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A review on exposure and effects of arsenic in passerine birds

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HIGHLIGHTS

- This review presents a comprehensive overview of As exposure and effects in birds.
- A clear tendency is found in the last years to the use of non-destructive samples.
- Diet and migration are crucial on the differences in As exposure between species.
- Few field studies on As exposure and effects in passerines have been done.
- Further research is recommended, especially in the southern hemisphere.

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ABSTRACT

Arsenic (As) is a metalloid of high concern because of its toxic effects for plants and animals. However, it is hard to find information on this metalloid in passerines. This review presents a comprehensive overview of As exposure and effects in birds, and more particularly in passerines, as a result of an extensive search of the literature available. Internal tissues are the most frequently analyzed matrices for As determination in passerines (37.5% of the reviewed studies used internal tissues), followed by feathers and eggs (32.5% each), feces (27.5%), and finally blood (15%). A clear tendency is found in recent years to the use of non-destructive samples. Most studies on As concentrations in passerines have been done in great tit (*Parus major*; 50%), followed by pied flycatcher *Ficedula hypoleuca*; (22.5%). Some factors such as diet and migratory status are crucial on the interspecific differences in As exposure. More studies are needed to elucidate if intraspecific factors like age or gender affect As concentrations in different tissues. The literature review shows that studies on As concentrations in passerines have been done mainly in the United States (30%), followed by Belgium (Ficedula hypoleuca; 22.5%), and Finland (20%), making evident the scarce or even lack of information in some countries, so we recommend further research in order to overcome the data gap, particularly in the southern hemisphere. Studies on humans, laboratory animals and birds have found a wide range of effects on different organ systems when they are exposed to different forms of As. This review shows that few field studies on As exposure and effects in passerines have been done, and all of them are correlative so far. Arsenic manipulation experiments on passerines are recommended to explore the adverse effects of As in free-living populations at similar levels to those occurring in the environment.
Capsule: This review summarizes the most interesting published studies on As exposure and effects in passerines.

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1. Introduction

Monitoring chronic exposure of animals and humans to toxic metals and assessing their effects is a global health concern. Essential metals represent a crucial part in normal biological functioning of cells. However, metal-induced adverse effects are well reported in literature (Flora et al., 2007, 2008; García-Fernández, 2014; Koivula and Eeva, 2010; Liu et al., 2008; Outridge and Scheuhammer, 1993; Scheuhammer, 1987). Arsenic (As) is a metalloid, having both properties of a metal and a non-metal, although it is frequently referred to as a metal (or even a heavy metal). It is present ubiquitously in the environment and occurs naturally in soil and in several types of rock, especially in minerals and ores that contain copper (Cu), lead (Pb), cobalt (Co), and gold (Au) (ATSDR, 2007). Regarding anthropogenic sources, the main causes of As pollution are mining-related activities, but other important sources include coal burning, pesticides and wood-preserving arsenicals (Garelick et al., 2008). Plants transfer elements such as As from the abiotic environment to the biotic one. The As transfer from soil to plants depends on its availability in the soil and the soil characteristics, along with the capacity of the plant to uptake and transport it through its tissues (Huang et al., 2006; Martínez-López et al., 2014). Animals feeding on plants incorporate As into their organism. These consumers may also serve as food for other animals, thus completing the soil-plant-animal transfer (Kabata-Pendias and Mukherjee, 2007; Morrissey et al., 2007). Consequently, the accumulation of As in soils represents a pathway for the incorporation of this element into the food chain (Martínez-López et al., 2014; Moreno-Jiménez et al., 2009).

Arsenic is of high concern because of its toxic effects for plants and animals, especially in its inorganic form. According to the Agency for Toxic Substances and Disease Registry (ATSDR), As is ranked as the first compound in the Substance Priority List 2013, a list of hazardous substances that are most commonly found and which are determined to pose the most significant potential threat to human health due to their known or suspected toxicity and potential for human exposure (ATSDR, 2013).

Different organisms have been used as biological indicators of metals. Due to the sensitivity of birds to environmental changes and the position of some of them in the food chain, they can accumulate high levels of contaminants and, thus, are widely used in biomonitoring studies of environmental pollution (Furness et al., 1993). In general, since environmental pollutants magnify up to the food chain, top predators such as raptors and seabirds have been widely used in metal biomonitoring studies (Burger et al., 2008; Burger and Gochfeld, 1999; Dauwe et al., 2003; Espín et al., 2012, 2014b; García-Fernández et al., 1995, 2008; Lodenius and Solonen, 2013). In contrast, fewer studies have focused on passerine birds, probably because of the assumption that these species are in a lower position in the food chain and they are relatively short-lived (Burger et al., 1999, 2004). However, passerine birds have successfully been used to monitor environmental pollution by metals (Belskii et al., 2005; Berglund et al., 2012; Dauwe et al., 2002; Eeva et al., 2005b, 2006, 2009; Mora, 2003; Mora et al., 2003; Rainio et al., 2013). Some passerines such as the great tit (*Parus major*) are suitable bioindicators of metal pollution since (i) they are ubiquitous, living in different habitats and often in large densities; (ii) they are mainly insectivorous during the breeding season, and they are high in the food chain; (iii) they are resident in many populations and forage in small home ranges reflecting local contamination; (iv) they readily nest in holes and man-made nest boxes, so they are rapidly established and easily monitored; and (v) ecological and behavioral infomation is abundant (Cramp and Perrins, 1993; Dauwe et al., 1999, 2000, 2004, 2005a; Eens et al., 1999; Janssens et al., 2002).

Previous studies on metal exposure and related effects on birds have been mainly focused on Pb, mercury (Hg) and cadmium (Cd); and several reviews have summarized the concentrations found in biota and their main effects (Burger and Gochfeld, 1997, 2000; García-Fernández, 2014; García-Fernández et al., 2008; Rainbow, 2002; Scheuhammer, 1987; Sethy and Ghosh, 2013). However, As is not a well-documented element when it comes to biota and particularly to birds. Thus, a comprehensive overview of As levels at which bird populations are exposed and its possible effects is required. Even for those metals widely reported in literature, most critical threshold levels remain unknown in bird species. However, recently, some studies have shown new threshold concentrations at which some metals may cause sublethal effects on wild birds in relation to the antioxidant system (Espín et al., 2014a,c; Martínez-Haro et al., 2011).

The aim of this literature review is to collect and discuss information on the current status of As-related research in birds. For this purpose, we have created a database providing As concentrations in different tissues of passerines, such as feces, feathers, eggs, blood and internal tissues; and compiling the As-related effects in passerines and other bird species.

2. Methods: data sources

An extensive search of the literature available was conducted in the present review using different databases including PubMed, Science Direct, Springer, and Web of Science. In addition, the reference lists of each paper containing As data were scanned to identify additional documents on the issue that had been missed. Different keywords and combinations of terms were used, such as 'arsenic', 'heavy metals', 'trace element', 'metalloid', 'pollution', 'passerine', 'songbird', 'bird', 'great tit', 'pied flycatcher', 'parus major', 'effects', 'health', 'status', 'oxidative stress', 'breeding', 'reproductive', 'performance', 'condition', 'survival', 'success', 'feathers', 'egg', 'excrement', 'feces', and 'tissues'. Several Google searches were also done to look for reports of projects and other documents that are not available in the major databases.

3. Arsenic exposure in passerines

3.1. Samples used: interpreting arsenic concentrations

Arsenic concentrations in birds can be assessed using a variety of samples. In total, 40 studies on As levels in passerines were reviewed, and data on As concentrations in different tissues of passerines is