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Effect of landscape tree cover, sex and season on the bioaccumulation of persistent organochlorine pesticides in fruit bats of riparian corridors in eastern Mexico

Carolina Valdespino [a, *], Vinicio J. Sosa [b]

[a] Red de Biología y Conservación de Vertebrados, Instituto de Ecología, A.C., Carretera Antigua a Coatepec 351, Xalapa, Ver., 91070, Mexico
[b] Red de Ecología Funcional, Instituto de Ecología, A.C., Carretera Antigua a Coatepec 351, Xalapa, Ver., 91070, Mexico

HIGHLIGHTS

- Persistent organochlorine pesticides (OCPs) are present in neotropical fruit bats.
- Most bats were positive for at least two of six OCPs families.
- Landscape tree cover, season or bat sex affects OCPs concentrations.
- Some high concentrations of OCPs were found.
- This is of great environmental concern considering that wild fruit is the bats' diet.

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ABSTRACT

Riparian forests are recognized as important ecosystems for biodiversity conservation in transformed landscapes. Many animal species that use this type of vegetation facilitate its recovery through pollination and seed dispersal. In landscapes dominated by agrosystems and cattle ranching, persistent organochlorine pesticides (OCPs) in the riparian system may have an effect on the physiology and fitness of animals. In this study, we measured bioaccumulation of OCPs in the most abundant frugivorous bat, *Sturnira hondurensis*, from the upper part of La Antigua basin, Veracruz, Mexico and, from these data, estimated accumulation by the frugivorous bat community of riparian forests in contrasting, transformed (TL) and forested (FL) landscapes. Concentration of ΣDDT, Σdrines, Σclordano, ΣHCH, Σheptachlor and Σendosulfan was measured by gas-chromatography in 23 female and 33 male adult *Sturnira* captured during the dry and rainy seasons. Using censored data statistics, we found that the sex of the individual was significant for ΣHCH, and that interactions of landscape type (TL *vs.* FL) and season (dry *vs.* wet), and sex and season were significant for Σendosulfan and Σdrines, respectively. Mean ΣDDT (6.86 μg/g) and ΣHCH (28.22 μg/g) concentrations were lower than those reported for frugivorous bats in India but concentrations of Σdrines (13.86 μg/g) were higher than those reported in insectivorous bats. In our study sites, frugivorous bats are bioaccumulating higher amounts of OCPs in TL than in FL. We discuss the potential of this species as a bio-indicator of OCPs contamination in river basins.

1. Introduction

Persistent organochlorine compounds (POCs) are deemed a potential risk for the survival of species. High concentrations of POCs can lead to death while trace amounts have negative effects on reproductive morpho-physiological traits, thus threatening the capacity to leave progeny (Matthiessen, 2000; Rattner, 2009). The POCs include the persistent organochlorine pesticides (OCPs), used in agriculture and livestock and domestic animals ectoparasite control, and polychlorobiphenyls (PCBs) used as industrial flame-retardants.

From the site of their application, OCPs are transported by water in organic matter particles (O'Brien et al., 2016) and, due to their lipophilic nature and complex molecular structure, they are

* Corresponding author. Tel.: +52 2288421853.
E-mail addresses: carolina.valdespino@inecol.mx (C. Valdespino), vinicio.sosa@inecol.mx (V.J. Sosa).

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bioaccumulated by organisms that feed on the contaminated material. Biomagnification takes place throughout the food chain when plants or animals that have bioaccumulated OCPs are subsequently consumed by herbivores or predators. While their production has been prohibited since the last century (ONU, PNUMA & FAO, 2008), their lipophilic and bioaccumulative nature has maintained OCPs in the environment and their presence has been reported far from where they were originally applied 20–60 years after usage (Nakataa et al., 2005; Bajaj and Singh, 2015) and, in some developing countries, they are still illegally used (Albert and Loera-Gallardo, 2014; Hernández-Antonio and Hansen, 2011; Hinojosa-Garro et al., 2016).

Information on the use of OCPs in Mexico is scarce and imprecise. The use of significant quantities of DDT, aldrin, endrin, lindane and dieldrin has been reported since 1971 (Albert, 2014; Benítez and Bárcenas, 1996; Chanon et al., 2003; López-Carrillo et al., 1996), but their application was prohibited in 2000 (Chi-coyoc et al., 2016). The presence of OCPs in wildlife has been reported at < 500 m a.s.l. in the Gulf of Mexico region (García-Besné et al., 2015; Gonzalez-Jaregui et al., 2012; González-Jáuregui et al., 2014; Valdespino et al., 2105).

In individuals that have bioaccumulated OCPs, endocrine disruption (Rattner, 2009) has been reported in the development of embryos, the formation of the reproductive tract and on the concentration of sexual steroids. Sexual differences have been described in bioaccumulation of OCPs (Thies et al., 1996; Guillén et al., 1994; Allinson et al., 2006; Mispagel et al., 2004; Gonzalez-Jauregui et al., 2012; García-Besné et al., 2015), with females normally showing lower concentrations than males. The physiological explanation of this pattern is that females eliminate OCPs through transference to their offspring in the lipid content of the yolk during egg formation in oviparous species and in the milk produced during lactation in mammals (Orlando and Guillette, 2007).

Recent research has cited riverine corridors as important ecosystems for biodiversity conservation (Ramos and dos Anjos, 2014; Hilty and Merenlender, 2004). These are maintained either because they are situated in inaccessible slopes or because they provide useful shade for farm animals. Nearly 70% of vertebrate species in a region will use riparian corridors in some significant way during their life cycle (Naiman et al., 1993). Therefore, biodiversity conservation strategies have recommended maintaining and connecting riverine vegetation at both local and national levels (Fremier et al., 2015; Bleich et al., 2014).

Because of their position alongside rivers, riparian strips provide important ecosystem services, such as the deposition of organic matter, capture of chemicals and sediments from the watershed (Jackson et al., 2015) and temperature buffering (Fernández et al., 2014). Contaminants that are used on livestock ranches and crop fields adjacent to the river will reach the riparian strip by transportation in runoff from the farmlands within the catchment (Tabacchi et al., 1998). Wider riparian forests strips have been reported to have naturally higher metabolic rates, primary production, organic material cycling, and nitrogen intake than in narrow strips (Bott et al., 2006; Sweeney et al., 2004). Therefore, the ability of wider strips to keep and cycle the contaminants retained in organic matter will probably be higher than that of their narrow counterparts.

The presence of organic matter (Tabacchi et al., 1998) and contaminants retained in the riparian forest soil and sediment (Díaz-Cárdenas, 2013) may lead to higher risks of acquisition of disruptive compounds for the wildlife using riparian corridors (Bartels et al., 2012). Contaminants that are absorbed through root systems might be transported to the aerial parts of the plant, including fruits, depending on soil texture, the affinity of the contaminant for lipids and the lipid content of the plant (Collins et al., 2006). At the same time, seasonal fluctuations in flow level cause changes in contaminant concentrations (Latorre, 2013; Ramos-Rosas et al., 2013) that may have a consequence on the quantities of these contaminants that are accumulated by the animals.

Bats are one of the vertebrate groups that use riparian forests to move between habitats and as a source for food and water. Clark (2001), Clark et al. (1995), Geluso et al. (1976) and Guillén et al. (1994) studied bats in sites where population reduction was associated with the effect of persistent contaminants. Bioaccumulation of OCPs by bats has now been reported in different species worldwide (23 insectivorous, three frugivorous and one nectarivorous) and its long-term prevalence in bat populations was recently reviewed (Bayat et al., 2014). However, assessment at the community level in a particular location may be important for the accurate evaluation of OCPs bioaccumulation in a given animal group; for example, differences in the abundance of bat species within a riparian forest may imply a differential risk of intoxication.

Bat communities are important due to the number of species they normally comprise and the ecosystem services they provide, such as arthropod control, pollination and seed dispersal (Muscarella and Fleming, 2007; Kalka et al., 2008; Kunz et al., 2011). Along with rodents, bats are among the ecologically most diverse and specious groups of mammals, accounting for most of Earth's mammal biomass (Simmons, 2005). In the wild, the effect of OCPs on insect density and the presence of insectivorous bats has been described (Kalcounis-Rueppell et al., 2007); however, the effect on bats of another type of foraging guild may not be as direct and has not been reported to date. For example, we lack information regarding the effect on Neotropical frugivorous bats, a guild of great importance for seed dispersal and forest regeneration. In this regard, Bayat el al. (2014) recommend the collation of a more comprehensive and standardized database of accumulation concentrations and to investigate an improved prediction and definition of toxicity end points in bats. Finally, due to their abundance and relative easiness of capture, bats could be used as indicator species in pollutant monitoring programs.

Here, we investigated the presence of OCPs in frugivorous bats at high elevations on the eastern (Gulf of Mexico) slope of the central mountain range of the state of Veracruz, Mexico. Land use in this region is mainly livestock production and agriculture and man-made pastures, a few forest remnants and riparian forest corridors characterize the landscape. This represents a common land use throughout tropical Central and South America at an elevation of between 1400 and 2500 m a.s.l. where tropical montane cloud forest was originally distributed.

In order to minimize the impact on the bat community, we quantified the OCPs bioaccumulated by the most abundant frugivorous bat species in the riverine system and extrapolated these values to the entire frugivorous bat community of the upper part of the La Antigua watershed. This species was the highland yellow-shouldered bat, *Sturnira hondurensis* (Velazco and Patterson, 2013). Our objectives were: (1) To analyse differences in the concentration of OCPs bioaccumulated by *Sturnira* from riparian systems immersed in contrasting forested (FL) and transformed (TL) landscapes; (2) to determine whether there were differences in the quantities of OCPs bioaccumulated by *Sturnira* females and males and between the dry and the rainy seasons; and (3) to infer the health status of the bat community in terms of the concentrations of OCPs that may be present in the riverine systems studied.

2. Materials and methods

2.1. Study sites

Second and third order independent rivers were selected from the highest portion of the La Antigua basin (1700-1400 m a.s.l.) in