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Influence of cadmium-contaminated soil on earthworm communities in a subtropical area of China

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ABSTRACT

Research was conducted to examine the influence of historical cadmium (Cd) contamination and soil properties on the biomass, diversity and structure of earthworm communities in a subtropical area (Hunan province) of South China. Fourteen earthworm species were identified across the twelve field sampling sites. *Metaphire californica* was the most widespread and dominant species. Results showed that both earthworm density and the Simpson diversity index decreased inversely with increasing soil Cd concentrations. The proportion of adult earthworms was greater in soils with high levels of Cd contamination. The abundance of earthworms was also correlated with soil organic carbon and total nitrogen contents. Cd concentrations in *M. californica* were well predicted by both the total and available soil Cd concentrations ($R^2 = 0.83$, $R^2 = 0.90$, $p < 0.01$, respectively), and suggested that this species may have particular applications for risk assessment and use in bioremediation.

1. Introduction

Over several decades, the mining, smelting, and other industrial activities of metal ores has resulted in soil pollution, which is now a serious problem in many areas across the world. A joint report on the current status of soil contamination in China issued by the Ministry of Environmental Protection (MEP) and the Ministry of Land and Resources (MLR) of China indicates that cadmium (Cd) ranks first among the metals and metalloids of concern based on the percentage of soil samples (7.0%) that exceed the limits established by the MEP (MEP and MLR, 2014). Among the potentially toxic elements that are introduced into the environment, Cd is generally more mobile than other metals and can cause acute or chronic toxicity to living organisms (Sparks, 2003; Steinnes and Friedland, 2006; Kirkham, 2006; Smith, 2009; Alguacil et al., 2011; Margesin et al., 2011; Aghababaei et al., 2014). Recently, the concentrations of metals in soils in some areas of southern China such as Hunan Province still appear to be increasing. Minimizing the transfer of contaminants from soil to the food chain has therefore become a top priority, and numerous studies have been carried out in this area to examine the potential for Cd exposure to the food chain and methods for remediation of contaminated soils to better assure food safety (Zhao et al., 2015, Williams et al., 2009; Schreck et al., 2012; Austruy et al., 2013; Liu et al., 2013). However, there have been relatively few studies focusing on how the earthworm communities vary with different levels of metal contamination in the field. Such information is needed as baseline information to evaluate of impact of metals on the earthworms, which may be used as bioindicators for risk assessement of soil contaminants.

Earthworms are key members of the soil fauna, and have important roles in many soil functions (Nahmani et al., 2007), being involved in nutrient cycling, soil organic matter decomposition, and modification of soil structure, all of which affect plant productivity (Edwards and Bohlen, 1996; Butenschoen et al., 2009; Koutika et al., 2001). By incorporating organic matter into the soil and soil mixing, earthworms also influence the distribution and bioavailability of contaminants in soils (van Gestel et al., 2009). They are increasingly recognized as indicators of soil health and serve as ecotoxicological sentinel species that are constantly exposed to soil contaminants (Lanno et al., 2004; Suthar et al., 2008; Pérès et al., 2011; Lévêque et al., 2013).

At present, a large set of ecotoxicological data on contaminated soils has been collected for diagnosis and evaluation of ecological risks. Most studies on metal toxicity to earthworms have been carried out using methods that examine the effects of short-term exposure to high doses of metals in freshly-spiked soil (OECD, 1984; Depledge and Fossi, 1994; Martikainen, 1996; Lowe and Butt, 2007; Ramadass et al., 2015; Asensio et al., 2007; Lijun et al., 2005; Hobbelen et al., 2006; Hankard

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et al., 2004). However, such tests do not accurately reflect the actual type of exposure or the potential toxicity of metals that occurs in the field, where soils are instead slowly contaminated over time through processes involving wet and dry deposition and metal availabilities are affected by long-term partitioning into different mineral phases and compartments (Bolan et al., 2014; Li et al., 2014; Nannoni and Protano, 2016). Information gathered from laboratory studies thus might not comprehensively provide useful information for ecological risk assessment of contaminated soils (Nannoni et al., 2014). Laboratory studies also ignore the adaptability of organisms to long-term environmental contamination, and may overestimate the risks of metals to earthworms where the indigenous communities are comprised of members having different levels of metal tolerance (ISO 11268-2, 1998; OECD 222, 2004; McBride et al., 2009; Smolders et al., 2009; Spurgeon and Hopkin, 1995).

To address these concerns, some authors have performed field studies or have exposed earthworms to field-contaminated soils in the laboratory (Hobbelen et al., 2006; Nahmani et al., 2009; Pérès et al., 2011; Lévêque et al., 2013; Nannoni et al., 2014; Beaumelle et al., 2016). In addition, it is recognized that variations in soil chemical factors, and the adaptability and tolerance of different earthworm species also affect earthworm community composition and structure (Pérès et al., 2011; Vijver et al., 2003; Harmsen, 2007; Peijnenburg et al., 2007). In field-contaminated areas, sensitive earthworm species may decrease in abundance or even disappear when they are exposed to heavily polluted soil, and earthworm community structure tends to become simplified or unstable. Despite these apparent differences in metal tolerance, many studies have still used sensitive species for the assessment of environmental risks, ignoring the advantages of tolerant species that might dominate contaminated areas. The latter species also may have the ability to bioaccumulate metals to higher levels, in this way potentially contributing to their food-chain transfer (Vijver et al., 2003; Hobbelen et al., 2006; Harmsen, 2007; Peijnenburg et al., 2007). Therefore, this study was aimed at understanding the variation of earthworm community composition and metal bioaccumulation in dominant species in field-contaminated soils, and addresses differences in earthworm species that are relevant to the use of earthworms for ecological risk assessment and soil remediation.

The research described here was carried out in Hunan province, a subtropical area of South China, which has severe metal contamination due to the historical mining and metal smelting activities. We aimed to investigate (i) the earthworm community structure, species composition in different levels of historical contaminated soil; (ii) the impact of soil properties on earthworm community; (iii) the uptake and accumulation of Cd in the dominant earthworm species. The effects of soil contaminants on earthworms in field experiments are influenced by multiple interacting factors. By investigating the earthworm community from various perspectives (species composition, density, diversity and biomass), we hope to achieve a better understanding in the risk of metals on earthworm communities.

2. Materials and methods

2.1. Location and site descriptions

This study was conducted in the vicinity of the cities of Changsha (E113°04″30′, N28°02″30′), Zhuzhou (E113°04″42′, N27°54″26′) and Hengyang (E112°47″29′, N27°00″20′) in Hunan province, south China. The specific coordinates of the sample locations and site elevations are shown in Table 1, the elevations of the sites ranged from 59 to 70 m. Before the survey, site selection criteria were defined as: located near an abandoned industry/factory at distances of 0.5–2 km, similar land use (agricultural land) with loam-based typical red soil. The general area has a subtropical monsoon climate, with mean annual temperatures ranging from 16 °C to 19 °C and average annual precipitation ranging between 1200 and 1700 mm. The pollution sources in the study

Table 1
Mean soil properties and metal concentrations of the selected sampling sites in Hunan province, south China (n = 5, ± SE).

Site	Latitude	Longitude	Elevation (m)	pH	CEC (cmol kg^{-1})	SOC (g kg^{-1})	TN (g kg^{-1})	Pb (mg kg^{-1})	Cu (mg kg^{-1})	Zn (mg kg^{-1})	Cd (mg kg^{-1})	DTPA-Cd (mg kg^{-1})
S1	28°25′44″	113°08′13″	66	6.0 ± 0.3	18.1 ± 0.9	21.2 ± 1.0	3.0 ± 0.2	66.8 ± 2.1	24.9 ± 1.4	123 ± 7.3	0.81 ± 0.2	0.2 ± 0.0
S2	28°27′01″	112°56′60″	69	5.3 ± 0.1	16.1 ± 0.4	20.8 ± 1.0	3.1 ± 0.3	78.6 ± 6.9	28.8 ± 3.2	130 ± 16.0	1.31 ± 0.2	0.2 ± 0.1
S3	28 °28′15″	112°54′13″	63	5.3 ± 0.1	16.0 ± 0.3	18.2 ± 2.1	3.2 ± 0.1	67.2 ± 2.2	55.0 ± 9.0	131 ± 10.4	1.75 ± 0.1	0.3 ± 0.1
S4	28°21′59″	113°05′39″	68	6.2 ± 0.2	18.9 ± 0.7	18.5 ± 1.5	2.9 ± 0.4	64.8 ± 5.0	19.5 ± 1.8	140 ± 7.1	2.39 ± 0.2	0.6 ± 0.1
S5	26°32′46″	112°28′03″	64	6.1 ± 0.3	18.8 ± 0.8	18.5 ± 1.1	2.9 ± 0.3	102 ± 10.5	207 ± 14	164 ± 32.9	3.45 ± 0.7	1.4 ± 0.2
S6	28°24′34″	112°53′16″	59	5.8 ± 0.3	17.4 ± 1.0	18.3 ± 0.9	2.1 ± 0.3	58.4 ± 4.0	20.1 ± 1.4	127 ± 10.7	4.03 ± 1.0	1.3 ± 0.6
S7	26°59′51″	112°26′38″	70	6.7 ± 0.3	15.4 ± 0.3	17.0 ± 1.4	2.2 ± 0.3	78.7 ± 5.3	24.4 ± 1.1	227 ± 22.4	4.30 ± 1.0	2.2 ± 0.3
S8	28°21′48″	113°10′32″	65	5.6 ± 0.1	17.1 ± 0.4	15.8 ± 1.4	2.4 ± 0.3	61.3 ± 4.4	23.9 ± 1.8	129 ± 2.0	4.53 ± 0.4	2.1 ± 0.2
S9	27°06′05″	112°29′28″	61	6.3 ± 0.2	19.4 ± 0.6	19.5 ± 0.7	2.7 ± 0.1	127 ± 18.3	39.8 ± 1.7	131 ± 4.3	4.65 ± 0.8	1.8 ± 0.3
S10	27°21′43″	113°08′05″	70	6.0 ± 0.1	18.3 ± 0.5	21.4 ± 0.7	3.0 ± 0.2	158 ± 8.9	55.8 ± 3.2	276 ± 26.6	5.11 ± 1.0	1.2 ± 0.3
S11	26°32′20″	112°26′39″	66	6.5 ± 0.2	20.1 ± 0.3	20.8 ± 0.4	3.0 ± 0.3	429 ± 32.2	217 ± 22.7	160 ± 10.9	7.49 ± 1.5	2.2 ± 0.5
S12	27°00′13″	112°28′27″	70	6.7 ± 0.1	15.4 ± 0.4	18.6 ± 2.1	2.1 ± 0.2	139 ± 16.4	26.6 ± 1.6	374 ± 42.4	17.8 ± 2.6	9.7 ± 1.8
Mean				6.02	17.7	18.9	2.67	119	54.1	176	4.8	1.92
Maximum				4.88	14.2	12.2	1.24	45.7	12.9	95.2	0.18	0.06
Minimum				7.24	22.4	24.9	3.93	528	229	505	24.1	14.1
Threshold [a]								250	50	200	0.3	

Abbreviations: CEC, cation exchange capacity; SOC, soil organic carbon; TN, total nitrogen; DTPA-Cd, DTPA-extractable Cd.
[a] Threshold based on Chinese Environmental Quality Standard for Soils (GB 15618-1995) (State Environmental Protection Administration of China, 1995).