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Metal accumulation and performance of nestlings of passerine bird species at an urban brownfield site

Charles Hofer [a], Frank J. Gallagher [a], Claus Holzapfel [b,*]

[a] *Department of Ecology, Evolution and Natural Resources, Rutgers, the State University of New Jersey, 14 College Farm Rd., New Brunswick, NJ 08901-8551, USA*

[b] *Department of Biological Sciences, Rutgers, the State University of New Jersey, Newark, 195 University Ave., Newark, NJ 07102-1811, USA*

Nestlings of birds in an urban brownfield accumulated soil contaminants but did not show signs of reduced breeding success or growth.

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ABSTRACT

The use of passerine species as bioindicators of metal bioaccumulation is often underutilized when examining the wildlife habitat value of polluted sites. In this study we tested feathers of nestlings of two common bird species (house wren and American robin) for accumulation of Pb, Zn, As, Cr, Cu, Fe in comparison of a polluted, urban brownfield with a rural, unpolluted site. House wren nestlings at the study site accumulated significantly greater concentrations of all target metals except Zn. At the polluted site we found significant species differences of metal concentrations in feathers, with house wrens accumulating greater concentrations of Pb, Fe, and Zn but slightly lesser accumulations of Cr and Cu than American robins. Although house wren nestlings demonstrated significant accumulation of metals, these concentrations showed little effect on size metrics or fledge rates during the breeding season compared to nestlings from the control site.

1. Introduction

Elevated concentrations of metals in the environment are often a direct result of human activities and their presence poses a serious problem for the sustainability of important yet fragile urban ecosystems (Furness and Greenwood, 1993; Burger, 1993). Metals are released into terrestrial environments primarily through waste produced by industrial manufacturing, combustion products, or agricultural run-off (Burger, 1993). Once released into an environment, these inorganic pollutants do not break down and persist. These metals found in the soil either from point-source pollution or from deposition can be taken up by plants directly through root absorption, whereafter they may enter the food chain through herbivory (Hopkin, 1989). Once in the food chain, metals often bioaccumulate as they pass between trophic levels (van Straalen and Ernst, 1991). Organisms occupying higher trophic levels experience increased concentrations of metals, which can eventually lead to a suite of problems, both physically and neurologically (Burger, 1993). The potential hazards of fauna feeding on a polluted site is not well documented (Beyer et al., 2004) and while urban soils have garnered modest attention as functional ecosystems, studies tend to focus on identification of bioavailable contaminants (Hursthouse, 2001) rather than their effects on the ecosystem in question. However, using certain species as biological indicators is one commonly used method to quantify the abundance and bioavailability of metals and their ultimate effect on the ecosystem's food web (Furness and Greenwood, 1993).

Most birds occupy higher trophic levels where bioaccumulation of pollutants influences the health and fitness of individuals (Burger, 1993). In birds, the bioaccumulation of metals can lead to a variety of problems, both neurologically and physically. These problems include smaller clutch sizes, reduced fertility, hatching failure, nestling mortality (Burger, 1993), behavioral abnormalities of chicks (Burger and Gochfeld, 1998), reduced body mass and delayed fledge time (Jansenns et al., 2003). O'Flaherty (1998) showed that the uptake of non-essential metals such as lead (Pb) inhibits uptake of essential metals such as zinc (Zn) and copper (Cu). On a broader scale, these effects on the reproductive mechanisms of individual birds have the potential to greatly affect population dynamics, both in the short and long term (Burger, 1993). The impact may be of particular concern if the populations are in decline for other reasons, as is the case with many migratory species (Newton, 2004).

The use of avian populations as biological monitors is an effective method in quantifying the overall health of the ecosystem in question (Burger, 1996). In recent decades, metal accumulation in birds has garnered some attention. Most of these studies deal with raptors (Clark and Scheuhammer, 2002; Burger, 2001) and wetland

* Corresponding author. Tel.: +1 973 353 5385; fax: +1 973 353 5518.
E-mail address: holzapfe@andromeda.rutgers.edu (C. Holzapfel).

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species (Burger, 1995), while comparatively very few studies have looked at the effects of metals on passerine species in terrestrial ecosystems (Eens et al., 1998; Dauwe et al., 2000; Beyer et al., 2004). Likewise, many studies trace the effects of lead shot used for hunting and fishing (De Francisco et al., 2003) instead of the effects of point-source contaminants. Other studies have focused on heavily polluted sites focusing on pollution gradients near active smelters (Dauwe et al., 2000, 2005; Jansenns et al., 2003; Eens et al., 1998, etc.). Few, if any studies have focused on moderately-polluted sites that are abandoned or restored, yet such open spaces are critical for sustaining urban biodiversity in an increasingly crowded world. The viability of abandoned or restored open space can act as a crucial link in the often-times scattered network of green space found in urban areas that are suitable for both breeding grounds for resident avifauna as well as stopover habitat for sensitive migratory species. (McKinney, 2002; Chace and Walsh, 2006).

Using body or contour feathers is one popular method for examining heavy metals concentrations in birds (Burger, 1993; Dauwe et al., 2000; Furness and Greenwood, 1993). A feather grows from a small follicle that has a blood vessel attached to it (Gill, 2007). During growth feathers accumulate certain heavy metals in proportion to blood levels at the time of feather formation (Eens et al., 1998). Since heavy metals are deposited in feathers only during the period of feather growth when the blood supply is intact, the feather acts as a record of metal levels circulating in the bloodstream during the weeks of feather formation. Feathers reflect a long-term indication of exposure because of the several weeks it takes for feather to grow (Burger, 1993), as opposed to blood concentrations which reflect more of a short-term exposure to metals (Furness and Greenwood, 1993).

Feathers are not only accurate measure of metal concentrations in birds, but are relatively easy to collect and store. Collecting feathers is a non-invasive method and feathers can be stored properly with minimal effort and for prolonged periods until ready for analysis so long the storage facility is metal-free (Burger, 1993). Using feathers to analyze heavy metal accumulation can also be done over several seasons to assess changes in the environment (Burger, 1993) or at different times of the year to assess a change in metals accumulation after molt, and when adults' diet changes from primarily an insectivorous diet during the breeding season to increased granivory and fruigivory during the fall and winter months.

The primary goal of this study was to document whether polluted habitat contributes to reduced production among avian species breeding at a naturally-assembled urban brownfield site, Liberty State Park (LSP) in Jersey City, NJ. Alternatively, perhaps such brownfields are merely an "attractive nuisance" that may be detrimental to bird individuals and populations over time. The United States Environmental Protection Agency defines an attractive nuisance as an area or habitat that is attractive to wildlife and has, or has the potential to have, waste or contaminants on site that may be attractive to plants and animals (EPA, 1999). In turn, the attractive nuisance can affect wildlife by providing exposure to harmful pollutants, either directly or through bioaccumulation up through the food chain. As a result, exposure to these compromised habitats may result in bioaccumulation, where organisms occupying higher trophic levels (such as birds), accumulate pollutants in elevated concentrations that can lead to sub-lethal or lethal effects.

Because of its history of industrial use, the soil at LSP today is contaminated by an array of metals, most of which occur at concentrations above those considered ambient for New Jersey (Gallagher et al., 2008a,b, in press). Since much of these common brownfield contaminants are present in the soil, the metals remain active in the site's ecosystem. Recent studies conducted at LSP have shown that high levels of Zn, and to a lesser extent Pb, are accumulating in leaf and root tissue of trees and shrubs at the site (Gallagher et al., 2008b) where they become available to the greater food web. This evidence of the movement of metals around LSP from point-source soil contaminant to leaf tissue presents a cadre of questions concerning the site's potential role as an ecological "attractive nuisance."

In order to better understand the brownfield role as a viable habitat or attractive nuisance, we used breeding populations of house wrens (*Troglodytes aedon*) and American robins (*Turdus migratorus*) as biomonitors. We chose two common species as they represented the urban avifauna community well. House wrens are territorial during the breeding season and define a small territory immediately around their nest site (Johnson, 1998). Their feeding habits are consistent with many birds that feed their young by gleaning protein-rich invertebrates from shrub and understory layers (Johnson, 1998). A cavity-nesting species, providing house wrens with nest boxes allows for easy access and monitoring of the breeding population. American robins are a common species that are found in edge habitats and are representative of the thrush and thrush-like ground-feeding species (Sallabanks and James, 1999). Unlike House wrens, American robins often provide a mixed diet to their young, containing up to 30% plant material with the remaining being invertebrates (Sallabanks and James, 1999). Since American robins feed young with invertebrates taken from the ground or from within the soil itself, nestlings will not only consume prey items in direct contact with contaminated soil but also consume soil particles along with these prey items. Because of this, we hypothesized that American robins would have much higher metal concentrations than house wrens – a species feeding higher in the habitat structure and having little direct contact with polluted soil.

We also examined metal concentrations on a temporal scale. Some plants demonstrate seasonal fluxes in metal concentrations with very clear peaks during the summer months (Ross, 1994). Because of these seasonal peaks, invertebrate prey species captured and fed to nestlings later in the season will have longer exposure time to bioavailable pollutants and should display higher rates of bioaccumulation. We therefore hypothesized that fledglings from clutches later in the summer would have higher rates of metal concentrations in their feathers due to consuming these invertebrates. Our results provide an interspecific comparison of metal accumulation at a contaminated study site, as well as an intraspecific comparison of metal accumulation at the study site and an uncontaminated control site.

2. Material and methods

2.1. Study sites

Our study site was the approximately 100 ha brownfield wild area of Liberty State Park (LSP) located in Jersey City, NJ (40°42′16 N, 74°03′06 W). For much of the 20th-century, the site at LSP was used as a railyard and experienced heavy industrial use while acting as a major transportation hub for New York City. By the late 1960s the railyard was abandoned and since then the wild area of LSP has undergone a natural, unaided succession that resulted in a diverse mosaic of plant communities (Gallagher et al., 2008b). At first glance, today the site appears to be a fairly healthy urban ecosystem consisting of a rather eclectic collection of early- and mid-successional habitats, including shrublands (dominated by sumac *Rhus* spp.), pioneer hardwood forests dominated by cottonwood (*Populus* spp.) and birch (*Betula populifolia*), forested wetlands, emergent marsh, and more open forb dominated old-field communities and grasslands (Gallagher et al., 2008b). Because of this variety in habitat and the large area of contiguous open space in the middle of a dense urban environment, LSP supports a diverse avifauna community who use the site for nesting, foraging, or migratory stopover habitat. With 239 species recorded in the park over the years (US Army Corps of Engineers, 2004) there is little doubt that LSP is an ecologically significant green space supporting avian populations in the greater New York City area.

Feather samples collected from Hutcheson Memorial Forest (HMF) located in Somerset Co., NJ (40°30′10N, 74°33′18W) served as a control for the study.

Administered by Rutgers University, this historic forest consists of approximately 26 ha of old growth forest surrounded by more than 70 ha of new growth forest with a recorded history dating back to the early 18th century (Pickett, 1982). The land is some of the last uncut forest stands in New Jersey and is listed on the National Park Service Register of National Landmarks and experienced no known industrial use. Soil metal loads at the site are therefore assumed to be within the range considered normal for the urban piedmont area of New Jersey (Saunders, 2002). The area of HMF used in this study spanned two distinct habitat types, one dominated by red cedar (*Juniperus virginiana*) and multiflora rose (*Rosa multiflora*), while the other area was mixed hardwood buffers surrounding agricultural fields. Both study areas at HMF had previously-existing nest boxes providing nest locations for breeding populations of house wrens and other cavity-nesting species.

2.2. Field collection methods

Prior to the 2007 breeding season we constructed and mounted about 70 nest boxes around LSP to attract cavity-nesting birds. More than 50 nest boxes were already established at the HMF control site. Nest boxes at both sites were surveyed weekly beginning in mid-April 2007 and ending in early August. Once a breeding pair of house wrens established a full nest, we visited the nest box every 2–3 days until egg laying had commenced. After the clutch was complete we returned 12–14 days after the final egg day to determine hatch day. When at least half of the clutch had hatched, we established this day as D0. We then returned on day 11 of the nestling period (D11) to measure and band nestlings using US Geological Survey bands. On D11 we weighed each nestling to the nearest 0.01 g and measured wing chord and tarsus length to the nearest 0.01 mm. We collected biological fledge metric data from 72 house wren nestlings at LSP and from 26 nestlings at HMF. Nests were considered successful if more than one nestling fledged. During the banding session we also collected breast feather samples from house wren nestlings for metal analysis. Feather samples were stored in metal-free containers and refrigerated until sample preparation. We did not band adults of either species, house wren or American robin.

For American robins, we performed nest searches throughout much of the breeding season to locate active nests. Since American robin nests were found at different periods of the breeding cycle (egg to late nestling stage), collection of fledge metrics data was not as rigorous as that performed with the house wrens, and therefore not presented here. However, once active nests were identified, we monitored the nest until fledglings were large enough to collect feathers for metal analysis shortly before expected fledge date (approx. at D18). In total we collected feather samples from 42 American robin fledglings at the LSP only. All methods of data collection were performed under appropriate permits from the U.S. Fish and Wildlife Service, the New Jersey Department of Environmental Protection as well as Rutgers University guidelines. Because we were unable to collect breast feathers of American robins at the control site due to nest predation, no comparative study of this species has been made in this study.

At the polluted study site (LSP) we collected breast feather samples from 69 house wren nestlings representing 19 nests at the site (Several nestlings were too small to collect feather samples on D11). We collected 26 feather samples from nine nests that reached D11 at our control site (HMF) for comparison (three nestlings from the study site and seven nestlings from the control site were deemed too small on D11 to collect breast feather samples). We also collected feather samples from 42 American robin nestlings from 16 nests at the study site only.

2.3. Metal analysis

Feathers were stored in metal-free containers and refrigerated until samples preparation and analysis was performed at the Rutgers Inorganic Analytical Lab at the Institute for Marine and Coastal Sciences, New Brunswick, NJ. Dry weight of feather samples were determined to the nearest 0.001 mg. Feathers were then washed three times in deionized water alternated with acetone to remove external contamination and later air-dried in metal-free 2 mL teflon vials (Gochfield et al., 1996). Feathers were then digested in a solution of 70% HNO_3 and 30% H_2O_2 (Burger, 2001). All metals – Pb, Zn, Cr, Cu, Fe, and As – were analyzed using a high-resolution sector field inductively couple mass spectrometer (ICP-MS) and all concentrations measured in parts per billion (μg/kg; ppb) using dry weight. Detection limits were <1 ppt for As, 10 ppq for Cr, 10 ppq for Pb, 500 ppq for Zn, and 100 ppq for Fe and Cu. Samples were analyzed in batches with known standards, calibration curve, and spiked samples.

2.4. Statistical analysis

We used SAS statistical software (Proc GLM; version 8.2) and SPSS (version 17) to perform all statistical analysis. We performed linear mixed model with clutches nested within site or species (fixed effects) to compare growth metrics data and feather-metal contamination between house wrens at the two sites and between the two species at the polluted site. We calculated coefficients of variation to assess the intra- and inter-clutch variation of metal contamination levels. We performed simple linear regression (PROC REG) between clutch means and nestling dates to assess the temporal variation of metal concentrations over the course of the breeding season. Raw data of metal concentrations by element were log transformed to standardize the data sets. The level of significance was set at $\propto = 0.05$.

3. Results

We monitored 21 house wren nests at the study site, LSP, and 45 nests at the control site (HMF). In the test site (LSP) 19 nests were considered successful (fledged $\geq$ 1 nestling) out of the 21, while only one nest was lost to predation and another to abandonment. In contrast, at HMF we found only nine successful nests out of 45 nests that contained at least one egg. Thirty-two nests were lost to predation while another four nests were lost to abandonment. Thus house wrens in the urban study site were much more successful (90.4%) than those in the more rural control site (20%). This difference is likely attributed to the higher predator density found at the control site, a more rural habitat home to more abundant raccoons, snakes, short-tailed weasels, and other common nest predators. Indeed, trail camera purveyance revealed in one case a northern raccoon (*Procyon lotor*), as the predator.

All measured metals (Pb, Cr, Fe, Cu, Zn) and As were found in detectable concentrations in house wren nestling breast feathers at both the study site and control site. All of these contaminants in nestling feathers, with the exception of Zn, at the study site were found to be significantly higher than those at the control site (Fig. 1. Pb: $F_{28} = 119.5$, $p < 0.001$; Cr: $F_{27} = 26.9$, $p < 0.001$; Fe: $F_{28} = 144.8$, $p < 0.001$; Cu: $F_{28} = 98.2$, $p = 0.006$, Zn: $F_{28} = 3.7$, $p = 0.0591$; As: $F_{27} = 68.0$, $p < 0.001$). Mean Pb levels at the study site were nearly seven times higher than those found at the control site, Cr levels five times, Fe more than 6 times, while mean As concentrations at

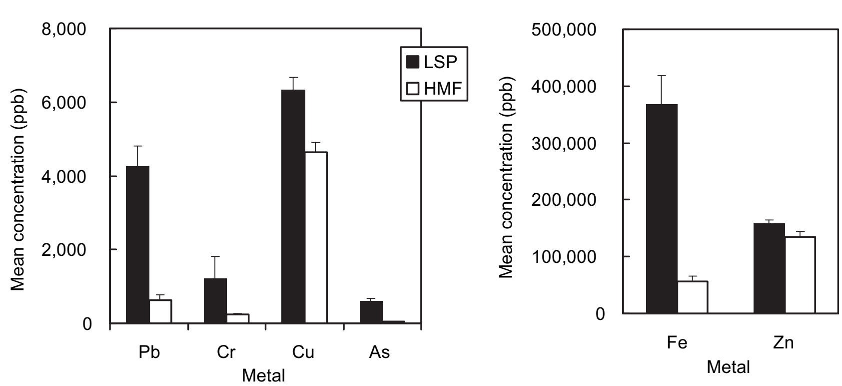

Fig. 1. Comparison of intraspecific metal concentrations in house wren nestling feathers between the two sites. Shown are dry-weight means in parts per billion (ppb) with 1 SE. For statistical significance of differences between sites see text.

the study site were 14 times greater than concentrations found in nestling feathers at the control site. Mean concentrations of Cu and Zn at the study site were only slightly higher than those found at the control site.

Differences between American robins and house wrens within the study sites (LSP) were less pronounced than those found for house wrens between study and controls sites (LSP vs. HMF) yet species differences for most of the analyzed metals were statistically different (Fig. 2. Pb: $F_{32} = 26.9$, $p < 0.001$; Cr: $F_{32} = 20.9$, $p < 0.001$; Fe: $F_{32} = 145.2$, $p < 0.001$; Cu: $F_{32} = 11.2$, $p = 0.0013$, Zn: $F_{32} = 5.4$, $p = 0.023$; As: $F_{31,}$ $p = 0.04$, $p < 0.838$). House wren nestlings at the study site accumulated much greater concentrations of Pb (3 times as much) and Fe (almost 4 times) than nestlings of American robins. In contrast American robins acquired slightly higher concentrations of Cr and Cu (double resp. 1.2 times) than house wrens. Other species differences were either borderline significant (Zn) or not at all (As).

Intra- and inter-clutch variation among house wrens differed between the two sites (Table 1). For the six metals, we found considerably less variation among nestlings in a clutch at the study site than at the control site. Only Cr concentrations at the study displayed slightly larger intra-clutch variation than those concentrations found at the control site. In stark contrast the amount of variation between clutches at the control site was greater, often extremely so, for all metal concentrations than that at the study site.

Linear regression between nestling age, expressed as days since hatching, and feather concentration of metals did not reveal significant relationships (Pb: LSP $r^2 = 0.015$, HMF $r^2 = 0.010$; Zn: LSP $r^2 = 0.009$, HMF $r^2 = 0.004$; Cr: LSP $r^2 = 0.01$, HMF $r^2 = 0.357$; As: LSP $r^2 = 0.002$, HMF $r^2 = 0.216$; all p values <0.05), indicating that the concentration did not change with the age of nestlings.

Fledge metric data recorded on day 11 (D11) of the nestling period showed no significant differences (tarsus, $F_{37} = 2.36$, $p = 0.12$; wing chord, $F_{32} = 2.21$, $p = 0.14$; weight, $F_{31} = 23.61$, $p = 4.28$) between house wren nestlings at the two sites for weight, wing chord length, or tarsus length (Fig. 3). We found no significant differences in fledge metric parameters (weight, wing chord, tarsus length) between the two sites nor any significant difference in fledge date among house wrens at the two sites.

Linear regression analysis between concentrations of Zn or Pb with nestling weights failed to reveal a statistical relationship. Zn has been shown to be translocating into root/leaf tissue in the area (Zn; Gallagher et al., 2008b), and Pb is known to inhibit growth in higher concentrations. Among house wren nestlings at the study site we found no significant relationships (Pb/wt: $r^2 = 0.001$; Pb/tarsus: $r^2 = 0.027$; Pb/wing chord: $r^2 = 0.009$; Zn/wt: $r^2 = 0.007$; Zn/tarsus: $r^2 = 0.03$; Zn/wing chord: $r^2 = 0.002$; all p values <0.05) between the level of elevated metal concentrations and various parameters of growth. Because we did not collect data on American robin nestlings at the control site, we did not perform a comparative study of this species between the study and control sites.

Table 1
Inter- and intra-clutch coefficient of variance among house wrens at the control (HMF) and study site (LSP).

	Intra-clutch variation		Inter-clutch variation	
	HMF	LSP	HMF	LSP
Pb	32.88	244.37	3897.70	671.15
Cr	82.66	74.51	1094.99	277.38
Fe	32.73	12 143.41	345 392.03	60 206.48
Cu	58.15	1124.70	6365.47	4786.20
Zn	56.30	28 210.81	155 901.53	137 398.31
As	36.20	114.79	561.59	47.49

4. Discussion

The main objective of our study was to compare level of metal contamination and nestling performance of house wren populations between a relative polluted and a less polluted habitat. While metal concentrations were significantly higher in individual house wrens from the contaminated study site compared with the control site, fledge metrics and fledge dates were nearly identical between the two sites. (Overall nest success between the two sites for house wrens could not be adequately addressed in this study due to the high rate of nest predation at the control site.) In addition, we found no correlation between elevated metal concentrations and fledge metrics in house wren nestlings suggesting that elevated contamination did not directly affect nestling size and development. The results of our study indicate that there is no significant relationship between elevated metals concentration in nestlings and overall nestling growth performance.

Both Zn and Pb contamination in the soil at Liberty State Park is high and previous studies have shown that these metals are translocating to leaf and root tissues of dominant plants at the site (Gallagher et al., 2008a,b, in press). Zn has been shown to accumulate within the leaf tissue of both *Betula populifolia* and *Populus deltoides* at concentrations that exceed those found in the soil (Gallagher et al., 2008b). The metal of most concern in this study is Pb because of its expected and documented adverse effects on physical and neurological development in young birds (Jansenns et al., 2003; Burger, 1993; Burger and Gochfeld, 1998), as well as its documented effect on reducing overall survival rate (Burger, 1995). While our results clearly document elevated metal concentrations in higher trophic levels that were not unexpected, one

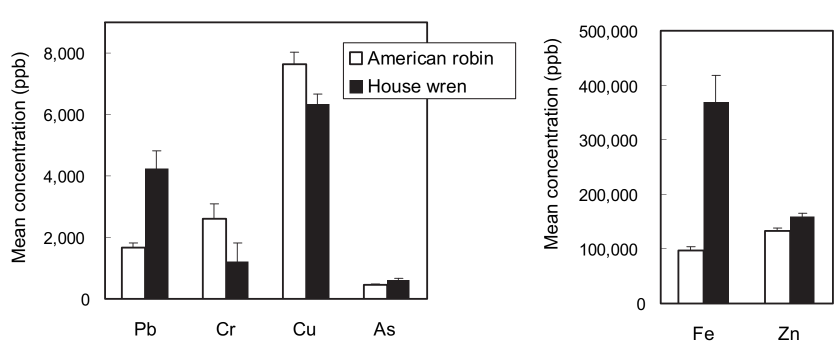

Fig. 2. Interspecific differences between American robin and house wren in mean metal concentrations (shown with 1 SE) found in nestling feathers at the polluted study site. For statistical significance of differences between species see text.

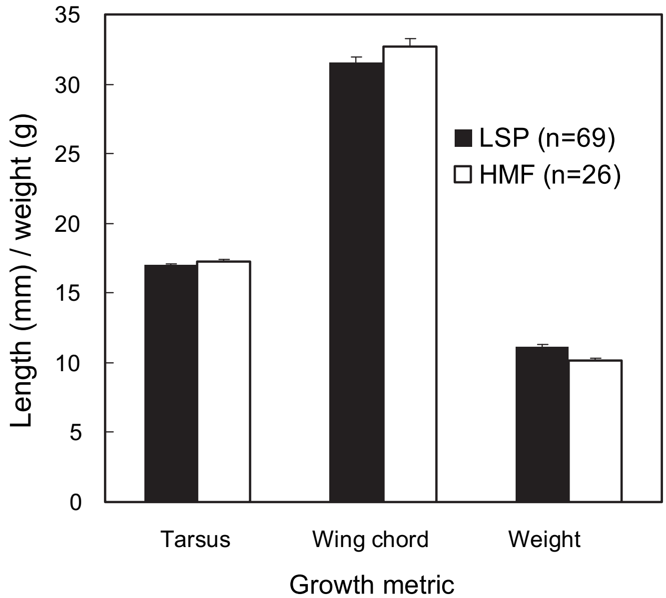

Fig. 3. Growth metrics data (tarsus length, wing chord length, and weight) of nestling house wrens collected at both sites (LSP = Liberty State Park, polluted study site; HMF = Hutchinson Memorial Forest, control site). Shown are means with 1 SE. No significant statistical differences were found between sites (see text).

aspect that needs further investigation is the effect of absolute levels of contaminants themselves. For instance, studies have indicated that Pb levels exceeding 4000 ppb will begin to manifest itself in adverse effects (Eisler, 1988). Our results from LSP appear to be near this clinical level. Our biological data, however, indicate that elevated Pb concentrations in the nestlings are having no adverse effects during the nestling stage and juvenile house wrens are fledging successfully from nests at the contaminated study site. The observation of banded house wrens in the year following the study (2008) even suggest that fledglings were able to complete migration and returned to the site, therefore demonstrating no detectable long-term negative effects.

Previous studies on elevated metal levels in birds have produced varied results. Dauwe et al. (2000) performed a comparative study examining great and blue tits (*Parus major* and *Cyanistes caeruleus*) at both a polluted and non-polluted site near Antwerp, Belgium. At their polluted site, the authors found mean Pb levels in nestling feathers of 4830 ± 1080 ppb and 3680 ± 1110 ppb, respectively, for both species of birds – mean concentration levels very similar to our data. Meanwhile Tsipoura et al. (2008) found very different Pb concentration levels in feathers of two species of wetland passerine birds nesting in polluted marshland in New Jersey, red-winged blackbirds (*Agelaius phoeniceus*) and marsh wrens (*Cistothorus palustris*). Blackbirds showed Pb concentrations in nestling feathers of 1080 ± 142 ppb, while marsh wrens resulted in 432 ± 73.6 ppb – both results significantly lower than ours. While study methods were similar in both studies to our own, one obvious difference is the type of habitat in which the study took place. The study by Tsipoura et al. (2008) that documented lower concentrations of metals was conducted in the New Jersey Meadowlands, a sprawling wetland dominated by common reed (*Phragmites australis*), while the study by Dauwe et al. (2005) was conducted in more comparable habitat to ours, upland forest surrounded by a dense urban environment.

Burger (1993) reviewed using avian feathers as bioindicators and averaged metal concentrations in feathers of 20 species from about 25 sites around the world. Data show that the metal concentrations of Pb, Cr, Ar, and Cu found in nestling house wrens at LSP are still lower than mean concentrations from a suite of species gathered from a large pool of study sites. Only concentrations of Zn and Fe were higher in house wrens at LSP than those species found in Burger's review.

A comparison between American robins and house wrens at the study site showed clear species-dependent differences in concentrations of metals. At this point it is not clear whether these differences are attributed to species-specific metabolic pathways or are more reflective of varying foraging behavior and diets. Comparing our results to other studies using similar methods also indicate a strong interspecific variance among metal concentrations in feathers (Tsipoura et al., 2008; Dauwe et al., 2005). We found that the ground-feeding species (American robin) carried much lower metal concentrations than the understory-feeding species (house wren). Metals concentrations that differed between species (Pb, Fe, and Zn) were each at least three times higher in house wrens than in American robins. We initially hypothesized that ground-feeding species such as robins that capture prey directly from the soil where metal loads are highest would have higher feather-metal concentration relative to understory-feeding species, such as house wrens. Not only are American robins' prey in direct contact with the soil, but actual particles of the soil would be fed directly to their young, presumably resulting in higher metal concentrations in the nestlings. This present interspecific difference in feather-metal concentrations may lead to other important questions regarding a brownfield's food web and how metals bioaccumulate. For instance, American robins may be feeding their young with prey species from lower trophic levels, such as earthworms. House wrens on the other hand may be feeding their young with prey species occupying higher trophic levels, such as spiders and predatory long-horned grasshoppers – species that likely will have already accumulated metals through biomagnification along the food chain. A second alternative explanation of the lower concentrations in American robins is that this species often provides a mixed diet to their young, containing up to 30% regurgitated plant material (Sallabanks and James, 1999), unlike house wrens which will feed their young almost exclusively invertebrates. As a third alternative explanation it is possible that American robins forage over larger territories that might include less polluted areas in the surrounding parkland (Sallabanks and James, 1999), an area rich in turf lawns that have been remediated in the past. An increased foraging territory, much of which contains restored and remediated habitats combined with regular prey species that feed lower on the food chain, could easily result prey materials with considerably less accumulated metals fed to nestlings.

The fact that metal concentration in feathers of nestlings did not increase with nestling age suggests that there was no increased rate of metal accumulation in house wren nestlings as the breeding season progressed. The variation of metal concentration within clutches remained similar as breeding season commenced (early May) to when it ended in early August.

Even though metal concentrations at LSP were higher than those found at the control site (HMF), we found no correlation between elevated metal concentrations and fledge metrics. This suggests that elevated metal concentrations in our study are having little to no effect on nestling production and thereby on fecundity.

We also found that overall inter-clutch variation of metal concentrations in feathers was much higher in the control site than in the polluted site. In addition we found the opposite trend in intra-clutch variation among nestlings where the study site demonstrated greater variation within clutches compared with the control site. This pattern appears to be in contrast to a study on a passerine species in Belgium that demonstrated marked variation within clutches especially in polluted sites (Janssens et al., 2002). One explanation for these variations that may warrant greater investigation is the influence of exogenous contamination within clutches. Other studies have identified variation of metal concentrations depending on the length of exposure of certain feathers (Jaspers et al., 2004). However, this study investigated variation among tail feathers, including the initially removed outermost tail feather and subsequently the regrown tail feather that was collected for analysis approximately 40 days later. In our study we used only body contour feathers, all of which were grown just days from one another during the nestling stage. Considering 20–30 body contour feathers comprised each sample for each individual nestling these samples represent average metal concentrations per individual and should not reflect metal variation between individual feathers.

One possibility that may in fact influence intra-clutch variation and warrants further investigation is hatch order. Like most cavity-nesting passerines, house wrens hatch and reach fledge stage in little over two weeks, a remarkable growth spurt. However, it may take up to three days for an entire clutch (4–6 eggs typically) to hatch. In this study, like others, we collected feathers for analysis on one day (D11), as long as the majority of eggs in a clutch had hatched. Therefore, if one individual hatched on D0 and another hatched on D2, the first individual would have 18% more time for exposure to metal contaminated food items by D11 when we collected feathers for analysis. This difference in hatch day may play a significant role during the growth period when nestlings are fed contaminated food.

This contrasting pattern of intra- and inter-clutch variation could prove useful in future studies of bioaccumulation at polluted sites. Our results showed that intra-clutch variation of metal concentration was considerable at the polluted study site. Previous studies by Gallagher et al. (2008a,b) found distinct areas of elevated metal loads in the soil at the study site. When compared spatially to the location of our nest sites, however we found no direct correlation between nest site and soil metal loads. This suggests that either adult house wrens gathered food for their young outside of their territorial range as described by Johnson (1998), or that the type and abundance of prey at a micro scale may be more significant than the local soil metal load. In either case further examination of soil metal loads and prey selectivity is needed to fully understand the translocation potential.

One final consideration of note is the interspecific differences of metal concentrations in feathers. Any literature search will clearly demonstrate that metal accumulation in feathers between species is highly variable (USEPA, 1998; Burger and Gochfeld, 1998; Janssens et al., 2003; Llacuna et al., 2004; and Tsipoura et al., 2008), and the comparison of metal concentrations between species will lead to erroneous conclusions of metal concentrations at any one site with any one species. Therefore this study should be regarded as a measure of using common cavity-nesting passerines as bioindicators of heavy metal accumulation. The ease of constructing nest boxes to attract common cavity nesters to be used as bioindicators can be a highly useful tool when investigating the role metal accumulation plays in a food web. However, study design is paramount as conclusive results will appear only when a clean control site is utilized. Since metal concentration in feathers is so highly variable between species, the use of one species paired with a control population is the only way to fully understand the rate of metal accumulation at any one study site.

5. Conclusion

The role of a brownfield site as an attractive nuisance still needs much investigating. While we found significant accumulation of metals in feathers of birds occupying high trophic levels, the concentrations of metals showed no significant effects on fledge metrics or nest productivity at the study site. While the effects of these concentration for birds at post-fledging stages still need investigation at the site, our current study suggests that the brownfield site can act as viable habitat for communities of urban birds. Our analysis of metal concentrations in nestling feather provides a baseline for future studies to better understand how metals are bioaccumulating through the food web and identify the routes of such accumulation at the study site.

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