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Age-dependent accumulation of heavy metals in liver, kidney and lung tissues of homing pigeons in Beijing, China

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Abstract Biomonitoring provides direct evidence of the bioavailability and accumulation of toxic elements in the environment. In the current study, 1–2, 5–6, and 9–10+ year old homing pigeons collected from the Haidian District of Beijing during 2011 were necropsied and concentrations of cadmium, lead, and mercury were measured in liver, lung, and kidney tissue. At necropsy, gray/black discoloration of the margins of the lungs was observed in 98 % of the pigeons. There were no significant differences in metal concentrations as a function of gender. Cadmium concentrations in all tissues and Pb concentrations in the lung tissues were significantly greater in 9–10+ year old pigeons compared to other age groups indicating that Cd and Pb were bioavailable. Mercury concentrations were not significantly different among age groups. Cadmium concentrations in kidney and lung tissues of 9–10+ year old pigeons were similar to or exceeded concentrations of Cd reported in pigeons from another high traffic urban area and most wild avian species from Korea suggesting that Cd in this region of Beijing may be of concern. Homing pigeons provide valuable exposure and bioaccumulation data not readily available from air monitoring alone, thus providing information regarding potential health effects in wildlife and humans in urban areas. As environmental quality standards are implemented in China, homing pigeons will serve as a valuable bio-monitor of the efficacy of these actions.

Keywords Heavy metals · Homing pigeons · Tissues · Distribution · Age

Introduction

There is public concern about atmospheric heavy metals as a potential risk to human and animal populations (Mailman 1980; Merian 1991; Swaileh and Sansur 2006). Atmospheric concentrations of heavy metals primarily result from burning of urban and industrial wastes, mining, smelting processes, gas emission from motor vehicles, and combustion of fossil fuels (Harrop et al. 1990; Mohammed et al. 2011) and are known to have long lasting toxic effects that cannot be easily alleviated through biodegradation (Clark 1992). Chronic exposure to toxic elements, even at very low concentrations, have damaging effects on humans and animals (Falandysz 1994; Ikeda et al. 2000; Nam and Lee 2006), and detrimental impacts become apparent after several years of exposure (Furness 1996). Mechanical air monitoring provides data on atmospheric concentrations of various pollutants; however, animal species have increasingly been used as bio-monitors and provide bioavailability, bioaccumulation, and effects data not available from mechanical air monitoring (Eens et al. 1999; Gragnaniello et al. 2001; Kim et al. 2009; Liu et al. 2010).

In previous studies, wild birds have been used to evaluate environmental contamination; however, semi-tamed homing pigeons may add to the usefulness of avian species for monitoring atmospheric pollution (Tansy and Roth 1970; Ohi et al. 1974; Ohi et al. 1981). Because homing pigeons are relatively long-lived (18+ years) (Johnston

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and Janiga 1995; Carey and Judge 2000) are exposed to the same atmosphere as humans, and the age, diet, and life histories are usually known, they may to be very useful as environmental biomonitor in urban areas. In China and the United States, homing pigeons were useful as biomonitors of polycyclic aromatic hydrocarbons and mercury (Hg) in major urban areas (Liu et al. 2010; Cizdziel et al. 2013), and feral pigeons have been used as a biomonitor in Korea and the Netherlands (Schilderman et al. 1997; Nan and Lee 2006; Kim et al. 2009). The current study evaluates heavy metals in tissues of homing pigeons from Beijing, China. The objectives of the present research were: (1) to measure cadmium (Cd), lead (Pb), and mercury (Hg) concentrations in liver, kidney, and lung tissues of homing pigeons collected from the Haidian District of Beijing, China; (2) to evaluate differences in metal concentrations due to age and sex; and (3) qualitatively evaluate the usefulness of homing pigeons as biomonitors of heavy metals in urban areas.

Materials and methods

Individual collection and processing

During May, 2011, 49 homing pigeons (18 females and 31 males) were collected from a loft located on top of the Modern Plaza, a large shopping center in the southern region of the Haidian District of Beijing approximately 1 km from Peking University. The Haidian District is located northwest of the center of Beijing. Collected pigeons were raised by a homing pigeon hobbyist and, as homing pigeons, have a high fidelity for their birth location and spend their life within approximately 1 km (usually 500 m) of the loft where they were born. When the pigeons hatch, a leg band identifying the hobbyist and containing the hatch year is attached to the pigeon's leg; therefore, ages are known. Sex was initially determined by the pigeon hobbyist and confirmed at necropsy. Pigeons collected for our study were randomly selected from different age groups of homing pigeons that were maintained by the hobbyist. During the day, the pigeon cages were open and the pigeons could fly at will, and commercial bird food and water were provided ad libitum. From observations, pigeons would fly for 20–30 min several times a day and spend the rest of the day feeding or resting. Pigeons were killed by cervical dislocation and immediately necropsied on the day of collection. During necropsy, lung, liver, and kidney tissues were removed, wrapped in aluminum foil, and kept at −20 °C until heavy metals analysis.

The tissue samples were analyzed for Cd, Hg, and Pb according to EPA Method 3050B (USEPA 1996) and EPA Method 200.8 (USEPA 1994). All the samples were oven dried at 60 °C for 8 h, 80 °C for 12 h, then 105 °C to a constant mass. Approximately 0.1–0.5 g of tissue samples was digested with 5 mL nitric acid (HNO_3, Merck, Darmstadt, Germany) and 3 mL hydrogen peroxide (H_2O_2, Sinopharm Chemical Reagent Co., Ltd, Shanghai, China). After 1 hour, the samples were placed in a microwave oven (Mars-5, CEM Company, USA) and the temperature raised to 100 °C within 8 min and maintained for 5 min, raised to 150 °C within 5 min and maintained for 5 min, and finally the temperature was raised to 190 °C within 8 min and maintained for 15 min. Samples were removed from the microwave and cooled at room temperature. Each digested sample was transferred to a 50 mL polypropylene test tube, the digestion vessel rinsed three times with 5 % HNO_3 and three times with Milli-Q deionized water (Millipore, Bedford, MA, USA), and the digested sample was diluted to a final volume of 50 mL with ultra pure water. Then metal concentrations were measured by inductively coupled plasma mass spectrometry following USEPA Method 200.8 (USEPA 1994, ICP-MS, Agilent 7500cx, Agilent Technologies Inc., Palo Alto, USA).

Quality control

Laboratory reagent blanks, metals standard reference material (GSB-9 chicken), and replicate samples were analyzed with every batch of samples (1 blank, 1 standard, 2 duplicates for 9 samples). The reference values of the metals standard were: Cd (5 ng/g), Pb (110 ± 20 ng/g), and Hg (3.6 ± 1.5 ng/g). Batches were re-analyzed if metals standards exceeded ±20 % of their expected values or analytical error of replicate samples exceeded ±10 %. The method blanks were carried throughout the entire sample preparation and analytical process and whenever a new sample matrix was analyzed. Furthermore, all samples were analyzed three times by the ICP-MS and the RSD was lower than ±5 %. The method detection limits were 0.15, 0.16, and 2.99 ng/L for Cd, Hg, and Pb, respectively.

All laboratory glassware and containers were soaked in 1:4 HNO_3 for 24 h and then rinsed prior to use. The chemical reagents for the metal analyses were of superior grade or higher. The solutions were prepared using ultra-pure water (18.2 MΩ).

Data analysis

Descriptive and inferential statistical analyses were performed using SPSS 16.0 (SPSS Inc., Chicago, USA). Data were log transformed to obtain normal distributions that satisfied the homogeneity of variance required by one-way analysis of variance (ANOVA). An ANOVA was used to evaluate differences in metal concentration among tissues (kidney, liver, and lung) and among age groups, followed by Tukey's test to separate means. Independent-sample *t* test was used to evaluate differences between male and female pigeons. A *p* value less of 0.05 was considered statistically significant. The concentrations of metals in tissues were expressed as ng/g dry weight. The authors changed metal concentration reported by some referenced authors as wet wt to dry wt assuming lung, kidney and liver moisture content of 74, 73, and 68 %, respectively. These moisture percentages were the averages calculated from pigeons evaluated in our study.

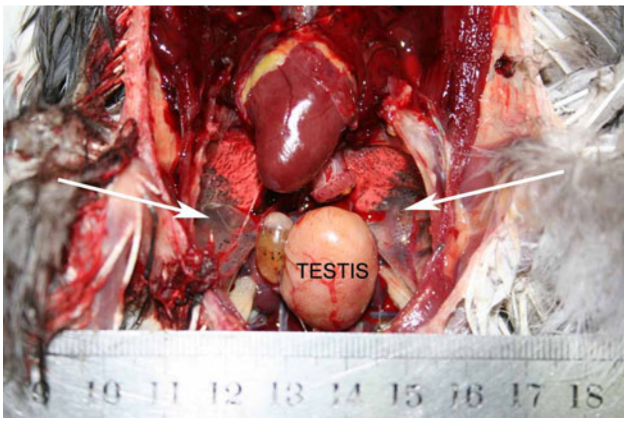

Fig. 1 *Gray/black* lung margins (*Arrows*) observed in 98 % of homing pigeons and enlarged tumorous testis observed in 10 % of male pigeons collected from Beijing during May, 2011

Results

The marginal edges of the lungs of all necropsied pigeons had grey to black discolorations except for one 1–2 year old pigeon whose lungs were pale (Fig. 1). In addition, 10 % of male pigeons had enlarged and tumorous testes similar to that shown in Fig. 1. There were no statistically significant differences between male and female pigeons in concentrations of Cd, Hg, and Pb in any tissue; therefore, genders were combined for subsequent statistical analysis. In all following uses the word "significant" implies that the results of the statistical tests were statistically significant.

In evaluations of differences among age groups, Cd concentrations in all tissues and Pb concentrations in lung tissue of 9–10+ year old pigeons were significantly greater ($p < 0.001$, df = 47) than concentrations in 1–2 or 5–6 year old pigeons (Table 1). Mercury concentrations were not statistically significantly different among age groups for any tissue.

In evaluations of differences among tissues, there were significant differences ($p < 0.001$, df = 47) in Cd, Hg and Pb concentrations among liver, lung, and kidney tissues within each age group (e.g., see Fig. 2 for differences within 9–10+ year old pigeons). Concentrations of Cd and Hg followed the order kidney>liver>lung. Cadmium concentrations were approximately 10 times and 77 times greater in kidney ($\bar{x} = 11137$ ng/g dry wt) than in liver

Table 1 Age-based mean concentration and one standard error (mean ± SEM ng/g) of heavy metals in the lung, kidney, and liver tissues of homing pigeon collected from Beijing during May, 2011

	Tissue	Age (1–2) ($n = 10$)	Age (5–6) ($n = 15$)	Age (9–10+) ($n = 24$)	F	*p* value age
Cd	Lung	55.7 ± 14.6[a]	58.6 ± 5.6[a]	116.4 ± 6.4[b]	22.178	<0.001
		(16.4–83.4)	(17.1–93.4)	(37.4–169.5)		
	Kidney	2,141.8 ± 685[a]	2,676 ± 419[a]	11,137 ± 1,400[b]	18.560	<0.001
		(270.7–6,326.0)	(262.4–6,707.0)	(2,444.0–30,760.0)		
	Liver	299.1 ± 74.4[a]	382.8 ± 59.3[a]	947.3 ± 119[b]	11.300	<0.001
		(97.7–644.7)	(71.4–805.9)	(226.6–3,040.0)		
Hg	Lung	14.3 ± 2.7	14.9 ± 1.5	16.4 ± 1.2	0.470	0.15
		(5.9–33.0)	(5.3–25.6)	(2.1–30.0)		
	Kidney	40.7 ± 6.1	54.7 ± 4.5	47.9 ± 3.8	1.393	0.436
		(13.3–64.3)	(24.5–91.4)	(15.9–104.7)		
	Liver	20.2 ± 3.0	26.9 ± 2.7	22.3 ± 2.3	1.276	0.644
		(6.8–36.6)	(11.58–44.4)	(6.8–64.5)		
Pb	Lung	265.3 ± 41.5[a]	261.0 ± 22.2[a]	467.8 ± 27.7[b]	18.613	<0.001
		(143.1–537.1)	(141.2–449.9)	(272.8–791.8)		
	Kidney	535.7 ± 88.8	441.0 ± 37.1	459.1 ± 27	0.605	0.346
		(184.7–1,131.0)	(149.8–700.9)	(130.2–821.3)		
	Liver	242.4 ± 38.9	200.2 ± 28.2	272.5 ± 76.9	0.322	0.996
		(87.0–433.1)	(66.3–431.0)	(61.0–431.8)		

Column means with different superscripts are significantly different (One-way ANOVA, 47 df, $p < 0.05$)

Superscript letters (a, b) show significant difference in each tissue among three age groups ($p < 0.05$)

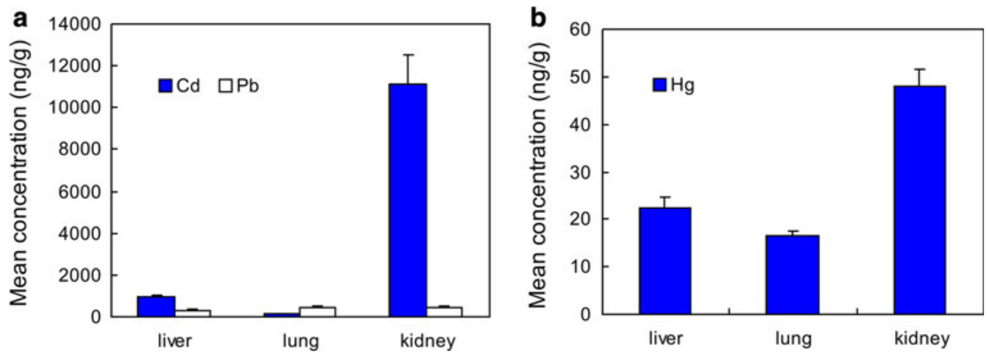

Fig. 2 Mean concentrations (ng/g, dry wt, $n = 24$) of **a** Cd, Pb, and **b** Hg in liver, lung, and kidney tissues of 9–10+ year old pigeon collected from Beijing during May, 2011. *Error bars* represent standard error of the mean

($\bar{x} = 947.3$ ng/g dry wt) and lung ($\bar{x} = 116.4$ ng/g dry wt) tissue, respectively, within the 9–10+ year old pigeons. Lead concentrations followed the order kidney>lung>liver in 1–2 and 5–6 year old pigeons and the order lung>kidney>liver in 9–10+ year old pigeons. Heavy metal differences among tissues were much greater in the older age group pigeons (Table 1).

Discussion

Our research has focused on evaluating the use of homing pigeons as a biomonitor of environmental pollution in urban areas with emphasis on atmospheric pollution. The atmosphere is continually changing, and therefore contaminants in the atmosphere are also in a state of flux. Because homing pigeons are continuously breathing surrounding air, they are exposed to whatever contaminants are in the air during each inhalation, whether the contaminant is present only periodically (perhaps resulting from an accidental release or some irregular pulsing), or present on a more-or-less continuous bases (daily factory releases, traffic exhaust, coal burning, etc.). Results of the current study indicate that Cd and Pb concentrations in lung tissue and Cd concentrations in liver and kidney tissues increased with age in monitored homing pigeons. Therefore, we know the pigeons were exposed and were accumulating these contaminants, but we are uncertain of the exact interactions between respiratory and oral routes of exposure. Increased concentrations of both Cd and Pb in lung tissues in older pigeons and the observed lung lesions provide evidence of respiratory exposure. The increased concentrations of Cd in the liver and kidney tissue of older pigeons may result from ingestion of contaminated grit or food, from swallowing contaminated particles trapped and then cleared from the respiratory system, or possibly from absorption into blood circulating within the respiratory system and then transported and accumulated in liver and kidney tissues. Regardless of the route of exposure, there is some evidence that the exposure is chronic rather than acute. For instance, liver-to-kidney Cd ratios >1 indicate acute exposure to relatively high dietary cadmium concentrations, while ratios <1 suggest chronic exposure to low concentrations (Scheuhammer 1987). In the current study, the liver-to-kidney Cd concentration ratios were <1, suggesting chronic exposure, whether from food and/or grit ingestion or from respiratory exposure. We are currently planning additional studies to clarify the impacts of both oral and respiratory routes of exposure.

Although the dynamics of particulate deposition in the respiratory system is quite complex, and the avian respiratory system is quite different from the mammalian system, there does appear to be some similarities in particulate deposition between mammalian and avian species (Stuart 1976; Brown et al. 1997). The gray/black lung margins observed in homing pigeons in the current study indicate that the clearance mechanisms, although not as clearly understood in avian species compared to mammalian species (Brown et al. 1997), may be overwhelmed by excessive particulate exposure and suggests diminished respiratory capacity. Although we did not quantify differences associated with age, this lesion, along with the observed tumorous testes, indicates adverse effects potentially associated with atmospheric pollution. Additional study will be necessary before associations between metal concentrations, or perhaps some other environmental contaminant, and the observed lung and testicular lesions can be clarified.

Cadmium concentrations measured in kidney, liver, and lung tissues, and Pb in lung tissue increased with age in monitored pigeons from Beijing providing evidence that these metals were bioavailable and did accumulate in an avian species in this urban area. The question arises as to whether the measured concentrations were greater than background concentrations and whether they are comparable to concentrations reported in avian species from other locations.

Cadmium

Cadmium concentrations in kidneys of 92 % of 9–10+ year old pigeons from Beijing ($\bar{x} = 11{,}895.78$, range

4,903–30,760 ng/g dry wt) exceeded background concentrations reported in kidney (<3,703 ng/g dry wt) of adult Mallards (*Anas platyrhynchos*) raised under controlled conditions and fed commercially available seed-based diets (White and Finley 1978), and kidney concentrations in 67 % of these pigeons ($\bar{x}$ = 14,150.94, range 8,019–30,760 ng/g dry wt) exceeded the concentrations reported for wild freshwater duck species (2,000–8,000 ng/g dry wt kidney, Di Giulio and Scanlon 1984). Similarly, kidney Cd concentrations in 9–10+ year old homing pigeons from Beijing (range 2,444–30,760 ng/g dry wt) exceeded concentrations reported in most wild birds from Korea (range 40–7,620 ng/g dry wt) and were similar to concentrations reported in ancient murrelet (*Synthliboramphus antiquus*) from Korea (range 3,700–23,500 ng/g dry wt, Kim et al. 2009). The ancient murrelet is a seabird and has been reported to feed, at least in part, on food sources high in Cd and thus they tend to accumulate greater concentrations than most other bird species (Bull et al. 1977; Cheng et al. 1984). Mean kidney Cd concentrations measured in 9–10+ year old pigeons from Beijing ($\bar{x}$ = 11,137 ng/g dry wt) also were similar to concentrations reported in feral (city) pigeons collected from an Amsterdam high traffic area ($\bar{x}$ = 10,111 ng/g dry wt, Schilderman et al. 1997).

Cadmium concentrations in lung tissue of 9–10+ year old pigeons from Beijing ($\bar{x}$ = 116, range 37–169 ng/g dry wt, n = 24) also appear to be greater than mean concentrations measured in feral pigeons collected from a high traffic area of Amsterdam ($\bar{x}$ = 77 ng/g dry wt) (Schilderman et al. 1997). However, mean liver Cd concentrations (947 ng/g dry wt) appear to be slightly lower than mean concentrations reported in feral pigeons from high ($\bar{x}$ = 1,343 ng/g dry wt) and medium ($\bar{x}$ = 1,656 ng/g dry wt) traffic locations in Amsterdam, and slightly greater than mean concentrations reported in pigeons from low traffic areas (Maastricht $\bar{x}$ = 844 ng/g dry wt, Assen $\bar{x}$ = 406 ng/g dry wt, Schilderman et al. 1997).

These comparisons suggest that kidney and lung Cd concentrations measured in pigeons from the Haidian District in Beijing were greater than background concentrations measure in other avian species and similar to concentrations measured in feral pigeons from a high traffic area in the Netherlands, and similar to concentrations in another avian species reported to have a diet high in Cd. However, liver Cd concentrations measured in monitored homing pigeons appear to be lower than concentrations measured in feral pigeons from high traffic areas in the Netherlands. Because ages were not reported for pigeons from the Netherlands, here, and throughout this manuscript, caution should be used in comparing reported tissue concentrations between homing pigeons collected in Beijing with those collected in the Netherlands.

Another interesting result of the current study is the relationship between Cd concentrations in kidney and liver tissues of the monitored homing pigeons. Liver Cd concentrations in adult birds have been reported to range between ½ and 1/10 the concentrations in kidney tissues (Lee et al.1987; Scheuhammer 1987; Thompson 1990; Lock et al. 1992; Furness 1996). In the current study, the ratio of liver to kidney Cd concentration in 1–2 and 5–6 year old pigeons was approximately 1/7, which is within the range reported above. However, in 9–10+ year old pigeons the ratio was 1/12 suggesting a greater relative concentration of Cd in kidney tissue compared to liver tissue. Kidney concentrations in monitored pigeons tended to increase in older age pigeons at a much greater rate compared to concentrations in liver tissue. For instance, there was an approximate 1.2-fold increase in Cd concentrations in both kidney and liver tissues between 1–2 and 5–6 year old pigeons, while there was a 4 and 2.5-fold increase in Cd concentrations in kidney and liver tissues, respectively, between 5–6 and 9–10+ year old pigeons. The reason for this difference is unknown. Although chronic exposure to Cd results in continued accumulation in liver and kidney tissue (Scheuhammer 1987), a rather gradual increase would be expected over time rather than the sharp increase observed between the 5–6 and 9–10+ age groups. It is possible that exposure to Cd was greater when 9–10+ year old pigeons were younger, thus accumulation in kidney and liver was greater; although, we have no data to support this assertion. It is also possible that, in older pigeons, there has been damage to the intestinal lumen due to intestinal parasites (Bafundo et al. 1984) or perhaps Cd itself (Richardson and Fox 1974), which has resulted in increased absorption of Cd with a concomitant increased accumulation in kidney and liver. Additional study, including histological evaluation of tissues, will be necessary to determine the cause of the observed increase in Cd in older aged pigeons.

Lead

Lead is a highly toxic metal and incidents of toxicity have been reported in avian species (Hutton and Goodman 1980; Schilderman et al. 1997). Lead concentrations in lung tissue of 1–2 and 5–6 year old pigeons were similar, while there was a 1.7-fold increase in Pb concentrations in lung tissues between 5–6 and 9–10+ year old pigeons. Very little data regarding atmospheric exposure of avian species to Pb and potential adverse effects in lung tissue were found. Mean lead concentrations in lungs of 9–10+ year old pigeons from Beijing ($\bar{x}$ = 467, range 272–791 ng/g dry wt, n = 24) appear to be less than mean concentrations measured in feral pigeons collected the unindustrialized

Korean island of Duckjuk ($\bar{x} = 3{,}615$ ng/g dry wt, $n = 8$, Nam and Lee 2006).

Mean lung Pb concentrations measured in 9–10+ year old pigeons from Beijing were lower the concentration reported in low traffic areas of the Netherlands (Maastricht $\bar{x} = 1{,}192$ ng/g, dry wt, $n = 5$ and Assen $\bar{x} = 961$ ng/g, dry wt, $n = 7$, Schilderman et al. 1997). Similarly, Pb concentrations in the kidney of monitored pigeons from Beijing (range 130–1,131 ng/g dry wt) did not exceed the background concentrations in kidney of adult bird living in relatively uncontaminated areas (1,000–10,000 ng/g, dry wt, Connors et al. 1975; Kendall and Scanlon 1981; Custer et al. 1984) and appear to be lower than concentrations reported in herons and egrets from Korea (range 250–12,200 ng/g dry wt, Kim et al. 2009) and pigeons from low traffic density areas of the Netherlands ($\bar{x} = 1{,}111$ ng/g dry wt, $n = 5$, Schilderman et al. 1997). However, they were similar to concentrations reported in most other wild birds (other than herons and egrets) from Korea (range 400–7,730 ng/g dry wt, Kim et al. 2009). Lead concentrations in the liver of pigeons form Beijing (range 61–433 ng/g dry wt) also were lower than background concentrations reported in liver of adult birds living in relatively uncontaminated areas (500–5,000 ng/g in liver, dry wt, Connors et al. 1975; Kendall and Scanlon 1981; Custer et al. 1984), and lowed than the concentrations reported in feral pigeons from cites with low traffic density in the Netherlands (Maastricht $\bar{x} = 406$ ng/g dry wt, $n = 5$ and Assen $\bar{x} = 500$ ng/g dry wt, $n = 7$, Schilderman et al. 1997). These comparisons suggest that environmental Pb concentrations were either relatively low in the monitored region of Beijing or that Pb was not in a bioavailable form.

Mercury

In the current study we measured total Hg concentrations in pigeon tissues, and in order to distinguish methylmercury (MeHg) exposure from exposure to inorganic Hg, the kidney: liver ratio of Hg concentrations was used (Heinz 1980). In response to inorganic Hg exposure, it is normal for only the kidney to accumulates high levels of Hg, thus the kidney:liver ratio will be much greater than unity; whereas, if the exposure is to MeHg, the ratio will be closer to unity (<2, Heinz 1976; Finley et al. 1979; Heinz 1980). In the current study, the kidney:liver ratios for monitored pigeons were 2.1, 2.2, and 2.3 in the age group 1–2, 5–6, and 9–10+, respectively, suggesting Hg measured in the Beijing pigeon tissues was mostly MeHg.

Mercury concentrations in liver and kidney tissues of pigeons collected from Beijing were lower than concentrations reported in birds raised in captivity and exposed only to background concentrations of Hg (<740 ng/g dry wt in kidney and <625 ng/g dry wt in liver, Pass et al. 1975; Heinz 1976; Stickel et al. 1977). In the current study, Hg concentrations in pigeon liver and kidney tissues appear to be similar to concentrations associated with low Hg exposure and similar to Hg concentrations reported in Beijing pigeons collected from this same region of Beijing during 2007 (Cizdziel et al. 2013).

Conclusions

In the current study, we measured Cd, Pb, and Hg concentrations in liver, kidney, and lung tissues of homing pigeons collected from the Haidian District of Beijing during 2011. There were no differences in metal concentrations between male and female pigeons in any tissue within any age group. Cadmium concentrations in all tissues and Pb concentrations in lung tissue were significantly greater in 9–10+ year old pigeons compared to 1–2 or 5–6 year old pigeons. Mercury concentrations in all tissues were not different among age groups.

Study results indicate that homing pigeons in Beijing are accumulating environmental contaminants that are potentially toxic to animal species and humans. The gray/black marginal regions observed in lungs of monitored pigeons are thought to result from chronic exposure to particulate matter and would suggest diminished respiratory capacity. Whether the enlarged and tumorous testes are a result of exposure to heavy metals, or some other environmental pollutant, is yet to be determined. Additional study will be necessary to evaluate the cause of these gross lesions and to better understand differences between ingestion and respiratory routes of exposure. Cadmium concentrations in kidney and lung tissue of monitored pigeons appear to be greater than concentrations reported in other avian species indicating that Cd in this region of Beijing may be of concern.

Homing pigeons do appear to be useful as a biomonitor of heavy metals in urban areas. Because their home ranges are relatively small, they live relatively long lives (18+ years), and ages are known, it is possible to evaluate accumulation of environmental contaminants over time in a specific area or to compare exposure among areas. Additional study comparing contaminant concentrations among different age groups of pigeons collected from different urban areas and correlations with atmospheric concentrations is ongoing, as well as, studies to evaluate the influence of ingestion vs respiratory routes of exposure. As environmental quality standards are implemented in China, homing pigeons will serve as a valuable biomonitor of the efficacy of these actions.

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Conflict of interest The authors declare that they have no conflict of interest.

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