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SHORT COMMUNICATION

Invasive fire ants contain high levels of mercury

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Abstract Mercury contamination is a serious environmental concern usually associated with aquatic food webs. We tested for the presence of mercury in winged queens and males of four ant species and found that invasive red imported fire ants (*Solenopsis invicta*) contain high levels of mercury typical of aquatic insects. Mercury concentrations in male fire ants were 51 % higher than those in females and 89–199 % higher than those in other ant species from the same location. Fire ant sexuals fly long distances on their mating flights and are a major food source for arthropod and vertebrate predators and may thus transfer mercury through food webs.

Keywords Invasions · Mating flights · Mercury · *Solenopsis invicta*

Mercury is a pervasive toxin that has been introduced into ecosystems around the globe (Selin 2009). In the form of methylmercury (MeHg), it bioaccumulates in the tissues of organisms, especially in longer-lived or predatory species (Scheuhammer et al. 2007). The conversion of mercury to methylmercury is mediated by aquatic microbes, and mercury contamination is thus usually associated with aquatic food webs (Selin 2009). Mercury can be transferred to terrestrial food webs, however, by predatory animals feeding on aquatic organisms (Gerrard and St. Louis 2001; Cristol et al. 2008; Tweedy et al. 2013; Speir et al. 2014).

Social insect species may be at risk of mercury contamination, especially those living near water bodies. This is particularly true of ants, due to their usually predatory lifestyles and the long life spans of reproductive individuals (Tschinkel 1987; Hölldobler and Wilson 1990). Exposure to mercury interferes with ant metabolism and may reduce colony survival and reproductive success (Migula et al. 1997). We are unaware, however, of studies examining mercury contamination of naturally occurring social insect colonies.

Here, we test for the presence of mercury in winged queens and males of four species of ants. Winged ant sexuals, as opposed to wingless workers, are especially relevant to mercury transfer. By engaging in mating flights, sexuals may disperse contaminants up to several kilometers away from the original site of exposure (Markin et al. 1971; Helms and Godfrey 2016). Ant queens and males are also important prey for arthropod and vertebrate predators (Whitcomb et al. 1973; Helms et al. 2016a, b) and may thereby transfer mercury through food webs.

We collected queen and male ants during mating flights at the University of Oklahoma Biological Station on Lake Texoma, Marshall County, Oklahoma, USA (33° 52′ 50″ N, 96° 48′ 02″ W, elevation 196 m) from 29 May through 13 June 2014. To examine the role of ants in mercury transfer, we collected individuals that had been captured by avian insectivores (Purple Martins, *Progne subis*). We did this by entering bird nest boxes immediately after parents delivered prey to their young, and removing the prey from the mouths of nestlings (Helms et al. 2016a, b). The protocol was approved by the University of Oklahoma Institutional Animal Care and Use Committee (protocol R12-019C). We then identified the collected ants and analyzed their mercury

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content (ng Hg/ng body mass). To provide enough material for chemical analysis, conspecific specimens collected from the same feeding event—found in the same feeding bolus from the mouth of one bird—were analyzed together as a single sample.

Mercury analysis was conducted via gas chromatography on a Milestone Direct Mercury Analyzer (DMA-80) using EPA Method 7473 (US EPA 1998). For QA/QC, we ran standards (DORM) approximately every 10 samples, while blanks and duplicates were run approximately every 20. Standards had an average calibration factor of 1.1073 with a standard error of 0.0216 ($n = 7$). Blanks (empty sample runs) detected an average 0 ng of Hg with a standard error of 0 ($n = 5$). The height for all blanks was less than 0.0100. Duplicates had an average difference of 5.3267 ng/g with a standard error of 3.3745 ng/g ($n = 3$).

Data analysis was performed in R (R Core Team 2012). We compared ant mercury contents using ANOVA and Tukey's post hoc tests. Variables were tested for normality using the Shapiro–Wilk test.

We measured mercury contents of four species of ants—the carpenter ant *Camponotus pennsylvanicus*, the acrobat ant *Crematogaster laeviuscula*, the pyramid ant *Dorymyrmex flavus*, and the red imported fire ant *Solenopsis invicta* (Table 1). All species contained some mercury, but *S. invicta* had extremely high concentrations that were comparable to aquatic insects developing in mercury-contaminated reservoirs, or to predators feeding on such insects (Gerrard and St. Louis 2001; Tweedy et al. 2013; Speir et al. 2014). Mercury concentrations in male fire ants were 51 % higher than those in females (63.6 ± 20.7 ng/g versus 42.0 ± 6.4 ng/g, $p = 0.04$) and 89–199 % higher than those in the other three species (*Ca. pennsylvanicus*, 25.9 ± 14.4 ng/g, $p = 0.001$; *Cr. laeviuscula*, 33.6 ± 2.3 ng/g, $p = 0.06$; *D. flavus*, 21.3 ± 5.3 ng/g, $p = 0.00009$; Table 1, Fig. 1). Concentrations in female fire ants were 97 % higher than those in *D. flavus* ($p = 0.05$), but did not differ from those of the remaining two species (versus *Ca. pennsylvanicus* $p = 0.3$, versus *Cr. laeviuscula* $p = 0.9$).

The mercury concentrations in fire ants are high enough to be of potential health concern for predators that feed on them (Gerrard and St. Louis 2001; Speir et al. 2014). Birds

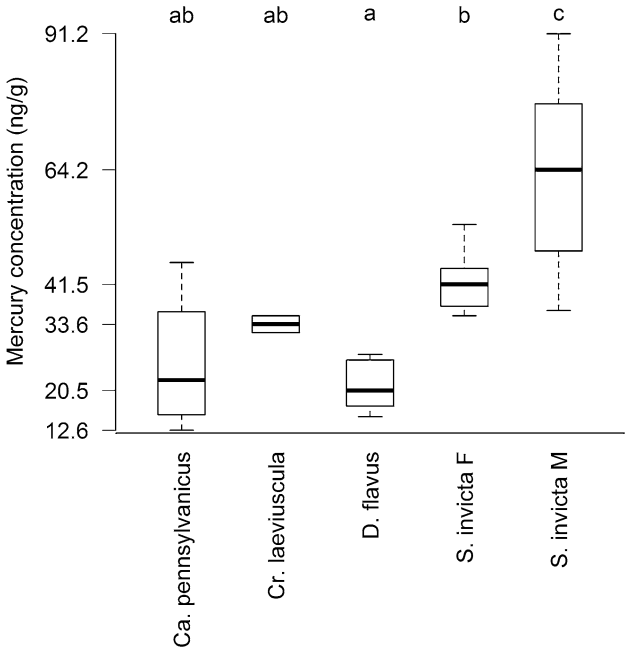

Fig. 1 Mercury contents of ants captured by Purple Martins. *Box plots* with *different letters* differ at $p < 0.05$ ($p < 0.06$ for *S. invicta* males versus *Cr. laeviuscula*)

experience reduced reproductive success at body mercury concentrations above 1000 ng/g (Scheuhammer et al. 2007). This threshold may be achieved by consuming prey with mercury concentrations as low as 300 ng/g wet weight (Scheuhammer et al. 2007) or 100–200 ng/g dry weight (Gerrard and St. Louis 2001). Whether fire ant consumption causes adverse effects, however, depends on the number of ants consumed and on the mass, developmental stage, and lifespan of the predator.

Our analysis did not discriminate between different chemical species of mercury, but the majority is probably aquatically derived methylmercury. Unrealistic exposure to inorganic mercury would be necessary to achieve the same concentrations in the absence of methylmercury. If that were the case, other species would contain high amounts of mercury as well. But *D. flavus*, which has similar habitat preferences as *S. invicta* (Trager 1988), had much lower

Table 1 Mercury concentrations in ants

Species	*n*	Total individuals	Hg (ng/g)
Camponotus pennsylvanicus	4	5 females and 4 males	25.9 (14.4)
Crematogaster laeviuscula	2	8 females	33.6 (2.3)
Dorymyrmex flavus	6	120 females	21.3 (5.3)
Solenopsis invicta Female	7	34 females	42.0 (6.4)
Solenopsis invicta Male	6	62 males	63.6 (20.7)

Mercury concentrations are means; parentheses show standard deviations

n shows the number of sampled predation events. Total individuals describes the number of ants analyzed from those samples

mercury concentrations that were more typical of terrestrial animals.

The high mercury content in fire ants may result from feeding at higher trophic levels than other species. Alternatively, they may feed more heavily on aquatic food sources—either emergent aquatic insects or detritus washed up by waves and floods. Fire ants often occupy wetland or shoreline habitats (Tschinkel 1988, 2013), and at our study site they frequently nested on sandy beaches at the lake's edge. We lack detailed nest site information for our specimens, however, as they were collected after capture by birds feeding over several square kilometers. Likewise, we do not know why males have higher mercury concentrations than females of the same species. Females may be more efficient at metabolically removing toxins, or dietary or developmental differences may result in lower exposure to or accumulation of mercury. Finally, it is worth noting that our study is limited to four species and that further investigation may reveal other ants with similarly high mercury contents.

Red imported fire ants are abundant across the southeastern USA and occur at high densities in disturbed or anthropogenic habitats near water bodies—the environments most at risk of mercury contamination (Tschinkel 1988; Selin 2009; Tschinkel 2013). Their peak flight season coincides with the nesting periods of spring-breeding birds (e.g., Helms et al. 2016a), with smaller mating flights occurring in warm wet areas throughout the year (Morrill 1974). Fire ant sexuals are a major food source for invertebrate and avian predators (Whitcomb et al. 1973), and even in relatively dry climates can make up over half of the prey items and a quarter of prey biomass eaten by developing Purple Martins (Helms et al. 2016a, b). Queens routinely fly several kilometers, and occasionally over 30 km, from their colony of origin (Markin et al. 1971; Wojcik 1983; Helms and Godfrey 2016), allowing mercury to be transported long distances from aquatic sources. Mercury contamination in fire ants is thus a potentially serious and widespread environmental concern.

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