Ecotoxicological Effects of Heavy Metal Pollution on Economically Important Terrestrial Insects

Oksana Skaldina and Jouni Sorvari

Abstract Pollution is among the major anthropogenically induced drivers of environmental change. Heavy metals, released from industry and transport, can contaminate aquatic and terrestrial environments, inducing further ecotoxicological effects in different organisms. Insects play crucial ecological roles in maintenance of ecosystem structure and functioning and deliver such ecosystem services as food provisioning, plant pollination, dung burial, pest control and wildlife nutrition. Economically important terrestrial insects vary in an ability to accumulate heavy metals and demonstrate substantial difference in heavy metal tolerance. Despite global pollinator decline, only limited information is available about effects of heavy metals on wild bees. Ants, wasps and beetles are key-predatory insect groups in many terrestrial ecosystems. Responses in ants are investigated to higher extent than in wasps and revealed ecotoxicological effects of heavy metal pollution in beetles are biased to model species. Insect pests such as aphids and butterfly larvae respond to heavy metal pollution with modifications in their morphology and physiology, however more studies are needed to understand general directions of adaptations in this functional group of economically important insects. When investigated the problem of insect decline, heavy metal pollution should be thoroughly considered. In addition to natural habitat transformation, use of insecticides and modifications in agriculture, ecotoxicological effects of heavy metals on useful insects might have direct consequences to food security, agricultural economy and human welfare.

Keywords Ecosystem services · Ecotoxicology · Insecta · Heavy metals · Pests · Pollinators · Predators

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1 Introduction

Climate change, forest clearing, intensive agriculture, global trade and pollution are main man-induced defendants of life transformations on the Earth. Afore global environmental change understanding of living beings' adaptability to various environmental stresses is crucial for decision making policy, environmental management and environmental law (Chasek 2018). Despite vast scientific studies and public efforts, environmental pollution remains among key environmental concerns globally. Such pollutants as chlorofluorocarbons (CFCs), organochlorine (OC), polychlorinated biphenyls (PCBs), perfluorinated compounds (PFCs), organotins (OTs) and heavy metals (HM), released from industry and transport, penetrate into aquatic and terrestrial ecosystems and cause acute or chronic threats to biota (Mateo et al. 2016). However, the lack of knowledge about direct effects of pollution on different biological compartments of terrestrial ecosystems requires further analyses on the topic.

Heavy metal pollution may affect all components of terrestrial ecosystems, from soil and microbes to vertebrates (Gall et al. 2015). As trace elements, the heavy metals such as cobalt (*Co*), copper (*Cu*), iron (*Fe*), manganese (*Mn*), molybdenum (*Mo*), selenium (*Se*) and zinc (*Zn*) are essential micronutrients for plants, animals and humans. While some of the other elements, like arsenic (*As*), cadmium (*Cd*), chromium (*Cr*), mercury (*Hg*), lead (*Pb*) and nickel (*Ni*) have no useful biological function and might cause toxic effects even at low concentrations (He et al. 2005).

Revealing biological responses towards heavy metal pollution in living organisms, particularly in those, which are of great ecological and economic importance, and developing practical biomonitoring tools, may effectively facilitate progress in modern terrestrial ecotoxicology (Skaldina and Sorvari 2017). Especially since "*the concept of biological monitoring, based on the study of the biological response of organisms to pollutants, termed biomarkers, is today well established*" (Romeo and Giamberini 2013). This is practically important for further development of ecotoxicology, aiming to discover causal linkages between the source of pollution and range of its biological effects with the purpose to reduce an impact via different kinds of legislative, social and environmental interventions (Elliott et al. 2011).

2 Economic Importance of Insects

Insects represent one of the most diverse groups of living organisms, with estimated possible number of species up to 10 million (Gaston 1991). They are important drivers of key ecosystem processes, which are ultimately mediated through interactions between all ecosystem components. Even though cumulative biomass of insects contributes less to global carbon and nutrient cycling than, for example, the total biomass of plants and microbes (Yang and Gratton 2014).

Insects provide substantial provisioning, regulating, supporting and cultural ecosystem services such as plant pollination and food provisioning, medicine services, biological control, recycling organic matter, soil nutrient and fertility regulation, biodiversity protection, bioindicators and conservation tools, religion and spiritual value and cultural heritage (Noriega et al. 2018). So what kind of beneficial tasks do terrestrial insects perform? They pollinate plants and disperse seeds, protect crop and control pests, maintain soil structure and cycle nutrients, maintain food webs and favor ecosystem health (Scudder 2017). Economic value of the ecosystem services such as dung burial, pest control, pollination and wildlife nutrition, provided by wild not domesticated or mass-reared insects in the USA is estimated as $57 billions per year (Losey and Vaughan 2006).

Economically important, beneficial insects belong to various systematic categories. For instance, bees, hover flies, lacewings, predatory bugs, caterpillar parasitoids and ants. However, insects are responsible for numerous adverse environmental and ecological concerns as well. Many insect species, belonging to the orders Lepidoptera, Coleoptera, Orthoptera and Hymenoptera (Van Emden and Wearing 1965; Del Toro et al. 2012), are serious agricultural pests. Therefore, economic role of various insects should be thoroughly considered in different types of environmental surveys.

3 Current State of Environmental Heavy Metal Pollution and General Ecotoxicological Effects in Terrestrial Insects

Although, current levels of industrial heavy metal pollution have been decreasing in European Union (Tóth et al. 2016) the opposite tendency is occurring in China (Li et al. 2014) and several other eastern countries (Järup 2003).

Different metal ions are vital for normal physiological processes in small concentrations, however, poisonous in higher amounts. Therefore, organisms should possess proper regulatory mechanisms for metal uptake, assimilability and excretion. Insects' adaptability to heavy metal pollution depends on their dispersal capacities, as mobile organisms may drift to better habitats, while sessile species should derive phenotypic and genetic adaptations (Merritt and Bewick 2017). Profound investigation of heavy-metal tolerance (*Cd*) in soil-living springtail *Orchesella cincta* revealed that in metal-exposed field populations the metallothionein gene is overexpressed in this species (Janssens et al. 2009). Therefore, it was suggested that *cis*-regulatory change of genes, engaging into cellular stress response, might be significant for the evolution of tolerance mechanisms towards heavy metal pollution in insects.

Heavy metals induce diverse ecotoxicological effects on terrestrial insects and affect some taxa more than the others. Thus, knowledge on the responses in few species cannot be generalized over different insect orders.

4 Ecotoxicological Effects of Heavy Metals on Pollinators

Pollinators is, probably, one of the most important functional group of insects, providing crucial ecosystem services for crops and wild plants. Pollinator decline and consequent loss of pollination services will rapidly result in adverse effects on crop production, food security and human welfare (Potts et al. 2010). Both honey bees (*Apis mellifera*) and bumble bees (*Bombus* sp.), which are key pollinators in diverse terrestrial ecosystems, accumulate heavy metals in their bodies (Lindqvist 1993; Fakhimzadeh and Lodenius 2000; Szentgyörgyi et al. 2011; Satta et al. 2012). Meindl and Ashman (2013) suggested that soil metals, especially *Ni*, can impair foraging behaviour of bumble bees in polluted areas. In their experimental study, it was shown that nectar solutions with elevated levels of nickel were visited for shorter time periods than the control ones.

Besides honey bees and bumble bees, heavy metals might affect other pollinators. However, ecotoxicological effects of heavy metals on wild bees are poorly understood. Szentgyörgyi et al. (2017) failed to reveal any association between heavy metal contamination and developmental instability, measured as fluctuating asymmetry (FA) of forewing. Therefore, more studies are needed to understand the effect of heavy metal pollution on various pollinating insects.

5 Ecotoxicological Effects of Heavy Metal Pollution in Important Predatory Insects

Many insect species are important natural predators in food chains and crucial biological control agents in pest management programs. Ants, wasps, bugs and lacewings comprise the most economically valuable groups of predatory insects.

Being important predatory insects, ants (Formicidae) can tolerate heavy metal pollution quite well (Folgarait 1998; Grześ 2010). Nevertheless, it can induce ecotoxicological responses related to morphology or physiology and alter behaviour in this group of insects. Recently we have found that hairy wood ant *Formica lugubris* respond to heavy metal contamination with decreased body mass and head melanin-based colouration (Skaldina et al. 2018). Grześ et al. (2015b) found that the size-distribution of workers in black garden ant *Lasius niger* colonies in a polluted area was biased to small workers.

In heavily polluted areas, ants demonstrate disturbed immune responses and therefore may be subject to higher risk of infections (Sorvari et al. 2007). Physiological ecotoxicological responses in ants to heavy-metal pollution correlates with exposure time. Under experimental set-up it was shown that prolonged feeding with *Cd* and *Hg* contaminated food diminished their ability to maintain proper energetic balance and resulted in decreased activity of several vital enzymes (Migula et al. 1997). It was also discovered that heavy metal pollution can decrease normal aggressive behaviour between workers of different ant colonies in *Formica aquilonia* (Sorvari and Eeva 2010). Aggressive territorial behaviour is needed to maintain proper population structure and colony integrity. Potentially, this behavioural alteration might modify structure of invertebrate communities in boreal and temperate forests, as *F. aquilonia* is an ecologically dominant species in these areas (Sorvari and Eeva 2010). No signs of developmental instabilities have been revealed in ants. Red wood ants *Formica pratensis* and yellow meadow ants *Lasius flavus*, inhabiting heavily metal-contaminated sites in Austria and Poland did not show signs of fluctuating asymmetry (Rabitsch 1997; Grześ et al. 2015a). It was suggested that some ant species might possess effective mechanisms of heavy metal regulation (Grześ 2009), therefore not every ant species are suitable for monitoring heavy metal pollution.

Ecotoxicological responses of wasps to heavy metal pollution are practically unrevealed. To our knowledge, one study about wasps as bioindicators, addressed levels of pollutants in wasps' feces (Urbini et al. 2006) and the other one revealed elevated lead concentrations in midgut epithelium of paper wasps (Polidori et al. 2018). Our results revealed that common wasp *Vespula vulgaris* accumulates heavy metals such as *As*, *Co*, *Cu*, *Fe*, *Ni*, *Pb*, *Sr* and *Zn*, and from those the levels of *As*, *Cd*, *Cu* and *Pb* decreased with an increase in distance from Harjavalta *Cu-Ni* smelter (Skaldina et al. unpublished). Biochemical and physiological mechanisms of such responses to heavy metal pollution in wasps should be studied further.

Beetles (Coleoptera) are generally less capable for heavy metal accumulation in compare with some other invertebrates (Heikens et al. 2001; Butowski 2011). The majority of studies about ecotoxicological effects of metals in beetles were done with the model species and very limited information is available about the other .

6 Heavy Metals and Pest Insects

Aphids and butterfly larvae are among the most damaging pest insects. Heavy metal pollution may lead to morphological and physiological alterations in these organisms as well. Görür (2006) revealed that metals, accumulated in host plant, might result in expression of morphological traits (size of various body parts) in aphids. It was shown that cadmium significantly affects life-history traits and metabolic enzymes in cotton bollworm *Helicoverpa armigera*. Experimental setup with an increased *Cd*-supplemented diet resulted in belated larval development, decreased survival rate, decreased female fecundity and altered enzymes (GST, CarE, P450 and AChE) activity in this species (Zhan et al. 2017). Sun et al. (2011) found immune sensitivity of important Asian Lepidopteran pest *Spodoptera litura* to nickel pollution, and it was dependent on the *Ni* concentrations and periods of exposure.

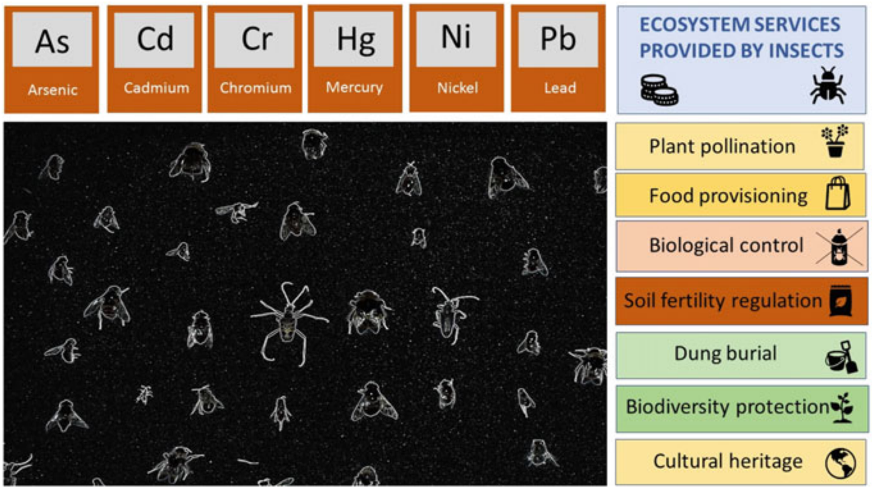

Fig. 1 Effects of toxic heavy metals on economically important terrestrial insects, providing crucial ecosystem services, may induce morphological, physiological and behavioural alterations and threaten biodiversity with further consequences to food security and human welfare

7 Conclusions

To summarize, heavy metal pollution may induce different morphological, physiological and behavioural alterations in economically important insects, such as pollinators, predators and pests. Current knowledge about ecotoxicological effects of heavy metals in important terrestrial insects is quite scarce. Most of studies on the topic addressed model species with no or little significant consideration of the ecological or economical role of the organisms. Ecotoxicological effects of heavy metal pollution in economically important insects should receive more scientific attention, as it has direct consequences to food security, human welfare and health (Fig. 1).

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