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**Article** *in* Archives of Environmental Contamination and Toxicology · September 2007

DOI: 10.1007/s00244-006-0174-4 · Source: PubMed



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Arch. Environ. Contam. Toxicol. 53, 261–268 (2007)
DOI: 10.1007/s00244-006-0174-4

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# The Presence and Impact of Environmental Lead in Passerine Birds Along an Urban to Rural Land Use Gradient

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Received: 7 August 2006 /Accepted: 21 January 2007

**Abstract.** Contamination of wetlands by lead shot and lead fishing weights has generated a tremendous amount of research into the impact of lead poisoning on wildlife. Less well known are the potential threats to wildlife posed by lead contaminants still prevalent in urban environments. Despite a U.S. federal ban on lead-based paint and gasoline in 1978 and 1986, respectively, lead residue is still prevalent at hazardous levels in urban and suburban environments and may present a health concern for people and wildlife, particularly birds. We quantified soil lead content in residential properties across a rural-to-urban land-use gradient in the metropolitan Washington, D.C. area and then assessed the impact of lead contamination on body condition in adult and nestling passerine birds at the same sites. Soil lead concentration was significantly higher in urban sites compared to rural sites. Accordingly, adult and nestling birds captured in urban sites had significantly higher blood lead concentrations than their rural counterparts. However, only gray catbird nestlings exhibited lower body condition as a result of lead contamination. Birds continue to breed in urban habitats despite numerous negative attributes to these environments including light, noise, pedestrian and toxic contaminants, such as lead. These sites often contain habitat that appears suitable for roosting, nesting, and foraging and thus may act as an ecological trap for breeding birds because breeding success is often negatively associated with increasing urbanization. Lead contamination is one more feature of urbanization that birds and other wildlife must face in an increasingly developed world.

## Introduction

Lead poisoning has long been a concern for public health officials. The impact of lead poisoning in children due to ingestion of paint chips and soil has been studied in depth (*e.g.*, Haley and Talbot 2004; Koller *et al*. 2004; Mathee *et al*. 2004; Niskar *et al*. 2005). Lead poisoning has also been a problem for wildlife. Concern over lead poisoning in wildlife has generated research efforts that focused on wetlands (*e.g.*, Daury *et al*. 1993; Pain 1996; Miller *et al*. 1998; Hui 2002) contaminated with lead shot used for waterfowl hunting and lead weights for fishing (Scheuhammer and Norris 1996). Such research resulted in a federal ban of lead shot in 1991 (Federal Register 1995) and a proposed similar ban on lead fishing weights in designated ''lead-free fishing areas'' on some national refuges (Federal Register 1999).

Urban environments are also contaminated by lead and thus are potentially toxic to wildlife. Lead-based paint and leaded gasoline, two significant sources of lead in the urban environment, were phased out of use in the United States in 1978 and 1986, respectively. However, because of the persistent properties of lead, contamination remains a legitimate health concern for people and wildlife including birds. Soil lead concentrations are typically higher in larger, older, inner cities compared to those found in rural environments (Mielke 1999). Such elevated levels pose potential health threats to wildlife such as birds living in contaminated urban areas, yet little research has examined this issue.

Lead is primarily transferred from the environment to birds through their diet and secondarily through inadvertent soil consumption (Beyer *et al*. 1994). Birds accumulate lead in their tissues via multiple mechanisms. Lead moves from soil to plants (Labare *et al*. 2004) through the root system and is stored primarily in leaves (Olivares 2003) and seeds (Teissedre *et al*. 1994; Olivares 2003). Transfer to birds may then occur directly through consumption of fruits or indirectly through phytophagous insects or soil invertebrates (Price *et al*. 1974; Dmowski and Karolewski 1979; Kaminski 1995; Labare *et al*. 2004). In addition, birds may consume contaminated soil while foraging. Beyer *et al*. (1994) suggested that ground-foraging birds also take up lead by inadvertently consuming soil along with their prey.

In one case, insectivorous blackbirds (*Turdus merula*) feeding at contaminated sites in Aachen, Germany had significantly higher levels of lead in their feathers and organs than blackbirds feeding at uncontaminated sites (Weyers *et al*. 1985). In addition, insects sampled at the contaminated locations had lead levels closely approximating those found in the contaminated bird tissues (Weyers *et al*. 1985). In another study, Labare *et al*. (2004) reported earthworms from lead-contaminated areas showing 90% greater tissue lead

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concentration than earthworms from uncontaminated areas. Earthworms, with up to 30% of their body weight comprising soil, are capable of accumulating large concentrations of lead in their tissues (Beyer *et al*. 1994; Kennette *et al*. 2002). Contaminated earthworms, therefore, probably provide a primary mechanism for the movement of lead into ground-foraging species such as the American robin (*Turdus migratorius*).

Effects of lead poisoning in birds can have both physiological and behavioral impacts. Physiological effects include anemia (Pain 1989; Franson 1996), emaciation (Beyer *et al*. 1988; Kaminski and Matus 1998), and brain damage (Dieter and Finley 1979; Douglas-Stroebel *et al*. 2004). Anemia is the primary consequence of lead poisoning in adult (Beyer *et al*. 1988) and nestling (Kostelecka-Myrcha *et al*. 1997) birds and can severely affect body condition and survival. Classic behavioral symptoms of lead poisoning include increased aggressiveness (Janssens *et al*. 2003) and difficulty with flying, landing, and walking (Sanderson and Bellrose 1986). Such behavioral difficulties may affect a bird's ability to attract a mate, build a nest, and adequately feed nestlings (De Francisco *et al*. 2003).

To date, most research on lead contamination in populations of wild birds and other wildlife has been conducted at shooting ranges (Vyas *et al*. 2000; Lewis *et al*. 2001; Hui 2002; Labare *et al*. 2004), in wetlands contaminated with lead shot and lead fishing sinkers (O'Halloran *et al*. 1988; Scheuhammer and Norris 1996; Tsuji *et al*. 1998), or at industrial (Nyholm 1998; Spahn and Sherry 1999) and mining (Dmowski and Karolewski 1979; Blus *et al*. 1991; Henny *et al*. 2000; Meharg *et al*. 2002) runoff sites. Within human-populated urban environments, only a few studies have been conducted; these studies focused on birds near heavily used highways (Grue *et al*. 1984, 1986) or in countries that still used leaded gasoline at the time of the research such as in Germany (Weyers *et al*. 1985), Poland (Kaminski 1995; Kostelyecka-Myrcha *et al*. 1997), and the United States (DeMent *et al*. 1986). Few studies have assessed lead and its impact on wild birds within urban and rural land-use areas (Getz *et al*. 1977; Johnson *et al*. 1982) and only one since the ban on leaded gasoline and paints was implemented (Chandler *et al*. 2004).

The objectives for this study were to quantify lead concentrations along an urban-to-rural land-use gradient in (1) soil, and (2) blood lead levels of seven species of adult and nestling passerine birds. As a third objective, we also examined the impact of lead on the body condition of adult and nestling birds living in areas along this same land-use gradient.

## Materials and Methods

### *Study Sites*

This study was conducted as part of a citizen science program called Neighborhood Nestwatch (hereafter NN) operated through the Smithsonian Migratory Bird Center at the National Zoo (hereafter SMBC) in Washington, DC (http://www.sio.si.edu/Nestwatch). Nestwatch participants help find nests and monitor their success in their own backyards. A total of 53 NN properties were selected as study sites in the metro-Washington, DC, and Baltimore City, MD region (32 urban sites) and surrounding rural areas (21 rural sites). This study was conducted over the course of two breeding seasons, during the months of May through early August of 2003 and 2004.

Density of housing and other man-made structures are common landscape characteristics used to classify study sites as urban or rural (Cam *et al*. 2000; Marzluff *et al*. 2001; Thorington and Bowman 2003). Marzluff *et al*. (2001) suggested standardizing the classification of urban sites as those areas having more than 10 buildings per hectare and rural sites having fewer than 2.5 buildings per hectare. All urban sites in this project were located in towns and cities that have a building density greater than 10 structures per hectare and rural sites fewer than 2.5 buildings per hectare (U.S. Census Bureau 2000).

### *Soil Lead*

Soil lead was evaluated for each site by collecting and testing three samples of soil at each site. Soil was collected from bare patches on the surface or directly underneath grass. One sample was taken close to a road, a second in the back yard, and a third from a randomly chosen location in the yard. Soil samples were dried and all noticeable vegetative matter, such as grass and roots, was removed before analysis. The mean of the three samples was used to represent the soil lead of each site.

### *Study Species*

Seven bird species were included in this study: American robin (*Turdus migratorius*, AMRO), gray catbird (*Dumatella carolinensis*, GRCA), song sparrow (*Melospiza melodia*, SOSP), Northern cardinal (*Cardinalis cardinalis*, NOCA), Northern mockingbird (*Mimus polyglottos*, NOMO), Carolina wren (*Thryothorus ludovicianus*, CARW), and house sparrow (*Passer domesticus*, HOSP). All seven study species have diets comprised of plant and animal material but in different proportions. With respect to the area included in our study, AMRO and GRCA are short- and long-distance migratory species, respectively, and SOSP, NOCA, NOMO, CARW, and HOSP are all year-round resident species.

Adults were captured with mist nets, sometimes accompanied with a song playback to attract territorial birds. At the time of capture, each bird received a unique band combination including one U.S. Fish and Wildlife Service (USFWS) aluminum band and two colored plastic leg bands. Body mass, right wing chord, right tarsus, and tail length were all measured. In addition, sex and breeding status were recorded for each bird. A blood sample of 100 μl was drawn from the brachial vein and placed in a uniquely identified tube lined with the anticoagulant ethylene diamine tetraacetic acid (EDTA). In the field, tubes of blood were immediately stored in a cooler and then placed in a freezer upon returning to the laboratory. All adults were released after banding and were monitored throughout the season. Nests containing AMRO and GRCA nestlings were located by either following adults to their nests or by searching vegetation. All nests were monitored until the fledging or failure stages. Nests were not disturbed during the egg laying and incubating stages, because adults are more likely to abandon nests during these stages. Aside from times when nestlings had to be removed from the nest, a mirror on an extendable pole was used to check the status of nests to minimize disturbance.

Nestlings were measured and had blood taken 7 to 9 days after hatching. Body mass (g), right wing chord (mm), and the length of the right tarsi (mm) were all measured. Blood samples were drawn and stored in the same manner as described for adults. Each nestling also received one USFWS aluminum band and one color band. All procedures with wild birds were approved by the Institutional Animal Care and Use Committee at the Smithsonian Institution.

### Lead Analysis

Soil and blood were tested for lead content at the Lead Laboratory of the Maryland Department of Health and Mental Hygiene (hereafter MDHD) in Baltimore, MD. Soil samples were subjected to an acid digestion with nitric acid and digested in a microwave digester. The resulting digestate was analyzed with a flame atomic absorption spectrometer (Flame-AA). Blood samples were also subjected to an acid digestion, but analyzed with a graphite furnace atomic absorption spectrophotometer (GFAA). Soil and blood samples were each analyzed twice to ensure accuracy. The detection limit of lead was 5 ppm in soil and 0.02 ppm in blood.

### Statistical Analysis

A Student's *t*-test was used to assess statistical significance between soil lead of urban and rural study sites. We also compared lead levels between samples taken close to the road with those taken in the back yard. If lead levels were higher near the road, this provides some evidence that the origin of the lead was from gasoline residue vs. lead-based paint.

To determine whether adult blood lead at each site correlated to lead concentration in local soil, each species' blood lead was regressed against soil lead from the same location in which birds were captured. Blood sample results that were below the detection limit were entered as 0.01 ppm because of the assumption that blood lead could be 0.01 ppm or less. Analysis of variance was used to test for differences between land-use type, sex, resident versus migratory status, ground-foraging versus mixed foraging, and body condition for each species. To assess the impact of lead on the body condition of birds, body mass was divided by tarsus$^3$ (m/t$^3$). To analyze lead levels in nestlings, blood lead concentrations for all nestlings within each nest were averaged. Mean nestling lead concentrations were then regressed against both the local mean soil concentrations and the parental blood lead levels. Student's *t*-test was used to test for statistical significance between land-use type and nestling body condition. Finally, body condition was regressed against levels of blood lead for both adults and nestlings.

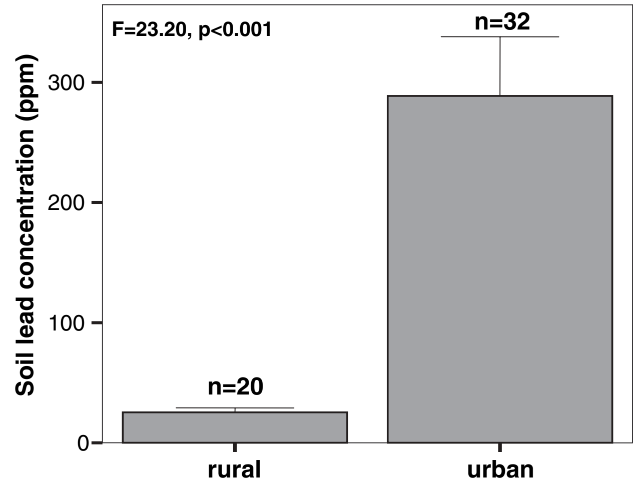


**Fig. 1.** Mean soil lead concentrations found within rural and urban study sites of the metro Washington, DC and Baltimore, Maryland region

**Table 1.** Blood lead concentrations of all adult study species in rural and urban environments

| Species | Rural (*N*) | Urban (*N*) |
|---|---|---|
| American robin | 0.079 ± 0.009 (27) | 0.264 ± 0.035 (24) |
| Gray catbird | 0.014 ± 0.002 (42) | 0.094 ± 0.011 (67) |
| Song sparrow | 0.015 ± 0.003 (12) | 0.053 ± 0.009 (10) |
| Northern cardinal | 0.029 ± 0.007 (37) | 0.112 ± 0.027 (22) |
| N. mockingbird | 0.011 ± 0.001 (8) | 0.187 ± 0.065 (6) |
| Carolina wren** | 0.026 ± 0.01 (8) | 0.067 ± 0.025 (6) |
| House sparrow | 0.02 ± 0.004 (29) | 0.148 ± 0.013 (91) |

Data shown represent mean blood lead (ppm) ± standard error for the mean. Number of individuals captured is shown as (*N*). Significant difference in blood lead between environments determined with a $p$ value < 0.05. Nonsignificance is indicated by **

## Results

### Soil Lead

Soil lead concentration differed significantly between rural (25.34 ± 16.51 ppm) and urban (288.7 ± 278.33 ppm) study sites (F = 23.320, $p$ < 0.001, Figure 1). Soil taken from the roadside (231.85 ± 50.25 ppm) tended to be higher in lead concentration than soil taken from the backyard (141.23 ± 33.57 ppm; F = 1.91, $p$ = 0.17) although these differences were not significant.

### Adult Birds

All species of adult birds breeding in urban land-use areas had significantly higher blood lead than birds in rural land-use areas with the exception of CARW (Table 1). When species were examined individually against soil lead, five of seven species exhibited a positive and significant relationship between soil lead and blood lead, with the exceptions of SOSP and CARW (Figure 2).

With respect to land-use, blood lead concentrations varied significantly within species (F = 2.34, $p$ = 0.03). Overall, land-use explained the majority of variation in blood lead concentration (F = 11.82, $p$ < 0.0001) for all birds. Migratory status did not influence these findings: both migrants (F = 28.47, $p$ = 0.001) and residents (F = 79.25, $p$ = 0.001) continued to have significantly different blood lead concentrations between the rural and urban study sites (Figure 3). No significant differences in blood lead concentration were found between migratory and resident birds (F = 1.42, $p$ = 0.23). There was, however, a significant difference between birds that foraged on the ground compared to those that foraged in shrubs and canopy (F = 18.70, $p$ < 0.0001; ground foraging birds = 0.12 ± 0.0073 ppm; shrub/canopy foragers = 0.06 ± 0.0074 ppm). In particular, we found a significant interaction between land-use type and foraging method (F = 3.84, $p$ = 0.05), with urban ground foraging birds (0.16 ± 0.009 ppm) having greater blood lead concentrations than urban shrub/canopy foragers (0.10 ± 0.01 ppm) and all rural equivalents.

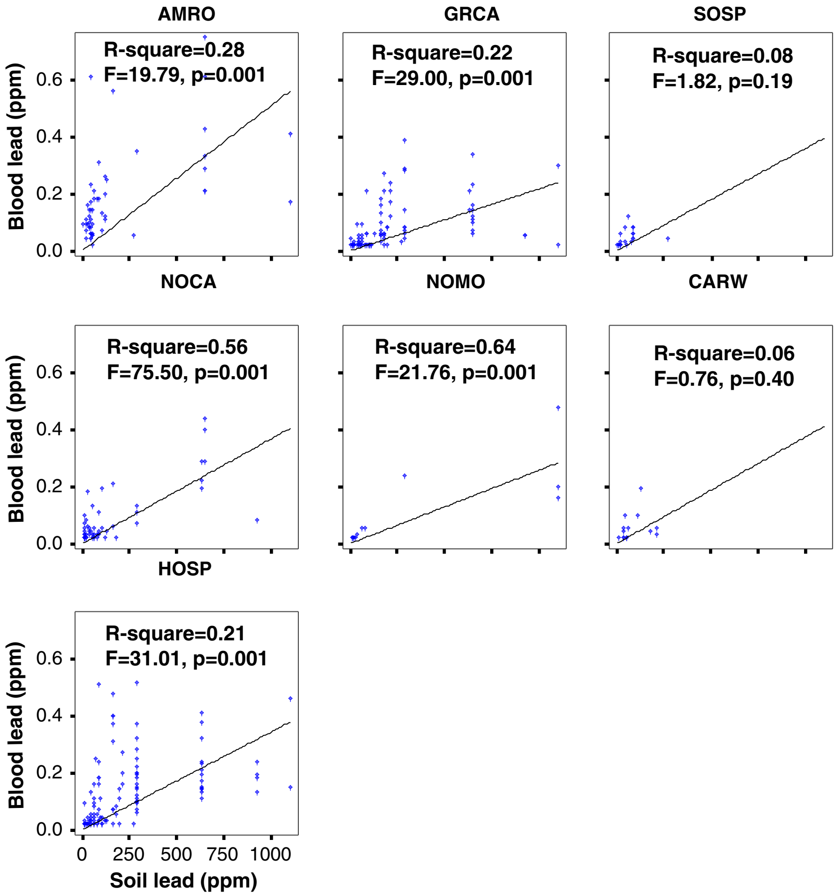


**Fig. 2.** Relationship between lead concentrations in bird blood and corresponding soil for sampled individuals of each focal species sampled in the Washington, DC and Baltimore, Maryland region. *AMRO* American robin, *GRCA* gray catbird, *SOSP* song sparrow, *NOCA* Northern cardinal, *NOMO* Northern mockingbird, *CARW* Carolina wren, *HOSP* house sparrow

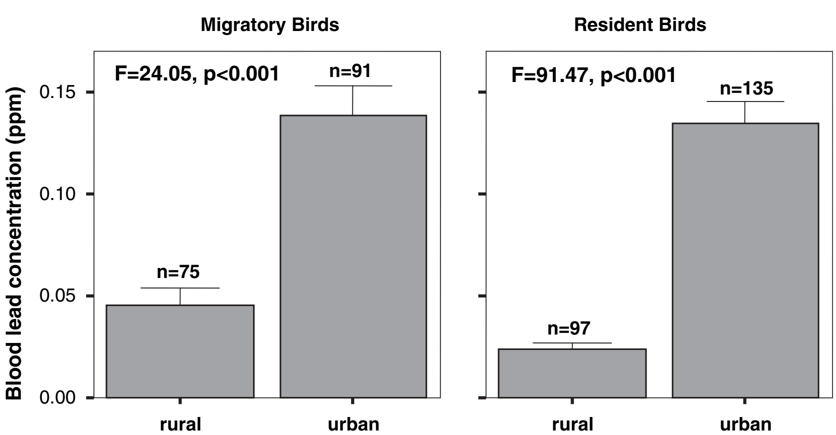


**Fig. 3.** Lead concentrations in blood of migratory and resident birds in rural and urban environments of the Washington, DC and Baltimore, Maryland region

We found no relationship between blood lead concentration and body condition for any adult bird species ($R^2$ range from 0.00 to 0.30, all $p$ values > 0.10).

## *Nestlings*

AMRO and GRCA nestlings found at urban sites exhibited significantly greater blood lead concentrations (AMRO: 0.20 ± 0.04 ppm, GRCA: 0.10 ± 0.01 ppm) than rural nestlings of the same species (AMRO: 0.06 ± 0.02, GRCA: 0.01 ± 0.00) and across both land-use types (Figure 4) and blood lead concentration increased significantly with soil lead concentration for both nestling species (AMRO: $R^2 = 0.21$, $F = 7.26$, $p = 0.01$; GRCA: $R^2 = 0.25$, $F = 15.4$, $p = 0.001$). Blood lead concentrations in nestlings were significantly correlated with parental blood lead for both species (AMRO: $R^2 = 0.53$, $F = 7.86$, $p = 0.03$; GRCA: $R^2 = 0.44$, $F = 12.4$, $p = 0.003$).

Neither AMRO ($F = 0.38$, $p = 0.54$) nor GRCA nestlings ($F = 0.72$, $p = 0.40$) exhibited any indication of blood lead concentrations impacting the size of the tarsus on Day 6 of the

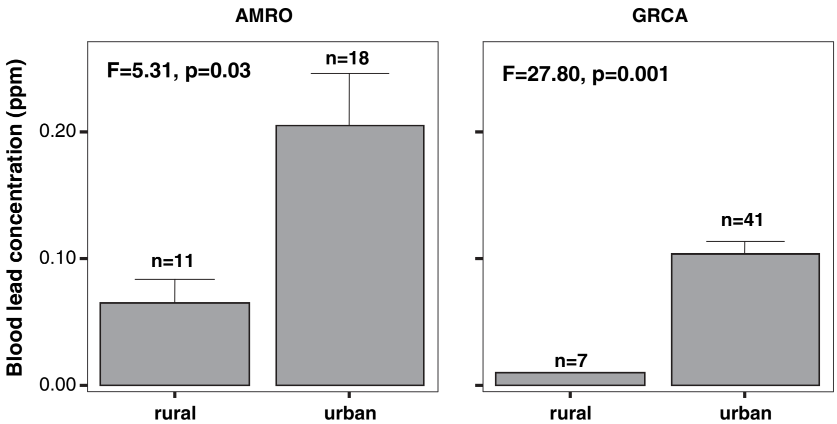


**Fig. 4.** Lead concentrations of blood from American robin (AMRO) and gray catbird (GRCA) nestlings in rural and urban environments of the Washington, DC and Baltimore, MD region

nestling cycle. In addition, we found no significant evidence of a decrease in body condition with increasing levels of blood lead (F = 0.86, $p$ = 0.36) for AMRO nestlings. GRCA nestlings, however, did exhibit a significant decline in body condition with increasing blood lead concentration (F = 11.25, $p$ = 0.002).

## Discussion

Increasing urbanization can have a multitude of negative impacts on the environment. In our study, we found that soil lead increased significantly from the expected natural levels in and around rural land-use areas to well above what are considered hazardous concentrations in urbanized land-use areas. Not surprisingly, blood lead concentrations in organisms, specifically in adult and nestling birds, also increased across the same gradient in almost all species examined. We are aware of only two previous studies examining lead contamination in birds in urban areas, and both found results consistent with ours (Chandler *et al*. 2004; Getz *et al*. 1977).

The primary source of the anthropogenic lead in our study sites is probably from leaded gasoline, although lead-based paint is likely also a contributing factor. In analyzing soil lead in several large cities in the United States (including Baltimore, MD, New Orleans, LA, and Minneapolis, MN), Mielke (1999) found that the density of high-traffic roadways was a stronger predictor of soil lead concentration than the amount of lead-based paint used on buildings. Such results suggest that the principal source of lead in urban soil is leaded gasoline residue. Our finding of higher lead concentrations near roadsides compared to backyards is also consistent with this theory. Birds in our study likely acquired the lead via their foraging methods and behaviors. Ground-foraging birds, whether migratory or resident, are more exposed to lead than birds that forage above ground or primarily on foliage.

The Environmental Protection Agency deems soil lead concentrations less than 50 ppm to be natural and soil lead concentrations above 400 ppm to be hazardous to human health and will recommend remediation. It has been observed that determining general implications of lead poisoning in birds can be difficult because there is a tremendous amount of variation in individual and species' symptoms and responses to lead poisoning (Pain 1989). Generally, abnormal behaviors are noticeable when blood lead is above 0.05 ppm and lead poisoning is confirmed at 0.2 ppm and above (De Francisco *et al*. 2003). The level of blood lead considered toxic but sublethal is 0.5 ppm (Sanderson and Bellrose 1986). In our study, despite blood lead concentrations at and above 0.2 ppm, no negative impact on body condition was found for adults. With nestling birds, however, gray catbird nestlings with higher blood lead concentrations were also found to be in poor physical condition.

Nestlings can be accurate reflections of the environment in which they are raised, because the location and conditions of their food source are limited to the area surrounding their nests (Spahn and Sherry 1999). Previous studies have found increased embryo and nestling mortality (Nyholm 1998) and significant negative impact on physiological condition (Kostelecka-Myrcha *et al*. 1997; Kaminski 1995; Pinowski *et al*. 1993) associated with lead-contaminated areas. However, lead-dosed Northern bobwhites exhibited no clear external symptoms of lead poisoning despite levels of tissue lead that have produced external symptoms in other studies (Connor *et al*. 1994). For an additional example, barn swallows feeding near a heavily used highway in Maryland had greater lead intake and higher tissue lead than barn swallows feeding in rural areas but showed no physiological symptoms of lead poisoning (Grue *et al*. 1984).

The lack of a physiological impact on birds may be explained by the ability of birds to rid their vascular systems of lead through excretion or by depositing lead in bone and feathers, thereby removing lead from circulation throughout organ systems (Sanderson and Bellrose 1986). If no additional exposure occurs, blood lead levels in waterfowl can drop from high to normal levels 1 to 2 months after exposure (Pain 1989). It does remain surprising that resident birds do not show a physiological impact given the constant exposure to environmental lead throughout the year. Our study, however, did not consider the annual survival of adult birds and it is possible that birds may succumb to the toxic effects of lead poisoning over time frames longer than this current study (Connor *et al*. 1994).

One possible explanation for the absence of physiological impact in our study may be related to the fact that high levels of protein and calcium in bird diets can reduce the absorption and retention of lead, thus alleviating the impact of lead toxicity on weight loss (Sanderson and Bellrose 1986; Berg *et al*. 1980). Our focal species all consume diets high in protein. During the breeding season, American robins have a diet that largely comprises protein-rich earthworms (Sallabanks and James 1999). Additionally, mockingbirds (Derrickson and Breitwisch 1992) and cardinals (Halkin and Linville 1999) both consume quantities of invertebrates and seeds that could contribute to a high protein diet. As ground foragers and insectivores, robins, mockingbirds, and cardinals are highly vulnerable to lead contamination. However, it appears that although the high protein diet of invertebrates may be a primary source of lead for birds, it may also offer a mitigating effect to the potential toxicity resulting in asymptomatic individuals.

Another explanation for asymptomatic birds in lead-contaminated sites is offered by a study conducted on captive herring gull chicks subjected to exercise sessions that required individuals to learn new behaviors (Burger and Gochfeld 2004). Lead-dosed chicks that were exercised daily performed better in regard to endurance and learning capability compared to both lead-dosed chicks and nondosed chicks that received no exercise regimen. Burger and Gochfeld (2004) concluded that exercise, a component of wild birds' life, mitigates the effects of lead exposure through one or multiple pathways: allowing birds to excrete more lead, sequester more lead in their bones, which results in less lead crossing the brain/blood barrier, or increasing appetite, thereby diluting the effect of lead. Many altricial nestlings, such as robins (McRae *et al*. 1993), move around in the nest, stretching their wings and jockeying for position at feedings. These movements may involve enough exercise to reduce the effects of lead poisoning. It is possible that the compromised physical condition we saw in catbird nestlings is due to a combination of diet and a lack of exercise while in the nest. Determining exercise rates of nestlings would require direct observation of the nest and nestlings.

Our single blood sample to examine the presence and influence of lead in breeding birds may not be sufficient for understanding the degree to which these animals are exposed to and impacted by environmental lead. Lead concentrations in blood have historically been considered the most reliable indicator of an animal's exposure to environmental lead (Pain 1989), but using these concentrations to predict the impact of lead poisoning can be misleading (Franson 1996). Sampling birds multiple times throughout the year might help isolate seasonal effects and perhaps provide additional insight into the long-term impacts of lead on passerine birds. Adverse environmental conditions, such as those birds would experience in winter, have been considered a contributing factor to the impact of lead poisoning by other researchers (Buerger *et al.* 1986). Given the extreme sensitivity of passerine birds to lead poisoning that some studies have reported (Beyer *et al*. 1988), a better understanding of the contamination threats and potential impacts facing passerines in urban environments should be fully investigated.

Lead contamination in urban environments is only one of many challenging factors that birds living in this land-use type encounter. Examples of other detrimental factors include other contaminants such as mercury, the replacement of native vegetation with exotic vegetation (Germaine *et al*. 1998), free-roaming cats as predators (Lepczyk *et al*. 2004), light (Gorenzel and Salmon 1995), and noise pollution (Fernandez-Juricic 2001) and pedestrian disturbance (Fernandez-Juricic and Telleria 2000). All of these factors are known to impact roosting, breeding, and foraging behavior of birds.

Given the increasing number of detrimental features associated with urban areas, it is possible that the urban environment serves as an ecological trap to birds, an environment that attracts birds to settle and breed but one that is actually low in quality and unable to sustain a population (Donovan and Thompson 2001; Kokko and Sutherland 2001; Schlaepfer *et al*. 2002). Birds in urban environments continue to select these habitats based on environmental cues that were reliable in more natural settings (Schlaepfer *et al*. 2002). Such traps are likely to occur in highly altered landscapes such as in urban environments (Battin 2004). As urbanization increases across the landscape of the United States, organisms such as birds must either adapt to the challenges of these environments or go extinct in these areas. Increasing our understanding of the challenges that animals face in the urban environment will be our only solution to reducing the impact that urbanization has on our wildlife populations.

*Acknowledgments.* This research was only possible thanks to the dedicated interest and help from the Neighborhood Nestwatch participants, some of whom provided vast amounts of information. Indispensable field assistants included Sara Campbell, Aviva Glaser, Joanna Hubbard, Michael Newhouse, and Sarah Rohrbach. Funding was provided by a Smithsonian Institution Graduate Fellowship, Mark Johnson of the U.S. Army Center of Health and Preventive Medicine, Toxicology Department and The Maryland Ornithological Society.

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