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Review

Bats as bioindicators of heavy metal pollution: history and prospect

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ABSTRACT

Bats today face a number of important threats, including that of heavy metal exposure. While the numerous adverse health effects of heavy metals have long been documented, exposure to heavy metal pollution continues, and is even increasing in some parts of the world. The eleven heavy metal elements of highest wildlife protection concern are arsenic, cadmium, cobalt, chromium, copper, mercury, manganese, nickel, lead, tin and thallium. This paper reviews 52 studies reporting on heavy metal concentrations in bats, their organs and guano, and aims to provide an overview of heavy metal research on wild bat populations, and particularly its temporal, geographic, methodological and biological aspects.

The published data are biased both temporally and spatially, with the greatest number of articles published over the last decade. While most studies reporting on heavy metal contamination have come from North America and Europe, these are generally restricted to one or two reports per country/state. General trend analysis of heavy metal content in bats is not possible due to variation in the data and the analysis of stratigraphically dated guano deposits provides inconsistent results. Moreover, variability in heavy metal content observed in bat bodies is influenced by background levels and a direct comparison of results between geographically distant areas is, therefore problematic. Comparison of contaminated and reference localities at a regional scale is useful and is regularly used. From a methodological point of view, the determination of heavy metal concentration in tissues may be limited by the typically small sample sizes available. Heavy metals have been analyzed in a range of matrices, with the four most sampled types (liver, kidney, whole body/carcass and guano) and the actual number of compounds analyzed gradually increasing over time as more sophisticated and precise instrumentation are developed. Non-lethal sampling methods are increasingly used for monitoring as these have minimal impact on threatened and highly protected animals. In total, heavy metal content has been studied in 65 bat species, though the species, sex, age, year of collection and locality varies widely with no clear pattern. Only four species (big brown bat *Eptesicus fuscus*, gray bat *Myotis grisescens*, greater mouse-eared bat *Myotis myotis* and common pipistrelle *Pipistrellus pipistrellus* sensu lato) have been analyzed more than five times, and only five heavy metals (cadmium, chromium, copper, lead, and zinc) have been measured in fructivorous/nectarivorous species. Insectivorous bats have lower mean contaminant values in tissues than both fructivorous/nectarivorous species and guano. While exposure pathway may have influenced differences between the various food guilds, lowered bioavailability of heavy metals from digested food displaying lower bioaccumulation factors may account for differences observed between guano and other types of samples.

While the number of articles confirming direct adverse effects and toxicity of heavy metals on bats is low some impacts and poisoning cases have been documented, including hepatopathy, DNA damage, hemochromatosis, renal inclusion bodies, ascending paralysis, and changes in cholinergic functions. Moreover, results suggest that the effects of chronic sub-lethal exposure to heavy metal contamination may be a more important threat to bat populations as bats under natural environmental conditions are frequently exposed to multiple anthropogenic stressors at the same time. One of the main challenges facing bat ecotoxicology today is the preparation of standardized monitoring programs using modern analytical technologies that offer more precise data on heavy metal contamination.

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Introduction

Bats occur on every continent except Antarctica and represent the second largest mammal order, comprising around 20% of mammal species, with the greatest diversity in the tropics (Nowak 1994). Given their wide distribution and high species richness, it is not surprising that bats face an unprecedented array of threats in the early 21st century, from traditional concerns such as habitat disturbance and loss of roost sites (*e.g.* through deforestation or building reconstruction) to pollutants, light pollution, diseases such as white nose syndrome, and collisions with wind turbines. Most of these threats are directly related to an ever increasing human population, with the greatest pressure in tropical countries.

Although the adverse health effects of heavy metals have long been documented, exposure to heavy metal pollution continues, and is even increasing in some parts of the world (Melancon, 2003; Li et al., 2014). Heavy metals occur naturally in the environment and there is always a natural background concentration in soils, rocks, sediments, water, and living organisms, with concentrations varying greatly. However, anthropogenic pollution results in higher concentrations of these metals relative to the normal background values. Emissions of heavy metals into the environment occur *via* a wide range of processes and pathways, including air pollution through combustion, extraction and processing; surface water pollution *via* runoff and releases from storage and transport; into soils and consequently into ground waters, insects and crops (Clark, 1981).

There is no clear definition of what a heavy metal is and, in most cases, elemental density is taken to be the defining factor. Heavy metals are thus commonly defined as "elements having a specific density of more than 5 g/cm^3" (Järup, 2003). Eleven elements are recognized as being of greatest wildlife concern: arsenic, cadmium, cobalt, chromium, copper, mercury, manganese, nickel, lead, tin and thallium (Beyersmann and Hartwig, 2008). The heavier metals, such as lead, mercury, arsenic and cadmium, are amongst the most hazardous; however, even light metals such as aluminum and selenium can be toxic to living organisms at higher concentrations. Some heavy metals play no physiological role in living organisms, and these can be toxic at low concentrations; others are essential elements, yet can be toxic at elevated concentrations. Further, while all heavy metals are potentially hazardous to health, local environmental conditions, such as alkalinity, pH, or water hardness, can affect both the bioavailability and toxicity of the elements (Laskowski et al., 1995). In all living organisms, heavy metal ion levels tend to be strictly controlled at the cellular level (Bremner and Beattie, 1990) as free ions can cause many serious problems, including oxidative stress or permanent signaling within the cell.

Exposure to contaminants, including heavy metals, has been implicated as a major factor contributing to recent decreases in bat populations (Mickleburgh et al., 2002). Bayat et al., (2014), in summarizing actual data on organic contaminants (mainly pesticides) and their effects on bats, was able to show that organic pesticides and PCBs (polychlorinated biphenyls) are still being detected in bat tissue, many years after their use was banned. On the other hand, potential detrimental effects of heavy metals on wild bat populations are poorly documented, despite bats being recognized as a potential bioindicators species (Jones et al., 2009). There are many features of bat life-history and biology that make bats a perfect species for monitoring of environmental contaminants including heavy metals. First, bats are long-lived, with life-spans much longer than those of other similarly-sized mammals. The oldest bats, for example, live up to 40 years, and most have an average age of between five and six years (Gaisler et al., 2003). Such longevity not only makes bats more susceptible to the negative effects of heavy metals through bioaccumulation, it can also result in large concentrated doses of lipophilic contaminants being transferred to offspring in milk. Second, the metabolic processes of insectivorous bats are very rapid and these small animals must consume a great deal of food, with individuals catching prey weighing up to 100% of their body mass in one night (Kurta et al., 1989). Greater food intake increases the amount of contaminant available for concentration in body fat. Moreover, insectivorous bat species occupy a relatively high trophic level, which increases their susceptibility to environmental contaminant accumulation through their diet and ability to show the consequences of toxic pollution. Third, bats often coexist with humans in urban, industrial, and agricultural landscapes (Gaisler et al., 1998; Bartonička and Zukal, 2003; Park, 2015; Russo and Ancillotto, 2015), thereby potentially exposing themselves to increased pollution levels. While synanthropy (living with humans) has allowed bats to spread into regions were the suitable natural shelters are limited (Russo and Ancillotto, 2015), it has also increased the threat of heavy metal contamination through proximity to human activities. In polluted areas, bats accumulate metals through the food chain and long-term exposure to elevated levels can result in a variety of pathological conditions or even death. Fourth, bats also feed on insects emerging from the water surface. Riparian habitats support large numbers of insects and are prime foraging areas for insectivorous bat species (Vaughan et al., 1996; Korine et al., 2015). Inflow of heavy metals and other toxins from industrial waste, however, can not only affect water quality but accumulate in the invertebrate community, which then forms food for bats (Van De Sijpe et al., 2004; Jones et al., 2009). Finally, heavy metals often accumulate in fat, and are more likely to have adverse physiological effects in bats when they are depleting their fat reserves during hibernation, migration, or lactation (Speakman and Thomas, 2003).

Some factors, such as their high mobility, limit the use of bats as bioindicators, with long distances travelled to foraging areas (several kilometers every night) resulting in low geographical accuracy for detection of specific polluting sites. Further, the nocturnal and reclusive nature of these mammals makes recognition of die-offs associated with contaminants more difficult than in other wild animals.

In general, both bioindication and ecological risk assessment in wildlife is limited by a lack of data, including toxicological sensitivity and geographical variability. Furthermore, many bat species are rare or threatened and their protected status means that acquisition of such data may be strictly limited, or be totally unavailable. Strict world-wide protection and conservation of most bat species also prevents their use in standardized monitoring programs for environmental contaminants, such as those undertaken with game animals (Mickleburgh et al., 2002). There is, however, a great need for ecotoxicological support with respect to decision making in wildlife conservation.

As a first step, this review sets out to provide an overview of heavy metals research on wild bat populations to date; to point out major gaps in our present knowledge; and to suggest future directions and approaches for the study of heavy metal contamination and its possible direct adverse effects on bats.

Material and methods

In this review, we summarize all primary literature sources, including original papers, reports and published theses that present original data on heavy metal contamination in bats. Abstracts from conferences and methodological chapters in books were excluded as these tended not to present new data on heavy metal content. Only three theses (Hariono, 1991; Massa, 2000; Land, 2001) were not included as we were unable to obtain copies; however, some results from these studies have already been published as original scientific papers (*e.g.* Hariono et al., 1993).