Biodiversity of Collembola in urban soils and their use as bioindicators for pollution

Cristina Fiera[(1)]

[(1)]Institute of Biology, Romanian Academy, 296 Splaiul Independentei, P.O. Box 56-53, 060031 Bucharest, Romania. E- mail: cristina.ivanescu@ibiol.ro

Abstract – The objective of this work was to evaluate the effects of pollutants on the abundance and diversity of Collembola in urban soils. The research was carried out in three parks (Cişmigiu, Izvor and Unirea) in downtown Bucharest, where the intense car traffic accounts for 70% of the local air pollution. One site in particular (Cişmigiu park) was highly contaminated with Pb, Cd, Zn and Cu at about ten times the background levels of Pb. Collembola were sampled in 2006 (July, September, November) using the transect method: 2,475 individuals from 34 species of Collembola were collected from 210 samples of soil and litter. Numerical densities differed significantly between the studied sites.The influence of air pollutants on the springtail fauna was visible at the species richness diversity and soil pollution levels. Species richness was lowest in the most contaminated site (Cismigiu, 11 species), which presented an increase in springtails abundances, though. Some species may become resistant to pollution and occur in high numbers of individuals in polluted sites, which makes them a good bioindicator of pollutants.

Index terms: heavy metals, soil contamination, species diversity, urban parks.

Biodiversidade de Collembola em solos urbanos e o seu uso como bioindicadores de poluição

Resumo – O objetivo deste trabalho foi avaliar os efeitos de poluentes na abundância e na diversidade de Collembola em solos urbanos. A pesquisa foi conduzida em três parques (Cişmigiu, Izvor e Unirea) no centro de Bucareste, onde o tráfego intenso de carros é responsável por 70% da poluição do ar local. Um local em particular (parque Cişmigiu) está altamente contaminado com Pb, Cd, Zn e Cu, com nível de Pb dez vezes superior aos níveis de fundo. Os Collembola foram coletados em 2006 (julho, setembro, novembro), usando o método de transecto: foram coletados 2.475 indivíduos de 34 espécies de Collembola a partir de 210 amostras de solo e serapilheira. As densidades numéricas diferiram significativamente entre os locais estudados. A influência da poluição do ar na fauna de colêmbolos foi visível em termos de riqueza de espécies e do grau de poluição do solo. A riqueza de espécies foi menor no local mais contaminado (Cismigiu, 11 espécies), que apresentou, no entanto, aumento na abundância de colêmbolos. Algumas espécies podem tornar-se resistentes à poluição e ocorrer com elevada abundância em locais poluídos, o que as torna boas bioindicadoras de poluentes.

Termos para indexação: metais pesados, contaminação do solo, diversidade de espécies, parques urbanos.

Introduction

Urban ecosystems are characterized by high-density human habitation, intense transport processes and only remnants of natural habitats (McIntyre et al., 2001). It is necessary to understand the ecosystem responses to the influence of urbanization in order to ensure that urban areas are managed for the well-being of both city-dwellers and nature (Niemelä, 1999). Since urban development is spreading and intensifying, knowledge about the functioning of urban ecosystems has vital importance in planning future urban development in order to minimize its negative environmental impacts (Niemelä, 1999; McIntyre et al., 2001). Urbanization causes several forms of disturbance, such as alteration, fragmentation and isolation of indigenous habitats, changes of temperature, moisture and edaphic conditions, and pollution. Urban sites are often harsh and characterized by many pressures and threats – from limited growing space to adverse climatic conditions and air pollution. Thus, there is an urgent need to develop ‘simple’ protocols to assess the effects of air pollution on native biodiversity, and, where possible, to minimize adverse effects (Andersen, 1999).

Recently, a multinational research framework to assess air pollution in urban soils using bioindicator species (plants, animals and fungi) has been initiated under the Life05Env/RO/000106 Air Aware Project. Springtails (Collembola) were selected as the focal taxa since they are sufficiently varied, both taxonomically and ecologically, abundant and sensitive to the changes of the microenvironment and to the human disturbance. Other taxa (moss, high plants, Thysanoptera, Oribatid mites, carabids and fungi were also studied within the mentioned project).

Collembola communities are characterized by a great diversity of species. These organisms have varied feeding strategies and functional roles within the soil processes. They influence nutrient availability through their interactions with soil microorganisms (Cassagne et al., 2004), such as the rate of bacteria and fungi consumption and spore transportation. The relationships of soil collembolan fauna with their ecological niches and the stability of community composition at a specific site provide good starting points for bioindication of changes in soil properties and impact of human activities.

In order to be useful in measuring environmental change, an indicator must provide measurable and repeatable information in response to whatever question is being posed about the environment more rapidly than it would be obtained by a superficial visual inspection (Greenslade, 2007). According to Markert et al. (2003), a bioindicator is an organism, a part of an organism or a community of organisms, which contains information on the quality of the environment. Hence, any indicator used for a temporal change in environmental quality – as must be expected after the application of soil amelioration measures – must not show any random fluctuations that bear no relevance to the factor to be indicated (Van Straalen, 1997). The interest in research on the effects of air pollutants (Rusek & Marshall, 2000; Fountain & Hopkin, 2004), or on the effects of heavy metals on springtail populations from urban soils of Chişinău town, (Republic of Moldova) (Buşmachiu & Poiras, 2003), or on other type of ecosystems, has increased (Filser et al., 2000; Chauvat & Ponge, 2002). The patterns and responses of springtail assemblages to air pollution may help guide urban management practices.

Scientific interest in studying urban ecosystems has increased, and the analysis of Collembola communities in these areas may help increase the knowledge on springtail diversity. A few studies on springtail communities of urban environments have been performed, e.g. in Moscow (Russia) and Warzaw (Poland) (Sterzynska & Kuznetsova, 1997), Lviv and Kryvyj Rig (Ukraine) (Shrubovych, 2002; Tarashchuk & Horban, 2006) and São José do Rio Preto (Brazil) (Trueba et al., 2002). In Romania, however, springtail-fauna studies from urban soils are still insufficiently developed (Fiera, 2008a, 2008b).

The present study investigated the abundance and diversity of springtails, and its objectives were: to describe and analyze changes of species richness and numerical abundances of Collembola in selected parks from Bucharest; to demonstrate if soil parameters, such as pH or heavy metal concentrations, affect springtail community characteristics (e.g., abundance of the species); and to establish the species which are most sensitive to air pollution.

Materials and Methods

Bucharest, the largest city in Romania, is located in a plain zone in the southern part of the country (44º25'N, 26º06'E, two million inhabitants, 228 km^2). Its main pollution sources are the numerous industrial activities that take place mainly in the outskirts of the city, and the road traffic in the central part of the town. The city's development occurred on natural Chernozems and by human action, these natural soils have become urban soils: Haplic Luvisols, Regosols and Humic Regosols (Lăcătuşu et al., 2008).

For this study, three parks in urban Bucharest were selected: Cişmigiu (44º26'09"N; 26º05'28"E, 73 m a.s.l.); Izvor (44º25'53"N; 26º05'19"E; 68 m a.s.l.); and Unirea (44º21'41"N; 26º06'08.56"E, 71 m a.s.l.). Cişmigiu, a complex park, was treated as a complex of ecosystems; the other two parks had simplified ecosystems and different degrees of management. The distance between the studied areas was of less than 1 km. No control (''clean'') site could be found in the area because of the widespread air pollution.

The research was carried out on a pollution transect from the park edge, more exposed to air pollution, to the centre, which is less exposed. A total of 210 soil and litter samples were collected on three occasions (July, September and November 2006); 25 sample units were sampled from Izvor and Unirea parks and 20 samples were collected from the Cişmigiu park. The sampling was performed using the transect method (T): T1, long side (parallel with the boulevard or forest road); T2, short side (parallel with street or forest path); and T3, middle side (in the middle of the park or forest). The sampling methods are detailed in a previous publication (Fiera, 2008a). The taxonomic system of the species list and the nomenclature were arranged according to Bellinger et al. (1996). Collembola were identified to the species level using the most recent keys: Pomorski (1998), Fjellberg (1998, 2007), Hopkin (2000) and Potapov (2001).

In order to determine the degree of heavy metal pollution and the pH, the following parameters were determined: pH, by potentiometer methods with H_2O and KCl; total content of heavy metals (Pb, Cd, Zn, Cu), assayed by atomic absorption spectrophotometry.

Results and Discussion

Following the Romania (1997) categories, which establish concentrations of 20 mg kg^{-1} Pb, 100 mg kg^{-1} Zn, 1 mg kg^{-1} Cd, and 20 mg kg^{-1} Cu as normal values for soils, the analyzed urban sites can be classified as follows: Cişmigiu park (C) is the most polluted site (Table 1), with 199,8 mg kg^{-1} Pb, 1,21 mg kg^{-1} Cd, 168,5 mg kg^{-1} Cu and 330,3 mg kg^{-1} Zn; this park is followed by Unirea (U) and then by Izvor (I). In Cişmigiu park, the concentration of Pb was ten times higher than the maximum allowable limits. The pH values are characteristic for alkaline soils. The presence of carbonates in these urban soils, which originate from parent materials without natural carbonates, can be explained only by human-associated influence, mainly by building activities.

A total of 2,475 individuals from 34 species, 27 genera and 10 families (Table 2) were collected. Abundance means of collembolan assemblages found at the individual sites ranged considerably depending on the sampling season, i.e. between 1,150 and 36,650 individuals m^{-2} (Cişmigiu park), 5,960 and 17,600 individuals m^{-2} (Unirea park), 1,440 and 9,320 individuals m^{-2} (Izvor park) (Figure 1).

Pollutants in the form of acid depositions, which contain SO_4^{-2}, NOx, H^+, heavy metals and some organic compounds, are not homogeneously distributed in the urban habitat. They could indirectly affect Collembola by damaging food resources, or directly through breathing. This study detected an increase in Collembola populations in the most contaminated site at Cişmigiu park. The mechanisms behind these responses are poorly understood. A population can become extinct or decrease in numbers due to direct metal toxicity, but trophic interactions also play an important role. Some species may even become resistant to pollution, and occur in high numbers of individuals. If the metals have a toxic effect that results in lower abundance of the main food source of a species, this will cause a decrease in any related consumer-population density. Conversely, toxic effects on predators or competitors may result in increased populations (Filser et al., 2000).

The influence of air pollutants on the springtail fauna was visible at the species richness diversity and soil pollution levels. Species richness was highest in the less polluted area (Izvor park – 23 species, Unirea park – 20 species) and lowest in the most contaminated site (Cişmigiu – 11 species). The "basic nucleus" of springtail fauna from urban soils was represented by four common species: *Entomobrya dorsalis*, *Hemisotoma thermophila*, *Protaphorura armata*, *Parisotoma notabilis*. The analysis of the springtail fauna showed that even if several species were common to all parks, their qualitative and quantitative representation was different, generating distinct coenosis. Regarding the effect of the pollution transect, *H. thermophyla* was very abundant in the most polluted site, Cişmigiu park. Previous studies have shown that this species is often found in contaminated sites and is very abundant in certain types of industrial polluted urban soils (Sterzynska & Kuznetsova, 1997; Fountain & Hopkin, 2004). We consider this

Table 1. Statistical parameters of pH and heavy metals determined in the urban soils from each study site: Cişmigiu park (C); Unirea park (U) and Izvor park (I) in Bucharest, Romania.

Parameter	pH			Pb (ppm)			Cd (ppm)			Cu (ppm)			Zn (ppm)		
	C	U	I	C	U	I	C	U	I	C	U	I	C	U	I
Mean	7.15	7.5	7.15	70.52	44.92	40.27	0.71	0.47	058	62.22	43.01	35.88	184.52	107.96	106.83
Max.	7.21	7.73	7.28	199.8	104.6	92.87	1.21	0.8	0.78	168.5	105	89.74	330.3	214.5	194
Min.	7.06	7.17	7.02	30.3	27.68	15.02	0.43	0.36	0.44	22.9	19.16	12.32	98.5	64.81	63.94

species to be sensitive to the air pollution in these urban areas, which makes it a very good bioindicator of pollutants.

At the same park, *P. armata* was found at the edges, but was more abundant in the central section, which was less polluted. In the present study, this species was considered a "metal-tolerant species". Laboratory tests have shown that heavy metals can cause increased mortality and reduced growth and reproduction even in metal-tolerant Collembola like *P. armata* (Bengtsson et al., 1985). This species could be used as a possible bioindicator for long-term effects of pollutants by demonstrating the possible changes that occur in the species future reproductive ability.

Table 2. Number of springtail individuals of each species encountered in the three urban parks, Bucharest, Romania.

Species	Unirea	Cişmigiu	Izvor
Neanuridae	-	-	-
Thaumanura carolii (Stach, 1920)	10	-	-
Pseudachorutes subcrassus Tullberg, 1871	16	-	24
Hypogastruridae	-	-	-
Hypogastrura manubrialis (Tullberg, 1869)	-	-	10
Schoettella ununguiculata (Tullberg, 1869)	18	62	-
Onychiuridae	-	-	-
Hymenaphorura nova Pomorski, 1990	17	-	-
Protaphorura armata (Tullberg, 1869)	30	75	47
Protaphorura pannonica (Haybach, 1960)	10	-	39
Protaphorura sakatoi (Yosii, 1966)	15	-	25
Tullbergiidae	-	-	-
Stenaphorurella denisi (Bagnall, 1935)	-	-	45
Metaphorura affinis (Börner, 1902)	9	-	20
Tomoceridae	-	-	-
Tomocerus vulgaris (Tullberg, 1871)	-	50	-
Isotomidae	-	-	-
Cryptopygus ponticus (Stach, 1947)	-	-	10
Desoria nivalis (Carl, 1910)	-	37	-
Folsomia quadrioculata (Tullberg, 1871)	40	-	-
Folsomia fimetaria (Linnaeus, 1758)	36	-	-
Folsomides parvulus Stach, 1922	35	-	60
Hemisotoma thermophila (Axelson, 1900)	32	792	125
Isotoma anglicana Lubbock, 1862	25	-	32
Isotomiella minor (Schäffer, 1896)	28	45	-
Parisotoma notabilis (Schäffer, 1896)	40	46	60
Proisotoma minuta (Tullberg, 1871)	-	46	-
Entomobryidae	-	-	-
Orchesella sp.	-	-	8
Heteromurus major (Moniez, 1889)	-	-	35
Entomobrya dorsalis Uzel, 1891	10	20	17
Lepidocyrtus lanuginosus (Gmelin, 1790)	-	-	30
Lepidocyrtus cyaneus Tullberg, 1871	-	75	15
Lepidocyrtus lignorum (Fabricius, 1775)	-	54	-
Pseudosinella cf. *imparipunctata* Gisin, 1953	10	-	-
Pseudosinella duodecimpunctata Denis, 1931	8	-	17
Seira domestica (Nicolet, 1842)	-	-	24
Entomobrydae	-	-	-
Cyphoderus albinus Nicolet, 1842	-	-	10
Cyphoderus bidenticulatus (Parona, 1888)	20	-	59
Sminthurididae	-	-	-
Sphaeridia pumilis (Krausbauer, 1898)	-	-	10
Katiannidae	-	-	-
Sminthurinus elegans (Fitch, 1862)	7	-	35
Total of individuals	416	1,302	757

Folsomia fimetaria was found only at the edges of the Cişmigiu park, so this species could be considered resistant to air pollution. This species has also been found in Copşa Mică, one of the most polluted industrial cities of Romania. Some experimental studies have already shown the effects of some pollutants, e.g. nonylphenol (Scott-Fordsmand & Krogh, 2004), on adult and juveniles of *F. fimetaria,* including effects on mortality, growth and reproductive output.

However, total Collembola abundance does not seem to be affected in long-term (decades) metal-contaminated sites (Fountain & Hopkin, 2004). Abundance may not change because Collembola are relatively resistant to metals due to their ability to excrete contaminants stored in the gut lining when they molt (Humbert, 1977). Species that are prevalent in uncontaminated soils may be better competitors, but less able to tolerate metals (Fountain & Hopkin, 2004). Disturbances caused by pollutants in the soil results in both qualitative and quantitative changes in fauna, which affect soil functioning. It can be said that these changes in Collembola communities depend on the distance to the pollution source and on the direction of the dominant winds (Călugăr et al., 1983).

Collembola can be considered good candidates for bioindicator studies. Further research must be

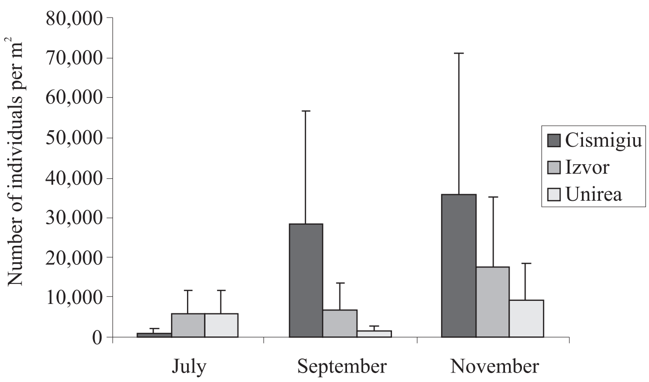

Figure 1. Numerical density of springtails found in three urban parks in Bucharest, Romania.

conducted, especially laboratory tests, to assess the toxicity of pollutants using "standard" organisms, such as *F. fimetaria* or *P. armata*.

Conclusions

1. Collembola are important components of the soil fauna biodiversity in the urban soils of Bucharest.
2. Disturbances caused by pollutants are visible in species diversity, which is higher in the less polluted area and lower in the most contaminated site.
3. *Hemisotoma thermophila* and *Protaphorura armata* are metal-tolerant species, and *Folsomia fimetaria* may be considered a bioindicator of pollutants.
4. The influence of air pollutants on the springtail fauna was visible at the species richness diversity and soil pollution levels.

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