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A preliminary study on the effect of Cu, Pb and Zn contamination of soils on community structure and certain life-history traits of oribatids from urban areas

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ABSTRACT

The effect of pollution of urban soils by traffic exhausts on oribatid mites was studied along a traffic gradient of the city of Thessaloniki. Although the population density of the main orbatid species appeared increased in polluted areas, the total oribatid numbers were reduced due to the reduction in species richness. The highest species diversity was recorded in moderately polluted areas. The morphometric characteristics as well as certain life-history traits did no correlate with the level of traffic influence. Nevertheless, these characteristics were considered important for the understanding of the pollution impact on life in soils. Moderate body size, sexual reproduction, increased reproductive effort and wide habitat preferences characterize species in urban sites. *Scheloribates latipes* and *Tectocepheus sarekensis* can be used as bioindicators for Pb and Zn pollution of soils, respectively.

Key words: Oribatids, life-history traits, contamination, Cu, Pb, Zn

INTRODUCTION

The combustion of materials of different kinds is the principal source of pollution in cities. Heavy metals enter urban soils by use of antiknock agents, antiwear protectants, lubricants, diesel oils, etc. The accumulated toxic substances in soils may have either lethal or sublethal effects on fauna inhabiting the urban green areas. These effects are expected to be exemplified either on community structure or on population characteristics, respectively. In general, a decline in species richness and species diversity, as well as an impairment of growth rate and the modification of life-history tactics are expected to occur in the heavily polluted commercial centres of large cities (e.g. Steiner, 1990; Siepel, 1994).

Oribatid mites appear sensitive to pollutants. Moss-dwelling species have frequently been used for assessing and even for monitoring air pollution (Lebrun *et al.*, 1977, 1978; Andre *et al.*, 1984). On the other hand, only a few papers deal with the interaction between soil-dwelling oribatids and urban pollution (Weigmann, 1984; Weigmann and Kratz, 1987). Accumulation of pollutants in urban soils creates different kinds of permanently disturbed biotopes, offering the opportunity of studying implications of anthropogenic impacts on life in soils. These studies are of both theoretical and practical interest. Due to their abundance, species richness and species diversity, oribatid mites provide a good material for these studies.

The objective of this paper is the study of the effect of pollution by heavy metals (Cu, Pb and Zn) on community structure and morphometric characteristics as well as on certain life-history traits of soil oribatids in the green sites of the city of Thessaloniki.

SITE

Thessaloniki is the largest city of Northern Greece (approximately 1 million people) and extends Northwest–Southeast along a narrow land strip. A main traffic gradient links the northwest commercial centre to the south-eastern residential area (Fig. 1).

Cook *et al.* (1994) have estimated the concentration of Cu, Pb and Zn in the soils of roadside lawns as well as in the plant parts of the dandelion *Taraxacum* spp. along this main traffic gradient and identified it as contaminated by a heavy metals gradient. Along this gradient, Lanaras *et al.* (1994) demonstrated that urban pollution had a crucial implication on chlorophyll fluorescence of the dandelion.

MATERIALS AND METHODS

Eight sampling sites were confined in artificially created and maintained roadside lawns along the main traffic gradient from the new residential zone (St1–St3) to the commercial centre (St4–St8) of Thessaloniki. Sites St1–St3 exhibit a low pollution level, sites St4 and St5 are moderately polluted, while sites St6–St8 are more heavily polluted (Table 1). The traffic gradient coincides with the main road linking the south-eastern part of the city to the north-western commercial centre. In each site, five sample units were taken with a steel cylinder (diameter = 5.4 cm) in June 1994.

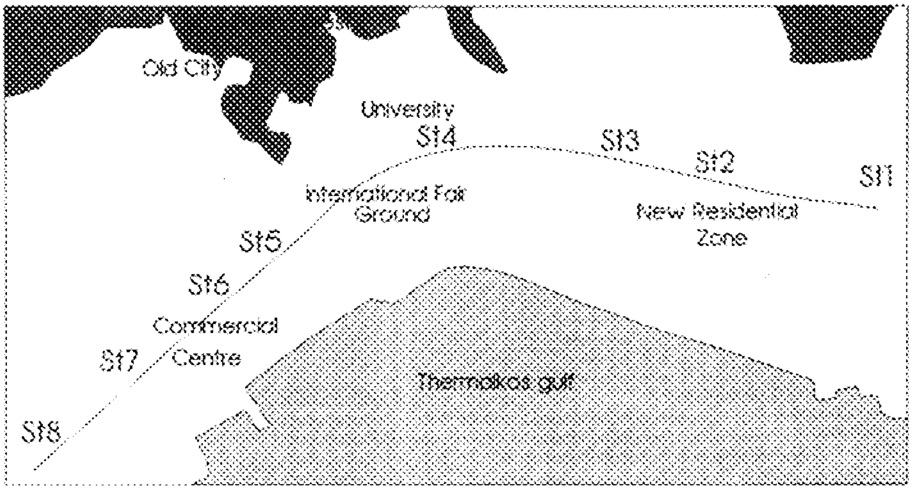

Fig. 1. Map of Thessaloniki indicating the sampling sites along the main traffic gradient (modified from Lanaras *et al.* (1994).

Animals were extracted from samples by means of a modified Berlese–Tulgren apparatus. Specimens were collected into a 5% salicylic acid solution, to which 80% ethyl alcohol and glycerine were added. The numbers were counted under a stereomicroscope. Then, all specimens of oribatid mites were treated with lactic acid and examined microscopically for taxonomic classification, body and egg length measurement and sex determination, as well as for counting the number of eggs in females' abdomens.

Data were analysed by using canonical correlation analysis (CCA; ter Braak, 1988; ter Braak and Prentice, 1988). The mean numbers in the eight samples were the faunistic data, while the concentrations of Cu, Pb and Zn in the plant parts of the dandelion and in the soil (data from Cook *et al.* (1994)) represent the environmental variables. By CCA, the variation in environmental variables is related to community composition and the ordination axes are linear combinations of these environmental variables. The analysis did not reveal colinearity between variables (the variation inflation factor was lower than 20) and, thus, no variables were omitted from the analysis. Finally, for testing the significance of the eigenvalue corresponding to the first axis, a Monte Carlo permutation test was used (ter Braak, 1988). CCA also provides the parameter N_2, which is a measure of the extent to which species numbers are distributed to samples. Thus, it represents the species habitat width. Moreover, the method

TABLE 1

Concentration of Cu, Pb and Zn (mg kg^{-1} dry weight) in the soil and the plant parts of *Taraxacum* spp. at each sampling site (data from Cook *et al.* (1994)

	St1	St2	St3	St4	St5	St6	St7	St8
Roots-Cu	0.03	0.0	0.02	0.0	0.0	0.07	0.10	0.0
Leaves-Cu	0.03	0.0	0.02	0.0	0.0	0.06	0.0	0.0
Soil-Cu	0.08	0.0	0.03	0.10	0.10	0.21	0.10	0.10
Roots-Pb	0.02	0.0	0.04	0.10	0.0	0.06	0.10	0.10
Leaves-Pb	0.05	0.0	0.03	0.10	0.0	0.09	0.0	0.10
Soil-Pb	0.14	0.10	0.05	0.30	0.20	0.31	0.30	0.60
Roots-Zn	0.08	0.10	0.04	0.10	0.10	0.10	0.10	0.10
Leaves-Zn	0.10	0.10	0.07	0.10	0.10	0.09	0.10	1.0
Soil-Zn	0.03	0.10	0.05	0.40	0.10	0.59	0.40	0.30

estimates the parameter N_2', which is a measure of Simpson's species diversity in each habitat.

RESULTS

On average 13 894 individuals per m^2 were recorded and classified into four taxa. Acarina dominate over Collembola (the ratio of Acarina : Collembola is 3.93). Acarina were evenly distributed in samples (Simpson's diversity indices are 0.74 for prostigmatids, 0.67 for mesostigmatids and 0.68 for oribatids), whereas large numbers of Collembola were only recorded in two sites (Simpson's index; 0.51). In comparison with surrounding natural land where the overall number of oribatids was 18 330 individuals per m^2, the corresponding number in urban areas appears significantly reduced (9459 individuals per m^2; Table 2). Furthermore, in the present, case, oribatids were the most numerous group among the Acarina (e.g. the ratio of oribatids : prostigmatids is 13.97).

Another result of pollution on soil animals is the reduction in oribatids' species richness. In relation to the species richness recorded in the above-mentioned surrounding natural land (28 species; Asikidis and Stamou, 1991), only 11 species were identified in the roadside lawns. Among them, *Eremaeus* sp., *Sphaerozetes* sp. and *Oppia ornata* (Oudemans) were recorded in a single site. *Scheloribates pallidulus* (Koch) is the most frequent species, while *Tectocepheus sarekensis* (Tragardh), *Philogalumna allifera* (Oudemans), *Scheloribates laevingatus* (Koch) and *Scheloribates latipes* (Koch) are relatively abundant and broadly dispersed into samples.

TABLE 2

Mean population density (individuals per m^2) of microarthropods sampled in eight stations along the traffic gradient of the city of Thessaloniki. The habitat width (N_2) for oribatid species and species diversity (N_2') estimated by CCA are also given

	St1	St2	St3	St4	St5	St6	St7	St8	Mean	N_2
Collemboles	262	87	14071	0	0	7079	961	87	2818	
Mesostigmatids	175	612	2535	0	787	3321	0	87	940	
Prostigmatids	87	961	1136	437	262	2272	87	175	677	
Oribatids	12498	1835	39104	2922	8215	9788	699	612	9459	
Total	13022	3495	56846	3359	9264	22460	1747	961	13894	
Oribatid species										
S. laevingatus	961	0	87	699	961	350	0	0	382	3.79
S. latipes										
Matures	2709	961	0	97	524	1049	0	0	668	2.95
Immatures	0	87	961	97	787	1311	262	0	438	2.96
S. pallidulus	7516	0	26256	290	961	2884	262	175	4793	3.65
Galumna ssp.	0	0	175	0	0	262	0	0	55	1.92
Z. cognata										
Matures	175	0	6380	483	0	0	0	0	880	1.19
Immatures	0	0	175	0	0	0	0	0	22	1.00
T. sarekensis										
Matures	175	787	787	0	2972	1398	0	350	809	3.44
Immatures	175	0	350	0	175	0	0	87	98	3.24
P. allifera										
Matures	612	0	2010	1256	787	961	0	0	703	4.18
Immatures	0	0	350	0	0	262	0	0	76	1.96
Sphaerozetes sp.	0	0	1311	0	0	0	0	0	164	1.00
Oppia ssp.	175	0	0	0	87	175	175	0	76	3.72
Oppia ornata	0	0	0	0	961	0	0	0	120	1.00
Eremaeus sp.	0	0	0	0	0	175	0	0	22	1.00
Non-identified immatures	0	0	262	0	0	961	0	0	153	1.51
N_2'	2.39	2.17	4.33	3.57	5.13	6.28	2.91	2.33		

Data for oribatid mites were analysed by means of CCA (Fig. 2). The arrows indicate environmental gradients and their lengths are linked to the correlation of the specific variable with the ordination axis. Thus, longer arrows indicate the greater importance of the corresponding factor for sites and species variation. On the CCA plot only the important oribatid species and environmental variables are depicted. The two first axes of the canonical ordination account for the 38.8 and 24.3%, respectively, of the total data variability.

The most important factors for the ordination of samples and species on the first axis are those relating to the concentration of all three pollutants in the soils rather than in the plant parts (the concentration of soils in Zn although important was omitted from the graph for the sake of clarity). The concentration of Pb and Zn in the roots was also important for the ordination. It is worth noting that all the contaminant factors (with the exception of the Pb concentration in roots) are positively correlated with most samples scores.

The end-points of the gradient are occupied by samples from the less-polluted new residential areas (St2 and St3), while samples from the moderately and the heavily polluted sites (St4–St8) are ordinated close to the middle of the gradient. In general, samples from the moderately polluted areas display high values of species diversity (Table 2), whereas the more heavily contaminated sites St7 and St8 display extremely low species richness, due to the predominance of *S. pallidulus* and *T. sarekensis*, which bias their ordination. The ordination of the samples along the second axis is mainly conditioned by the concentration of plant leaves in Pb.

Most species are ordinated close to the centre of the CCA biplot graph. Only *Zygoribatula cognata* (Oudemans) (both matures and immatures) was sampled almost exclusively in samples from site St3. *Pilogalumna allifera*, *S. laevingatus*, *T. sarekensis* and *O. ornata* display high values of habitat width, although for the latter species this can be attributed to the low numbers with which it was sampled. In addition, the two other species of the genus *Scheloribates* are relatively broadly dispersed in samples.

The ordination of species along the CCA axes is irrespective of their

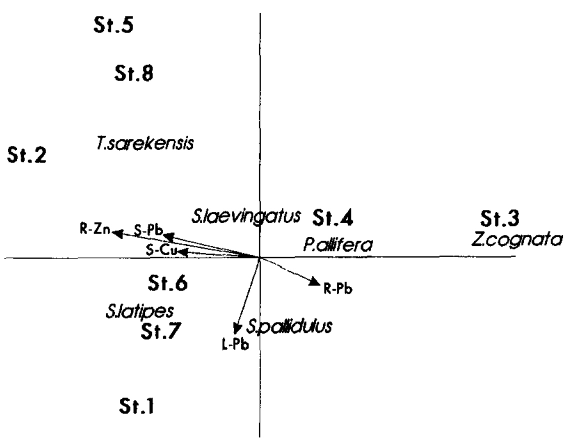

Fig. 2. Ordination of sampling sites and oribatid species on the CCA biplot. Arrows indicate environmental variables.

morphometric characteristics (body dimensions and eggs' length). The same also holds for some life-history traits such as sex ratio and the number of eggs per female. Only the ratio of egg length to body length seems to correlate with pollution. Indeed, species with relatively small eggs such as *Z. cognata* and *P. allifera* tend to be ordinated towards the right end-point of the first CCA axis.

Bravais–Pearson correlation coefficients were estimated in order to reveal relationships between the numbers of arthropods and the concentration of heavy metals in plant parts and soils (data were logarithmically transformed). The distribution of Collembola in samples was not correlated with the concentrations of heavy metals. Mesostigmatids and prostigmatids were affected by the concentration of Cu, while overall oribatid numbers were inversely related to the Pb content. More specifically, the distribution of *S. latipes* was inversely correlated with the Pb concentration in roots ($r = -0.61$), immature *S. latipes* were also inversely correlated with the Pb concentration in leaves ($r = -0.67$), whereas immature *T. sarekensis* were negatively related to the contamination of soils by Zn ($r = -0.72$).

DISCUSSION

Oribatids is the most abundant microarthropod group in the sampled roadside lawns. The ratio of oribatids: prostigmatids which is often used as an index of biotopes dryness (Wallwork, 1967; DiCastri and Vital-DiCastri, 1981; Asikidis and Stamou, 1991) appears high, indicating good hygric conditions.

The mean density of five out of the six main oribatid species (*S. laevingatus*, *S. pallidulus*, *Z. coganata*, *T. sarekensis* and *P. allifera*) is higher than the mean density of these species recorded in surrounding natural land (20 km east of Thessaloniki). Only numbers of *S. latipes* appear slightly reduced (Asikidis and Stamou, 1992). This observation is in accordance with the one reported by Steiner (1990) for the city of Zurich. However, overall numbers of oribatids were significantly reduced in polluted urban areas. This is due to the decline in the number of species in comparison with that recorded in the above-mentioned surrounding natural land. This is in agreement with observations reported by Weigman and Kratz (1987) and Steiner (1990). It seems plausible that in polluted areas, ruderal species take advantage of the extinction of the vulnerable ones to prosper in numbers.

It is often reported that urban pollution decreases oribatid species diversity (Weigmann, 1984; Weigmann and Kratz, 1987; Steiner, 1990), while opposite suggestions have been made by Lebrun (1976). In the present case, samples from the moderately contaminated sites display the highest species diversity. In order to explain this finding, the following explanatory scheme can be proposed. The community structure of soil oribatids in the majority of representative Greek natural habitats is determined by the influence of temperature and humidity (jointly referred to as the thermohygric complex) (Sgardelis *et al.*, 1981; Sgardelis, 1988; Stamou and Sgardelis, 1989; Asikidis and Stamou, 1992). It was also demonstrated that the effect of anthropogenic disturbances such as fire and overgrazing on the community structure of soil arthropods is of lesser importance than changes driven by the seasonally varying thermohygric complex (Sgardelis and Margaris, 1993; Argyropoulou *et al.*, 1994). Since the hygric conditions appeared to be favourable in all sites, temperature must be the dominant environmental factor for community structure in sites with low levels of pollution. It might be possible that heavy metal accumulation in these areas creates specific conditions, where specialized, narrow habitat-selected and temperature-dependent species, such as *Z. cognata* (see Asikidis and Stamou, 1992) can increase their numbers. Thus, a low species diversity is expected to occur in these areas. On the contrary, in the moderately polluted areas the accumulation of contaminants seems to dominate over the other environmental factors. The pollutants create a rather homogeneous and constant environment and wide habitat-selected, resistant to pollution species may establish. Thus, in these latter areas species diversity is expected to increase. The extent to which species diversity increases in moderately polluted areas depends on the availability of ruderal species able to establish themselves. Finally, in heavily contaminated sites the severe conditions allow only a few tolerant species to survive, which results in a decline in species numbers.

Our findings do not agree with Siepel (1994), who suggested that thelytoky is favoured in heavily and permanently contaminated sites. However, consideration of morphological and life-history traits of the recorded species can be useful for an understanding of the impacts of pollution. The body size of the collected animals is of medium length (size class II of Sgardelis (1995)), with the exception of *P. allifera* which belongs to size class IV. All species recorded, with the exception of *T. sarekensis*, are sexually reproducing. Species with relatively large eggs dominate the most polluted areas. According to Asikidis and Stamou (1992), all species display an annual life cycle, a high reproductive potential in their natural habitat and, with the exception of *Z. cognata*, are wide habitat selected. All six dominant oribatid species initiate a single generation per year and, with the exception of *P. allifera*, exhibit a short main oviposition period. Egg deposition starts early after animals attain adulthood. Immature of the genus *Scheloribates*, as well as those of *T. sarekensis*, *P. allifera* and probably *Z. cognata*, develop rapidly in their natural biotopes (Asikidis, 1989; Asikidis and Stamou, 1992). Thus, it seems plausible that pollution favours sexually reproducing species of medium size, with increased reproductive effort, rapid ontogenetic development and wide habitat preferences.

Finally, from the point of view of bioindicator species, *T. sarekensis*, which is the most constant species in the urban sites of Berlin (Weigmann, 1984) and Zurich (Steiner, 1990), also proved constant in sites from Thessaloniki. Its distribution is significantly correlated with the soil content in Zn. Thus, this species may be used for bioindication purposes. *Scheloribates latipes* also appears promising, since its distribution is significantly correlated with the Pb content of roots and leaves of the dandelion.

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