Risk analysis of heavy metal contaminated habitats using a wolf spider, *Pardosa astrigera* (Araneae: Lycosidae)

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Abstract

Using biological indicators to evaluate the healthiness of ecological habitats is increasingly important. Spiders are considered very useful candidates for this purpose, but few studies have been conducted. This study was conducted to investigate a relationship between heavy metal (cadmium (Cd) and lead (Pb)) contamination levels in soil habitats and their accumulations in a wolf spider, *Pardosa astrigera,* and to develop a bio-evaluation system for soil risk assessment of Cd and Pb using *P. astrigera*. Contents of Cd and Pb in a female adult *P. astrigera* and soil were estimated in nine sites in September, 2004 in Korea. Cd and Pb contamination levels in soil were well described by the Cd and Pb content of female adult *P. astrigera* by power functions. A bio-evaluation system is proposed for a soil risk assessment of Cd and Pb with *P. astrigera* using the amount of bioaccumulation and the lethal body concentration.
Keywords: Pardosa astrigera, heavy metal, Cd, Pb, biological indicator, bioaccumulation.

1 Introduction

The practical soil quality evaluation methodology has not been improved much because the progress in soil ecology theory has not led to practical strategies for soil evaluation [1]. One way of improving soil quality evaluation methods is to develop ecological indicator systems that can be used in soil quality assessments. Ecological indicators are useful instruments to bridge the gap between soil science and soil regulation practice [2].

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Heavy metals (*e.g.* Cd and Pb) are commonly investigated components of soil pollution because of their toxicity and stability. Field and laboratory studies were carried out to investigate bioaccumulation and effect of heavy metals on soil invertebrates [3–10]. However, few attempts have been made to predict heavy metal contamination levels in soil by estimating bioaccumulation of heavy metals in soil invertebrates. Although direct measurement of soil for heavy metal contamination is useful, it may be costly and often incorrect because of high variation in soil contaminations within the site. In this regard, using biological indicators for evaluation of healthiness of ecological habitats for heavy metal contamination is perhaps more reliable because actively moving carnivorous arthropods can cover a relatively wide range and accumulate heavy metals by bio-concentration through a food chain as well as by direct soil contact in the habitats. Spiders are considered very useful candidates for this purpose. Ground-dwelling hunting spiders may reflect the pollution level of their habitats better than web-building spiders [11]. *Pardosa astrigera* can be a good candidate because it is a ground-dwelling hunting spider, can be easily sampled, is one of the dominant species in terrestrial ecosystems and its major diets are springtails and dipterans which inhabit soil [12–14].

Objectives of this study, therefore, are to quantify relationships between Pb and Cd levels in soil and their accumulations in a wolf spider, *P. astrigera* and to develop a bio-evaluation system for soil risk assessment of Pb and Cd using *P. astrigera*.

2 Materials and methods

2.1 Study sites and sampling methods

Five agricultural (A, B, F, H, and I), two residential (C and G), and two industrial sites (D and E) were selected according to expected differences in Cd and Pb contamination levels in soil (Figure 1). Five sites (A, B, C, D, and E) were selected along the Singil stream between Ansan and Sihueng city in Korea. Residential and industrial sites were located along the Singil stream.

Hand-collecting was used to collect female adult *P. astrigera* in each site to estimate bioaccumulation in September, 2004. Thirty individuals were collected at the same time from each site. Three topsoil samples (ca. 500g each) were taken at the area where spiders were collected.

2.2 Exposure of heavy metals and determination of heavy metal contents in *P. astrigera* and soil

Cd and Pb levels in field sampled soil and female adult *P. astrigera* were measured. For the measurement of heavy metal content in the spiders, five *P. astrigera* were grouped as one and measured. Thus, six measurements were made for each site. For measurement of soil, three measurements were made for each site. Also, dry weights of examined *P. astrigera* were measured.

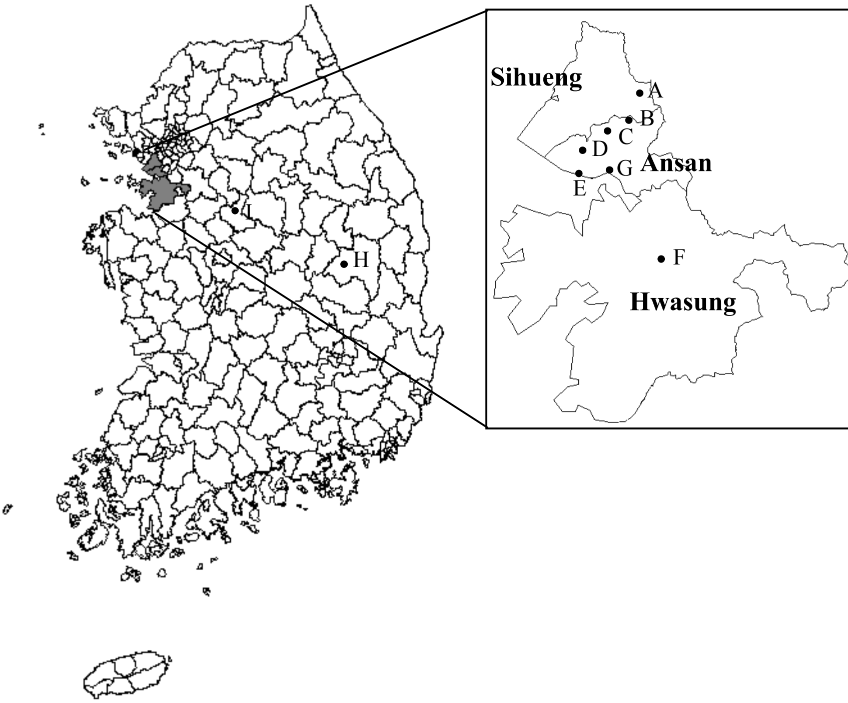

Figure 1: Map of study sites.

Female, sub adult or adult *P. astrigera* were collected from the unpolluted site and were exposed to Cd and Pb by dietary uptake in the laboratory. Adult *Drosophila melanogaster* reared by exposing Cd 10mg/kg and Pb 100mg/kg, respectively, were used as foods. Three fruit flies per day were provided to individual *P. astrigera* until *P. astrigera* died. Then, Cd and Pb levels of five *P. astrigera* were analyzed to estimate lethal body concentration. Ten replications were conducted in this experiment. Also, dry weight of examined *P. astrigera* was measured.

For the measurement of Cd and Pb, ICP (Inductively Coupled Plasma Emission Spectrometer) was used at the NICEM (National Instrumentation Center for Environmental Management) in Seoul National University.

2.3 Statistical analysis

Power functions were used to describe the relationship between bioaccumulation of *P. astrigera* and heavy metal contents in soil. The equations are:

$$y_1 = a_1 + b_1 x_1^{c1} \quad (1)$$

$$y_2 = a_2 x_2^{b2} \quad (2)$$

where, y_1 and y_2 are Cd and Pb concentration in soil, respectively. x_1 and x_2 are Cd and Pb concentration in female adult *P. astrigera*, respectively.

3 Result and discussion

3.1 Relationship of bioaccumulation of *P. astrigera* and concentration in soil of Cadmium and Lead

The lethal concentrations of Cd and Pb for *P. astrigera* in this experiment were measured. The Cd and Pb concentration in the female adult *P. astrigera* and soil varied among sites: very high in site C, E, and G (residential or industrial sites), low in site A and I (agricultural sites) (Table 1). The Cd concentration in *P. astrigera* was higher by 10-700 times than that in soil. The Pb concentration in *P. astrigera* was higher by 1-20 times than that in soil. It was reported that spiders accumulated Cd, Cu, and Zn to the concentrations greater than those present in the soil but did not accumulate Pb [11]. Like *Steatoda bipunctata* (Theridiidae) [14], *P. astrigera* may behave as a regulator for Pb, which accumulates heavy metals to a certain level and then excretes them beyond the level, but as an accumulator for Cd.

Table 1: Mean concentration of cadmium and lead in female adult *P. astirgera* and soil.

Sites	Cd (μg/g)		Pb (μg/g)	
	Female adult	Soil	Female adult	Soil
A	7.14	0.03	37.97	1.60
B	11.33	0.25	51.35	8.50
C	17.04	1.46	79.31	52.20
D	22.79	0.27	61.35	17.20
E	36.60	1.41	101.78	96.70
F	16.17	0.10	66.55	2.80
G	30.14	0.95	105.96	69.50
H	8.00	0.28	69.93	30.20
I	7.20	0.01	53.88	2.70

The relationship between bioaccumulation of female adult *P. astrigera* and heavy metal concentration in soil was well described by power functions (Figure 2). However, these models must be applied to the conditions of <2mg/kg for Cd and <120mg/kg for Pb in soil, respectively because two models were developed using *P. astrigera* collected in mostly moderately contaminated habitats. Further calibration studies may be needed in habitats of a higher contamination level.

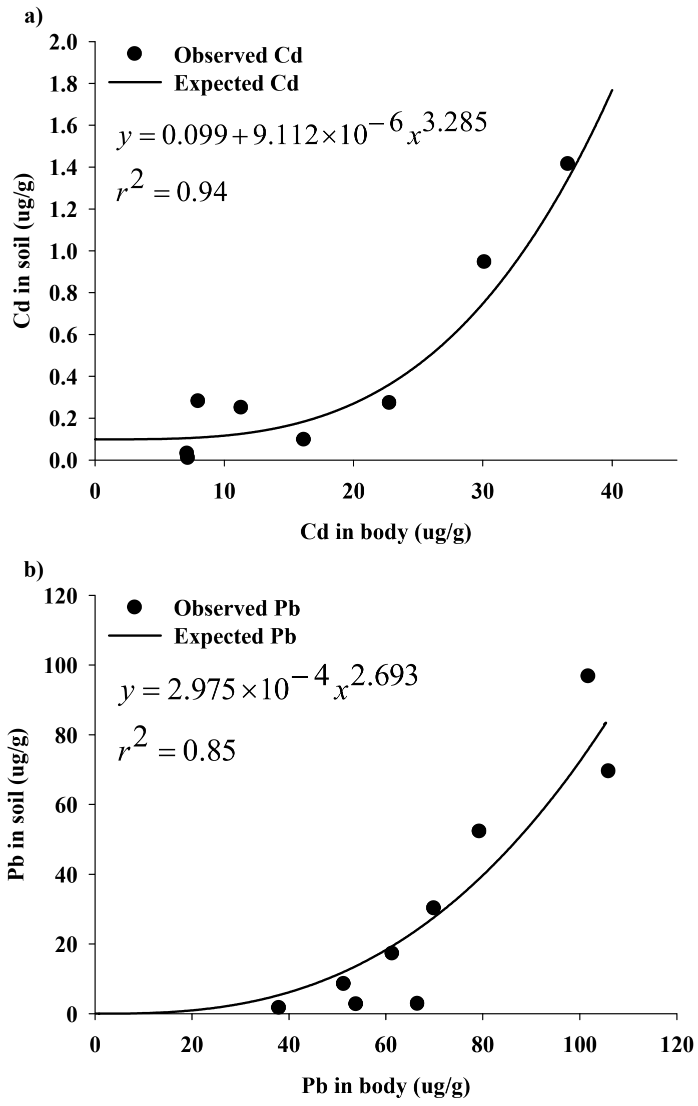

Figure 2: Relationships between heavy metal content in adult female of *P. astrigera* and soil. a: Cd, b: Pb.

3.2 Use of *P. astrigera* in risk assessment of heavy metal contamination in soil

The bio-indicator index for toxicant residues, β, as the average of the quotient of the observed residue in a species and the internal threshold concentration, and the reference system for evaluating bio-indicator index for toxicant residues (Figure 3a) were proposed by van Straalen [10]. The bio-indicator index for toxicant residues can be interpreted as the fraction of the internal threshold concentration that is occupied by the residue: *e.g.* <0.01 as negligible risk in the reference system. In our study (*i.e.* the modified reference system), the threshold of negligible risk was modified as <0.02 because the amount of bioaccumulation of *P. astrigera* was very diverse from 0mg/kg to 20mg/kg for Cd, and from 0mg/kg to 60mg/kg for Pb in uncontaminated sites. In Korea, action level for Cd and Pb contamination in soil is 4 mg/kg and 300 mg/kg in agricultural areas, respectively. The modified reference system is shown in Figure 3b.

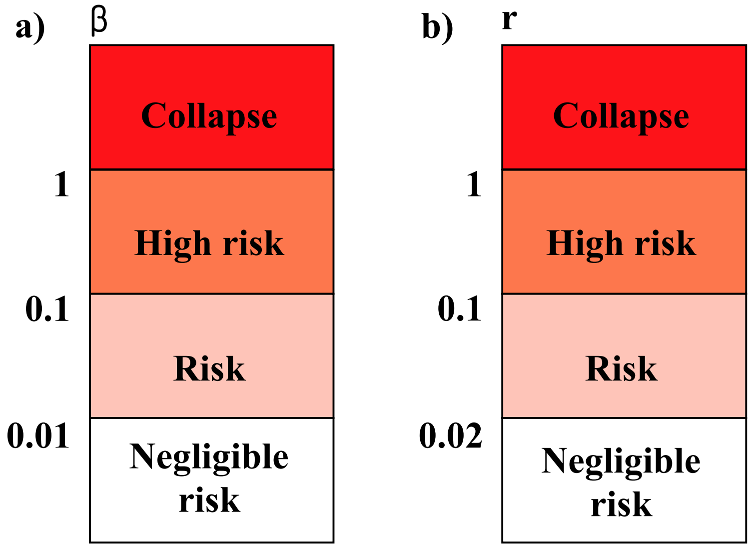

Figure 3: a) The reference system for evaluation the bioindicator index for toxicant residues, β proposed by Van Straalen [10]. b) The modified reference system for evaluation the heavy metal contamination in soil. r is risk ratio (the quotient of the observed residue in a species and the internal threshold concentration).

In the laboratory experiment, estimated lethal body concentration (mean±s.e) of *P. astrigera* for Cd and Pb was 1,050.5±18.61mg/kg and 3,122.8±35.04mg/kg, respectively. Using these values, the risk ratios (the quotient of the observed residue in a species and the internal threshold concentration) for study sites for Cd and Pb were calculated (Table 2). According to the modified reference system, for Cd, the site A, B, C, F, H, and I were characterized as a negligible risk zone, while the site D, E, and G were evaluated as a risk zone. For Pb, the site A, B, and I were evaluated as a negligible risk zone while other sites were as a risk zone. This system is highly compatible with direct measurement of soil and is applicable for evaluation of soil habitat contamination.

Further calibration and validation studies are necessary since there are some limitations in using lethal body concentration [10]: *e.g.* physiological conditions and presence of other metals in the body can affect the lethal dosage.

Table 2: Risk assessment of this nine study sites using risk ratio (r) estimated from Cd and Pb concentration in *P. astrigera*.

Sites	Cd		Pb	
	Observed residue	r	Observed residue	r
A	7.14	0.007	37.97	0.012
B	11.33	0.011	51.35	0.016
C	17.04	0.016	79.31	0.025
D	22.79	0.022	61.35	0.020
E	36.60	0.035	101.78	0.033
F	16.17	0.015	66.55	0.021
G	30.14	0.029	105.96	0.034
H	8.00	0.008	69.93	0.022
I	7.20	0.007	53.88	0.017

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