Chemosphere 161 (2016) 274–279

Contents lists available at ScienceDirect

Chemosphere

journal homepage: www.elsevier.com/locate/chemosphere

Seasons and neighborhoods of high lead toxicity in New York City: The feral pigeon as a bioindicator

Fayme Cai [a], Rebecca M. Calisi [b, c, *]

[a] *Department of Ecology, Evolution, and Environmental Biology, Columbia University, New York City, NY, USA*
[b] *Department of Biology, Barnard College, Columbia University, New York City, NY, USA*
[c] *Department of Neurobiology, Physiology and Behavior, University of California, Davis, Davis, CA, USA*

HIGHLIGHTS

- We assessed the feral pigeon as a lead bioindicator in New York City.
- We collected blood lead levels of 825 pigeons over 5 years.
- Blood lead levels were highest in summer.
- Neighborhood pigeon blood lead levels recapitulated in children.

ARTICLE INFO

Article history:
Received 23 April 2016
Received in revised form
29 June 2016
Accepted 1 July 2016
Available online 18 July 2016

Handling Editor: R Ebinghaus

Keywords:
Lead
Pb
Lead toxicity
Pigeon
Columba livia
Bioindicator
New York City

ABSTRACT

Human-induced rapid environmental change has created a global pandemic of neurobehavioral disorders in which industrial compounds like lead are the root cause. We assessed the feral pigeon (*Columba livia*) as a lead bioindicator in New York City. We collected blood lead level records from 825 visibly ill or abnormally behaving pigeons from various NYC neighborhoods between 2010 and 2015. We found that blood lead levels were significantly higher during the summer, an effect reported in children. Pigeon blood lead levels were not significantly different between years or among neighborhoods. However, blood lead levels per neighborhood in Manhattan were positively correlated with mean rates of lead in children identified by the NYC Department of Health and Mental Hygiene as having elevated blood lead levels (>10 μg/dl). We provide support for the use of the feral pigeon as a bioindicator of environmental lead contamination for the first time in the U.S. and for the first time anywhere in association with rates of elevated blood lead levels in children. This information has the potential to enable measures to assess, strategize, and potentially circumvent the negative impacts of lead and other environmental contaminants on human and wildlife communities.

1. Introduction

Heavy-metal toxicity is a relatively newly identified problem to human health, with leaded paints and gasoline in widespread use up until a few decades ago. Despite the banning of most lead-containing products and abundant information about the hazards of heavy metals, the negative effects of heavy metals on human health persist. Lead paint can be found in older buildings, and demolitions can increase particulate lead levels in the air by several hundred times (Farfel et al., 2003). Before the 1990s, leaded gasoline was used worldwide. It was only prohibited in the United States in 1995, and even later in many countries. Residues from gasoline, however, have left lead contaminants on many roads (García et al., 1988; Hutton and Goodman, 1980; Nam and Lee, 2006; Ohi et al., 1981). This effect is particularly strong on major roadways or in high-traffic, industrial areas. For example, a study by Nam and Lee (2006) found that industrial areas in South Korea had much higher lead concentrations than rural areas due to greater car traffic and emissions. Despite the introduction of unleaded gasoline in 1993, lead still contaminates gravel and soil. In addition to lingering roadside toxicants, lead is still being used in some airplane fuels, which have been reported to be responsible for the release of 100 tons of lead into the atmosphere per year (Kessler,

* Corresponding author. 1 Shields Ave, 196 Briggs Hall, Davis, CA, 95616, USA.
E-mail address: rmcalisi@ucdavis.edu (R.M. Calisi).

http://dx.doi.org/10.1016/j.chemosphere.2016.07.002

2013).

Ever since the discovery of the negative effects of lead on human health, there have been large-scale attempts to reduce human contact with lead. The New York City Department of Health and Mental Hygiene conducts screenings of NYC resident blood lead levels (2014, 2010). Although blood lead levels have declined in NYC and the US in the last few decades, that does not mean lead poisoning is no longer a public health concern. Little is known about the effects of low amounts of lead on human health, but recent studies have shown that lead is harmful at all levels —no matter how low— affecting intelligence, neurodevelopment, social skills, and memory (Lanphear et al., 2000; Schnur and John, 2014). In fact, Canfield et al. (2003) found that at blood lead levels below 10 μg/dl, the USA Centers for Disease Control and Prevention's national acceptable threshold at the time, the inverse relationship between IQ in children and blood lead level is even stronger than at levels above 10 μg/dl. In light of this new information about the negative effects of low-dose lead exposure, the Centers for Disease Control and Prevention lowered their national threshold to 5 μg/dl in January 2012.

Lead poisoning is a considerable problem for not only humans, but wildlife in general. Heavy metals such as cadmium, zinc, and, most notably, lead are toxic in small amounts to both humans and feral pigeons (*Columba livia*) (Cui et al., 2013; Schilderman et al., 1997; Schnur and John, 2014). Pigeons have been presumed to be poisoned from a combination of atmospheric and particulate lead; the former is inhaled from the atmosphere, the latter is consumed. Because pigeons use small rocks and gravel to aid in mechanical digestion, they can ingest contaminated road particles, or particulate lead (Hutton and Goodman, 1980; Nam and Lee, 2006). Caravanos et al. (2006) demonstrated that almost 90% of dust samples taken throughout NYC's five boroughs exceeded the US government's environmental and housing standards for acceptable lead concentration. Dust containing lead from the outdoors can be brought into households by regular foot traffic or air drifting, which can increase human exposure (Caravanos et al., 2006).

In the last few decades, feral pigeons have received considerable attention as possible bioindicators for heavy-metal exposure. Pigeons have a longstanding association with humans that dates back to establishment of the first permanent agricultural settlements. Feral populations have since spread across the world and exist in almost all the different kinds of communities where people live, nesting on top of buildings and along building facades, under bridge overhangs, and on top of garage roofs (Gompertz, 1956; Humphries, 2008). Consequently, feral pigeons have thrived in NYC, where they have even been labeled as pests, with such monikers as "rats with wings" (Jerolmack, 2008; Humphries, 2008). The combination of densely-packed buildings, an abundance of food, and ample greenery, such as that found in Central Park, make NYC an ideal feral pigeon habitat. Compared to many other urban organisms, the pigeon's relatively long lifespan and hardiness, combined with its close relationship to humans, make it a suitable bioindicator, offering up the potential to gauge adverse environmental conditions that may affect humans and other wildlife (Drasch et al., 1987; Liu et al., 2010; Schilderman et al., 1997). The urban pigeon does not only walk the same pavement and live on the same blocks as humans, it also breathes the same air and often eats the same food. In this situation, the pigeon can serve as the proverbial canary in a coal mine.

Studies of pigeons as heavy-metal bioindicators from South Korea, China, Tokyo, Spain, France, the Netherlands, and the UK have indicated clear physiological differences between pigeons living in environments with varying amounts of heavy metals (Cui et al., 2013; Frantz et al., 2012; García et al., 1988; Hutton and Goodman, 1980; Nam and Lee, 2006; Ohi et al., 1981; Schilderman et al., 1997). Pigeons exhibit a high level of site fidelity to birth sites, generally remaining in a small area (<2 km) for their entire lives (Rose et al., 2006). This behavioral characteristic thus permits comparisons of pigeon lead toxicity among micro-urban environments (Frantz et al., 2012). For example, Frantz et al. (2012) measured heavy-metal concentrations in feral pigeon feathers in the urbanized region of Paris, France, and found that the levels contrast sharply between neighborhoods. Despite international attention on the pigeon as a bioindicator, as well as reports and studies investigating high lead level concerns in NYC residents and their environments (Caravanos et al., 2006; New York City Department of Health and Mental Hygiene, 2014, 2010; Schnur and John, 2014), the feral pigeon to our knowledge has never been the subject of a lead bioindication study in the United States. We investigated blood concentration levels of lead in 825 feral pigeons suspected of lead poisoning and collected across different neighborhoods and seasons in NYC over a period of five years (2011–2015). We also examined the relationship between pigeon blood lead levels per neighborhood in Manhattan as compared to mean rates of lead in children identified by the NYC Department of Health and Mental Hygiene as having elevated blood lead levels (>10 μg/dL; 2014). We provide support for the use of the feral pigeon as a bioindicator of environmental lead contamination and in association with rates of elevated blood lead levels in children living in NYC.

2. Materials and methods

Since 2011, citizen scientists have been collecting visibly ill or abnormally behaving feral pigeons throughout New York City and admitting them to the Wild Bird Fund, the only wildlife rehabilitation center in the city. Wildlife rehabilitators routinely sample blood from patients upon their admission via femoral vein puncture. Trained rehabilitators then measure and record lead levels in the blood using a LeadCare® II portable anodic stripping voltammetry (ASV) device.

With permission of the Wild Bird Fund, we analyzed these data, which included: assigned ID number, the location of the pigeon's collection, the date that blood level was tested, and their blood lead level in μg/dl if it fell within range detection (3.3–65.0 μg/dl). The location of the pigeon's collection was classified into neighborhoods according to the New York State Department of Health (New York City Department of Health and Mental Hygiene, 2014). The majority of pigeons admitted to the Wild Bird Fund were from Manhattan. Thus, we concentrated our analyses on neighborhoods within this borough, though we incorporate areas from other neighborhoods within NYC boroughs that offered sufficient data,

Table 1
NYC pigeon sample sizes by year, season, and neighborhood.

Year	N	Neighborhood	N
2011	92	Soho/Greenwich Village	39
2012	161	Lower Manhattan/Lower East Side	63
2013	243	Upper West Side	250
2014	287	Kingsbridge/Riverdale/Inwood/Washington Heights	46
2015	42	Chelsea/Clinton	66
		Upper East Side	81
		Gramercy Park/Murry Hill	65
		Southwest/West/West Central Queens	43
Season	**N**	Park/Southern/Southwest/Central Brooklyn	41
Spring	173	Harlem	30
Summer	263	Bushwick/Williamsburg/Greenpoint/Northwest Brooklyn	42
Fall	178	North Queens	41
Winter	57	Central/South Bronx	18

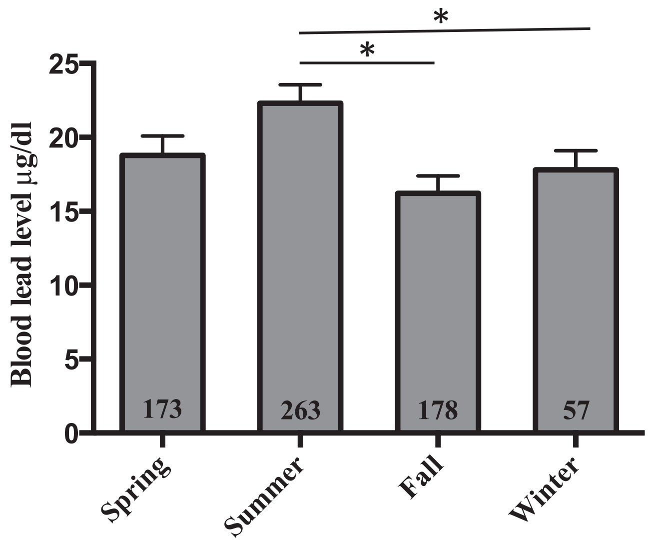

Fig. 1. Mean blood lead levels of NYC pigeons during the four seasons over the five years sampled. Lead levels were significantly higher in birds sampled in the summer as compared to those sampled in the fall or winter. An asterisk denotes significance at P < 0.05. Error bars indicate the standard error of the mean, and sample sizes are included within each column.

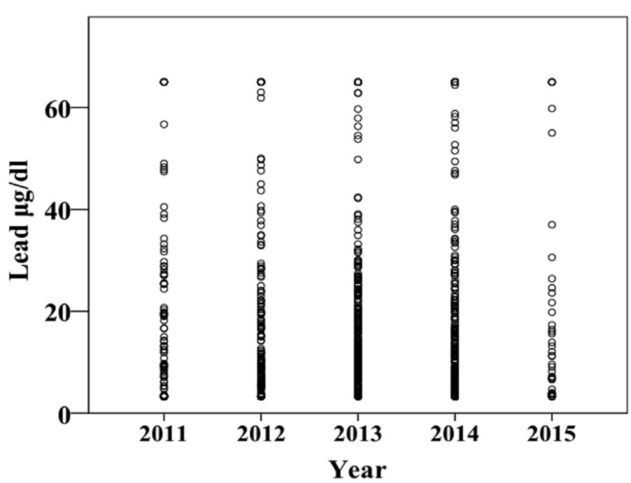

Fig. 2. Scatter plot depicting individual blood lead levels of NYC pigeons during years 2011–2015. Levels did not significantly differ between years.

including Brooklyn, Queens, and the Bronx. Smaller neighborhoods and/or areas with fewer than 10 data points were combined with directly adjacent neighborhoods. We assigned seasons from dates by using respective annual season equinox dates as cutoffs. In total, we compared the blood lead levels of 825 pigeons collected during the Fall, Winter, Spring, or Summer from 13 New York City neighborhoods from January, 2011, to March, 2015.

We performed statistical analyses using SPSS (SPSS Inc., Chicago, USA). We used Levene's test to assess equality of variances in our blood lead level data. If data lacked homoscedasticity, we used an appropriate transformation to meet the assumptions of a linear model. We conducted a univariate general linear model to examine if year (2011–2015), season (spring, summer, fall, winter), and/or neighborhood (N = 13) explained pigeon blood lead levels (N = 825). When we parsed data into neighborhood per season per year, sample sizes were too small to examine interaction effects with confidence. Also, we could not examine potential sex effects, as pigeons are not sexually dimorphic and rehabilitators did not determine sex through other methods (such as sex genotyping or laparotomy). Thus, we solely investigated year, season, and neighborhood as potential explanatory variables of pigeon blood lead levels. Pending a statistically significant model result (P < 0.05), we conducted Tukey's post-hoc analyses to examine pairwise relationships, which were deemed significant at P < 0.05. We report sample sizes in Table 1. In addition, we conduced a Pearson's correlation analysis to assess the relationship between the mean blood lead levels in pigeons per Manhattan neighborhood and the rates of children identified with elevated blood lead levels as reported by the NYC Department of Health and Mental Hygeine (2014). We determined a significant result at P < 0.05.

3. Results

Levene's test revealed that blood lead level data did not meet the assumptions of variance equality ($F_{51,773} = 1.666$, $P = 0.003$). Log-transformed data showed no statistical difference in variance ($F_{51,773} = 0.787$, $P = 0.858$) and were used for further analyses.

A general linear model examining the effect of year, season, and neighborhood on blood lead levels was statistically significant ($F_{165,659} = 1.338$, $P = 0.007$). Post-hoc tests revealed that blood lead levels were higher in the summer ($\bar{x} = 22.311$ µg/dl) as compared to the fall ($\bar{x} = 16.224$ µg/dl, $P = 0.003$) and winter ($\bar{x} = 17.795$ µg/dl, $P = 0.001$; Fig. 1). Year (Fig. 2) and neighborhood did not significantly predict blood lead levels (all statistical results are reported in Supplementary Materials). However, in general, pigeons from the Soho/Greenwich Village neighborhood had on average the highest levels of lead in their blood ($\bar{x} = 23.121$ µg/dL), followed by pigeons from Lower Manhattan/Lower East Side ($\bar{x} = 22.708$ µg/

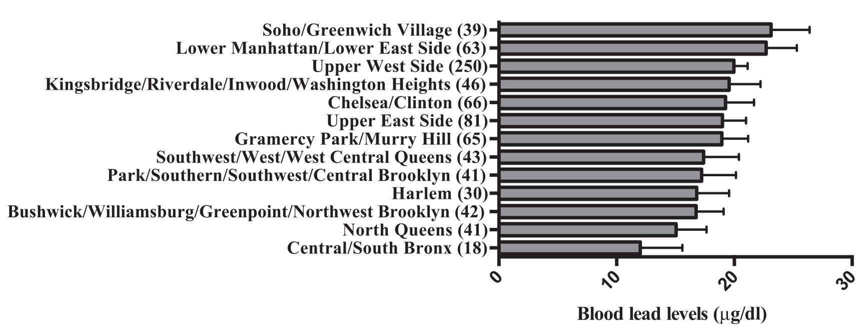

Fig. 3. Mean blood lead levels of NYC pigeons per neighborhood over the five years sampled. Error bars indicate the standard error of the mean, and sample sizes are included in parentheses.

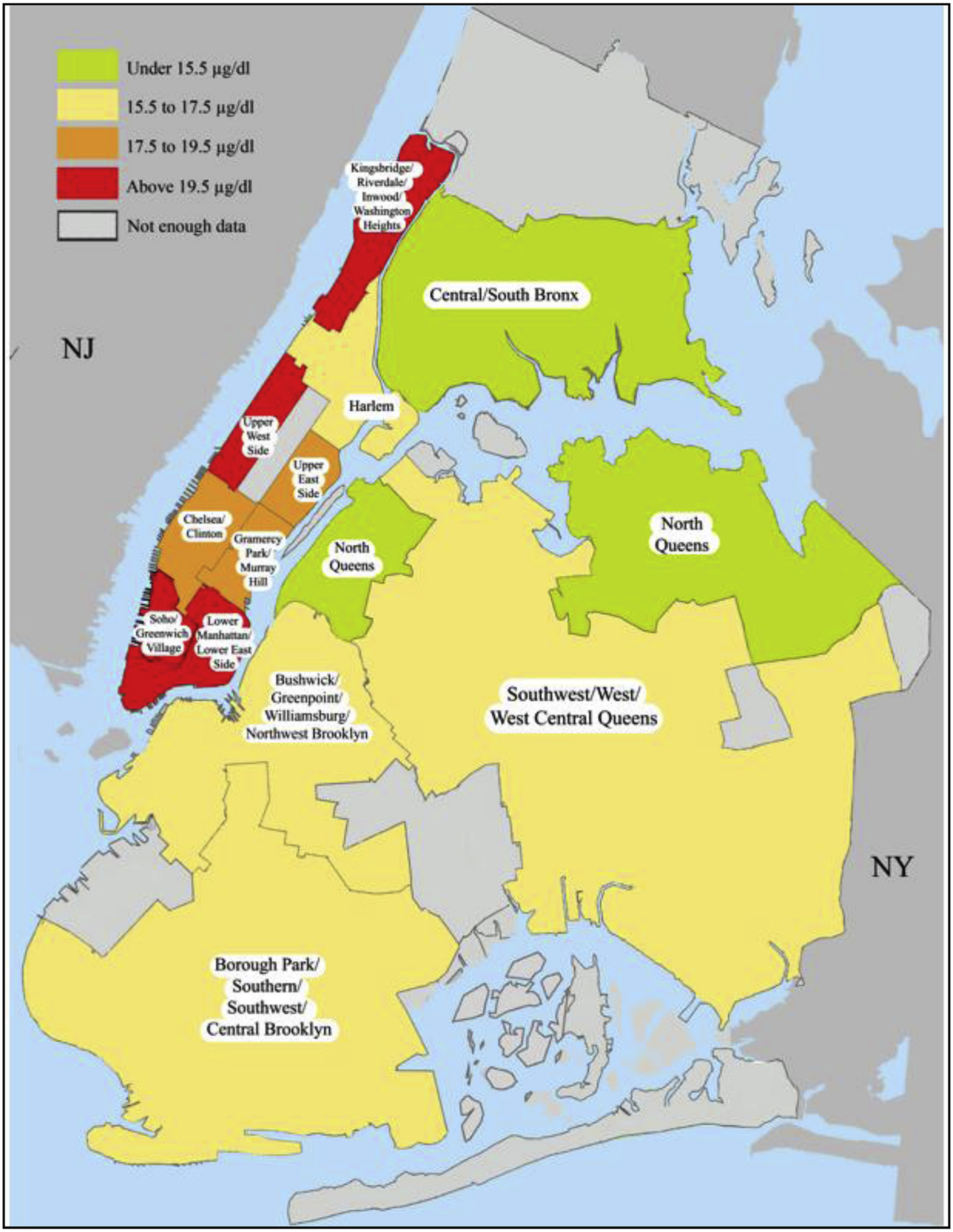

Fig. 4. A map of NYC depicting pigeon mean blood lead levels per neighborhood sampled. Neighborhood borders were classified according to the New York State Department of Health (2014).

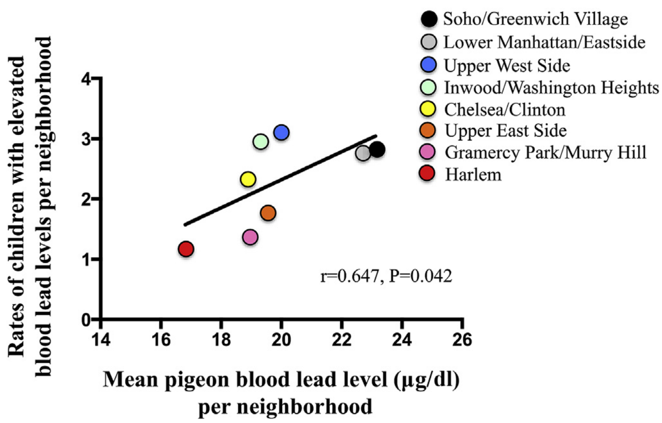

Fig. 5. Scatter plot depicting the positive correlation between pigeon mean blood lead levels in neighborhoods in Manhattan with rates of children (per 1000 tested) younger than 18 years of age with elevated blood lead levels of 10 μg/dl or greater.

dl) and then Upper West Side ($x^{-} = 19.957$ μg/dl; Figs. 3 and 4). A correlational analysis revealed that pigeon blood lead levels in Manhattan neighborhoods positively correlate with rates of children in those neighborhoods identified with elevated blood lead levels ($r = 0.647$, $N = 8$, $P = 0.042$; Fig. 5).

4. Discussion

We report that significant differences in New York City feral pigeon blood lead levels are apparent across seasons. Blood lead levels are highest in summer months as compared to fall and winter months, a phenomenon previously reported in children (Johnson and Bretsch, 2002, Haley and Talbot, 2004). Although levels did not statistically differ significantly by neighborhood, on average, lead circulating in the blood was in highest concentrations in the neighborhoods of Soho/Greenwich Village, Lower Manhattan/Lower East Side, and Upper West Side as compared to other neighborhoods examined. These relative levels of toxicity are positively correlated with reported relative rates of toxicity in children by the NYC Department of Health and Mental Hygeine (2014).

4.1. Lead and seasons

Seasonal variation in children's blood lead levels has been documented, with levels peaking during the summer months (Johnson and Bretsch, 2002, Haley and Talbot, 2004). Mean blood lead concentrations in the summer in NYC pigeons were also significantly higher than those during the fall and winter. This suggests that either 1) lead levels in the city are higher in the summer, 2) feral pigeons are more active in the summer and are exposed to greater amounts of atmospheric and/or particulate lead, 3) pigeons are able to incorporate lead more quickly into soft tissue or bone in the summer, or 4) a combination of these factors.

Lead levels in children may be higher in the summer due to increased activity outside accompanied by higher temperatures, which can lower the humidity of soil – soil that can contain particulate lead (Laidlaw et al., 2005). Solid matter that is less damp is easily re-suspended in the air, where it can be more easily accessed via inhalation or touch. During the winter months, particularly in the northeast U.S., frozen ground and snow cover may lessen such exposure (Johnson and Bretsch, 2002; Yiin et al., 2000).

Another explanation may be that in many avian species, including the pigeon, basal metabolic rate changes between seasons (McKechnie, 2008; Saarela and Vakkuri, 1982). Feral pigeons increase metabolism during the winter to account for lower temperatures (McKechnie, 2008). This increase in BMR could result in faster incorporation of lead into the body resulting in lower levels of lead circulating in the blood. However, further research must be conducted before drawing any conclusions about the effect of BMR on heavy metal processing in the avian system. In summary, whatever the cause may be for seasonal changes in blood lead levels in pigeons and children, sampling blood during the fall and winter months may not be representative of the peak level experienced or total amount of annual lead exposure.

4.2. Lead and neighborhoods

The lead concentrations of sick birds collected throughout NYC neighborhoods ranged from an average of 12 μg/dl (Central/South Bronx) to almost double that in some neighborhoods (Soho/Greenwich Village and Lower Manhattan/Lower East Side). Rates of children reported as newly identified with elevated blood lead levels of 10 μg/dl or greater in NYC were also higher in those living in Soho/Greenwich Village and Upper West Side as compared to other areas of Manhattan, North Queens and Central/South Bronx (New York City Department of Health and Mental Hygiene, 2014). Circulating lead in the blood has negative effects on human health and development at amounts as low as or below 10 μg/dl (Canfield et al., 2003; Schnur and John, 2014; Lanphear et al., 2000), and thus these levels in both pigeons and humans are cause for concern.

Heavy trafficked areas in midtown and downtown Manhattan may be the cause of high lead blood levels in NYC pigeons living in these areas. An NYC 2008–2009 Community Air Survey and the New York City Department of Transportation indicate heavy traffic density exists in midtown and downtown Manhattan (2011). Heavily trafficked areas have been suggested as the culprit for lead or, post the ban of its use in gasoline, residual lead particulate (Drasch et al., 1987; García et al., 1988; Hutton and Goodman, 1980; Johnson et al., 1982; Nam and Lee, 2006; Ohi et al., 1981).

Other potential sources of lead toxicants include deteriorating paint and lead dust accumulation, which can increase lead loading on streets, sidewalks, and alleys during demolition and particulate lead in polluted water and on the ground, including on the soil (Caravanos et al., 2006; Farfel et al., 2003). Deteriorating paint on steel structures and railways in NYC can also increase lead loading in soil and dust (Weiss et al., 2006). House dust and soil lead concentrations are strongly associated with child blood lead levels, and soil lead concentrations may have an even greater impact on lead toxicity than lead paint (Duggan, 1980; Mielke and Reagan, 1998). Atmospheric lead is also a common source, though it may account for only a very small portion of lead ingested by humans and pigeons (Duggan, 1980; Mielke and Reagan, 1998).

Whatever the source(s) may be causing lead toxicity in our subjects, there exists a parallel between high blood lead levels in the pigeons sampled and high rates of children with blood lead levels of 10 μg/dl or more in some NYC neighborhoods. Because of this, and the fact that pigeons and humans exhibit the same seasonal variations in blood lead levels (Johnson and Bretsch, 2002, Haley and Talbot, 2004), we present evidence for the use of the feral pigeon as a bioindicator of environmental lead contamination and human health in New York City.

5. Conclusion

Pigeons co-inhabit the built environment with humans all over the globe. They are exposed to many of the same environmental contaminants as humans, and often, they suffer similar health consequences. Outside of the U.S., pigeons have been successfully used as heavy-metal bioindicators. However, a study using the pigeon model as a bioindicator for lead has never, to our knowledge, been conducted in the U.S. Furthermore, to our knowledge, no study has investigated or corroborated the link between pigeon blood lead levels and those of children seasonally or living in the same neighborhoods. Here, we offer all three and provide a powerful example of how monitoring pigeon biology may help us to better understand the location and prevalence of lead, with the aim of providing greater awareness and devising prevention measures. This is an increasingly timely and important topic as new findings reveal that even miniscule amounts of lead are extremely detrimental to child health, and that lead is still a health concern to many communities in the United States and beyond (Lanphear et al., 2000; Canfield et al., 2003; Schnur and John, 2014).

Acknowledgments

We thank the Wild Bird Fund for the great work that they do rehabilitating NYC wildlife and for providing records of pigeon blood lead levels in the city for over the past 5 years.

Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.chemosphere.2016.07.002.

References

Canfield, R.L., Charles R Henderson, J., Cory-Slechta, D.A., Cox, C., Jusko, T.A., Lanphear, B.P., 2003. Intellectual impairment in children with blood lead concentrations below 10 ug per deciliter. N. Engl. J. Med. 348, 1517–1526.

Caravanos, J., Weiss, A.L., Blaise, M.J., Jaeger, R.J., 2006. A survey of spatially distributed exterior dust lead loadings in New York City. Environ. Res. 100, 165–172. http://dx.doi.org/10.1016/j.envres.2005.05.001.

Cui, J., Wu, Bin, Hallbrook, R.S., Zang, S., 2013. Age-dependent accumulation of heavy metals in liver, kidney and lung tissues of homing pigeons in Beijing, China. Ecotoxicology 22, 1490–1497. http://dx.doi.org/10.1007/s10646-013-1135-0.

Drasch, G.A., Walser, D., Kosters, J., 1987. The urban pigeon (Columbia livia, forma urbana) - a biomonitor for the lead burden of the environment. Environ. Monit. Assess. 9, 223–232.

Duggan, M.J., 1980. Lead in urban dust: an assessment. Water, Air, Soil Pollut. 14, 309–321.

Farfel, M.R., Orlova, A.O., Lees, P.S.J., Rohde, C., Ashley, P.J., J Julian Chisolm, J., 2003. A study of urban housing demolitions as sources of lead in ambient dust: demolition practices and exterior dust fall. Environ. Health Perspect. 111, 1228–1234. http://dx.doi.org/10.1289/ehp.5861.

Frantz, A., Pottier, M.-A., Karimi, B., Corbel, H., Aubry, E., Haussy, C., Gasparini, J., Castrec-Rouelle, M., 2012. Contrasting levels of heavy metals in the feathers of urban pigeons from close habitats suggest limited movements at a restricted scale. Environ. Pollut. 168, 23–28. http://dx.doi.org/10.1016/j.envpol.2012.04.003.

García, M.T.A., Martinez-Conde, E., Vazquez, I.C., 1988. Lead levels of feral pigeons (Columba livia) from Madrid (Spain). Environ. Pollut. 54, 89–96.

Gompertz, T., 1956. Some observations on the feral pigeon in London. Bird. Study 4, 2–13. http://dx.doi.org/10.1080/00063655709475863.

The New York City Community Air Survey: Results from Year One Monitoring 2008–2009. New York, NY, 2011.

New York City Department of Health and Mental Hygiene, 2014. Lead Poisoning in New York City, Continued Decline in 2012. New York, NY.

New York City Department of Health and Mental Hygiene, 2010. Lead Poisoning in New York City, Annual Data Report 2009. New York, NY.

Haley, V.B., Talbot, T.O., 2004. Seasonality and trend in blood lead levels of New York State children. BMC Pediatr. 4 (1), 8-5.

Humphries, C., 2008. Superdove: How the Pigeon Took Manhattan–and the World.

Hutton, M., Goodman, G.T., 1980. Metal contamination of feral pigeons Columba livis from the London area: Part 1-tissue accumulation of lead, cadmium and zinc. Environ. Pollut. 22, 207–217.

Jerolmack, C., 2008. How pigeons became rats: the cultural-spatial logic of problem animals. Soc. Probl. 55, 72–94. http://dx.doi.org/10.1525/sp.2008.55.1.72.

Johnson, D.L., Bretsch, J.K., 2002. Soil lead and children's blood lead levels in syracuse, NY, USA. Enviro. Geochem. Health 24, 375–385.

Johnson, M.S., Pluck, H., Hutton, M., Moore, G., 1982. Accumulation and renal effects of lead in urban populations of feral pigeons, *Columba livia*. Archives Environ. Contam. Toxicol. 11, 761–767.

Kessler, R., 2013. Sunset for leaded aviation gasoline? Environ. Health Perspect. 121, a54–a57.

Laidlaw, M.A.S., Mielke, H.W., Filippelli, G.M., Johnson, D.L., Gonzales, C.R., 2005. Seasonality and children's blood lead levels: developing a predictive model using climatic variables and blood lead data from Indianapolis, Indiana, Syracuse, New York, and New Orleans, Louisiana (USA). Environ. Health Perspect 113 (6), 793–800.

Lanphear, B.P., Dietrich, K., Auinger, P., Coz, C., 2000. Cognitive deficits associated with blood lead concentrations <10 μg/dL in US children and adolescents. Public Health Rep. 115, 521–529.

Liu, W.X., Ling, X., Halbrook, R.S., Martineau, D., Dou, H., Liu, X., Zhang, G., Tao, S., 2010. Preliminary evaluation on the use of homing pigeons as a biomonitor in urban areas. Ecotoxicology 19, 295–305. http://dx.doi.org/10.1007/s10646-009-0412-4.

McKechnie, A.E., 2008. Phenotypic flexibility in basal metabolic rate and the changing view of avian physiological diversity: a review. J. Comp. Physiol. B 178, 235–247. http://dx.doi.org/10.1007/s00360-007-0218-8.

Mielke, H.W., Reagan, P.L., 1998. Soil is an important pathway of human lead exposure. Environ. Health Perspect. 106, 217–229.

Nam, D.-H., Lee, D.-P., 2006. Monitoring for Pb and Cd pollution using feral pigeons in rural, urban, and industrial environments of Korea. Sci. Total Environ. 357, 288–295. http://dx.doi.org/10.1016/j.scitotenv.2005.08.017.

Ohi, G., Seki, H., Minowa, K., Ohsawa, M., Mizoguchi, I., Sugimori, F., 1981. Lead pollution in Tokyo- the pigeon reflects its amelioration. Environ. Res. 26, 125–129.

Rose, E., Nagel, P., Haag-Wackernagel, D., 2006. Spatio-temporal use of the urban habitat by feral pigeons (Columba livia). Behav. Ecol. Sociobiol. 60, 242–254. http://dx.doi.org/10.1007/s00265-006-0162-8.

Saarela, S., Vakkuri, O., 1982. Photoperiod-induced changes in temperature-metabolism curve, shivering threshold and body temperature in the pigeon. Environ. Health Perspect. 105, 322–330.

Schilderman, P.A., Hoogewerff, J.A., van Schooten, F.J., Maas, L.M., Moonen, E.J., van Os, B.J., van Wijnen, J.H., Kleinjans, J.C., 1997. Possible relevance of pigeons as an indicator species for monitoring air pollution. Environ. Health Perspect. 105, 322–330.

Schnur, J., John, R.M., 2014. Childhood lead poisoning and the new Centers for Disease Control and Prevention guidelines for lead exposure. J. Am. Assoc. Nurse Pract. 26, 238–247. http://dx.doi.org/10.1002/2327-6924.12112.

Weiss, A.L., Caravanos, J., Blaise, M.J., Jaeger, R.J., 2006. Distribution of lead in urban roadway grit and its association with elevated steel structures. Chemosphere 65 (10), 1762–1771.

Yiin, L.-M., Rhoads, G.G., Lioy, P.J., 2000. Seasonal influences on childhood lead exposure. Environ. Health Perspect. 108, 177–182.