POLISH JOURNAL OF ECOLOGY (Pol. J. Ecol.)	55	2	305–314	2007

Regular research paper

[1] Luboš PURCHART*, [2] Emanuel KULA

[1] Institute of Forest Ecology, [2] Department of Forest Protection and Game Management, Mendel University of Agriculture and Forestry, Zemědělská 3, 613 00 Brno, Czech Republic,
e-mail: xpurchar@node.mendelu.cz, kula@mendelu.cz
**Corresponding author*

CONTENT OF HEAVY METALS IN BODIES OF FIELD GROUND BEETLES (COLEOPTERA, CARABIDAE) WITH RESPECT TO SELECTED ECOLOGICAL FACTORS

ABSTRACT: The concentration of heavy metals in the bodies of invertebrates is dependent on their physiological equipment and prevalent environmental factors. To verify the effect of some of these factors on the content of metals (Pb, Cd, Zn, Cu, Mn) we analysed and then tested (using RDA, t-test) ten species of field ground beetles (Coleoptera, Carabidae).

A significant effect of Cu and Cd was discovered in terms of the sex; the males accumulated more Cu (27.520 mg kg^{-1}) than females (18.297 mg kg^{-1}) (P <0.01), which, on the contrary, accumulated more Cd (1.495 mg kg^{-1}) than males (0.663 mg kg^{-1}) (P <0.02). The content of all the metals differed significantly (P <0.03) according to the species, unambiguously showing species-specific models of accumulation. The effect of the feeding ecology was evident only on the essential elements; carnivores (Zn – 222.596 mg kg^{-1}, Cu – 27.211 mg kg^{-1}, Mn – 71.929 mg kg^{-1}) had a significantly (P <0.03) higher contents than omnivores (Zn – 168.198 mg kg^{-1}, Cu – 21.116 mg kg^{-1}, Mn – 58.452 mg kg^{-1}). Although there were differences (P <0.01) in the concentrations of Zn and Cu between the spring (Zn –163.749 mg kg^{-1}, Cu – 19.998 mg kg^{-1}) and autumn (Zn – 202.373 mg kg^{-1}, Cu – 25.496 mg kg^{-1}) species, the effect of the type of reproduction is considered to be only partial. At the same time the time of sampling affected the Zn and Mn (P <0.02) content. An important positive correlation was determined between the contents of Cu-Zn, Mn-Zn and Mn-Cu.

KEY WORDS: heavy metals, breeding type, carnivores, omnivores, trophic groups, accumulation, seasonal aspects, sex

1. INTRODUCTION

Metals such as Pb, Cd, Zn, Cu and Mn and microelements in general are widely distributed and naturally occurring elements in the environment. For most organisms their low concentrations are harmless; some of them occurring in trace amounts are of vital importance as essential elements for organisms to function (Clarkson 1979, Tyler *et al*. 1989). Increasing their concentrations in the ecosystems as a consequence of human activities (waste, fertilisation, combustion of fossil fuel etc.) may evoke developmental changes and weakening and even extinction of organisms living in these ecosystems (Beijer and Jernelöv 1979, Tyler *et al*. 1989).

Heavy metals in the soil find their way into invertebrates and into higher trophic levels through the food web from soil via detrivores or plants. Although the assumption of biological accumulation of anthropogenic foreign substances from the phytophages to carnivores was confirmed (Price *et al.* 1974), recent studies (e.g. van Straalen and van Wensem 1986, Lindquist and Block 1997) proved that this pattern cannot be applied as a general rule, at least not for metals (Kramarz 1999).

During the accumulation of metals in the bodies of invertebrates the concentrations do not increase in direct proportion to the trophic level and are not dependent on body size (van Straalen and van Wensem 1986, Lindquist and Block 1997). They are not even similar in the same ecologic groups – predators like in Carabidae and Araneae. Ground beetles have much lower levels of concentrations because of the different strategy in food intake. The concentration of metals in the bodies of invertebrates considerably differs among the taxonomic groups, species and specimens of the same species (Tyler *et al.* 1989). The content of metals in the body of invertebrates is dependent on the type of food and chemical form of the metal in the food (Lindquist and Block 1997), on concrete conditions during food intake (e.g. soil concentration, pH, availability of the metals etc.) and most of all on the physiological equipment of the individual invertebrate species (Ma 1982; Ma *et al.* 1983), which is the assimilation capacity and, above all, excretion of the element (Janssen *et al.* 1991, Lindquist *et al.* 1995; Kramarz 1999).

Ground beetles (Coleoptera, Carabidae) occurring in the Czech Republic generally have a one-year developmental cycle and according to the time of reproduction they can be divided into two groups. About two thirds reproduce in spring, their larvae develop in early summer and new imagos hatch in late summer or in autumn and then they overwinter; it is what we call reproduction without larval diapause (with gonad diapause). Characteristic of the remaining species is the development with larval diapause when reproduction takes place in autumn, the larvae overwinter together with the imagos and the new generation hatches from these larvae in spring or early summer (Hůrka 1996). In the temperate zone the ground beetles are a dominant component of the epigeic invertebrate fauna on most of the terrestrial sites. They are mostly non-specific predators who may feed on springtails (*Notiophilus, Leistus*), earthworms, snails (*Carabus*), molluscs (*Cychrus*), millipedes, larvae and adults of weevils, caterpillars of butterflies (*Calosoma*) etc. or they may behave as omnivores tending more to either herbivorous or carnivorous feeding (*Harpalus*), and/or as specific herbivores feeding on young plants or seeds (*Ophonus, Amara*) (Larochelle 1990, Hůrka 1996). The consequence of feeding specialisation is a different intake of heavy metals into their bodies.

With the exception of Read *et al.* (1987, 1998) most studies involved in the contents of heavy metals in ground beetles were focused more on the individual species and physiological processes than on communities and ecologic aspects. The objective of the study was to contribute to clarify the relations among the ecologic effects (type of reproduction, feeding ecology, seasonal aspect etc.) in ground beetle populations and their effect on the metal content (Pb, Cd, Zn, Cu, Mn) in bodies of ground beetles.

2. STUDY AREA, MATERIAL AND METHODS

The monitoring area is located in Chrlice (Brno, Czech Republic; 49° 08´ 04´´ N, 16° 39´ 31´´E) on altitude 190 m. It is warm climate district, moderately dry, average annual temperature = 9.9 °C and annual sum of precipitation = 509 mm. It is the sugar-beet production region, with flatland, arable soil (fluvisol, medium heavy sandy loam), cultivation of winter rape (*Brassica napus* L.) (2002) and spring wheat (*Triticum aestivum* L.) (2003). Hazardous elements (Cd – 2.25 mg kg^{-1}, Cr – 21.6 mg kg^{-1}) were in past introduced into the soil with applications of contaminated sludge from the sewage works. The sludge was mixed with the soil by ploughing.

In 2005 we analysed 906 specimens of 10 species of ground beetles entrapped during faunistic-ecological studies in a field biotope (agrocoenosis with winter wheat). The beetles (total number of collected specimens was 4793 belonging to 45 species) were entrapped (using pitfall Barber traps) in the field biotope of the monitoring area of the Central Institute for Supervising and Testing in Agriculture (CISTA) under long-term loading with heavy metals (Purchart and Kula 2005).

The samples were assorted according to species (Table 1), sex and date of collection. The number of specimens in one sample ranged from two specimens (the biggest species) to fifty specimens (the smallest species). After drying and weighing, the samples were subjected to dry mineralization for 14 hours in nitrogen dioxides (NO_x) and ozone at a maximal temperature of 400°C in the Apion mineraliser. The ash was hot-dissolved in 5% nitric acid and analysed using ICP MS (Inductively Coupled Plasma-Mass Spectrometry) (Ortega 2002) (ICP MS spectrometer Elan 6000 – Perkin Elmer, argon flow 0.85 $l.min^{-1}$, RF regenerator output 1000W; Department of Chemistry and Biochemistry, Mendel University of Agriculture and Forestry in Brno). The contents of Mn, Zn, Cu, Pb and Cd (mg kg^{-1}) were determined.

All the analysed species were classified according to their food preference (carnivorous, omnivorous) and type of reproduction (spring, summer) (Table 1) (Petruška 1967, 1986, Bousquet 1986, Larochelle 1990, Cole *et al*. 2002). The names of taxons of the ground beetles are in accordance with Hůrka (1996).

We used the redundancy analysis (RDA) in CANOCO for Windows 4.5 to find the connection between the content of metals (species data) in bodies of ground beetles and the type of reproduction, feeding ecology, seasonal aspects, concrete species and sex (environmental data). Due to an insufficient number of samples the effect of sex at the level of the species was not determined. CANOCO tested the significance of the effect of environmental factors using the Monte Carlo Permutation test. In our case the RDAs were run with CANOCO's default options: scaling focused on inter-species correlations, species scores divided by the standard deviation, species data were log transformed, species centred by species scores, samples not centred. Concrete environmental factors were tested separately and the significance of their effect on the content of the individual metals was explored. To confirm the RDA

Table 1. Body content of metals in analysed species of Carabidae (mg kg^{-1}; S.D. = standard deviation; N = number of analysed specimens; n = number of samples; α = 0.05), trophic groups (o = omnivores; c = carnivores) and breeding type (sb = spring breeder; ab = autumn breeder).

Species	N	n	Trophic group	Breeding type	Pb		Cd		Zn		Cu		Mn	
					mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.
Anchomenus dorsalis (Pontoppidan, 1763)	364	8	o	sb	1.295	0.432	0.901	0.408	179.241	32.603	23.931	4.745	78.44	25.786
Calathus erratus (C. R. Sahlberg, 1827)	84	8	c	ab	2.155	1.890	1.221	0.599	221.132	19.791	21.59	5.924	65.532	17.073
Calathus fuscipes (Goeze, 1777)	70	4	c	ab	0.657	0.173	1.185	1.041	216.553	5.156	33.628	16.672	83.763	32.163
Calosoma auropunctatum (Herbst, 1784)	8	4	c	ab	0.691	0.326	0.389	0.079	193.228	29.537	21.665	3.029	62.845	26.611
Harpalus affinis (Schrank, 1781)	133	8	o	sb	0.711	0.352	0.304	0.122	148.699	30.247	21.489	10.357	49.105	13.181
Harpalus distinguendus (Duftschmid, 1812)	19	8	o	sb	2.847	2.115	2.731	4.680	173.173	53.189	17.686	7.911	47.781	15.176
Leistus ferrugineus (Linnaeus, 1758)	33	4	c	ab	3.093	3.368	0.889	0.416	260.938	47.687	37.583	11.603	81.975	32.632
Poecilus cupreus (Linnaeus, 1758)	77	8	o	sb	0.604	0.262	0.488	0.173	153.885	41.845	16.885	5.783	62.803	26.652
Pseudoophonus rufipes (De Geer, 1774)	68	8	o	ab	1.150	0.463	0.489	0.208	166.624	24.050	20.155	6.277	57.883	20.817
Pterostichus melanarius (Illiger, 1798)	50	8	o	ab	0.648	0.329	1.805	1.343	187.566	41.943	26.551	12.066	54.700	14.106

Table 2. Content of metals in Carabidae (mg kg^{-1}; S.D. = standard deviation; N = number of analysed specimens; n = number of samples; α = 0.05) in respect to trophic groups, time of reproduction and sex.

species group			Pb		Cd		Zn		Cu		Mn	
	N	n	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.
omnivores	711	48	1.209	1.178	1.120	2.085	168.198	38.906	21.116	8.532	58.452	21.613
carnivores	195	20	1.750	2.016	0.981	0.663	222.596	33.838	27.211	11.429	71.929	24.743
spring breeders	593	32	1.364	1.387	1.106	2.439	163.749	40.611	19.998	7.709	59.532	23.675
autumn breeders	313	36	1.372	1.576	1.055	0.902	202.373	40.805	25.496	10.787	64.979	22.849
males	450	34	1.636	1.896	0.663	0.519	179.876	49.081	27.520	10.470	60.061	22.680
females	456	34	1.100	0.837	1.495	2.414	188.517	40.419	18.297	6.428	64.770	23.868

results, the significance of differences in average values for the respective variables (environmental factors) was assessed using the t-test (for the independent variables) in the STATISTICA Cz 6.1. programme, in which also the correlation coefficients were determined (Pearson's correlation coefficient) for correlations among the metals.

3. RESULTS

3.1. Lead

The content of lead in the soil of the locality was 31.6 mg kg^{-1} and was in the range of the natural concentration of Pb in the soil (2 – 200 mg kg^{-1}) (Tsuchiya 1979). In zoophages the content of lead was slightly higher (average of 1.750 mg kg^{-1}) than in omnivores (average of 1.209 mg kg^{-1}) but the difference was insignificant (Tables 2, 3, 4). The level of lead was the same in species reproducing in the autumn (average 1.372 mg kg^{-1}) and in spring (average 1.364 mg kg^{-1}) (Table 2). The effect of sex and time of sampling on the Pb content were also insignificant. A significant effect (RDA: F = 5.044, P = 0.001) on the concentration of lead in the bodies of ground beetles was detected only at the level of species; nevertheless significant differences were detected only among the omnivores (RDA: F = 8.173, P = 0.001) (Table 3). The highest absolute value was 8.11 mg kg^{-1} in a *Leistus ferrugineus* (Duftschmidt) male, while the lowest was noticed in a *Harpalus affinis* (Schrank) male – 0.31 mg kg^{-1}.

3.2. Cadmium

In study area the cadmium concentration in the soil was not very high (2.44 mg kg^{-1}) compared to the natural concentration (<1mg kg^{-1}) reported by Friberg *et al.* (1979). The cadmium content was significantly higher in omnivores (average 1.120 mg kg^{-1}) than in carnivores (average 0.981 mg kg^{-1}) (Tables 2, 3, 4). No significant differences were detected among the carnivorous or omnivorous species. The content was slightly higher (insignificant) in spring species (average 1.106 mg kg^{-1}) than in autumn species (average 1.055 mg kg^{-1}) (Tables 2, 3, 4). In general a significant effect on the cadmium concentration appeared only in terms of sex (RDA: F = 5.491, P = 0.017; t-test: P = 0.053) (Tables 3, 4) and pertinence to a concrete species (RDA: F = 2.432, P = 0.018). The effect of the seasonal aspect was not proved. The highest absolute value was detected in a *Harpalus distinguendus* (Duftschmidt) female – 13.43 mg kg^{-1} and the lowest in a *Calathus fuscipes* (Goeze) male – 0.10 mg kg^{-1}.

Table 3. Metal content in Carabidae: Results of renundancy analysis (RDA); x = compared with, n = number of samples, NS = non significant (P >0.05).

		Pb		Cd		Zn		Cu		Mn	
	n	F	P	F	P	F	P	F	P	F	P
omnivores x carnivores	68		NS		NS	26.916	0.001	6.132	0.015	5.915	0.023
carnivores x carnivores	20		NS		NS	3.678	0.038	3.288	0.043		NS
omnivores x omnivores	48	8.173	0.001		NS		NS		NS		NS
spring b. x autumn b.*	68		NS		NS	15.964	0.001	6.769	0.006		NS
male x female	68		NS	5.491	0.017		NS	21.829	0.001		NS
species	68	5.044	0.001	2.432	0.018	4.407	0.002	2.821	0.011	2.435	0.021
aspects	68		NS		NS	5.073	0.005		NS	11.489	0.001

* spring b. - spring breaders, autumn b. - autumn breeders

Table 4. Metal content in Carabidae: Results of t-test (x = compared with, n = number of samples, NS = non significant).

	n	Pb	Cd	Zn	Cu	Mn
omnivores x carnivores	68	NS	NS	<0.001	0.018	0.028
spring b. x autumn b.*	68	NS	NS	<0.001	<0.001	NS
males x females	68	NS	0.053	NS	0.001	NS

* spring b. - spring breaders, autumn b. - autumn breeders

3.3. Zinc

Natural concentrations of zinc in the soil ranged from 10 to 30 mg kg^{-1} (Elinder and Piscator 1979), while the Zn values detected in study area (214.2 mg kg^{-1}) were approximately 10 times higher. The difference between males and females was not significant. On the contrary, the feeding habit, whether omnivores or carnivores (RDA: F = 26.916, P = 0.001; t-test: P <0.001), type of reproduction (RDA: F = 15.964, P = 0.001; t-test: P <0.001), pertinence to a concrete species (RDA: F = 4.407, P = 0.002) and time of sampling (RDA: F = 5.073, P = 0.005) significantly affected the content of Zn (Tables 3, 4). Significant differences were discovered among carnivorous species (RDA: F = 3.678, P = 0.038); no significant differences were found among the omnivorous species (Table 3). The *L. ferrugineus* female contained the highest level of Zn – 292.16 mg kg^{-1} and the lowest levels were detected in the *H. distinguendus* male – 89.63 mg kg^{-1}.

3.4. Copper

Natural concentrations of copper in unpolluted soils vary from 2 to 250 mg kg^{-1} (median 30 mg kg^{-1}) (Bowen 1985). The detected content of copper in the soil (containing the sludge) in study area (82.43 mg kg^{-1}) was within the range of natural concentrations. The effect of the seasonal aspect on Cu concentration in the insect bodies was not significant. The effect was significant in the case of trophic groups (omnivores and carnivores) (RDA: F = 6.132, P = 0.015; t-test: P = 0.018), type of reproduction (RDA: F = 6.769, P = 0.006; t-test: P <0.001), sex (RDA:

F = 21.829, *P* = 0.001; t-test: *P* = 0.001) and species (RDA: F = 2.821, *P* = 0.011) (Tables 3, 4). Much like Zn, significant differences in the level of Cu were detected among the carnivores (RDA: F = 3.288, *P* = 0.043) (Table 3). As with Pb the *L. ferrugineus* male had the highest amount of Cu – 51.68 mg kg^{-1} and a *Poecilus cupreus* (L.) female had the lowest amount – 7.84 mg kg^{-1}.

3.5. Manganese

Average concentrations of Mn in the soil range between 500 and 900 mg kg^{-1} (Piscator 1979). The amount monitored in the study area locality was on the lower limit of natural concentration (453.3 mg kg^{-1}). The difference between the spring (average 59.532 mg kg^{-1}) and autumn (average 64.979 mg kg^{-1}) species (Table 2) and the sex was insignificant. As significant we see the effect of trophic groups (RDA: F = 5.915, *P* = 0.023; t-test: *P* = 0.028) and pertinence to species (RDA: F = 2.435, *P* = 0.021); highly significant was the effect of the time of sampling (RDA: F = 11.489, *P* = 0.001) (Tables 3, 4). No differences were discovered among the carnivores and omnivores. The highest absolute value of Mn was noticed in the *L. ferrugineus* female – 129.81 mg kg^{-1} and the lowest in the *H. distinguendus* male – 26.79 mg kg^{-1}.

4. DISCUSSION

The differences in the levels of Cd, Cu and Zn are dependent more on the type of food and chemical form of the metal in the food than on the trophic level, and although significant differences between males and females appear on localities under low pollution load, at the level of sex they do not show specific accumulation models (Lindquist and Block 1997). In study area (Chrlice in the Czech Republic) the differences between the sexes were significant only in the content of Cd (RDA: *P* = 0.017; t-test: *P* = 0.05), with higher concentrations in females, and Cu (RDA: *P* = 0.001; t-test: *P* = 0.001), with higher concentrations in males (Table 2). *Pseudoophonus rufipes* (De Geer), *Pterostichus melanarius* (Illiger) and *Anchomenus dorsalis* (Pontoppidan) gave the same results (Novák 1985, 1988, 1989). *Pterostichus niger* (Schaller) females had a higher content of Cd and males had a higher content of Cu (Lindquist and Block 1997). The content of Zn did not differ significantly between the males and females; however the higher content of Zn in females corresponds with results discovered in *Pterostichus oblongopunctatus* (F.) (Lagisz *et al.* 2005). In the vicinity of the cadmium-zinc smelting plant in Austria, Rabitsch (1995) investigated the content of metals in invertebrates. Out of the studied ground beetles (*Aptinus bombarda* (Illiger), *Abax parallelepipedus* (Piller et Mitterpacher), *Carabus hortensis* (L.), *P. rufipes*, *Poecilus versicolor* (Sturm), *Pterostichus burmeisteri* Heer, *P. oblongopunctatus* and *Calathus erratus* (C. R. Sahlberg)) only *A. bombarda* and *A. parallelepipedus* showed a distribution model of accumulation between sexes. *A. bombarda* males had a significantly higher content of Cu and Zn, and the level of Pb and Cd was higher in females. A higher content of Pb, Cd and Zn was detected in *A. parallelepipedus* females and a higher content of Cu in the males. Species-specific distribution models of accumulation between sexes appeared in some species only. The only exception is Cu, where a higher accumulation was discovered almost exclusively in males, independent of the species, feeding ecology or type of reproduction.

In the study area significant interspecies differences in all the studied elements were detected (RDA: Pb – *P* = 0.001; Cd – *P* = 0.018; Zn – *P* = 0.002; Cu – *P* = 0.011; Mn – *P* = 0.021). The content of microelements in the animal bodies is dependent on the species-specific equipment and their content in food (Ma 1982, Ma *et al.* 1983, Pokarzhevskii and van Straalen 1996). Essential elements, to which Zn, Cu and Mn belong (Elinder and Piscator 1979, Piscator 1979a, 1979b), are accumulated in the body in relatively constant amounts and all surplus is rapidly released from the body; their amounts in the body are dependent particularly on the excretion abilities (Kramarz 1999), while elements such as Cd are accumulated particularly in dependence on their amount in food and effectiveness of their assimilation (Janssen *et al.* 1991). Nuorteva (1999) pointed out the interspecies differences in Cd accumulation in ground beetles; they were discovered in our studies too.

Carnivorous insect species take up metals in various forms from different parts of the food and their relative amounts differ in dependence on the type of food and on the feeding behaviour of their prays (Lindquist and Block 1997). Carnivores had significantly higher values of Zn (RDA: $P = 0.001$; t-test: $P < 0.001$), Cu (RDA: $P = 0.015$; t-test: $P = 0.018$) and Mn (RDA: $P = 0.023$; t-test: $P = 0.028$), and also of Pb (insignificant). A slightly higher (insignificant) concentration of Cd was noticed only in omnivores (Table 2). Significant differences in Zn accumulation were discovered in carnivorous species (RDA: $P = 0.038$) and Cu (RDA: $P = 0.043$). In omnivorous species the differences in the concentration of metals were significant only in the case of Pb (RDA: $P = 0.001$). The generally significant differences in Pb concentration among the species can be due to the highly significant differences in the content of Pb among the omnivores. In carnivorous species these differences were insignificant (Table 3). Apparently the omnivorous species are exposed to much differentiated values of taken up Pb, due to the wider spectrum of food and greater variability in food preferences, than the carnivorous species. These differences are probably due to the plant component of the food, which contains less energy than animal-based food (Roth 1993). To obtain the same amount of energy one omnivorous species feeding plant-based food must therefore take up more food (and thus also Pb) than other omnivorous species feeding animal-based food.

The type of reproduction affected only Zn (RDA: $P = 0.001$; t-test: $P < 0.001$) and Cu concentration (RDA: $P = 0.006$; t-test: $P < 0.001$); the values of both metals were significantly higher in species reproducing in the autumn than in the spring species (Table 2). As was mentioned above the values of Zn and Cu were significantly higher in carnivores and so these differences can at least partly be explained by the composition of the tested species spectrum, which consisted of autumn omnivores and carnivores and only spring omnivores (Table 1). On top of that significant differences in Zn and Cu concentrations were discovered only within the group of carnivorous species (Table 3). According to Novák (1985) nutrients (Zn, Cu) stored in the fat body are exhausted during overwintering. This could also be the reason why the Cu and Zn values are higher in the autumn species (overwintering in the larval stage) than in the spring species (wintering in the stage of imago). This may mean that the Zn and Cu content in ground beetles is dependent on the type of reproduction only partly and that the concentration of metals is affected by the feeding mode of the individual species.

The effect of the seasonal aspect (time of sampling) was important for Zn (RDA: $P = 0.005$) and Mn (RDA: $P = 0.001$). In ground beetles Hunter *et al.* (1987) discovered significant differences in Cu and Cd accumulation during the vegetation period. This finding, however, was not confirmed in our study. In accordance with our results Novák (1985) noticed changes in Mn concentrations in populations of *P. rufipes.* The Mn content in the bodies of ground beetles changed with the length of their life and, in addition, it was dependent on the species pertinence and food ecology (Table 3). Rabitsch (1995) noted that the time of imago entrapping had a significant effect on Pb concentration. Novák (1988) indicated that the concentration of lead (and other metals) is higher in older specimens exposed to a polluted environment for a longer period of time. Novák (1985) also pointed out that the age composition of the populations had a considerable effect on the annual dynamics of metals in the bodies of the ground beetles. Especially in the period of increased feeding activity the supplies of nutrients are stored in the fat body; on the other hand, during sexual activity and during wintering these nutrients are drawn away. In addition, the population composed of juvenile specimens, feed-active or reproducing individuals may have a considerable effect on the annual dynamics of the metals.

We found a significant ($P < 0.01$) positive correlation between Cu-Zn, Mn-Zn and Mn-Cu (Table 5). These three metals belong to the essential elements (Elinder and Piscator 1979, Piscator 1979a, 1979b, Dmuchowski and Bytnerowicz 1995), the lack of which may cause changes in the

Table 5. Correlation coefficient between metals (significant values are marked with bold letters; P <0.001, n = 68) in Carabidae.

	Pb	Cd	Zn	Cu	Mn
Pb	1.00				
Cd	0.02	1.00			
Zn	0.17	0.18	1.00		
Cu	–0.09	–0.15	**0.37**	1.00	
Mn	–0.11	0.04	**0.59**	**0.33**	1.00

growth of the beetles (Hopkin 1989). Due to the discovered correlations it is possible that bio-accumulation of these elements interacts, similarly as Cd and Zn in *Porcellio laevis* (Isopoda) (Odendaal and Reinecke 2004). It was also discovered that the uptake and excretion of Cd and Zn in *Porcellio scaber* (Isopoda) is affected by the presence of other metals (Witzel 2000).

ACKNOWLEDGEMENTS: The project was supported by grant No. 526/03/H036 of the Czech Science Foundation and Research plan of the Czech Ministry of Education MSM 6215648902. Our thanks are due to Eng. Provazník (CISTA) for providing the characteristics of the sites, Dr. Z. Fric for his valuable advice on statistical data processing, Eng. I. Buchta and Eng. D. Matoušek for their assistance in field activities and Dr. J. Hedvábný for chemical analysis of the ground beetles.

5. REFERENCES

Beijer K., Jernelöv A. 1979 – General aspects and specific data on ecological effects of metals. (In: Handbook on the toxicology of metals, Ed: L. Friberg, G.F. Nordberg, V.B. Vouk) – Elsevier / North-Holland Biomedical Press, Amsterdam, pp.197–209.

Bousquet Y. 1986 – Observations on the life cycle of some species of *Pterostichus* (Coleoptera: Carabidae) occuring in Northeastern North America – Naturaliste Can. (Rev. Écol. Sys.), 113(4): 295–307.

Bowen H.J.M. 1985 – The natural environment and the biogeochemical cycles (In: Handbook of environmental chemistry, Ed. D. Hutzinger) – Springer-Verlag, New York, Basel, pp. 1–26.

Clarkson T.W. 1979 – Effects – General principles underlying the toxic action of metals (In: Handbook on the toxicology of metals, Eds: L. Friberg, G.F. Nordberg, V.B. Vouk) – Elsevier / North-Holland Biomedical Press, Amsterdam, pp. 99–117.

Cole L.J., McCracken D.I., Dennis P., Downie I.S., Griffin A.L., Murphy K.J., Waterhouse T. 2002 – Relationships between agricultural management and ecological groups of ground beetles (Coleoptera: Carabidae) on Scottish farmland – Agric. Ecosyst. Environ., 93: 323–336.

Dmuchowski W., Bytnerowicz A. 1995 – Monitoring environmental pollution in Poland by chemical analysis of Scots Pine (*Pinus sylvestris* L.) needles – Environ. Poll., 87: 87–104.

Elinder C.G., Piscator M. 1979 – Zinc (In: Handbook on the toxicology of metals, Eds: L. Friberg, G.F. Nordberg, V.B. Vouk) – Elsevier / North-Holland Biomedical Press, Amsterdam, pp. 674–685.

Friberg L., Kjellström T., Nordberg G., Piscator M. 1979 – Cadmium (In: Handbook on the toxicology of metals, Eds: L. Friberg, G.F. Nordberg, V.B. Vouk) – Elsevier / North-Holland Biomedical Press, Amsterdam, pp. 355–381.

Hopkin S.P. 1989 – Ecophysiology of metals in terrestrial invertebrates – Elsevier, London, New York, 366 pp.

Hunter B.A., Johnson M.S., Thompson D.J. 1987 – Ecotoxicology of copper and cadmium in a contaminated grassland ecosystem. II. Invertebrates – J. Appl. Ecol., 24: 587–599.

Hůrka K. 1996 – Carabidae of the Czech and Slovak Republic – Kabourek, Zlín, 565 pp.

Janssen M.P.M., Bruins A., De Vries T.H., Van Straalen N.M. 1991 – Comparison of cadmium kinetics in four soil arthropod species – Arch. Environ. Contam. Toxicol, 20(3): 305–312.

Kramarz P. 1999 – Dynamics of accumulation and decontamination of cadmium and zinc in carnivorous invertebrates. 1. The ground beetle, *Poecilus cupreus* L. – Bull. Environ. Contam. Toxicol., 63: 531–537.

Lagisz M., Kramarz P., Niklinska M. 2005 – Metal kinetics respiration rates in F_1 generation of carabid beetles (*Pterostichus oblongopunctatus* F.) originating from metal-contaminated and reference areas – Arch. Environ. Contam. Toxicol., 48: 484–489.

Larochelle A. 1990 – The food of carabid beetles (Coleoptera: Carabidae), including Cicindelinae) – Fabreries, Quebec, (Supplément) 5: 1–132.

Lindqvist L., Block M. 1997 – Influence of life and history on metal accumulation in two beetle species (Insecta: Coleoptera) – Bull. Environ. Contam. Toxicol., 58: 518–522.

Lindquist L., Block M., Tjälve H. 1995 – Distribution and excretion of Cd, Hg, Methyl-Hg and Zn in the predatory beetle *Pterostichus niger* (Coleoptera: Carabidae) – Environ. Toxicol. Chem., 14: 1195–1201.

Ma W. 1982 – The influence of soil properties and worm-related factors on the concentration of heavy metals in earthworms – Pedobiologia, 24: 109–119.

Ma W., Edelman T., Van Beersum I., Jans T. 1983 – Uptake of cadmium, zinc, lead, and copper by earthworms near a zinc-smelting complex: Influence of soil pH and organic matter – Bull. Environ. Contam. Toxicol., 30: 424–427.

Novák B. 1985 – Roční dynamika obsahu kovů v imaginálních populacích druhu *Harpalus rufipes* (De Geer) (Col., Carabidae) [Annual dynamics of metal content in imaginal populations of *Harpalus rufipes* (De Geer) (Col., Carabidae)] – Acta Univ. Pal. Olomuc., Fac. Rer. Nat., Biol. XXV, 84: 185–198. (in Czech, Engl. Summ.)

Novák B. 1988 – Metalle in den Imaginalen Populationen der Art *Pterostichus melanarius* (Illiger) (Coleoptera, Carabidae) – Acta Univ. Pal. Olomuc., Fac. Rer. Nat., Biol. XXVIII, 93: 131–145. (in German)

Novák B. 1989 – Mettallelemente in den Populationen der Arten *Agonum dorsale* Pont. und *A. sexpunctatum* L. (Col., Carabidae) – Acta Univ. Pal. Olomuc., Fac. Rer. Nat., Biol. XXIX, 96:123–138. (in German)

Nuorteva P. 1999 – Levels of cadmium and some other metals in insects (In: Proceedings of the XXIV Nordic Congress of Entomology, 1997) – Tartu, Estonia, pp.125–137.

Oodendaal J.P., Reinecke A.J. 2004 – Evidence of metal interaction in the bioaccumulation of cadmium and zinc in *Porcellio laevis* (Isopoda) after exposure to individual and mixed metals – Water Air Soil Pollut., 156: 145–161.

Ortega R. 2002 – Analytical methods for heavy metals in the environment: quantitative determination, speciation, and microscopic analysis (In: Heavy metals in the environment, Ed. B . Sarkar) – Dekker, New York: 35–68.

Petruška F. 1967 – Střevlíkovití jako součást entomofauny řepných polí Uničovské roviny. (Col. Carabidae) [Carabidae as a constituent of the entomological fauna of sugar-beet fields in the Uničov plain. (Col. Carabidae)] – Acta Univ. Pal. Olomucensis Fac. Rer. Nat., Biol., 25: 121–243. (in Czech, Engl. Summ.)

Petruška F. 1986 – Fluktuace v populacích střevlíkovitých v agroekosystémech Uničovské roviny v letech 1981 až 1984. (Coleoptera, Carabidae). I. část [The fluctuation in the populations of the carabid beetles in the fields of the Uničov plain in the years 1981 to 1984. (Coleoptera, Carabidae). I. part] – Acta Univ. Pal. Olomucensis Fac. Rer. Nat., Biol. XXVI, 87: 119–142.

Piscator M. 1979a – Copper (In: Handbook on the toxicology of metals, Eds: L. Friberg, G.F. Nordberg, V.B. Vouk) – Elsevier / North-Holland Biomedical Press, Amsterdam, pp. 411–420.

Piscator M. 1979b – Manganese (In: Handbook on the toxicology of metals, Eds: L. Friberg, G.F. Nordberg, V.B. Vouk) – Elsevier / North-Holland Biomedical Press, Amsterdam, pp. 485–501.

Pokarzhevskii A.D., Van Straalen N.M. 1996 – A multi-element view on heavy metal biomagnification – Appl. Soil Ecol., 3: 95–98.

Price P.W., Rathcke B.J., Gentry D.A. 1974 – Lead in terrestrial arthropods: evidence for biological concentration – Environ. Entomol., 3(3): 370–372.

Purchart L., Kula E. 2005 – Ground beetles (Coleoptera, Carabidae), agrocenoses of spring and winter wheat – Acta univ. agric. et silvic. Mendel. Brun., 53(5): 125–132.

Rabitsch W.B. 1995 – Metal accumulation in arthropods near a lead/zinc smelter in Arnoldstein, Austria. I. – Environ. Poll., 90(2): 21–37.

Read H.J., Wheater C.P., Martin M.H. 1987 – Aspects of the ecology of Carabidae (Coleoptera) from woodlands polluted by heavy metals – Environ. Poll., 48: 61–76.

Read H.J., Martin M.H., Rayner J.M.V. 1998 – Invertebrates on woodlands polluted by heavy metals – an evaluation using canonical correspondence analysis – Water Air Soil Pollut., 106: 17–42.

Roth M. 1993 – Investigations on lead in the soil invertebrates of a forest ecosystem – Pedobiologia, 37: 270–279.

Tsuchiya K. 1979 – Lead (In: Handbook on the toxicology of metals, Eds: L. Friberg, G.F. Nordberg, V.B. Vouk) – Elsevier / North-Holland Biomedical Press, Amsterdam, pp. 451–484.

Tyler G., Balsberg-Pahlsson A.-M., Bengtsson G., Baath E., Tranvik L. 1989 – Heavy-metal ecology of terrestrial plants, micro-organisms and invertebrates – Water Air Soil Pollut., 47(3–4): 189–215.

van Straalen N.M., van Wensem J. 1986 – Heavy metal content of forest litter arthropods as related to body-size and trophic level – Environ. Poll. (Series A), 42: 209–221.

Witzel B. 2000 – The influence of zinc on the uptake and loss of cadmium and lead in the woodlouse, *Porcellio scaber* (Isopoda, Oniscidea) – Ecotox. Environ. Safe., 47: 43–53.

(Received after revising October 2006)