7	O	0.695	0.515	0.488	0.535	0.053	1.553
Coloeus monedula	2	O	0.048	-	-	-	0.034	0.061
Corvus corax	3	O	0.138	0.186	0.113	0.105	0.054	0.256
Corvus frugilegus	26	O	0.400	1.569	0.127	0.099	0.030	6.556
Garrulus glandarius	2	O	0. 287	-	-	-	0.266	0.307
Grus grus	1	O	0.315	-	-	-	-	-
Pica pica	1	O	0.777	-	-	-	-	-
Asio otus	4	S	0.125	0.033	0.121	0.125	0.084	0.166
Buteo buteo	29	S	1.876	2.516	0.959	1.043	0.030	11.313
Circus aeruginosus	2	S	1.428	-	-	-	0.575	2.280
Falco tinnunculus	2	S	1.040	-	-	-	0.336	1.743
Strix aluco	8	S	0.918	0.447	0.815	1.545	0.702	2.884
Crex crex	1	T	0.532	-	-	-	-	-
Scolopax rusticola	2	T	1.270	-	-	-	0.829	1.712
Cygnus olor	1	H	0.136	-	-	-	-	-
Accipiter gentilis	9	Bl	0.418	0.271	0.335	0.343	0.105	0.804
Accipiter nisus	12	Bs	1.744	1.715	1.189	0.927	0.341	5.451

kg dw, range: 1.057–5.451 mg/kg dw). No statistically significant differences were noted ($Z = 0.243$, $n_1 = 5$, $n_2 = 7$, $P = 0.807$) between the median concentrations of mercury in the kidneys of males (1.057 mg/kg dw, range: 0.341–5.450 mg/kg dw) and females (0.797 mg/kg dw, range: 0.465–5.450 mg/kg dw) of Sparrowhawks, even though the values for males were higher. Table 1 presents the mean concentrations for all analyzed specimens of Sparrowhawk from Poland, irrespective of the abovementioned differences. Among the raptors studied, the results obtained for Buzzards deserve a special note, as the amounts of mercury found in the kidneys of those birds correspond to values characteristic for large piscivorous birds.

As mentioned earlier, analyses of key organs of sedentary species of top predators, connected for a long period of time with a given area, have a high bioindicative value. In the territory of eastern Poland, Barn Owl, Tawny Owl, and Goshawk can be considered as such species (Table 1). Tawny Owls accumulated more mercury than Goshawks; the differences in mean values of mercury concentrations between Goshawk and Tawny Owl were statistically significant (Student's t-test: $t = 2.82$, $df = 15$, $P = 0.013$). For Goshawks, statistically significant differences in median renal mercury concentration were shown between males (0.745 mg/kg dw, range: 0.673–0.804 mg/kg dw) and females (0.196 mg/kg dw, range: 0.191–0.495 m g/kg dw) (Mann–Whitney U test: $Z = 2.32$, $n_1 = 3$, $n_2 = 6$, $P = 0.020$).

As with Sparrowhawks, the analysis of the renal Hg concentration of Rooks was made for two groups of birds separately. For adult specimens found dead at breeding colonies, the median concentration of mercury in the kidneys was 0.143 mg/kg dw (range: 0.050–6.556 mg/kg dw), while for specimens that died during the winter in eastern Poland, the median concentration of mercury was 0.093 mg/kg dw (range: 0.036–0.403 mg/kg dw). However, the differences of median mercury concentrations in the kidneys of Rooks nesting in the territory of eastern Poland and those that only wintered there proved to be insignificant (Mann–Whitney U test: $Z = 0.134$, $n_1 = 9$, $n_2 = 17$, $P = 0.892$).

The Mallards and Kestrels included in our study are interesting, as all of them originated from Warsaw, the largest Polish city. For the first of those species, the mean renal concentration of mercury was 1.352 mg/kg dw, and for the other 1.040 mg/kg dw. In one Mallard specimen a very high mercury concentration was detected, at the level of 6.166 mg/kg dw. Analyses of all 39 specimens of corvids (Corvidae) revealed median levels of mercury concentration just like those for Rooks and Hooded Crow (Table 1). In one specimen of Rook from the breeding colony in Zamosc, the highest level of mercury content was assayed among all the representatives of the corvids studied. Also worth noting are the high levels of Hg accumulation recorded in the specimen of Magpie and one specimen of Hooded Crow (Table 1).

In addition to the analysis of renal concentrations for individual species, comparative analysis between the 4 most strongly represented trophic guilds (piscivorous, omnivorous, small mammal-eating, bird-eating) was conducted (see Table 2).

Herbivorous, terrestrial invertebrate-eating species represented by a very small number ($n = 4$) of specimens were omitted. The sequence of concentration of mercury in the kidneys in birds with food belonging to the indicated guilds is as follows, from highest to lowest: piscivorous >small mammal-eating > bird-eating > omnivorous.

Statistically significant differences in median values of renal Hg concentrations in birds representing the 4 indicated guilds were found (Table 2) (Kruskal–Wallis test: $H = 50.754$, $df = 3$, $n = 150$, $P = 0.0001$).

4. Discussion

The present study confirmed high renal concentrations of mercury in the trophic guild of aquatic piscivorous birds (Tables 1 and 2), which has also been ascertained by other authors (Boening, 2000; Falandysz et al., 2001; Houserova et al., 2005; Misztal-Szkudlinska et al., 2011). Birds that belong to the omnivorous guild accumulated the smallest amounts of renal Hg due to their wide food niche, which corresponds with the previously reported data (Kitowski et al., 2012).

Among the piscivorous species represented in this study, the highest median concentration of mercury was found among Cormorants (Tables 1 and 2). This value was higher than that determined for Cormorants from the Czech Republic; median renal mercury levels in those birds amounted to 7.61 and 4.61 mg/kg dw for adult and juvenile specimens, respectively (Houserova et al., 2005). However, in a study conducted in the region of the Vistula Lagoon (Baltic shore, northern Poland), Misztal-Szkudlinska et al. (2011) reported renal mercury concentration for Great Cormorants to be at the level of 30.21 mg/kg dw for adult and 17.6 mg/kg dw for immature individuals. In turn, Nastaran et al. (2011), in a study on adult and immature Cormorants from the southwestern coast of the Caspian Sea, reported a mean renal mercury content of 9.27 mg/kg

Table 2. Analysis of Hg content in kidneys of birds depending on birds' trophic preferences. Explanations as in Table 1.

Trophic guild	N	Geometric mean	SD	Mean	Median	Min.	Max.
Omnivorous (O)	55	0.558	1.215	0.218	0.220	0.030	6.556
Small mammal-eating (S)	45	1.493	2.109	0.774	0.740	0.030	11.313
Piscivorous (P)	29	4.073	4.224	2.150	1.437	0.233	14.447
Bird-eating (Bl + Bs)	21	1.176	1.449	0.691	0.726	0.1052	5.450

(range 3.35–23.96 mg/kg). Other authors reported a mean Hg concentration of 4.05 mg/kg dw (range: 1.71–6.88 mg/kg dw) in Cormorant species outside Europe (Saeki et al., 2000). Interestingly, two specimens of Cormorants from eastern Poland that we studied earlier (one adult and one immature individual) had accumulated in their kidneys only 3.32 and 1.76 mg/kg dw Hg, respectively (Kitowski et al., 2012). These values were decidedly lower than those given by the authors cited above. Most probably, in the case of Cormorants from eastern Poland the process is highly similar to that demonstrated for European White-tailed Eagles, where individuals associated with the coastal regions of the Baltic accumulated much more mercury in the key organs compared to individuals associated with heartland areas (Falandysz et al., 2001; Kenntner et al., 2001; Krone et al., 2006). That is supported by the results of our earlier analyses of kidneys of White-tailed Eagles from areas in eastern Poland (Komosa et al., 2009). The results obtained for White-tailed Eagles are difficult to interpret as most of the birds originated from NE Poland, where they foraged in areas with numerous lakes under strong anthropogenic pressure. Water and biota of these lakes have accumulated notable levels of mercury, which has been confirmed by several studies on this area (Luczynska et al., 2006; Dobicki et al., 2008; Spodniewska and Barski, 2013). In this study, no research was conducted on the extent of mercury contamination of fish eaten by birds. However, other authors conducted such studies, both in whole fish individuals and their organs, mainly muscles. Misztal-Szkudlinska et al. (2011) reported the following Hg concentrations for the Firth of Vistula for whole fish specimens: ruffe *Gymnocephalus cernuus*, 0.016 mg/g ww; herring *Clupea harengus*, 0.008 mg/g ww; roach *Rutilus rutilus*, 0.110 mg/g ww; tench *Tinca tinca*, 0.039 mg/g ww; European smelt *Osmerus eperlanus*, 0.029 mg/g ww. Lidwin-Kaźmierkiewicz et al. (2009) reported mercury levels for pike *Esox lucius*, bream *Abramis brama*, perch *Perca fluviatilis*, and common carp *Carpinus carpio* harvested from natural waters of West Pomerania. Mercury levels in the muscles, depending on the examined fish species, varied between 0.01 and 0.19 mg/kg ww. Similar mercury levels in muscles of perch (on average 0.015–0.030 mg/kg ww) were reported by Szefer et al. (2003). Polak-Juszczak (2003) reported mean mercury contents in muscle tissue of roach and perch caught in Wiślany Bay at the levels of 0.047 mg/kg and 0.060 mg/kg, respectively, while in Szczeciński Bay the amounts were 0.055 mg/kg and 0.052 mg/kg, respectively. Spodniewska and Barski (2013) reported that the mean concentrations of Hg in muscles of bream and pikeperch *Sander lucioperca* were 0.03 mg/kg and 0.13 mg/kg body weight, respectively. Generally, higher levels of accumulation of pollutants, including mercury, are noted for predatory species of fishes (Luczynska and Brucka-Jastrzebska, 2006).

In addition to data on the levels of accumulated mercury in prey organisms, the biomagnification factor (BMF) (Gray, 2002) for organs of predatory birds in the context of trophic relationships in the food web was determined. If the BMF is higher than unity, then biomagnification is stronger (Gray, 2002). Misztal-Szkudlinska et al. (2011) reported the BMF for the trophic relation between Cormorant (organs) and ruffe in the Vistula Lagoon (N Poland) food web, as ruffe is the basic prey of Cormorant: Cormorant (kidney)–ruffe: BMF = 420, and Cormorant (liver)–ruffe: BMF = 420. The record result of BMF has been demonstrated in the case of herring and Cormorant kidney and liver at BMF = 870 and 580, respectively, although herring is not a common prey of Cormorant.

Our analyses of renal mercury accumulation in gulls (Laridae) indicated interspecies differences in the levels of accumulated mercury related with the preferred food and sites of foraging. The results obtained can be connected with differences in the kind and quantity of consumed aquatic animals (invertebrate and fish) (Table 1). Such a mechanism permits us to understand the demonstrated lower renal concentration of mercury in the omnivorous Black-headed Gull, for which fish are not a significant diet component, as opposed to Herring Gull. For this latter species fish constitute a major (dominant in the biomass) food component (Bukacińska and Bukaciński, 2004; Gwiazda et al., 2011). However, in the case of Herring Gull, one can also observe an increasing tendency towards the utilization of rubbish dumps as foraging sites, especially in the central and northern parts of Poland (Meissner and Betleja, 2007). In the case of Black-headed Gull from eastern Poland, a slight decrease was noted in the mean renal content of mercury as compared with our earlier study (Kitowski et al., 2012). Nonetheless, the maximum mercury concentration in the kidneys of adult Black-headed Gulls proved in this study to be higher when compared with previous data (Kitowski et al., 2012).

The study of Sparrowhawks showed that individuals who died in winter had a statistically significant high renal accumulation of mercury. The increased mercury concentrations are likely caused by the fact that the Polish population of Sparrowhawk is partially migratory, and birds (mainly females) from the northeastern part of Poland most frequently spend the winter in the south of the country (Tomialojc and Stawarczyk, 2003). Migratory birds can often be exposed to higher mercury contamination as a result of their autumn diet largely consisting of passerines, which are grain-consuming birds. This grain is often illegally dressed with mercury-based fungicides. Older research, conducted at a time when the application of such fungicides was common (Johnels et al., 1979; Solonen and Lodenius, 1984), revealed that granivorous species can be the link in the transport of Hg into raptors feeding on terrestrial birds, such as Sparrowhawks. During the Sparrowhawk breeding period, passerines may constitute up to 20% of the prey, while in winter, due to the depletion of other food, their share in the Sparrowhawk diet significantly increases. Other studies (Cooke et al., 1982; Weber et al., 2001; Dauwe et al., 2003) show that in the case of some raptors, including Sparrowhawks, mean mercury concentration in key organs and blood can rise with the onset of the molt and then fall rapidly. This suggests seasonal fluctuations of mercury levels in the body, which are also observed in other bird species (Dauwe et al., 2003; Stewart et al., 2003). It is worth noting that recent studies on Finnish Sparrowhawks (Lehikoinen, 2011) indicated that they have changed their migration phenology, which may lead to a significant change in their diet. Unfortunately, we do not know how migration affects the level of mercury contamination and whether the Sparrowhawks examined by us were also subject to such processes.

The Tawny Owls analyzed in the present study originated from suburban and urban areas. On the other hand, the Goshawks were typically forest birds. These habitat differences account for the fact that Tawny Owls accumulated over 3-fold more mercury than Goshawks. The differences can also be attributed to the fact that Goshawks prefer larger prey, in which small passerines play only a marginal role. A similar relationship was observed by Castro et al. (2011) for both raptor species collected in Galicia (northern Spain), where adult male and female Goshawks accumulated mercury in their kidneys at median levels of 390 and 118 µg/kg dw, respectively, while the median levels for male and female Tawny Owls were 647 and 289 µg/kg dw, respectively. The importance of passerines in the Tawny Owl's diet increases in winter and with the level of urbanization, although small mammals still remain the major prey for Tawny Owls, irrespective of the environment that they inhabit (Goszczyński et al., 1993; Kitowski and Pitucha, 2007; Zawadzka and Zawadzki, 2007; Grzedzicka et al., 2013).

Among the two representatives of *Accipiter* spp., male Goshawks accumulated in their kidneys nearly 4-fold more mercury compared to the females, and male Sparrowhawks approximately 25% more than their females. However, no statistically significant differences were found in those cases. There is a possibility that the studied group of Sparrowhawks may not be representative due to the fact that almost all these individuals died in winter. In the case of Sparrowhawk, the intersex differences observed here may be the result of the extreme reversed sexual dimorphism typical for this species, whereby the smaller and lighter males are more often capable of catching the frugivorous passerines (Newton, 1986; Eldegard et al., 2003). The females prey on larger birds, which accounts for the lower accumulation of mercury in their organs.

The several-fold higher mercury concentration in the kidneys of the studied males of Goshawks compared with the kidneys of females corresponds with previously cited results obtained for Goshawks from Spain (Castro et al., 2011), where the median renal concentration in the kidneys of males exceeded that of females by over 3-fold. On the other hand, Kenntner et al. (2003) did not observe such intersex relationships concerning mercury renal concentrations for German Goshawks, even though they recorded higher lead concentrations in the kidneys of females in comparison to males. That result may indicate a reduced share of small avian items in the prey pool of females, due to the females catching game birds of medium or large size, birds wounded by lead bullets (pheasants, ducks), or birds having swallowed such bullets by mistake (Mateo, 2009).

Increased levels of mercury in the kidneys of some specimens of Buzzard and Marsh Harrier may be the result of consuming rodents feeding on grain treated with Hg-containing fungicides. An earlier study from eastern Poland indicated the presence of elevated levels of Hg concentration in the kidneys of birds of prey in areas where mercury-based pesticides and fungicides were applied more extensively (Komosa et al., 2012). Moreover, analyses on kidneys of Buzzards from eastern Poland (Komosa et al., 2009; Kitowski et al., 2012) indicated a distinct increase in mercury concentration over 3 years (from 2009 to 2012).

Apart from examination of raptors, analyses were performed on omnivorous birds such as corvids and Mallards. The analyses of the kidneys of corvids revealed the presence of mercury above the detection limit in all specimens tested, including Jay. However, our previous study on a few specimens of Jay from Warsaw revealed no mercury presence (Kitowski et al., 2012). The very different levels of geometric mean, median, and maximal (in spite of a very similar mean value) mercury concentrations in the kidneys of Rooks and Hooded Crow may result from different foraging tactics consisting of penetration of different habitats and consumption of different food (Czarnecka and Kitowski, 2010; Czarnecka et al., 2013).

In the case of Mallards from eastern Poland, a slight decrease was noted in renal concentrations of mercury compared to earlier studies (Komosa et al., 2012). However, as in the case of Rooks, the maximum renal content of mercury among all of the specimens analyzed proved to be higher than the results of our previous study (Komosa et al., 2012).

The most important source of mercury in eastern Poland is undoubtedly coal combustion (Hlawiczka and Cenowski, 2013). Numerous researchers have pointed to coal combustion as a major source of mercury in different abiotic components of the environment (Seshadri et al., 2010; Gusev, 2013; Nyberg et al., 2013; Speight et al., 2013). Eastern Poland is an agricultural area with the lowest economic development in the country, where there are no industrial sources of mercury but coal combustion is a principal source of heat in the municipal and housing sector (Stala-Szlugaj, 2011).

Other potential pathways of mercury intoxication of omnivorous birds in the area of eastern Poland have an undoubtedly less widespread character than coal combustion. Therefore, as their impact is rather pointwise, they can be considered accountable for maximum renal mercury concentrations only in certain instances. This pertains especially to omnivorous species and birds associated with urban areas. The first of those pathways is associated with the consumption of dressed cereal grain. Locally, cereal grain may constitute an important food resource for Rooks, especially in springtime (Czarnecka and Kitowski, 2010; Czarnecka et al., 2013). Hence, the birds may absorb mercury through the consumption of illegally dressed grain. An interesting source of mercury introduced into the environment and later to the organs of omnivorous birds may be dumped parapharmaceuticals of traditional Chinese medicine (TCM) (Bojarska et al., 2011) or Ayurvedic medicine (Kumar, 2006). Frequently, TCM parapharmaceutical composition, along with the plant components, includes some mineral substances containing mercury. For example, cinnabar, which chemically is a pure mercury sulfide, has been used in TCM for years, and about 40 cinnabar-containing TCM compounds are still present on the market today (Liu et al., 2008). However, the toxicology profiles and toxicokinetics of cinnabar are not widely recognized. Unfortunately, we have very little knowledge on the extent of TCM consumption in Poland, although the share of TCM products has undoubtedly been increasing recently (Bojarska et al., 2011). The third and, in our belief, most probable pathway of mercury intoxication of omnivorous birds (Rooks, Mallards) is consumption of mercury-containing wastes. For physiological reasons, Rooks consume large amounts of small pebbles, but they often ingest by mistake pieces of glass from fluorescent tubes found at dumping sites (Czarnecka and Kitowski, 2010). The latter pathway may account for a very high maximum level of mercury in a Mallard specimen from the Warsaw population. In Poland, no professional system of fluorescent tube waste management has been established yet. At present, such a system of e-waste treatment is in the process of organization. It is possible that, as in the case of lead poisoning, the high mobility of the urban population of Mallard is a significant factor affecting the level of mercury intoxication (Binkowski and Meissner, 2013).

In conclusion, the highest geometric mean concentrations of mercury were demonstrated for the food guild of piscivorous birds such as Cormorant, Grey Heron, and White-tailed Eagle. The maximum Hg level was noted in the case of White-tailed Eagle and Great Crested Grebe.

The share of small passerines in the diet of raptors (Goshawks and Sparrowhawks) is a differentiating factor for mercury concentration in the kidneys of males and females. Analyses conducted for three species of gulls revealed differences in the levels of renal accumulation of mercury in relation to the preferred diet and foraging sites. The demonstrated increase in mercury concentration in kidneys of birds from eastern Poland may be caused by the renewed use of mercury-based fungicides in agriculture. The present study justifies a need for continuation of mercury monitoring in various ecosystems in Poland. It seems that birds are the most suitable indicators for this purpose.

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