Chemosphere 154 (2016) 326–334

Contents lists available at ScienceDirect

Chemosphere

journal homepage: www.elsevier.com/locate/chemosphere

Organic contaminants in western pond turtles in remote habitat in California

Erik Meyer [a,*], Evan A. Eskew [b], Leah Chibwe [c], Jill Schrlau [c], Staci L. Massey Simonich [c], Brian D. Todd [b]

[a] Division of Resources Management and Science, Sequoia and Kings Canyon National Parks, Three Rivers, CA 93271, USA
[b] Department of Wildlife, Fish, and Conservation Biology, University of California, Davis, CA 95616, USA
[c] Environmental and Molecular Toxicology and Department of Chemistry, Oregon State University, Corvallis, OR 97331, USA

HIGHLIGHTS

- Organic pollutants are widespread in a California turtle with conservation status.
- Pesticides were prominent in Sequoia National Park downwind of heavy agriculture.
- PCBs and PAHs are associated with watersheds having historic mines and mills.
- HUP and PCB concentrations indicate potential bioaccumulation is occurring.

ARTICLE INFO

Article history:
Received 15 January 2016
Received in revised form
17 March 2016
Accepted 26 March 2016

Handling Editor: Caroline Gaus

Keywords:
Persistent organic pollutants (POPs)
Pesticides
Pollutant monitoring
Emys marmorata

ABSTRACT

Remote aquatic ecosystems are exposed to an assortment of semivolatile organic compounds (SOCs) originating from current and historic uses, of local and global origin. Here, a representative suite of 57 current- and historic-use pesticides, polychlorinated biphenyls, and polycyclic aromatic hydrocarbons were surveyed in the plasma of the western pond turtle (*Emys marmorata*) and their potential prey items and habitat. California study sites included Sequoia National Park, Whiskeytown National Recreation Area, and Six Rivers National Forest. Each was downstream of undeveloped watersheds and varied in distance from agricultural and urban pollution sources. SOCs were detected frequently in all sites with more found in turtle plasma and aquatic macroinvertebrates in the two sites closest to agricultural and urban sources. Summed PCBs were highest in Whiskeytown National Recreation Area turtle plasma (mean; 1.56 ng/g ww) compared to plasma from Sequoia National Park (0.16 ng/g ww; $p = 0.002$) and Six Rivers National Forest (0.07 ng/g ww; $p = 0.001$). While no current-use pesticides were detected in turtle plasma at any site, both current- and historic-use pesticides were found prominently in sediment and macroinvertebrates at the Sequoia National Park site, which is immediately downwind of Central Valley agriculture. SOC classes associated with urban and industrial pollution were found more often and at higher concentrations at Whiskeytown National Recreation Area. These findings demonstrate a range of SOC exposure in a turtle species with current and proposed conservation status and shed additional light on the fate of environmental contaminants in remote watersheds.

1. Introduction

Environmental contaminants present unique challenges for species conservation. Unlike habitat loss or other stressors that are often highly visible with discrete borders, environmental contaminants like pesticides and industrial pollution can be widely distributed to natural areas via overspray, drift, post-application volatilization, and windblown erosion (Majewski and Capel, 1995). Thus, even organisms in seemingly pristine areas, such as national parks, are exposed to harmful pollutants of local and global origin (Landers et al., 2008). One noteworthy example involves the San Joaquin Valley and adjacent Sierra Nevada foothills of California, USA. In 2011 and 2012, over 73 million kg of pesticides were

* Corresponding author. National Park Service, Sequoia and Kings Canyon National Parks, Division of Resources Management and Science, 47050 Generals Highway, Three Rivers, CA 93271, USA.
E-mail address: erik_meyer@nps.gov (E. Meyer).

http://dx.doi.org/10.1016/j.chemosphere.2016.03.128
0045-6535/Published by Elsevier Ltd.

applied to agricultural lands in the four counties upwind of Sequoia and Kings Canyon National Parks, accounting for nearly half of the state's total agricultural pesticide use for those years (CDPR, 2012, 2013). Despite a record drought and demand for limited water resources, California agriculture has still continued to grow to over 80,000 farms and ranches recording $44.7 billion in revenue (CDFA, 2015). This continued agricultural growth can be partly attributed to pesticides, which are used prominently in the state for pest management. The problems associated with heavy pesticide use are well documented, and in some California National Parks, pesticides are found ubiquitously across diverse biological and physical endpoints (LeNoir et al., 1999; Landers et al., 2008; Flanagan Pritz et al., 2014; Sparling et al., 2015).

At sublethal concentrations, many semivolatile organic compounds (SOCs), such as chlorinated historic-use pesticides (HUPs), polychlorinated biphenyls (PCBs), and polycyclic aromatic hydrocarbons (PAHs), cause deleterious impacts to organisms after exposure, resulting in effects that range from immunosuppression, genotoxicity, loss of secondary sex characteristics, decreased reproductive and endocrine function, and agonistic or antagonistic actions on hormone receptors (de Solla, 2010). Additionally, current-use pesticides (CUPs) such as organophosphates and carbamates, are prominently applied to California agriculture and can inhibit cholinesterase (ChE) enzymes in non-target wildlife, leading to acute or delayed neurological disorders (Sparling and Fellers, 2007). Possibly because of such effects, pesticides transported downwind to the Sierra Nevada foothills have been linked to declines and extirpations of amphibians in otherwise protected natural areas (Davidson et al., 2002). One species of state conservation concern, the Foothill Yellow-legged Frog (*Rana boylii*), has not been seen since the 1970s in the southern Sierra Nevada, where upwind pesticide use and agriculture has been prevalent and linked to their declines (Davidson et al., 2002; Sparling and Fellers, 2007) Although the relationship between amphibian declines and pesticide use has received much attention, other species may offer more promise for studying the accumulation and effects of environmental contaminants in wildlife.

Turtles can be key indicators of exposure to environmental contaminants; they readily bioaccumulate contaminants due to their long lifespans and generalist diets, integrating a lifetime of exposure from multiple sources, interactions with sediments, and ingestion of macroinvertebrates or aquatic plants (Bergeron et al., 2007; Rowe, 2008). Turtle populations can also persist in areas after other species have disappeared, partly because of their long lives and low generational turnover (Rowe, 2008). Thus, while it may be too late to study the accumulation of pesticides and their physiological effects in frogs that have been extirpated from the Sierra Nevada foothills, the western pond turtle (*Emys marmorata*), native to this region, still persists and may prove to be an appropriate biosentinel. In fact, a recent study of *E. marmorata* from the southern Sierra Nevada foothills found they had significantly reduced ChE activity compared to turtles from northern sites farther from agricultural areas (Meyer et al., 2013), offering support for the idea that heavy pesticide use in the San Joaquin Valley may be negatively affecting downwind ecosystems.

The goal of the present study was to examine baseline SOC concentrations by evaluating a representation of CUPs, HUPs, PAHs, and PCBs in *E. marmorata* at seemingly pristine locations that differed in their proximity to urban and agricultural land uses. *Emys marmorata* in the southern Sierra Nevada are considered to be in decline (Jennings and Hayes, 1994), and they have recently been petitioned for listing under the US Endangered Species Act (Dreher, 2015). Historical over-harvesting, habitat loss, and invasive species have been implicated as the primary factors threatening *E. marmorata* (Bury et al., 2008). However, negative biological effects from environmental contaminants have only recently received attention as a contributing factor, and the present study sheds further light on this possible cause of decline in a sensitive status species (Meyer et al., 2013, 2014). With these goals in mind, the presence of prominent environmental contaminants was examined at three California locations in three distinct sample types: 1) blood plasma of free ranging *E. marmorata*; 2) a composite sample of potential *E. marmorata* macroinvertebrate prey; and 3) stream sediments collected from *E. marmorata* habitat. The highest concentrations of CUPs and HUPs were expected at locations downwind of agriculture, and PCBs and PAHs were expected to be elevated at a location with legacy mines and mills.

2. Methodology

2.1. Sampling

2.1.1. Animal care and use

Animal handling and care approval was obtained through the University of California, Davis Institutional Animal Care and Use Committee (#16505). Research was also completed under approval from a California Department of Fish and Game scientific collecting permit (SCP 11633) and National Park Service (NPS) permits (CLCK-2011-SCI-0011, SEKI-2012-SCI-0456).

2.1.2. Study sites

Turtles, macroinvertebrates, and sediments were sampled at three lotic sites encompassing a 700 km latitudinal gradient across California (Fig. 1). The southernmost sampling site was the North Fork Kaweah River (NFKR), within Sequoia National Park in the southern Sierra Nevada foothills. The NFKR site (UTM 11S E 330211 N 4044134) lies to the east of, and downwind from, extensively cultivated agricultural areas of the San Joaquin Valley. This area is known to be influenced by atmospherically deposited pollutants originating from nearby San Joaquin Valley agricultural lands and surrounding urban areas (LeNoir et al., 1999; Landers et al., 2008). The topography of this region brings winds that transport pollution from the San Joaquin Valley east into the mountains during each day, and this diel wind pattern is more pronounced at foothill sites like NFKR than in the higher elevations of the Sierra Nevada (Ewell et al., 1989; Davidson et al., 2002). One northern California site was located at Clear Creek (CLCK) in Whiskeytown National Recreation Area (UTM 10T E 531265 N 4501103). This site is oriented facing south at the northernmost extent of the Sacramento Valley, and exhibits northerly and southerly predominant wind directions (Davidson et al., 2002). The winds blowing from the south have the potential to transport regional agricultural-related contaminants, but prior studies have indicated that environmental contaminants in this area are less pronounced than in the southern Sierra Nevada (Davidson et al., 2012; Smalling et al., 2013). Clear Creek is the most developed of the study locations, given its parallel proximity to California Highway 299 and its placement downstream of historic mines and mills responsible for elevated non-essential metals (National Park Service, 2014; Hothem et al., 2015). The third site was the South Fork Trinity River (SFTR), located in Six Rivers National Forest (UTM 10T E 448425 N 4525528). This site lies even farther west of the Sacramento Valley in the Klamath Mountains and is not immediately downwind of any industrial or agriculture areas. There is little expected influence from atmospheric deposition of contaminants from local sources given that northerly winds predominate over a landscape lacking traditional agricultural land-use (Davidson et al., 2002).