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Review

# Organic contaminants in bats: Trends and new issues

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ABSTRACT

Exposure to contaminants, often pesticides, has been implicated as a major factor contributing to decreases in bat populations. Bats provide essential ecosystem services and a sustained, thriving population is vital for ecosystem health. Understanding issues threatening their survival is crucial for their protection and conservation. This paper provides the first review for 12 years on organic pollutants in bats and aims to investigate trends and any new issues impacting bat resilience. Organochlorine (OC) pesticides have been reported most often, especially in the older literature, with the dichlorodiphenyltrichloroethane (DDT) metabolite, dichlorodiphenyldichloroethylene (DDE), present at highest concentrations in tissues analyzed. The OC pesticide concentrations reported in bat tissues have declined significantly since the late 1970s, presumably as a result of restrictions in use. For example, DDE study mean concentrations over time periods 1970–1980, 1981–1999 and 2000–2013 ranged from 2.6-62, 0.05–2.31, 0.08–0.19 ppm wet weight, respectively. Exposure, however, still occurs from remaining residues, many years after the compounds have been actively used. In recent years (2000–2013), a range of other organic chemicals have been reported in bat tissues including brominated flame retardants (polybrominated diphenyl ether at a mean concentration of 2.9 ppm lipid weight) and perfluorinated compounds (perfluorooctanyl sulfonate at a mean concentration 0.09 ppm wet weight). The persistent organic compounds concentrate in tissues with higher fat content notably back-depot fat. Numerous factors influence exposure, residues detected and concentrations in different individuals, species and tissues which must be understood to provide meaningful assessment of the impacts of exposure. Exposure can lead to not only acute and lethal impacts, but also physiological sub-lethal and chronic effects, often linked to the annual cycle of fat deposition and withdrawal. Current challenges for bat conservation include collation of a more extensive and standardized database of bat exposure, especially to current use pesticides and emerging contaminants, and better prediction and definition of toxicity end points notably for the sub-lethal effects. Understanding sub-lethal effects will be of greater importance for sustaining populations in the longer-term.



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## 1. Introduction

Bats comprise about 20% of all mammals and have a vital ecological function due to wide taxonomic and functional diversity, position in the food chain, feeding patterns and habits and relative longevity. They provide a range of essential ecosystem services including pollination, seed dispersal, and insect moderation (Brigham, 2007; Fenton, 1983; Kalcounis-Rueppell et al., 2007; Wickramasinghe et al., 2003). A sustained, thriving population provides a good representation of ecosystem health (Jenssen, 2006). Many studies report locally decreasing populations worldwide with anthropogenic influences often cited as a likely cause (Clarke et al., 2005a,b; Estrada and Coates-Estrada, 2001a, b; Estrada et al., 1993; Fenton et al., 1992; Hayes and Loeb, 2007; Kunz et al., 2007; Medellín et al., 2000; Moreno and Halffter, 2000, 2001). For example in 2007, Elliot reported that since 1979 the population of Indiana bats (*Myotis sodalis*) in Missouri, US has declined by 95%. Low reproduction rates with slow recovery of population losses make any decrease in bat population a concern (Barclay et al., 2004; Clark et al., 1998; Jones et al., 2009). In recent years, the ecological value of bat conservation has been further amplified by the threat to the species from white-nose syndrome, an important novel pathogen (Warnecke et al., 2012) which has resulted in mass mortality and population decline in North America (Frick et al., 2010) with significant impacts on ecosystem integrity. Consequently, it has become even more crucial to identify possible threats to bat populations to ensure the survival of these vital ecosystem members.

Exposure to organic contaminants, often pesticides, has been identified as one possible cause of declining bat populations (Braaksma and Van der Drift, 1972; Clark, 1981; Clark et al., 1978a,b; Dalquest, 1953; Humphry and Cope, 1976; Mitchell-Jones et al., 1989; Ransome, 1989; Stebbings and Griffiths, 1986) and also their susceptibility to white-nose syndrome (Kannan et al., 1995). Hundreds of different organic chemicals are and have been used by society. Bat exposure can occur through a range of different routes but exposure to pesticides can be especially significant because they are typically applied in agricultural areas near dusk or dawn coinciding with times of increased bat mobility, and target the insectivorous diets of many species. Exposure to residues of the now banned persistent organochlorine (OC) pesticides still remaining in the environment (Clark, 1988), and other more recently used persistent organic compounds such as polybrominated diphenyl ethers (PBDEs) present as a result of intentional or accidental releases, is also possible (Kannan et al., 2010). Many bat species use house roof spaces for breeding and can be vulnerable to exposure from chemicals in wood preservatives including lindane, pentachlorophenol (PCP) and more recently the pyrethroids (Bennett and Thies, 2007; Boyd and Myhill, 1988; Mitchell-Jones et al., 1989; Racey and Swift, 1986; Shore et al., 1990, 1991).

Risks associated with exposure to persistent compounds include food chain transfers and bioaccumulation. Exposure to these and other organic chemicals can manifest in acute and lethal impacts, but sublethal and chronic effects such as immune suppression are also of concern for the long-term survival of populations (Clark and Shore, 2001; Corraoa et al., 1985; Geluso et al., 1976; Reidinger and Cockrum, 1978; Warnecke et al., 2012). Many organic compounds, including certain PCBs, OC pesticides and brominated flame retardants, possess the ability to inhibit, interfere with or disrupt the action of the endocrine system (O'Shea and Clark, 2002). These compounds have been implicated as the cause of increasing incidence of reproductive disorders and abnormal developmental in some organisms (Shore and Rattner, 2001) and may contribute to decreased bat population density and survival resilience.

Effects of contaminants on bats, however, are little understood, particularly the sub-lethal effects, due often to difficulties in sampling populations, monitoring exposures and relating exposure to effect. Clark and Shore (2001) reviewed data on organic contaminant residue concentrations (mainly OC pesticides and PCBs) in bats available at that time (pre 1997) and any evidence for effects. The aim of our review is to revisit the issue now, more than three decades after many of the organochlorines were banned, building on the work of Clark and Shore (2001). We examine temporal trends in organic contaminant concentrations in bats, and assess whether new issues are emerging and the longevity of the organochlorine contaminant legacy. We also examine the new knowledge for associated lethal and sub lethal impacts to fully understand potential threats to populations now and where to prioritize research.

## 2. Contaminants, concentrations and trends

Studies reporting organic contaminant concentrations in bats, their organs and guano from the 1970s are summarized in chronological order in Table 1. All tissue concentrations are presented as ppm wet weight unless indicated otherwise throughout this manuscript. Data were collected from the primary literature. Most work reported in Table 1 is from the US and, pre-1997, includes many of the studies cited in the review of Clark and Shore (2001) available in the primary literature. This is, however, further supplemented by numerous post-1997 studies reporting a range of compounds in addition to the organochlorine pesticides and PCBs. It is important to understand that organic contaminant studies have historically suffered from difficulties with compound identification, method variability and interferences. The development, however, of more sophisticated instrumentation and analysis in more recent years has allowed detection of a wider range of compounds and more confidence in the results reported in the later studies reported in Table 1.

The compounds detected, their concentrations and any temporal trends have been discussed for individual compound groups below where possible. Many difficulties are presented when trying to statistically assess trends using data available on bats. Spatially studies are very limited with most work reported in the US and studies in other countries often restricted to one report. Data lack consistency and standardization. For example, concentration may be reported as wet, dry or lipid weight, as median or mean, are often presented for a range of different body components, and carcasses may either include whole body parts or some thereof. As a consequence we have only included data for time trend analysis from the US where sufficient data has been published to allow for reasonable statistical analysis. We also include only the body tissue data reported in wet weight. Statistical analyses were carried out using R-software version 3.0.0 (R Core Team, 2013).

### 2.1. Organochlorine pesticides and PCBs

The OC pesticides, introduced in the 1940s, were used ubiquitously in agriculture for pest control until concerns regarding their now well known persistence and toxicity led to restrictions and bans in the 1970s and 80s. Residues, however, still persist in the environment today and, indeed, use continues in some developing countries (Senthilkumar et al., 2001; Van den Berg et al., 2013). PCBs were widely used as dielectric fluids and coolants until they were banned in 1979, but incidental and accidental releases have resulted in residues still remaining in the environment. Both groups of compounds are included on the Stockholm Convention on Persistent Organic Pollutants (Colles et al., 2008; UNEP, 2009).

Table 1 shows that OC pesticides not only have been reported frequently in bat tissues historically (as also evidenced by Clark and Shore, 2001) but also in recent samples collected in the last 10 years, decades after compound use was restricted (Clark, 1981; Clark and Krynitsky, 1983; Clark and Lamont, 1976; Geluso et al., 1976; Kannan et al., 2010; Thies and McBee, 1994). A range of different OC pesticides have been detected including, DDT, dichlorodiphenyldichloroethane (DDD) and DDE, toxaphene, chlordane (CHLs), dieldrin and endrin (Table 1), but the main and most persistent DDT metabolite, DDE (a potent androgen receptor antagonist; Kelce et al., 1995), occurs most