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Ranking field site management priorities according to their metal transfer to snails

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ABSTRACT

Current soil quality evaluation does not include an assessment of metal bioavailability to organisms. However, sentinel soil-dwelling invertebrates can be used for such an assessment. This study aims to establish the modulating soil parameter of metal bioavailability to snails and a procedure for ranking field sites ($n = 9$; 43 plots) based on the evaluation of the transfer of metals to the land snails used as indicators of metal zooavailability. Multivariate regressions identify soil pH, organic carbon and iron oxides influence cadmium, chromium, copper, lead and zinc zooavailability to snails underlining the need to consider other parameter than total soil concentration during bioavailability assessment. However, for As, no influence of soil parameter on it bioavailability to snails was identified. Internal Concentrations of Reference (CIRef) of Cd, Pb, As, Cr, Cu and Zn were determined in *Cantareus aspersus* that were caged on unpolluted plots. CIRef allow for the identification of contaminated sites. CIRef have revealed unexpected metal transfer on some "unpolluted" sites and a lack of transfer on some contaminated sites, thus confirming the necessity for biological measures to evaluate metal mobility. The Sum of Excess of Transfers (SET) index ranked the industrially impacted sites as the top priorities for management.

We recommend that the SET methodology be used for future environmental risk assessment. By highlighting real metal transfers and considering the numerous parameters influencing environmental bioavailability, the snails watch provides information on environmental quality.

1. Introduction

Current risk assessment procedures assume that the total amount of metal contaminants in soil is available for uptake by organisms, including humans. For instance, risk management in France (IEM, 2007) focuses first on soil use (*e.g.*, gardens and parking) and secondly on the estimated exposure, based on the total concentration of metal in the soil. However, it is now recognized that soil characteristics such as pH or organic matter content (OM) influence the environmental and toxicological bioavailability of metals (Lanno et al., 2004; van Gestel, 2008) to organisms such as earthworms (Nahmani et al., 2007) or snails (Pauget et al., 2011). To prevent misinterpretation, soil risk assessment must consider metal transfer, based on the total concentration, as modulated by soil characteristics and for selected ecological receptors (Allen,

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2002; Luoma and Rainbow, 2005). Toward this aim, using biological data, such as the internal concentration of contaminants in soil invertebrates, is suitable because it considers both physicochemical and biological processes that modulate metal transfer from the soil to fauna. Living at the interface between soil, plants and air, snails provide information on both the retention and habitat functions of soil (ISO 17402, 2008). Moreover, the garden snail, as several land snail species, is involved in transfer of trace elements in food webs, because of its abilities to accumulate great amounts of metals in soft tissues and its position in trophic webs (detrivorous and herbivorous species, being dietary item of numerous invertebrate and vertebrate predators) (Allen, 2004; Gomot-de Vaufleury and Pihan, 2002; Laskowski and Hopkin, 1996). Snails are efficient soil quality bioindicators for *in situ* soil surveys using passive biomonitoring of wild organisms (Berger and Dallinger, 1993; Mourier et al., 2011). However this approach based on native populations among which differences may exist can confound simple comparisons between sites (Beeby, 2001). Thus, if the purpose is to compare bioavailability of contaminants between sites, active biomonitoring based on matched transplanted individuals of known feeding histories to reduce size variability and within site variability is recommended (Beeby and Richmond, 2003). Such as an assessment of metal transfer by analyzing the internal concentrations of chemicals in *Cantareus aspersus* with a known biological past, with the snails being caged for given durations on the studied sites (Fritsch et al., 2011). This approach first provides information regarding the bioavailability to snails of the metals in soils, and second provides information on the amount of contaminants in the soil that could be transferred through terrestrial food chains involving snails and their consumers (Soto et al., 2011; Vermeulen et al., 2010), including humans in some countries. Although the land snail *C. aspersus* has already been used in active biomonitoring for many metals on various field sites (Gomot de Vaufleury and Pihan, 2000; Regoli et al., 2006), no large-scale attempt to create a framework usable for risk assessment has been performed. Moreover, while the influence of soil properties on metal bioavailability to snails has been investigated under laboratory conditions (Pauget et al., 2011), it has never been quantified *in situ*.

To improve soil quality assessment and risk management of contaminated sites by using relevant soil quality bioindicators, a French program has been run for 3 years on 12 field sites (Bioindicators program, Bispo et al., 2009). Within this framework, the present study aims to determine the metal concentrations of the land snail *C. aspersus* caged in unpolluted sites; the internal concentrations of reference (CIRef) were determined for cadmium (Cd), lead (Pb), arsenic (As), chromium (Cr), copper (Cu) and zinc (Zn). The CIRef were then be used to distinguish sites that present metal transfer to snails. The second objective is to determine how metal accumulation in snails is influenced by soil properties using mono- and multivariate regressions. The third objective is to develop a method to evaluate the transfer of metals, using the CIRef to synthesize data of sites contaminated with multiple metals and to determine handling priorities, based on the total metal concentration in soil and biological assessments of metal bioavailability.

2. Materials and methods

2.1. Animals

Juvenile land snails (*C. aspersus*), obtained from our laboratory breeding and reared under controlled conditions until the age of 7–9 weeks, as described by Gomot-de Vaufleury (2000), and fed with uncontaminated (0.353 mg kg^{-1} Cd dry weight (DW), 0.696 mg kg^{-1} Pb DW, 1.11 mg kg^{-1} As DW, 14.5 mg kg^{-1} Cr DW, 10.4 mg kg^{-1} Cu DW, 182 mg kg^{-1} Zn DW) commercial snail meal (Helixal®, Berthon S.A., France). Snails used for the exposure were lab-reared subadultes and weighing 5.0 ± 0.6 g (n = 1230). This stage was selected to avoid strong modification of mass that occurred in fast growing snails or during reproduction that can confound the interpretation of changes in internal concentration of contaminants (Gimbert et al., 2008). At the beginning of the exposure, the metal concentrations in the snails' viscera were 0.73 ± 0.10 mg kg^{-1} Cd DW, 0.59 ± 0.26 mg kg^{-1} Pb DW, 0.33 ± 0.11 kg^{-1} for As DW, 2.19 ± 0.48 mg kg^{-1} Cr DW, 139 ± 40.1 mg kg^{-1} Cu DW and 881 ± 182 mg kg^{-1} Zn DW (mean ± SD, n = 10).

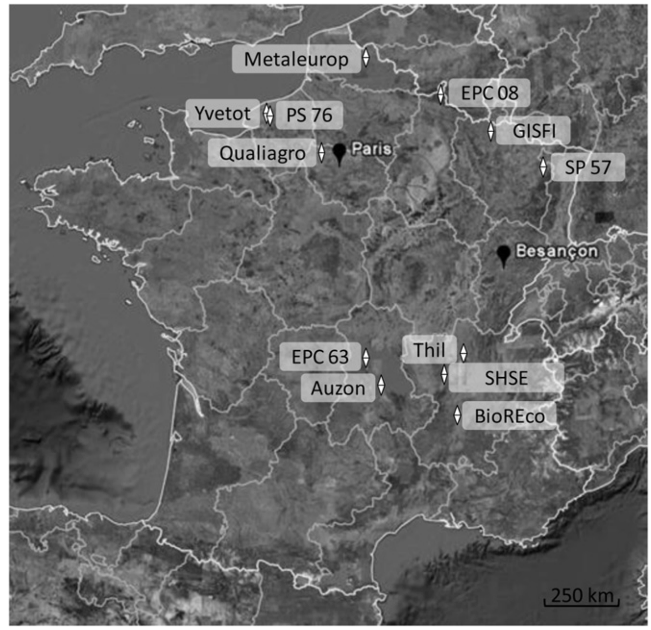

Fig. 1. Sites localization of the bioindicators program. http://ecobiosoil.univ-rennes1.fr/ADEME-Bioindicateur/.

2.2. Soils

Nine sites were selected throughout France, falling into three categories (cultivated sites, forests and contaminated sites) and five land uses (forest, arable, pasture, woodland and wasteland) (Fig. 1, http://ecobiosoil.univ-rennes1.fr/ADEME-Bioindicateur). These sites represent a large range of metal contamination and soil parameters, as summarized in Table 1 and in supplementary data (Table S1). The sites of Auzon, Metaleurop, the slag heap of Saint-Etienne (SHSE) and GISFI are sites impacted by industrial activities, which generally have high soil metal pollution (Table 1). The forest sites, part of the RENECOFOR network (http://www.onf.fr/renecofor), have low metal concentrations in their soils (Table 1). The sites of Qualiagro (Houot et al., 2002), BioREco, Yvetot and Thil are cultivated sites and have slight metal concentrations in soils (Table 1). Some of the sites were studied in 2009 (Qualiagro, Metaleurop, F08, F57, GIS-FI) and were previously described in Pérès et al. (2011). A brief description of the sites studied in 2010 is given below:

The Auzon site (45°23′12N, 03°21′32E) is an industrial waste site with trace element contamination, such as arsenic. Six plots (4 contaminated "Co", 2 controls "Ct") were selected according to a metal pollution gradient (from 62 to 3600 mg kg^{-1} As) and vegetation cover (woodland "W", woodland on hydromorphic soil "WW", woodland hedge "WH" and wasteland "Wa").

The SHSE site is a metallurgical landfill near Saint-Etienne (45°43′N, 4°39′E), with high metal contamination combined with