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The use of directional traps for the assessment of short-term phenanthrene effects upon soil springtail communities

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Abstract

Directional traps, both horizontal and vertical, were used to assess the behavioural impact of phenanthrene application on soil springtail communities. Avoidance was not detected. Rather, a vertical attraction of the dominant species, *Folsomia manolachei*, was demonstrated, as well as a decrease in horizontal movements of *Lepidocyrtus lanuginosus*, another important species mainly captured at the soil surface. Ecological consequences of the results are discussed.

Keywords: Phenanthrene; Springtails; Directional traps; Behaviour

1. Introduction

The assessment of environmental hazards is still mostly achieved through laboratory tests using species which have been selected for the ease to obtain them in high numbers (Dorn et al., 1998; Fountain and Hopkin, 2005). There is a need for field-relevant methods which can be used to predict changes that may occur at the

community level under the influence of a contaminant (Fent, 2003; Fountain and Hopkin, 2004b). Field sampling along transects of increasing contamination has been used for studying the impact of environmental hazards on soil animal communities (Bengtsson and Rundgren, 1988; Erstfeld and Snow-Ashbrook, 1999; Fountain and Hopkin, 2004a). Ecotoxicological tests and field monitoring of populations are reliable methods for the assessment of contamination end-points, but they do not inform us about the mechanisms in play and the way by which populations become depauperated.

The toxicity and the bio-accumulation of pollutants have been well studied in soil animals (Hopkin et al., 1989; Crouau et al., 1999; Johnson et al., 2002), but still little is known about behavioural aspects, in particular the effects of pollutants on the movement of animals in terrestrial ecosystems (Yardley et al., 1996; Michelozzi et al., 1997; da Luz et al., 2004). It has been shown that some springtail species are able to avoid contaminants while others, belonging to the same community, did not or even were attracted to them (Tranvik and Eijssackers, 1989; Filser et al., 2000; Chauvat and Ponge, 2002). Avoidance movement can be used by an animal to escape a pollutant, provided it can reach more or less rapidly a refuge (Shakir Hanna and Weaver, 2002), but attraction or paralysis might on the contrary entrap it in a toxic environment (Eijssackers, 1978; Fábíán and Petersen, 1994; Petersen and Gjelstrup, 1998). The choice of food is another important clue and, if as a general rule animals avoid toxic food (Visser and Whittaker, 1977; Filser and Hölscher, 1997; Michelozzi et al., 1997), definite attraction to harmful food items may sometimes be observed (Sadaka-Laulan et al., 1998).

Directional traps have been used to follow horizontal movements of surface animals in patchy environments (Duelli et al., 1990). We suggest that they can be also used to follow horizontal as well as vertical movements of soil animal populations in the

presence of contaminants, in particular hydrocarbons, the smell of which may act as a behavioural signal, as this has been demonstrated with fungal odours (Bengtsson et al., 1988, 1991; Hedlund et al., 1995). Avoidance of crude petroleum by earthworms has been observed (Shakir Hanna and Weaver, 2002), but what happens in the case of complex assemblages such as soil springtail communities? In an experimental study of the effects of naphthalene application on the ground, Best et al. (1978) concluded that the horizontal movement of arthropods was negatively affected by naphthalene and that vertical movement was probable, although their sampling methods were inappropriate to fully investigate the latter phenomenon. We thought that the incorporation of horizontal and vertical directional traps in the soil could allow to demonstrate the existence or inexistence of movements of invertebrate populations when hydrocarbons are deposited at the ground surface. Phenanthrene was used, being one of the main components of crude oil as well as of numerous industrial waste products (Bouchez et al., 1996). It is also known for its toxicity and mutagenicity to a wide range of organisms (Schirmer et al., 1998; Crouau et al., 1999; Landrum et al., 2003).

2. Material and methods

Phenanthrene, $C_{14}H_{10}$, a weakly-soluble 3-cycle PAH (1.6 mg.L^{-1} at 15°C in water), was used in solid state, in the form of a fine white powder (purity 98%) with moderate smell, purchased from Sigma-Aldrich Chemie GmbH (Steinheim, Germany).

The soil used for the experiment stemmed from a woodlot mainly comprised of oak [*Quercus petraea* (Mattus.) Liebl.] and hornbeam (*Carpinus betulus* L.) at the inside of the Park of the Laboratory (Brunoy, France, 20 km South-East of Paris). It was a black rendzina rich in clay (28.2%) and organic carbon (4.7%), with a near neutral $\text{pH}_{\text{H}_2\text{O}}$ (7.4) and a low C/N (11.8) in the top 10 cm (Vannier, 1970). The humus

form was an earthworm mull, called calcic Eumull according to Brêthes et al. (1995). Detailed vegetation, soil and climate data can be found in Vannier (1970). Collembolan communities living in the topsoil were described in Chauvat and Ponge (2002) and Ponge et al. (2002). Seasonal variations were studied in Ponge (1973). The vertical distribution of the main species and their food diets were analysed in Arpin et al. (1980).

In February 2004 around 300 L of soil were collected in the top 10 cm then homogenized over a plastic sheet before being distributed in 10 rectangular glass jars 60x30x30 cm (LxIxh). Before complete filling, two cylindrical (85x100 mm Øxh) and two rectangular (75x55x105 mm LxIxh) directional traps were positioned in each jar. The traps enclosed their own volume (ca. 500 cm³) of the same soil. They were made of polyvinyl chloride, one side being fitted with a 2 mm mesh plastic net, the opposite side with a 20 µm mesh nylon gauze. Cylindrical traps were entirely buried into the soil, their upper part (covered with either plastic net or nylon gauze) being at 1 cm from the ground surface. They were positioned side by side by inverted pairs at ¼ length of the glass jars, centered under the area where phenanthrene was further applied. Rectangular traps were positioned side by side by inverted pairs, with their upper part 1 cm above the ground level, the remaining 9.5 cm being buried. The side with either nylon gauze or plastic net was facing the area where phenanthrene was further applied. After complete filling of the experimental jars (15 cm soil, 15 cm free space above the soil), they were transported to the laboratory, then let in darkness during a week in a chamber at constant temperature (20°C). This incubation period was needed to let enough time for the animals to stabilize their vertical position according to species requirements and to acclimate to chamber conditions.

After the acclimation period, phenanthrene was applied in five randomly selected jars at the rate of 10 g per jar. The powder was applied as uniformly as

possible over half the surface of each jar (30 x 30 cm), thus amounting to 1.1 Kg.m². Then the jars were randomly put on wood trays along both sides of the climate chamber, randomization being effective on their horizontal and vertical position but also on the orientation of the jars on the trays. Ten days after, the trap boxes were collected then put in Berlese funnels, with the plastic net below, to extract microarthropods (Edwards and Fletcher, 1971). Animals were preserved in 95% ethyl alcohol until identification.

Springtails were sorted then identified at the species level using Gisin (1960), Zimdars & Dunger (1994), Jordana et al. (1997), Fjellberg (1998), Bretfeld (1999), Hopkin (2000) and Potapov (2001).

Prior to statistical testing, data were analysed by correspondence analysis, a multivariate method which allows to discern most prominent trends in the data matrix (Greenacre, 1984). Although not purposed for experimental data, this method was used to avoid repeated testing of a meaningless number of variables, by focusing on those species or those population parameters which responded the best to the treatments. Active (main) variables were the species, none being discarded. Passive (additional) variables were the treatments, and population variables such as sample species richness and total abundance. Passive variables did not influence the calculation of factorial axes, but they were projected among species and samples in order to better interpret the significance of factorial axes. As in previous studies on soil collembolan communities (Ponge et al., 2003; Gillet and Ponge, 2004), each variable was standardized (mean 20, standard deviation 1) and associated to a conjugate one ($x' = 40 - x$) in the search for possible gradients of global abundance.

Comparisons between traps of the same jar (either on the five control or phenanthrene jars) were achieved through paired t-tests, after due verification of the

gaussian distribution of residues. Comparisons between control and phenanthrene jars were achieved through unpaired t-tests, control and phenanthrene replicates being independent.

3. Results

Table 1 shows mean values for species abundances and population parameters according to treatments. At first sight, no outward change in total abundance or species richness seemed to occur within the ten days of the experiment.

The projection of active and passive variables in the plane of the first two factorial axes of correspondence analysis (13.7% and 23.2% of the total variance, respectively, thus totalling 36.9%) (Fig. 1) showed that the main effect of the experiment was a contrast between rectangular traps used for detecting horizontal movements (inwards vs outwards) and cylindrical traps used for vertical movements (upwards vs downwards). This effect was trivial, since springtail assemblages of rectangular and cylindrical traps differed according to behavioural requirements of the species. Species which were projected on the east (positive) side of Axis 1, such as *Lepidocyrtus lanuginosus* Gmelin (LLA), *Sminthurinus aureus* Lubbock (SAU), *Onychiurus pseudogranulosus* Gisin (OPS), *Heteromurus major* Moniez (HMA) and *Monobella grassei* Denis (MGR), could be considered typical of rectangular traps and thus as living at the surface in the conditions of our experiment, while those projected on the opposite side of the same axis, such as *Micranurida sensillata* Gisin (MSE), *Parisotoma notabilis* Schäffer (PNO), *Isotomiella minor* Schäffer (IMI) and *Pseudosinella immaculata* Lie-Pettersen (PIM) can be considered as living deeper in the soil, since they were found preferentially in buried cylindrical traps. There was also more specimens and more species in the traps used for capturing horizontal movements than for those used for vertical movements.

However, less trivial was the difference between phenanthrene and control traps which was shown on the east side of Axis 1. Treatments 'P out' (phenanthrene outwards) and 'P in' (phenanthrene inwards) were projected nearer the origin of the axes (barycentre) than corresponding control treatments ('C out' and 'C in'). This means that phenanthrene seemed to decrease the contrast between 'horizontal' and 'vertical' traps. This was tested on *L. lanuginosus*, the most typical species of the 'horizontal' traps, which was also one of the most abundant springtail species in the studied population (Table 1). *L. lanuginosus* was, as expected, more abundant in 'horizontal' than in 'vertical' traps, both in the presence and in the absence of phenanthrene (Fig. 2), but the difference between 'horizontal' and 'vertical' traps was lessened by the application of phenanthrene ($t = -3.195$, $P = 0.006$).

Axis 2 revealed an opposition between 'upwards' and 'downwards' traps, mainly in the presence of phenanthrene. This was tested on *Folsomia manolachei* Bagnall, which was projected far from the origin on the north (positive) side of Axis 2, more remote species being rather erratic in our samples. This species was also the main component of the collembolan community (Table 1). In the absence of phenanthrene, no difference occurred between upward and downward trapping, while upward movement was more important than downward movement in the presence of phenanthrene (Fig. 3).

4. Discussion

Despite the absence of any bulk effect of phenanthrene, neither on total abundance nor on sample species richness, some species among the dominant members of the community were markedly affected by the application of phenanthrene. *Folsomia manolachei*, an hemiedaphic species sensu Gisin (1943), was living mainly in

the first top cm of the soil in our study site (Arpin et al., 1980), but was found deeper as well in our experimental conditions (Table 1). The contrast between upward and downward trapping of this species, only in the presence of phenanthrene (Fig. 3), showed that this species was attracted vertically to phenanthrene. This attraction did not seem to proceed at large distance, since the contrast between 'upwards' and 'downwards' was more due to a deficit in 'downwards' specimens than to an increase in 'upwards' specimens (Fig. 3). Other studies showed that *F. manolachei*, as well as the nearby *F. quadrioculata*, was attracted to heavy metals such as lead (Chauvat and Ponge, 2002) and copper (Filser and Hölscher, 1997; Filser et al., 2000). This, together with results of the present study, may explain why this species, one of the three dominant springtail species in temperate soils, the other two being *Parisotoma notabilis* and *Isotomiella minor*, is absent or at least poorly represented in polluted sites (Bengtsson and Rundgren, 1988; Sterzynska, 1989; Sjögren, 1997; Fountain and Hopkin, 2004b), although some populations may be better adapted than others (Hågvar and Abrahamsen, 1990; Chauvat and Ponge, 2002). Another common species, *I. minor*, did not show any trend of attraction nor of avoidance to phenanthrene (Table 1). Tranvik and Eijsackers (1989) demonstrated that the absence of avoidance of pollutants by this species was detrimental to its survival in a metal-polluted soil.

The effect of phenanthrene on the contrast between 'horizontal' and 'vertical' traps in the other hemiedaphic *L. lanuginosus* can be explained by a decrease in horizontal movements of surface-living species. In our experiment, *L. lanuginosus* was living preferentially at the soil surface (Table 1, Fig. 2). The observed decrease in 'horizontal' minus 'vertical' densities of this species was mostly due to a decrease in 'horizontal' densities (Fig. 2), whether 'inwards' or 'outwards' (Table 1). Thus the main effect of phenanthrene was that fewer animals were trapped when moving horizontally at or near the soil surface. Since *L. lanuginosus*, as most entomobryid species, disperse easily (Ojala and Huhta, 2001), we can suspect that either (i) there was a

1 decrease in the whole population due to toxic effects, (ii) animals moved more slowly at
2 the soil surface. The first hypothesis can be ruled out, since no decrease was observed
3 in 'vertical' traps. The second hypothesis is largely plausible, due to well-known
4 narcotic effects of PAHs (Still et al., 2001; Landrum et al., 2003).

6 **5. Conclusion**

8 The use of horizontal and vertical directional traps may help to better
9 understand behavioural effects of PAHs upon soil animal communities. Although no
10 effect was detected at the community level, some of the most representative species
11 responded to the application of phenanthrene at the soil surface. *Folsomia manolachei*,
12 an isotomid species, was attracted to phenanthrene, which may in the long-term cause
13 its local disappearance. *Lepidocyrtus lanuginosus*, an entomobryid species mostly
14 living at the soil surface, was mostly affected by a decrease in its dispersal rate,
15 another mechanism which may be detrimental to its long-term survival in contaminated
16 soils.

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24 **References**

- Arpin, P., Kilbertus, G., Ponge, J.F., Vannier, G., 1980. Importance de la microflore et de la microfaune en milieu forestier. In: Pesson, P. (Ed.), *Actualités d'Écologie Forestière*. Gauthier-Villars, Paris, pp. 87-150.
- Bengtsson, G., Erlandsson, A., Rundgren, S., 1988. Fungal odour attracts soil Collembola. *Soil Biology and Biochemistry* 20, 25-30.
- Bengtsson, G., Hedlund, K., Rundgren, S., 1991. Selective odor properties in the soil Collembola *Onychiurus armatus*. *Journal of Chemical Ecology* 17, 2113-2125.
- Bengtsson, G., Rundgren, S., 1988. The Gusum case: a brass mill and the distribution of soil Collembola. *Canadian Journal of Zoology* 66, 1518-1526.
- Best, G.R., Nabholz, J.V., Ojasti, J., Crosssley, D.A.Jr, 1978. Response of microarthropod populations to naphthalene in three contrasting habitats. *Pedobiologia* 18, 189-201.
- Bouchez, M., Blanchet, D., Haeseler, F., Vandecasteele, J.P., 1996. Les hydrocarbures aromatiques polycycliques dans l'environnement. I. Propriétés, origines, devenir. *Revue de l'Institut Français du Pétrole* 51, 407-419.
- Bretfeld, G., 1999. Synopses on palaeartic Collembola. II. Symphypleona. *Abhandlungen und Berichte des Naturkundemuseums Görlitz* 71, 1-318.
- Brêthes, A., Brun, J.J., Jabiol, B., Ponge, J.F., Toutain, F., 1995. Classification of forest humus forms: a French proposal. *Annales des Sciences Forestières* 52, 535-546.

- 1 Chauvat, M., Ponge, J.F., 2002. Colonization of heavy metal-polluted soils by
2 Collembola: preliminary experiments in compartmented boxes. *Applied Soil*
3 *Ecology* 21, 91-106.
- 4
- 5 Crouau, Y., Chenon, P., Gisclard, C., 1999. The use of *Folsomia candida* (Collembola,
6 Isotomidae) for the bioassay of xenobiotic substances and soil pollutants.
7 *Applied Soil Ecology* 12, 103-111.
- 8
- 9 Dorn, P.B., Vipond, T.E., Salanitro, J.P., Wisniewski, H.L., 1998. Assessment of the
10 acute toxicity of crude oils in soils using earthworms, Microtox®, and plants.
11 *Chemosphere* 37, 845-860.
- 12
- 13 Duelli, P., Studer, M., Marchand, I., Jakob, S., 1990. Population movement of
14 arthropods between natural and cultivated areas. *Biological Conservation* 54,
15 193-207.
- 16
- 17 Edwards, C.A., Fletcher, K.E., 1971. A comparison of extraction methods for terrestrial
18 arthropods. In: Phillipson, J. (Ed.), *Methods of Study in Quantitative Soil*
19 *Ecology: Population, Production and Energy Flow*. Blackwell, Oxford, UK, pp.
20 150-185.
- 21
- 22 Eijsackers, H., 1978. Side effects of the herbicide 2,4,5-T affecting mobility and
23 mortality of the springtail *Onychiurus quadricellatus* Gisin (Collembola).
24 *Zeitschrift für Angewandte Entomologie* 86, 349-372.
- 25
- 26 Erstfeld, K.M., Snow-Ashbrook, J., 1999. Effects of chronic low-level PAH
27 contamination on soil invertebrate communities. *Chemosphere* 39, 2117-2139.
- 28

- 1 Fábíán, M., Petersen, H., 1994. Short-term effects of the insecticide dimethoate on
2 activity and spatial distribution of a soil inhabiting collembolan *Folsomia*
3 *fimetaria* Linné (Collembola: Isotomidae). *Pedobiologia* 38, 289-302.
4
- 5 Fent, K., 2003. Ecotoxicological problems associated with contaminated sites.
6 *Toxicology Letters* 140/141, 353-365.
7
- 8 Filser, J., Hölscher, G., 1997. Experimental studies on the reactions of Collembola to
9 copper contamination. *Pedobiologia* 41, 173-178.
10
- 11 Filser, J., Wittmann, R., Lang, A., 2000. Response types in Collembola towards copper
12 in the microenvironment. *Environmental Pollution* 107, 71-78.
13
- 14 Fjellberg, A., 1998. The Collembola of Fennoscandia and Denmark. I. Poduromorpha.
15 Brill, Leiden.
16
- 17 Fountain, M.T., Hopkin, S.P., 2004a. Biodiversity of Collembola in urban soils and the
18 use of *Folsomia candida* to assess soil 'quality'. *Ecotoxicology* 13, 555-572.
19
- 20 Fountain, M.T., Hopkin, S.P., 2004b. A comparative study of the effects of metal
21 contamination on Collembola in the field and in the laboratory. *Ecotoxicology*
22 13, 573-587.
23
- 24 Fountain, M.T., Hopkin, S.P., 2005. *Folsomia candida* (Collembola): a "standard" soil
25 arthropod. *Annual Review of Entomology* 50, 201-222.
26
- 27 Gillet, S., Ponge, J.F., 2004. Are acid-tolerant Collembola able to colonise metal-
28 polluted soil? *Soil Biology and Biochemistry* 26, 219-231.

- 1
2 Gisin, H., 1943. Ökologie und Lebensgemeinschaften der Collembolen im
3 schweizerischen Exkursionsgebiet Basels. *Revue Suisse de Zoologie* 50, 131-
4 224.
5
6 Gisin, H., 1960. Collembolenfauna Europas. Museum d'Histoire Naturelle, Geneva.
7
8 Greenacre, M.J., 1984. Theory and Applications of Correspondence Analysis.
9 Academic Press, London.
10
11 Hågvar, S., Abrahamsen, G., 1990. Microarthropods and Enchytraeidae (Oligochaeta)
12 in naturally lead-contaminated soil: a gradient study. *Environmental Entomology*
13 19, 1263-1277.
14
15 Hedlund, K., Bengtsson, G., Rundgren, S., 1995. Fungal odour discrimination in two
16 sympatric species of fungivorous collembolans. *Functional Ecology* 9, 869-875.
17
18 Hopkin, S.P., 2000. A Key to the Springtails of Britain and Ireland, AIDGAP Test
19 Version. Field Studies Council, Shrewsbury, UK.
20
21 Hopkin, S.P., Hames, C.A.C., Bragg, S., 1989. Terrestrial isopods as biological
22 indicators of zinc pollution in the Reading area, South East England. *Monitore*
23 *Zoologica Italiana, Monografia* 4, 477-488.
24
25 Johnson, D.L., Jones, K.C., Langdon, C.J., Pearce, T.G., Semple, K.T., 2002.
26 Temporal changes in earthworm availability and extractability of polycyclic
27 aromatic hydrocarbons in soil. *Soil Biology and Biochemistry* 34, 1363-1370.
28

Jordana, R., Arbea, J.I., Simón, C., Luciáñez, M.J., 1997. Fauna Iberica. VIII. Collembola Poduromorpha. Consejo Superior de Investigaciones Científicas, Madrid.

Landrum, P.F., Lotufo, G.R., Gossiaux, D.C., Gedeon, M.L., Lee, J.H., 2003. Bioaccumulation and critical body residue of PAHs in the amphipod, *Diporeia* spp.: additional evidence to support toxicity additivity for PAH mixtures. Chemosphere 51, 481-489.

da Luz, T.N., Ribeiro, R., Sousa, J.P., 2004. Avoidance tests with Collembola and earthworms as early screening tools for site-specific assessment of polluted soils. Environmental Toxicology and Chemistry 23, 2188-2193.

Michelozzi, M., Raschi, A., Tognetti, R., Tosi, L., 1997. Eco-ethological analysis of the interaction between isoprene and the behaviour of Collembola. Pedobiologia 41, 210-214.

Ojala, R., Huhta, V., 2001. Dispersal of microarthropods in forest soil. Pedobiologia 45, 443-450.

Petersen, H., Gjelstrup, P., 1998. Effects of the insecticide dimethoate on the behaviour of *Folsomia fimetaria* (L.)(Collembola: Isotomidae). Applied Soil Ecology 9, 389-392.

Ponge, J.F., 1973. Application de l'analyse factorielle des correspondances à l'étude des variations annuelles dans les populations de microarthropodes. Bulletin d'Écologie 4, 319-327.

1 Ponge, J.F., Bandyopadhyaya, I., Marchetti, V., 2002. Interaction between humus form
2 and herbicide toxicity to Collembola (Hexapoda). *Applied Soil Ecology* 20, 239-
3 253.

4
5 Ponge, J.F., Gillet, S., Dubs, F., Fedoroff, E., Haese, L., Sousa, J.P., Lavelle, P., 2003.
6 Collembolan communities as bioindicators of land use intensification. *Soil*
7 *Biology and Biochemistry* 35, 813-826.

8
9 Potapov, M., 2001. Synopses on Palaearctic Collembola. III. Isotomidae.
10 *Abhandlungen und Berichte des Naturkundemuseums Görlitz* 73, 1-603.

11
12 Sadaka-Laulan, N., Ponge, J.F., Roquebert, M.F., Bury, E., Boumezzough, A., 1998.
13 Feeding preferences of the collembolan *Onychiurus sinensis* for fungi colonizing
14 holm oak litter (*Quercus rotundifolia* Lam.). *European Journal of Soil Biology* 34,
15 179-188.

16
17 Schirmer, K., Dixon, D.G., Greenberg, B.M., Bols, N.C., 1998. Ability of 16 priority
18 PAHs to be directly cytotoxic to a cell line from the rainbow trout gill. *Toxicology*
19 127, 129-141.

20
21 Shakir Hanna, S.H., Weaver, R.W., 2002. Earthworm survival in oil contaminated soil.
22 *Plant and Soil* 240, 127-132.

23
24 Sjögren, M., 1997. Dispersal rates of Collembola in metal polluted soil. *Pedobiologia*
25 41, 506-513.

26

- 1 Sterzynska, M., 1989. Collembola from urban areas (Warsaw, Poland). In: Dallai, R.
2 (Ed.), Proceedings of the Third International Seminar on Apterygota. University
3 of Siena, Italy, pp. 347-354.
4
- 5 Still, K.R., Alexander, W.K., Nordholm, A.F., Wilson, C.L., Rossi III, J., 2001. A review
6 of the neurotoxicity risk of selected hydrocarbon fuels. Journal of Toxicology
7 and Environmental Health, Part B, Critical Reviews 4, 223-312.
8
- 9 Tranvik, L., Eijsackers, H., 1989. On the advantage of *Folsomia fimetarioides* over
10 *Isotomiella minor* (Collembola) in a metal polluted soil. Oecologia 80, 195-200.
11
- 12 Vannier, G., 1970. Réactions des microarthropodes aux variations de l'état hydrique du
13 sol. In: Vannier, G. (Ed.), Réactions des microarthropodes aux variations de
14 l'état hydrique du sol. Techniques relatives à l'extraction des arthropodes su
15 sol. CNRS, Paris, pp. 23-258.
16
- 17 Visser, S., Whittaker, J.B., 1977. Feeding preferences for certain litter fungi by
18 *Onychiurus subtenuis* (Collembola). Oikos 29, 320-325.
19
- 20 Yeardley, R.B.Jr, Lazorchak, J.M., Gast, L.C., 1996. The potential of an earthworm
21 avoidance test for evaluation of hazardous waste sites. Environmental
22 Toxicology and Chemistry 15, 1532-1537.
23
- 24 Zimdars, B., Dunger, W., 1994. Synopses on Palaearctic Collembola. I. Tullbergiinae.
25 Abhandlungen und Berichte des Naturkundemuseums Görlitz 68, 1-71.
26

Figure captions

Fig. 1. Correspondence analysis. Projection of active (collembolan species) and passive (treatments, population data) variables in the plane of the first two factorial axes. Variables were duplicated, except treatment variables (see text for further explanation). Higher values of each variable are indicated in bold roman, lower values in italic type. For the sake of clarity, only higher values of springtail species are shown (lower values are symmetrical of higher values around the origin of the axes)

Fig. 2. *Lepidocyrtus lanuginosus* in directional traps. Comparison between 'horizontal' and 'vertical' traps. Values are the sum of two conjugated (inverted) boxes, averaged over five replicates, with standard error of the means. Comparisons between both groups were done by paired t-test. *** = significant departure from null hypothesis at 0.001 level

Fig. 3. *Folsomia manolachei* in directional traps. Comparison between 'upward' and 'downward' animals trapped in 'vertical' traps. Values are means of five replicates, with standard errors. Comparisons between both groups were done by paired t-test. ** = significant departure from null hypothesis at 0.01 level

Table 1. Mean density and species richness of Collembola in horizontal and vertical directional traps, in the presence or absence of phenanthrene. Values are means of 5 replicates, followed by standard errors

		Phenanthrene				Control			
		Inwards	Outwards	Downwards	Upwards	Inwards	Outwards	Downwards	Upwards
AFU	<i>Allacma fusca</i>	0.6±0.2	1.6±0.2	0.6±0.2	0.6±0.6	0.6±0.2	1±0	0.8±0.4	0.4±0.2
CDE	<i>Ceratophysella denticulata</i>	0	0	0	0	0	0	0	0.2±0.2
DTI	<i>Desoria tigrina</i>	0	0.2±0.2	0.2±0.2	0.4±0.2	0	0	0	0
DSP	<i>Deuterostomus sp.</i>	0.2±0.2	0	0	0	0	0.2±0.2	0.2±0.2	0
DFU	<i>Dicytoma fusca</i>	1.8±0.6	1±0.4	0.6±0.2	1.4±0.7	1±0.6	3.2±0.9	1.2±0.4	1.2±0.4
EAL	<i>Entomobrya albocincta</i>	0	0.2±0.2	0	0	0	0	0	0
FMA	<i>Folsomia manolachei</i>	61.6±9.8	57.8±7.4	33.4±4.6	56.8±3.8	50.8±5.7	65±7.9	54.8±11.8	50.6±5.7
FTR	<i>Friesea truncata</i>	4.4±1	1.8±0.2	2.6±0.5	2±0.7	2.4±1.7	2.6±0.9	2.6±0.7	3±1.3
HMA	<i>Heteromurus major</i>	4±1.9	1.4±0.5	1±0.3	0.8±0.4	4±1.6	2.2±0.8	0.2±0.2	0.2±0.2
HNI	<i>Heteromurus nitidus</i>	0.2±0.2	0	0	0.2±0.2	0	0	0	0.2±0.2
IMI	<i>Isotomiella minor</i>	10.2±4.6	13.4±3.6	21±10.7	18.2±6.2	7.8±1.3	11.2±4.2	14.8±4.1	24.4±9
KBU	<i>Kalaphorura burmeisteri</i>	0.2±0.2	0.2±0.2	2.2±0.6	0	0.4±0.2	0.2±0.2	1.2±0.5	0
LCU	<i>Lepidocyrtus curvicolis</i>	0	0	0	0.2±0.2	0.4±0.2	0.2±0.2	0	0
LCY	<i>Lepidocyrtus cyaneus</i>	2.2±0.9	1.6±0.9	2±0.9	0.4±0.4	1.8±0.6	1.8±0.4	0.2±0.2	0
LLA	<i>Lepidocyrtus lanuginosus</i>	36.4±8.5	37.8±7.4	20.6±1.4	13.4±2.5	50.2±6.8	49.8±5.5	17.4±3.7	10.6±3.5
MIT	<i>Mesaphorura italica</i>	0.4±0.2	0.6±0.4	0.2±0.2	0.4±0.2	0	0	0	0.4±0.4
MKR	<i>Mesaphorura krausbaueri</i>	0.2±0.2	0.2±0.2	0	0.2±0.2	0.2±0.2	0	0.2±0.2	0
MPY	<i>Micranurida pygmaea</i>	0	0	0	0	0	0.2±0.2	0	0
MSE	<i>Micranurida sensillata</i>	0	0	0.2±0.2	0	0	0	0	0.6±0.2
MGR	<i>Monobella grassei</i>	0.2±0.2	0.4±0.2	0	0	0.2±0.2	0.2±0.2	0	0
NMU	<i>Neanura muscorum</i>	0	0	0.6±0.6	0	0.2±0.2	0	0	0
OCR	<i>Oncopodura crassicornis</i>	0	0	0	0	0	0	0.2±0.2	0
OPS	<i>Onychiurus pseudogranulosus</i>	10.4±2.2	7.8±1.1	3.2±0.8	4±1.2	10.2±0.9	13.2±3.7	3.2±1.2	7±3.5
PCA	<i>Paratullbergia callipygos</i>	1.4±0.5	0.8±0.4	0.2±0.2	0.6±0.2	0.4±0.2	0.4±0.2	0.4±0.4	1.2±0.6
PNO	<i>Parisotoma notabilis</i>	51.2±10.5	48±5.8	55.4±10.7	76.6±15.1	43.6±6.8	41.6±3.1	57.8±12.9	69±7.2
PPA	<i>Pseudachorutes parvulus</i>	1.2±0.4	2±0.7	0.2±0.2	0.2±0.2	2.2±1.7	0.6±0.2	0.4±0.2	0.6±0.6
PSE	<i>Pseudosotoma sensibilis</i>	0	0	0	0.2±0.2	0	0	0	0
PAL	<i>Pseudosinella alba</i>	2.6±1.2	4±1.4	2.4±0.5	7.6±3.6	1.4±0.6	4.4±2.2	2.6±0.7	4.2±2.3
PIM	<i>Pseudosinella immaculata</i>	0.4±0.2	0.2±0.2	0.4±0.2	0	0	0	0.6±0.2	0.4±0.2
SAU	<i>Sminthurinus aureus</i>	6±0.8	4.4±1.4	2.2±1	0.8±0.4	8±1.5	9±1.4	2.4±0.5	1±0.6
SPU	<i>Sphaeridia pumilis</i>	15.4±2.9	10.2±1.9	6.4±1.9	6±1.9	15.2±2	16.4±3.3	9.4±1.4	6.4±2.4
SDE	<i>Stenaphorura denisi</i>	0	0.2±0.2	0	0.4±0.2	0.4±0.2	0	0.2±0.2	0.4±0.2
WPO	<i>Wankeliella pongei</i>	0	0	0	0.2±0.2	0	0	0	0
Total abundance		211.2±28.7	195.8±15.7	155.6±20.7	191.6±27.6	201.4±13.3	223.4±5.5	170.8±19.6	182±22
Sample species richness		15.4±0.7	15.2±0.4	14.2±0.4	13.2±0.6	13.6±0.5	14.4±0.4	13.2±0.9	12.2±0.9

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2 Fig. 1

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Fig. 2

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2 Fig. 3