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Heavy metal bioaccumulation in two passerines with differing migration strategies

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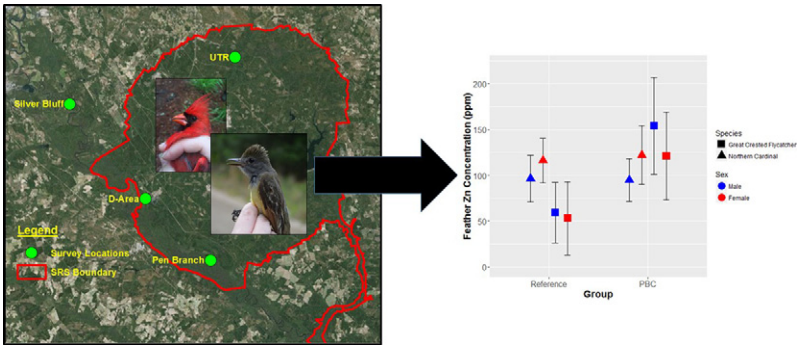
HIGHLIGHTS

- Heavy metal concentrations in songbirds indicate environmental conditions.
- Non-lethal tissue samples were obtained from two passerine species.
- Flycatchers are bioaccumulating higher concentrations some metals during migration.
- Sex-specific concentration differences were not present.
- Analyzed metal concentrations for were not at levels of concern.

GRAPHICAL ABSTRACT



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ABSTRACT

Various anthropogenic activities have resulted in concentration of heavy metals and contamination of surrounding environments. Historically, heavy metal contamination at the Savannah River Site (SRS) in South Carolina has resulted from accidental releases of stored waste generated from nuclear weapon production in the early 1950s. Songbirds inhabiting and using resources from these areas have the potential to bioaccumulate metals but there is limited information on metal concentration levels in areas suspected of contamination as well as uncontaminated sites. Nonlethal tissues samples from avian blood and feathers provide a reliable approach for determining the bioavailability of these pollutants (As, Cd, Cr, Cu, Hg, Ni, Pb, Se, and Zn). The objectives of this study were to survey terrestrial heavy metal contamination at the SRS on potentially bioavailable contaminated (PBC) sites through blood and feather samples from resident Northern Cardinals (*Cardinalis cardinalis*) and migratory Great Crested Flycatchers (*Myiarchus crinitus*) and quantify sex-specific concentrations within species. Samples were collected in April to June of 2016. Cardinals had lower blood concentrations of Hg ($\beta = -0.17$, 85% CL $= -0.26, -0.09$) and Se ($\beta = -0.33$, 85% CL $= -0.50, -0.16$) than flycatchers. Cr feather concentrations were less in cardinals ($\beta = -1.46$, 85% CL $= -2.44, -0.49$) and all feathers of both species from reference locations had significantly less Zn ($\beta = -67.92$, 85% CL $= -128.71, -7.14$). Results indicate flycatchers were exposed to differing heavy metal levels during feather formation on their wintering grounds as compared to their recent exposure (through bloods samples) on their breeding grounds. Sex of individuals did not have a significant impact on bioaccumulation in either species. Overall, metal concentration levels in both species indicate minimal

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risk for acute toxicity; however, there is limited research on wild passerine populations with similar concentration levels. Therefore, further research on reproductive success of these birds should be explored.

1. Introduction

Since the environmental revolution of the 1970s, cleanup efforts from anthropogenic environmental pollutants have been conducted nationwide, yet decades later residual repercussions to wildlife are still widespread. Heavy metal contamination results from improper disposal or release of specific chemical and nuclear byproducts. These metals can include essential (e.g., Se, Zn, and Cu) and non-essential elements (e.g., Hg, Pb, Cd, Cr, As, and Ni) with some exhibiting high toxicity at low concentrations. Biomonitoring of organisms inhabiting potentially polluted areas yields an assessment of overall ecosystem health (Burger and Gochfeld, 1996). Many of the current biomonitoring efforts rely on samples taken from aquatic organisms related to possible human consumption risks. However, many terrestrial organisms also consume resources from contaminated aquatic ecosystems exposing them to such pollutants.

Higher trophic level organisms, such as piscivorous birds and raptors, have been extensively studied and monitored for heavy metals (Battaglia et al., 2005; Lodenius and Solonen, 2013; Movalli, 2000; Solonen and Lodenius, 1990); however, heavy metal contamination from an aquatic source can bioaccumulate to levels sufficient to negatively affect organisms at a lower trophic level (Edwards et al., 2014). Jackson et al. (2011) indicated terrestrial songbird reproductive success was reduced in the terrestrial environment surrounding rivers contaminated by heavy metals. Chronic exposure to certain heavy metals can cause physiological abnormalities (Scheuhammer, 1987), reducing reproductive success (Jackson et al., 2011) which could lead to local population level changes. Songbirds are low- to mid- trophic level organisms and have the ability to accumulate heavy metals through air, food, or water resources but most often through dietary intake (Burger and Gochfeld, 2002). Assessing their exposure to environmental pollution can be indicative of overall ecosystem health from a ecotoxicological standpoint (Abbasi et al., 2015; Brait and Antoniosi-Filho, 2011; Burger and Gochfeld, 2000; Scheifler et al., 2006) and provide information of heavy metals in the environment of which they reside in (Dauwe et al., 2002a, b; Eens et al., 1999; Furness and Greenwood, 1993; Goede and de Bruin, 1984; Lodenius and Solonen, 2013).

Once inside the body, metals accumulate in internal tissues, are excreted in feces, or are deposited in feathers (Burger, 1993). Metal concentrations in feathers can provide information on body burdens at time of molt and feather growth (Dauwe et al., 2000), especially for mercury (Bearhop et al., 2000), but relationships between feather concentrations and body burdens vary greatly among metals (Beyer and Meador, 2011). Metal levels in blood provide an indication of recent short-term dietary exposure (Furness and Greenwood, 1993) before being excreted or accumulated into internal tissues. Both blood and feather concentrations supply dietary information on site-specific uptake of metals such as methylmercury (Evers et al., 2005). Mercury concentrations in blood and feather tissues are generally strongly correlated (Ackerman et al., 2011). Although it has been suggested that all other metal concentrations in feathers are related to external (atmospheric deposition) contamination (Dauwe et al., 2003), this suggestion has been questioned (Beyer and Meador, 2011; Burger, 1993).

Feathers obtained from migratory species indicate exposure to contaminants throughout the year as these birds molt and regrow feathers between breeding and wintering grounds (Braune et al., 2002). Concentrations in resident birds are likely sourced locally and can be used to identify contaminated areas (Burger, 1993). With very large home ranges, migrants are better adapted to handling toxic compounds (Rainio et al., 2012). Migratory birds have a higher basal metabolic rate (BMR) than non-migratory birds (Jetz et al., 2008) which would suggest that heavy metals are absorbed more rapidly into the body in migrants resulting in lower blood concentrations (Cai and Calisi, 2016) although this hypothesis has not been explored thoroughly.

Biomonitoring studies on songbirds rarely report the sex of individuals sampled though sex-specific differences in physiology and behavior could affect heavy metal concentrations (Deng et al., 2007; Robinson et al., 2012). For example, foraging behavior of passerines often differs among sexes during the breeding season based on their space use (Holmes, 1986) which, generally speaking, means that males forage at higher heights near song perches while females forage lower at nest heights. This contrast between sexes can explain the relationship of differing feeding habitats and bioaccumulation/detoxification rates (Fossi et al., 1995). Also, females have been shown to deposit trace elements into eggs and eggshells providing an alternative pathway of excretion compared to males during the breeding season (Burger, 2007) leading to decreased body burden. However, female to egg metal deposition rates are not consistent among species (Robinson et al., 2012).

The objectives of this study were to 1) determine the geographic extent of heavy metal contamination in songbirds in association with potentially bioavailable contaminated (PBC) sites on the U.S. Department of Energy's Savannah River Site (SRS), 2) evaluate the congruence of two non-lethal sampling techniques, 3) compare location-specific metal concentrations between a migratory songbird, Great Crested Flycatcher (*Myiarchus crinitus*) and a resident songbird, Northern Cardinal (*Cardinalis cardinalis*), and 4) assess the differences in metal concentrations between sexes. We hypothesize that feather concentrations from Great Crested Flycatchers will be similar across sites as these feathers were grown prior to reaching the SRS while Northern Cardinals will have higher levels in their feathers at PBC locations because they reside there year round (hereafter, migratory exposure hypothesis). We also hypothesize that both species with individuals breeding in close proximity to PBC areas will have higher concentration levels in their blood (and feathers for Northern Cardinals) compared to birds breeding in reference locations (hereafter, close proximity hypothesis).

2. Methods

2.1. Study species

Northern Cardinals (hereafter, cardinals) are an example of a year-round omnivorous resident species in eastern North America that generally spends its entire adult life within 2.3 km of its breeding territory (Halkin and Linville, 1999) which makes them an ideal species for biomonitoring of metals in a specific geographic location over a greater period of time compared to a migratory species. Great Crested Flycatchers (hereafter, flycatchers) migrate to our study area to breed from April to August and maintain a higher trophic level than cardinals as the majority (93%) of their diet consists of invertebrates (Miller and Lanyon, 2014). Cardinals complete a full molt from October–November while flycatchers body molt is poorly understood but likely takes place on or near wintering grounds in Central America from March–May (Dickey and van Rossem, 1938; Miller and Lanyon, 2014).

2.2. Study area

The study was conducted on the U.S. Department of Energy's Savannah River Site (SRS) south of Aiken, South Carolina and the Silver Bluff Audubon Center property west of Jackson, South Carolina. The SRS is