International Journal of Entomology Research
www.entomologyjournals.com
ISSN: 2455-4758
Received: 21-08-2024, Accepted: 20-09-2024, Published: 05-10-2024
Volume 9, Issue 10, 2024, Page No. 54-57

Morphological changes in ground beetles as bioindicators of zinc pollution in ecosystem: A comprehensive review

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Abstract
Beetles have emerged as effective bio indicators for environmental monitoring due to their sensitivity to ecological changes and pollutants. Bio indicators have been generating great interest in environmental pollution research. Insects and especially arthropod are useful to assess the effects of anthropogenic activities on the terrestrial ecosystem, because they are enclose contact with toxic elements present in soil and in leaf litter. Beetles are extremely sensitive to several ecological parameters, react quickly to environmental modifications and can be easily and cost-effectively sampled by various methods. This study examines the impact of zinc metal exposure on beetle morphology**.** Beetles are increasingly recognized as effective bio indicators for assessing zinc contamination in environmental studies. This research investigates the utility of beetles in monitoring zinc pollution by evaluating their morphological and behavioral responses.

Keywords: Beetles, pollution, ecosystem, zinc, morphology

Introduction

Beetles are used to monitor metal contamination in the environment by assessing the concentration of metals in their bodies. Their presence and metal accumulation reflect the levels of pollutants in their habitat. Worldwide pollution has increased to an unprecedented degree throughout the past three decades. According to Findorakova *et al*. (2017) [15], environmental pollution by potentially harmful materials is a global health concern. Some beneficial activities lead to the frequent release of toxins into the environment. Global urbanisation and neighboring industry are the main causes of anthropogenic metals contamination (Boldina-Cosqueric *et al*. 2010) [5]. The layout and function of the soil ecosystem are affected by the rising levels of heavy metal pollution in the environment, which negatively affects species (Zhou and Song 2004) [37]. The main cause of sediment pollution is the presence of environmental and hazardous substances in the soil, either as isolated entities or in groups (Chandrasekaran *et al*. 2015) [10].Metals is non-degradable, and unlike other contaminants, they have the ability to bioaccumulate and are biomagnified in the trophic chain (Kontas 2007) [19].

Organisms may get hazardously exposed to high quantities of these metals (Chandrasekaran *et al*. 2015) [10]. All biological levels are susceptible to toxic effects and all ecological interactions—including parasitism, predation, and the organisation of communities and ecosystems—are impacted by toxins. The toxic effects on apex predators may vary depending on the trophic chain, as the amounts of heavy metals in different food chain components vary in organisms. Examining the trophic distribution of trace metals in particular food chains within an ecosystem as a whole is crucial to determining the biomagnification potential (Kim and Kim 2016) [18]. The detrimental effects of toxic components on human health are evident, but it takes some time for the socioeconomic costs of pollution to start generating significant attention. According to Grant (2002) [17], evaluating the impacts of hazardous substances that are passed down via the food chain and their wider implications presents the biggest problem in ecotoxicology. Insects are frequently employed as harmful element evaluation tools. Because of their enormous abundance, biomass, and diversity, they are crucial to terrestrial habitats (Zodl and Wittmann, 2003) [38]. In addition, insects are essential components of the metal-transport networks at different trophic levels. Numerous researches have investigated how ground beetles bioaccumulate heavy metals. According to Cortet *et al*. (1999) [12], this occurrence allows for the collection of additional data regarding the bioavailability of trace elements as well as details regarding the biomagnifications of pollutants throughout their passage along the food chain. Different living entities, including insect groups, are affected differently by environmental contamination (Braun *et al*. 2009 [6]; Avgın and Luff 2010 [1]). Ground beetles, on the other hand, are useful for identifying a variety of environmental modifications and shifts. Given that they reside in the majority of terrestrial ecosystems with a high degree of diversity, their potential as biological markers of environmental toxins began to get attention (Zodl and Wittmann 2003) [38]. Pearce and Venier (2006) [31] conducted additional research that concentrated on using these beetles for biomonitoring of metals in field studies. The study of ground beetle (Coleoptera, Carabidae) has been done to review the connection between heavy metal contamination and morphological characteristics. The fauna of the ground that is closely related to the properties of the soil is best represented by carabid beetles. They are a well-researched group that is regularly covered in academic publications that address the impacts of environmental changes, including pollution, fragmentation, and land management.

Indicator beetles in ecological monitoring

According to Rainio and Niemela (2003) [32], bioindicators are seen to be useful instruments for observing and tracking alterations in the environment. According to Lindenmayerr *et al*. (2000) [22], using indicator species is a practical and significant technique for defining sustainable management when evaluating the impacts of both natural and man-made disturbances on forests. Furthermore, indicator species can be used to track environmental changes and serve as early warning systems for impending ecological shifts, according to Siddig (2016) [34]. In addition, indicator species are readily managed living things whose arrangement mimics or forecasts the state of the environment in which they live (Burger 2006) [7]. The idea behind using indicator species is that changes in the surrounding ecosystem could have an impact on the diversity, abundance, and rate of growth of one or more species there (Burrger 2006) [7]. According to Siddig *et al*. (2016) [34], the word "indicator species" is associated with a number of phrases, including:

a. Indicator species: One or more taxa chosen based on their susceptibility to a certain environmental factor, and subsequently assessed to draw conclusions about such factor, eventually incorporated into the ideas of habitat management, ecosystem restoration, and wildlife conservation (Caro 2010) [9];
b. Bioindicator/Biomonitor: One or more living species that serve as a biomarker for the biological component of their surroundings and the quality of the environment in which they live. In fields like ecotoxicology, bioindicators and biomonitors are primarily used to track chemical changes in the environment (Burger 2006) [7],
c. Umbrella species: These are species that favour expansive habitat areas and are frequently employed in protected area management and conservation applications (Morrison 2009; Caro 2010) [27];
d. Keystone species: These species are strongly impacted by the health of the ecosystem because of their interactions with other species. They are widely employed in the administration of protected areas, environmental quality monitoring, and restoration assessment (Ellison *et al*. 2005[14]; Morrison 2009[27]; Caro 2010[9]);
e. Flagship species: A species that is easily able to win over the public with its endearing traits and good conservation status. Usually used to categorise and track the state of the species' conservation (Morrison 2009[27]; Caro 2010[9]);
f. Ecosystem engineer: A species that modifies the physical state of biotic or abiotic supplies to regulate the availability of resources for other species.
g. Foundation species: A species that defines the structure of a community by guaranteeing the stability of local conditions for other species, the stabilisation of fundamental ecosystem processes, and their role in controlling ecosystem changes (Ellison *et al*. 2005) [14]. They are primarily used for ecosystem restoration and conservation (Morrison 2009) [27].

The beetles species used as bioindicators of metal pollution (Zn)

Numerous ecological and environmental applications have embraced indicator species. Numerous insect taxa have been thoroughly examined and are regularly included in research publications on the consequences of environmental changes, including pollution, fragmentation, and land management. These include the following groups: Diplura, Collembolla (Springtails), Coleoptera (Carabidae, Curculionidae, Staphylinidae), and Hymenoptera (Formicidae) (Avgin and Luff 2010 [1]; Bednarska *et al*. 2013 [4]). Because they are easily discovered in many types of terrestrial habitats, carabid beetles (Coleoptera: Carabidae) are often utilised for ecotoxicological investigations (Conti *et al*. 2017) [14]. They have drawn a lot of interest as possible bioindicators of disturbance effects. In a research of *P. oblongopunctatus*, Simon *et al*. (2016) [35] discovered high BAF values for Cu and Zn, suggesting that this species is preferred in the assessment of metal contamination. Furthermore, the carabid *Parallelomorphus laevigatus* has been shown by Conti *et al*. (2017) [11] to be a reliable indicator of hazardous substances. Furthermore, *Chlaenius olivieri* may be a useful indication of heavy metal contamination, according to the findings of Ghannem *et al*. (2016). Lagisz (2008) [20] showed that pollutants can affect Pterostichus oblongopunctatus development and, consequently, fitness. In six species of carabids (*Poecilus cupreus, Pterostichus melanarius, Pterostichus niger, Pseudophonus rufipes, Carabus nemoralis,* and *C. granulatus*), Butovsky (1994) [8] showed that distinct sexual variations were identified, and that males contained less zinc than females. Furthermore, females in Agonum dorsal and A. sexpunctatum populations have the ability to collect larger amounts of microelements (Zn) than males (Novak 1989) [30].

Morphological changes

Morphological changes in beetles serve as effective bioindicators of zinc pollution in ecosystems. Beetles, like many other organisms, are sensitive to changes in their environment, including metal contamination. Here’s how zinc pollution can affect beetles and what morphological changes might be observed.

In the characteristic of carabid species, the female ground beetle had a much higher absolute elytra length (i.e., body size) than the male P. oblongopunctatus (LÖvei & Magura, 2006) [23]. Body size and pollution level had a negative correlation, as expected. There are two possible reasons for the decrease in body size observed in carabids from polluted areas: either the larvae's growth rate is slowed down due to reduced nutrient availability, or the energy allocation is changed. It is hard to measure the real amount of food in the field, so establishing the former is hard. However, a large body of experimental data favours the latter. First, measuring the length of the elytra as well as other characteristics of Poecilus cupreus L., Maryan´ski and colleagues discovered that the size of the elytra shrank decreased as the quantity of metals in food increased (Maryanski *et al*., 2002) [24]. They came to the conclusion that those who consumed food tainted with metals had less energy available for development and fat storage. A second study (Mozdzer *et al*., 2003)[28] supported this finding by showing reduced larval development and survival in P. oblongopunctatus exposed to experimental metals. Despite the fact that both trials used ad libitum meals, a reduction in body bulk and size was noted. Notably, Zygmunt *et al*. (2006) [39] found a positive association between body mass and rising contamination levels of five sites along a metal-pollution gradient in a recent study including P. oblongopunctatus. Although body mass may be an excellent signal of short-term response to stress, it is a poor indicator of long-term response to stress due to its significant daily and seasonal changes, which can be difficult to account for (Den Nijs *et al*., 1996 [13]; Muller & Kaschuba, 1986 [29]). Since elytra length, which is the measure of body size used in this study, is not subject to these variations, it serves as a more reliable predictor of long-term and developmental reactions to stress (Bedick, 2006)[3]. Moreover table 1 shows the descriptive morphological change in species of ground beetles due to zinc exposure.

In contrast to expectations, the growth of flight wings was unaffected by local pollution levels since body size was taken into account while determining both absolute and relative wing length. The primary mode of migration for this species is walking. Despite this, ground beetles are frequently classified as non-flying species. However, other observations indicate that a tiny percentage of individuals actually flee (Lagisz *et al*., 2005) [21]. So it's not impossible that there will be sporadic cases of flight dispersal. It's probable that this species won't be able to detectably alter its wing size in response to environmental changes since the significance of flight dispersal is too low (Matalin, 2003) [25].

Table 1: Following table of morphological changes in ground beetle species due to zinc contamination

Species	Morphological changes	References
Carabus violaceus	- **Body Shape:** Alterations in overall shape, often resulting in a more elongated or distorted body. - **Size:** General reduction in body size.	Mizser *et al*., 2016
Pterostichus melanarius	- **Exoskeleton Structure:** Changes in the texture and rigidity of the exoskeleton, leading to surface irregularities. - **Wings:** Alterations in wing morphology, including deformities and reduced functionality	Bedick, 2006
Harpalus rufipes	- **Body Size:** Noticeable reduction in overall body size. - **Legs:** Malformations and deformities in the legs, affecting mobility and functionality.	Maryanski *et al*., 2002
Amara aenea	- **Reproductive Organs:** Deformities in reproductive structures, potentially impacting reproduction. - **Body Size:** General reduction in body size and alterations in body proportions.	Ward *et al*., 2011
Calathus fuscipes	-**Body Color:** Changes in pigmentation and coloration, often leading to a less vibrant appearance. - **Mandibles:** Alterations in mandible shape and size, affecting feeding and defense mechanisms.	Ruiz *et al*., 2012

Conclusion

Bioindicators are a good means for monitoring the effects of toxic compounds on invertebrates. In conclusion, beetles prove to be highly effective bioindicators for environmental monitoring and assessment. Their diverse responses to changes in habitat quality, pollution levels, and ecological disturbances make them valuable for detecting and evaluating environmental health. The sensitivity of beetles to pollutants and their role in reflecting broader ecological impacts highlight their potential as practical tools for monitoring ecosystem dynamics and guiding conservation efforts. Beetles have demonstrated significant potential as bioindicators for zinc contamination in environmental monitoring. Their sensitivity to zinc exposure allows for the detection of even low levels of contamination, making them effective indicators of environmental pollution. Utilizing beetles as bioindicators can enhance our ability to monitor and manage zinc pollution, offering a practical and cost-effective approach for assessing environmental health and guiding remediation efforts.

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