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Spatial variation of mercury bioaccumulation in bats of Canada linked to atmospheric mercury deposition

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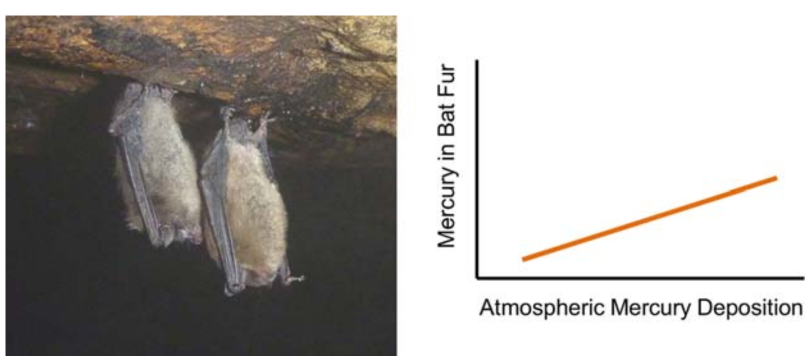
HIGHLIGHTS

- Mercury in bat fur was related to concentrations in brain, liver, and kidney.
- Bat species differed in their fur mercury concentrations.
- Fur mercury was higher in adult than juvenile bats, but not related to sex.
- Mercury in fur of adult little brown bats was higher in eastern Canada.
- Atmospheric deposition explained geographic variation of mercury in bats.

GRAPHICAL ABSTRACT



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ABSTRACT

Wildlife are exposed to neurotoxic mercury at locations distant from anthropogenic emission sources because of long-range atmospheric transport of this metal. In this study, mercury bioaccumulation in insectivorous bat species (Mammalia: Chiroptera) was investigated on a broad geographic scale in Canada. Fur was analyzed ($n = 1178$) for total mercury from 43 locations spanning 20° latitude and 77° longitude. Total mercury and methylmercury concentrations in fur were positively correlated with concentrations in internal tissues (brain, liver, kidney) for a small subset ($n = 21$) of little brown bats (*Myotis lucifugus*) and big brown bats (*Eptesicus fuscus*), validating the use of fur to indicate internal mercury exposure. Brain methylmercury concentrations were approximately 10% of total mercury concentrations in fur. Three bat species were mainly collected (little brown bats, big brown bats, and northern long-eared bats [*M. septentrionalis*]), with little brown bats having lower total mercury concentrations in their fur than the other two species at sites where both species were sampled. On average, juvenile bats had lower total mercury concentrations than adults but no differences were found between males and females of a species. Combining our dataset with previously published data for eastern Canada, median total mercury concentrations in fur of little brown bats ranged from 0.88–12.78 μg/g among 11 provinces and territories. Highest concentrations were found in eastern Canada where bats are most endangered from introduced disease. Model estimates of atmospheric mercury deposition indicated that eastern Canada was exposed to greater mercury deposition than central and western sites. Further, mean total mercury concentrations in fur of adult little brown bats were positively correlated with site-specific estimates of atmospheric mercury deposition. This study provides the largest geographic coverage of mercury measurements in bats to date and indicates that atmospheric mercury deposition is important in determining spatial patterns of mercury accumulation in a mammalian species.

1. Introduction

Mercury is a contaminant that can travel long distances through the atmosphere and be deposited onto terrestrial and aquatic ecosystems far from major emission sources (Fitzgerald et al., 1998; Lamborg et al., 2002; Lindberg et al., 2007). Human activities, particularly coal combustion, have released large quantities of mercury into the atmosphere, resulting in an estimated 3.2 fold increase in the atmospheric mercury pool since 1850 (Streets et al., 2017). Following deposition, inorganic mercury is transformed (principally by microbes) into methylmercury, which bioaccumulates in organisms, biomagnifies through food chains, and is toxic at elevated levels of exposure (Scheuhammer et al., 2012). Recognizing the global nature of mercury pollution and the need for international cooperation, the United Nations Environment (UNE) led the establishment of the Minamata Convention on Mercury (entered into force in August 2017) to protect human and environmental health through the reduction of global anthropogenic mercury emissions.

The mercury cycle is complex, and many processes contribute to its transport, chemical transformations, and bioaccumulation in the environment (Lehnherr, 2014; Travnikov et al., 2017). Experimental evidence clearly demonstrates that increased mercury loading to aquatic ecosystems results in greater bioaccumulation in food chains (Harris et al., 2007; Orihel et al., 2006), and large-scale spatial variation in mercury concentrations of fish and aquatic invertebrates is related to atmospheric mercury deposition in North America (Hammerschmidt and Fitzgerald, 2005a; Hammerschmidt and Fitzgerald, 2005b). However, ecosystems also vary in their sensitivity to inorganic mercury loading, and local biogeochemical conditions that control methylmercury production and bioavailability can play an important role in determining the extent of methylmercury contamination in biota (Eagles-Smith et al., 2016; Munthe et al., 2007).

Recent studies indicate that bats (Mammalia: Chiroptera) in eastern North America can contain elevated levels of methylmercury in their tissues (Little et al., 2015a; Little et al., 2015b; Yates et al., 2014). Greater mercury exposure has been found for bats collected close to contaminated sites with known mercury emissions (Nam et al., 2012; Wada et al., 2010; Yates et al., 2014), and close to remote acidic lakes in which higher methylmercury production has been observed (Little et al., 2015b). Limited information is available, however, on the geographic scope of elevated mercury levels in North American bats and more broadly on the toxicological risks to bat health (Zukal et al., 2015), although methylmercury is a known neurotoxin that can impair the reproduction, growth, and health of wildlife at elevated environmental exposure (Fuchsman et al., 2017; Scheuhammer et al., 2015). Nam et al. (2012) showed that little brown bats (*Myotis lucifugus*) at a contaminated site (in the eastern USA) had neurochemical biomarker responses associated with mercury concentrations that exceeded toxicity thresholds for other mammalian species. Big brown bats (*Eptesicus fuscus*) collected at the same contaminated site also had elevated mercury concentrations, but showed no adrenocortical response compared to bats from a reference area (Wada et al., 2010). Vampire bats in Central America (Belize) with higher total mercury levels were found to have impaired immune function (Becker et al., 2017). Several species of bats have been designated as endangered or threatened by federal authorities in Canada (ECCC, 2017) and the United States (U.S. Fish and Wildlife Service, 2017), including little brown bats and northern long-eared bats (*Myotis septentrionalis*) which have suffered large population declines from white-nose syndrome in eastern North America (Ingersoll et al., 2016; Vanderwolf et al., 2016). More information is needed to characterize exposure of bats because of the potential for mercury to be an environmental stressor in addition to introduced disease, habitat loss, pesticide contamination, and wind turbine fatalities (Jones et al., 2009).

Mammals, including bats, are exposed to methylmercury primarily through their diet (Wiener et al., 2003). Insectivorous bats consume a variety terrestrial and aquatic species, most of which are captured insects in flight. For example, diet characterization using molecular tools has shown that the eastern red bat (*Lasiurus borealis*) in southern Ontario (Canada) consumed 127 species of insects, mostly terrestrial prey in the lepidoptera order (Clare et al., 2009). Similarly, little brown bats in southern Ontario were found to consume 61 species of insect prey (mostly from aquatic environments) and five species of arachnids (Clare et al., 2011). The consumption of insects with aquatic life stages or spiders that prey on aquatic insects connects bats to aquatic food chains and can enhance their mercury bioaccumulation (Becker et al., 2018). Aerial insectivores have only recently begun to receive more attention in investigations of mercury bioaccumulation (Cristol et al., 2008; Jackson et al., 2011b; Rimmer et al., 2005; Whitney and Cristol, 2018), perhaps in part because they feed at a lower trophic position than predators found at the top of food chains and were assumed to have lower exposure as a result. There is increasing recognition that