GROUND BEETLES (COLEOPTERA: CARABIDAE) AS BIOINDICATORS OF HUMAN IMPACT

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ABSTRACT: Bioindicators are broadly used in scientific research to quantify environmental impacts such as the effects of disturbances due to anthropogenic activities. Ground beetles (Coleoptera: Carabidae) are frequently used to indicate habitat alteration since they are affected by anthropogenic activities such as urbanization, crop and forest management, overgrazing by domestic livestock, tourist flow in natural landscapes and soil pollution. Moreover carabids are well known both taxonomically and ecologically, are extremely sensitive to several abiotic and biotic factors, respond quickly to habitat alteration and can be easily and cost-effectively collected by using classic pitfall traps. For these reasons this group of ground-dwelling arthropods are increasingly being used in ecological studies in order to evaluate the environmental impacts of man in terrestrial ecosystems. In this work we present several case studies where carabids were employed as a bioindicator group of metal pollution.

KEY WORDS: bioindicators, carabid, environmental impacts, pollution

Environmental pollution is the release of chemical waste that causes detrimental effects on the environment. Environmental pollution is often divided into pollution of water supplies, the atmosphere, and the soil. In his book *Environmental Chemistry*, Manahan (2004) lists several different types of pollutants, including toxic inorganic and organic compounds, high concentrations of normally innocuous compounds, and heat and noise. While much pollution is produced by the chemical industry, domestic sources include human waste and automobile exhaust (http://www.chemistryexplained.com/Di-Fa/Environmental-Pollution.html).

Environmental pollution has different effects on different living things, including insect groups. The ground beetles (Coleoptera, Carabidae), as their popular English name implies, are largely confined to the ground. Logically, the influence of soil properties on their distribution soon became the subject of interest and experimental study (Thiele, 1977). Some of the especially important chemical properties of the soil which might exert an influence on the distribution of carabids include pH value, sodium chloride and calcium content (Thiele, 1977).

In the context of biodiversity, the term “indicator” is often used with very different definitions. These can be classified into at least four categories: (a) biotic indicators of abiotic conditions (Platen, 1995; Stumpf, 1997); (b) biotic indicators of human practices, including, e.g., pollution sensitive species (Basedow, 1990); (c) goal parameters, which are deducted from normally set nature conservation aims and translate these into measurable features, e.g., species diversity of a certain taxon (May, 1995); (d) correlates of goal parameters, which make it possible to reduce labour and costs in assessing biodiversity and at the same time minimise loss of information (Döring et al., 2003).

A bioindicator can be loosely defined as a species or a species group that reflects the abiotic or biotic state of the environment, represents the impact of environmental change on a habitat, community or ecosystems, or indicates the diversity of other species (McGeoch, 1998). Many species of ground beetles fulfil at least one of these criteria (Rainio & Niemelä, 2003).

Bioindicators are also a good way to monitor the effects of toxic materials on organisms (Bridgham, 1988). This might be difficult to assess through direct toxicity level assessment in nature.

Environmental change can cause different kinds of effects in the indicator species, including physiological changes or changes in species number or abundance (Rainio & Niemelä, 2003). The response of the species can be seen within the organism (e.g. heavy-metal concentrations), at the species level (species number and abundance) or at the community level (relations between species, e.g. pest–predator). Increase or decrease of species number or abundance might be caused directly by changes in abiotic and/ or biotic factors (Blake et al., 1996) or indirectly by change of assemblages of other species (Haila et al., 1994).

Changes in morphological characteristics of organisms have been used successfully as indicators of habitat quality and disturbance (Lagisz, 2008). At the interspecific level, body size generally is expected to decrease with increasing stress, because large organisms are assumed to be more sensitive to environmental disturbance compared with small-bodied, hardy, and fast-reproducing organisms. At the intraspecific level, a similar relationship between body size and environmental stress also is observed (e.g. Lagisz, 2008).

Human activities have caused severe pollution with heavy metals in aquatic and terrestrial ecosystems of many countries (Lagisz & Laskowski, 2008). Because heavy metals are non-degradable, they tend to accumulate in organisms' tissues and can be passed along food-chains, becoming toxic at high concentrations (Hopkin & Martin, 1985; Hopkin, 1989; Lagisz & Laskowski, 2008). Toxic effects can occur at all levels of biological organization, with toxins influencing ecological interactions such as predation, parasitism, competition, and the structure of communities and ecosystems (Hoffman & Parsons, 1994; Walker et al., 2001). Thus, one of the important challenges in ecotoxicology is assessing the effects of pollutants passed to higher levels of food-webs and their wider consequences (Grant, 2002).

In this brief review, we give examples of studies on the effects of some pollutants on ground beetle species. We then consider whether carabid populations or communities can be used as indicators of such pollution.

Effects of metal pollution on individual carabid beetles

As already stated, carabid beetles exemplify the ground-dwelling fauna strongly linked to soil characteristics. They are a well-studied group, frequently discussed in research papers concerning the effects of environmental changes, such as land management, fragmentation, and pollution. This taxonomic group is a poor accumulator of heavy metals; therefore, internal concentration of contaminants cannot be used as simple indicator of exposure levels (Lagisz, 2008). Consequently, direct toxicity of metals on individuals is not expected. However, a few recent studies have shown that accumulated toxic metals in carabid beetles can affect both physiology (Lagisz et al., 2002; Stone et al., 2002; Lagisz & Laskowski, 2008) and susceptibility to additional stressors (Stone et al., 2001). In the carabid *Poecilus cupreus*, high copper levels experienced by the beetle larvae, as well as having a direct toxic effect, altered the locomotor behaviour of the resulting adults (Bayley et al., 1995). This was presumed to result from developmental damage caused in the larval growth stages.

Other studies concerning toxic effects of metals in carabids have concentrated on reproduction parameters (e.g. Lagisz & Laskowski, 2008). Kramarz and Laskowski (1997) described a significant decrease in the number of eggs laid by *Poecilus cupreus*, after zinc treatment. Lagisz et al. (2002) showed a negative correlation between field exposure to chronic pollutants and production of eggs in *Pterostichus oblongopunctatus* collected along a metal-pollution gradient near Olkusz. Generally body size is likely to be reduced by pollution stress (Lagisz, 2008) but Zygmunt et al. (2006) found that the body size of *P. oblongopunctatus* actually increased along a gradient of increasing metal contamination. The calorific content of the beetles was not altered. The authors attributed the increase in body size to altered interspecies competition. This implies that other, competing, species were more adversely affected by the pollution, but more work would be needed to prove this. Skalski et al. (2002) showed that the timing of the seasonal occurrence and therefore phenology of ground beetles varied along a pollution gradient.

A few studies have shown the negative influence of metal pollution on gamete quality (Au et al., 2001) and hatchability of invertebrate eggs (Schmidt et al., 1992; Gomot 1998). In line with the above findings, it has been shown that quality of eggs produced by *P. oblongopunctatus* can be affected by metal pollution (Lagisz & Laskowski, 2008). In heavily air-polluted pine forests, genetic studies showed that the degree of polymorphism in various Coleoptera, including Carabidae, increased within the centre of pollution (Schneider et al., 1984).

The low hatching rate of eggs laid by females collected from the contaminated site suggests that *P. oblongopunctatus* is not fully able to protect developing eggs from toxic effects of metals (Lagisz & Laskowski, 2008). If this is the case, chronic long-term effects of metals are likely to be more dangerous in this species, especially if they are subjected to additional stressors causing reduction of egg production and/or life-span (Lagisz & Laskowski, 2008).

Any effects of pollutants may also interact with, or be dependant on, other environmental variables such as temperature (Bednarska & Laskowski, 2008). Bednarska et al. (2008) showed that the effect of nickel pollution on adult *P. oblongopunctatus* interacted not only with temperature, but also with that of the pesticide chlorpyrifos. A later study has shown that the same interactions affect the larval stage of the same species (Bednarska & Laskowski, 2009).

Maryański et al. (2002) found that feeding *Poecilus cupreus* with food contaminated by either zinc or cadmium resulted in smaller adults, but their body mass and calorific value was not reduced. Zinc concentrations were regulated in the beetles and were independent of contamination level, whereas cadmium accumulated and its concentration in the beetles increased with increasing contamination level: this has implications for higher predators that might feed on the carabid beetles. Lagisz (2008) also showed an effect of long-lasting, heavy metal pollution on the morphology of *P. oblongopunctatus* from heavily contaminated sites. The smaller adult body size of the beetles, expressed as shorter elytra, may reflect lower habitat quality. Such a change in body size may incur long-term negative effects of metal pollution on fitness (Lagisz, 2008).

Lagisz & Laskowski (2008) presented one of very few studies showing intergenerational effects of terrestrial pollution by heavy metals in a terrestrial predatory invertebrate. They demonstrated that *P. oblongopunctatus* inhabiting metal polluted environment have altered life-history parameters in comparison to those from reference area populations.

Effects of metal pollution on carabid assemblages

Despite these effects on individual species, there are relatively few examples of an overall population or community effect of pollution on carabid beetles. Šustek (1994) showed that nickel pollution reduced the species numbers of three families of beetles including Carabidae, as well as causing changes in carabid sex ratios. Read et al. (1987) found that the numbers of individuals and species of Carabidae at each site along a heavy metal gradient were not significantly correlated with metal concentration. However, species diversities (Shannon Weiner H') were correlated with the pollution level. Later dates of median capture of total Carabidae were found in the sites nearest to the pollution source. This also occurred with a common species, *Nebria brevicollis*. At the most polluted site, this species also showed an absence of its usual summer diapause, possibly related to scarcity of prey. Numbers of spring breeding species were negatively correlated with metal concentration but autumn breeders were positively correlated. The sites were also differed significantly in the relative distributions of individuals in each of four size categories.

However, in a subsequent ordination analysis of the same sites (Read et al., 1988) no clear patterns were shown when examining size or breeding season in carabids in relation to pollution. A similar study by Lock et al. (2001) concluded that activity and species richness of carabid beetles were not significantly correlated with total zinc concentration nor with the water-soluble and the calcium chloride extractable concentration. In fact, despite the high soil concentrations, carabid beetles did not seem to be affected in the study area. Jarošík (1983) also found no difference in carabid diversity in floodplain forests affected by different emissions of carbon disulphide and hydrogen sulphide.

CONCLUSIONS

It is evident from this relatively superficial review, that metal pollution, although not necessarily toxic to the ground beetle species studied, can affect their physiology, behaviour and reproductive ability. Despite this, there may be no clear effects on carabid assemblages in the field. The lack of overall community effects in some studies may be because diversity indices are not a suitable way of assessing the impact of environmental change on ground beetles. Belaoussoff et. al. (2003) found that there was no single diversity index or model that was better than any other at detecting disturbance. Their results were supplemented by a meta-analysis of 45 published data sets for the same taxon but in different habitats. They concluded that diversity indices and models are not useful for detecting the possible effect of disturbance on assemblages of carabid beetles. In a review of ground beetles as bio-indicators, Rainio & Niemelä (2003) also concluded that there is not enough research to determine how suitable carabids are for biodiversity studies, or how well they represent the response of other species. They concluded that carabids are useful bioindicators, but as crucial understanding of their relationship with other species is incomplete, they should be used with caution.

A further limitation of existing work on the effects of metal pollution on ground beetles, is that much existing recent work, as cited in this review, has been carried out on a restricted range of species in the genera *Pterostichus* and *Poecilus*, which latter genus was until recently considered as part of *Pterostichus* anyway. These species are relatively large, can be collected in substantial numbers and are rearable in the laboratory; they are also predatory so that the effects of contaminated prey organisms can be assessed. However many other carabids have differing life styles, including those that are either omnivorous scavengers, or which feed partially or even entirely on plant matter, including seeds. This includes many of the large tribes Harpalini and Zabriini, with speciose genera such as *Harpalus* and *Amara*. It is evident that the species of ground beetles already studied show marked effects of metal pollution. But only when similar studies are applied to a much wider range of carabid species will we be able to understand more fully any interspecific interactions, or the effects of metal pollution on these beetles at the assemblage or community level.

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