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An assessment of the influence of the urban environment on collembolan communities in soils using taxonomy- and trait-based approaches

Lucia Santorufo[a,b,c,*], Jérôme Cortet[b,c,d], Carmen Arena[a], Romain Goudon[b,c], Alain Rakoto[b,c], Jean-Louis Morel[b,c], Giulia Maisto[a]

[a] Department of Biology, University of Naples Federico II, via Cinthia, 80126 Naples, Italy
[b] Université de Lorraine, Laboratoire Sols et Environnement, UMR 1120, TSA 40602, 54618 Vandœuvre-lès-Nancy, France
[c] INRA, Laboratoire Sols et Environnement, UMR 1120, TSA 40602, 54618 Vandœuvre-lès-Nancy, France
[d] Université Paul Valéry Montpellier 3, CEFE, UMR 5175, Bâtiment Jean-Henri Fabre, 34000 Montpellier, France

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ABSTRACT

In this study we investigated collembolan communities using both taxonomy- and trait-based approaches in order to determine: (1) which soil or leaf litter characteristics are the main agents of species distribution and functional trait distribution in collembolan communities, and (2) which functional traits are more prevalent in species tolerant to urban environments. To investigate this, soil and leaf litter were sampled in the urban area of Naples, Italy and the collembolan community was analyzed using taxonomic and functional approaches. The results indicated that collembolan density was negatively affected by site pollution, and that species richness, diversity and evenness were positively affected by the organic matter content of the soil. *Folsomia lawrencei* was the most abundant species in sites with high metal contamination and low soil organic matter content, whereas *Mesaphorura* sp. and *Parisotoma notabilis* were the most ubiquitous taxa overall. The main agents affecting the frequency of functional traits were metal contamination of soil and litter, soil organic matter content, leaf specific mass and thickness of the litter. The species most tolerant to urban environmental conditions were found to have small body size, jumping motion strategy, sexual reproduction and presence of pigmentation.

1. Introduction

Urban soils are often composed of a mixture of natural and synthetic matter and are profoundly transformed by human activities, which result in the mixing, importing and exporting of materials (De Kimpe and Morel, 2000; Lorenz et al., 2006). These soils present atypical characteristics such as unpredictable layering, a basic pH and low organic matter content (Endlicher et al., 2011; Manta et al., 2002). In addition, as urban soils are impacted by busy roads and enclosed in built-up areas, they receive a large variety of pollutants. Metals tend to accumulate in these soils, altering their chemical composition and biological properties (Wong et al., 2006).

Heavy metals present in the urban environment can have a toxic effect on the biosphere, since they can be taken up by plants and fauna and accumulate in their tissues. The accumulation of metals in plant tissues can modify plant physiology, including at leaf level by changes in leaf characteristics, such as sclerophyllous adaptations and leaf-area reduction (Ambo-Rappe et al., 2011; Arena et al., 2013; Maisto et al., 2013; Seyyednejad et al., 2009, 2011; Tiwari et al., 2006). As the chemical composition and morphological characteristics of living leaves are transferred in leaf litter (Cornelissen and Thompson, 1997; Wardle et al., 1998), this in turn influences the structure and composition of the soil biota community, which thrives on litter as a source of nutrients and energy. For instance, leaf thickness and area-to-volume ratio affect organism colonization patterns and animals' ability to ingest litter as food, including the accessibility of enzymes in the leaves for organisms feeding on leaf litter. In addition, litter characteristics influence decomposition processes, as thin leaves decompose easily, whereas thick leaves are more recalcitrant (Cornelissen, 1996; Cornelissen and Thompson, 1997). Generally, leaves with a high specific leaf area and low dry matter content experience higher colonization by decomposers (Bakker et al., 2011), which in turn can transfer what they ingest to other organisms in the trophic chain (Wang et al., 2009).

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* Corresponding author at: Department of Biology, University of Naples Federico II, via Cinthia, 80126 Naples, Italy. Tel.: +39 081 679095; fax: +39 081 679223.
E-mail address: lucia.santorufo@unina.it (L. Santorufo).

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Among soil organisms, collembolans are both directly and indirectly involved in litter decomposition. Some feed directly on litter (Chahartaghi et al., 2005), whereas others feed on decomposers such as bacteria and fungi (Hopkin, 1997). High concentrations of metals in leaf litter or in certain microorganisms negatively affect the collembolan community, causing shifts in their food habits and/or in their habitats (Gillet and Ponge, 2003). Due to the variety of collembolan diets and habitats, these species have been widely used as biomonitors in recent years. Yet collembolan sensitivity to metal pollution in soil is species-specific, decreasing the abundance of sensitive species, while increasing the abundance of other tolerant species (Filser et al., 2000) that benefit from the extinction of their competitors in contaminated soils (Fountain and Hopkin, 2004; Gillet and Ponge, 2004). Recently, studies investigating functional traits have contributed to highlighting which characteristics allow organisms to face environmental stressors (Auclerc et al., 2009; Dias et al., 2009; Hedde et al., 2012; Makkonen et al., 2011; Salmon and Ponge, 2012; Vandewalle et al., 2010). Despite this growing research on functional traits, the relationship between metal contamination and the functional composition of the collembolan community are poorly understood.

To investigate such relationships, this study was carried out in an urban environment with the aim of highlighting: (1) which soil or litter characteristics are the main agents of species distribution and functional trait distribution in collembolan communities, and (2) which functional traits are more prevalent in species tolerant to conditions of the urban environment. To this purpose, the collembolan community in the soil was studied using both taxonomic and functional approaches. In the taxonomic approach, the collembolan community was investigated at species level, whereas in the functional approach, the presence of morphological, behavioural and physiological traits within the community was evaluated.

2. Materials and methods

2.1. Soil and litter sampling

Samples were collected in October 2011 at 6 urban sites in Naples, southern Italy, an area with a high population density (8182 inhabitants/km^2 according to the Italian Ministry of the Interior, 2011). We selected two sites near a motorway (M1, M2), two sites near roadsides (R1, R2) and two urban parks (P1, P2) (Table 1). The soils present in the urban area of Naples originated from extrusive igneous rocks and show, to a greater or lesser degree, characteristics derived from volcanic materials, with an accumulation of clay and iron oxides (www.soilmaps.it). The chosen sites contained soils that were not mixed with anthropogenic materials, were not intentionally fertilized and were at least 200 years old. At each site, at the base of five *Quercus ilex* L. (holm oak) trees, ten samples of surface soil (to a depth of 5 cm and a diameter of 5 cm) were randomly collected after removing the leaf litter. Five of the ten samples were used to extract the collembolan community, and the remaining five samples were mixed together for physical and chemical analyses (Fig. 1). In addition, undecomposed *Q. ilex* litter was collected under the same trees, stored in sealed plastic bags and kept at a temperature of about +5 °C until it was analyzed in the laboratory.

2.2. Physical and chemical analyses of the soil

The following chemical and physical analyses were performed in triplicate. The sieved (using a 2-mm sieve) and oven-dried (at 75 °C) soil samples were analyzed for: bulk density (BD), calculated as the ratio of dry soil weight to soil volume (Baize, 1988); water-holding capacity (WHC), determined by gravimetric method after saturating the soil with distilled water and then oven-drying (at 105 °C) to a constant weight; pH, measured in a soil:distilled water suspension (1:5 = v:v) by electrometric method (NF, 2005NF ISO 10390); soil organic matter content (SOM), calculated on the basis of soil organic carbon content (ISO 10694); cation-exchange capacity (CEC), the total and exchangeable Al, Ca, Fe, K, Mg, Mn and Na, measured in a solution of 50 mmol$_+$/L of hexamminecobalt(III) chloride (NF ISO 31-130); and for three texture fractions during the sedimentation process: sand (0.05–2 mm), silt (2–50 μm) and clay (<2 μm) in a soil:water suspension.

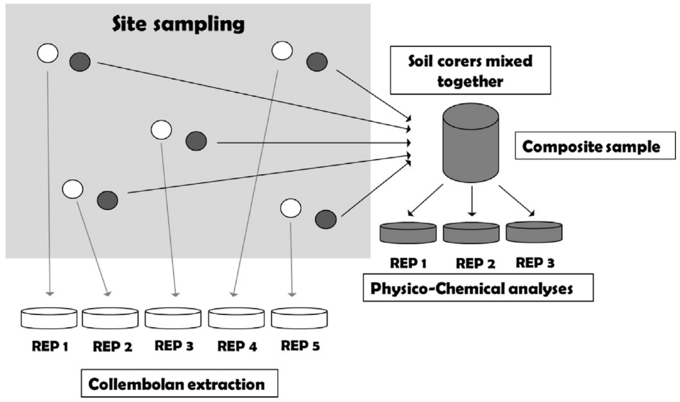

Fig. 1. Schematic representation of the sampling strategy and the physical, chemical and biological analyses performed on the urban soils collected in Naples, Italy.

2.3. Metal measurements in soil and leaf litter

The total and water-extractable content of Cd, Cr, Cu, Ni, Pb and Zn were measured in each soil sample. To measure total metal concentrations, 0.5 g of each soil sample was digested with 10 ml of HNO_3 (65%, Sigma–Aldrich, Germany), 5.5 ml of H_2O_2 (AnalaR Normapur, France) and 5 ml of HCl (37%, Carlo Erba, Italy) at 95 °C for 4 h. Then the solutions were filtered using a 0.45 μm Whatman filter (US-EPA 3050b). The water-extractable metal concentrations were measured using an oven-dried soil:distilled water suspension (1:2.5 = w:v), shaken for 2 h at 200 rpm and filtered with a 0.45 μm filter.

The content of Cd, Cr, Cd, Ni and Pb was measured in undecomposed litter leaves. Samples consisting of 250 mg of dry, ground leaves were digested with a mixture of HF (50%, Carlo Erba, Italy) and HNO_3 (65%, Carlo Erba, Italy) at a ratio of 1:2 (v:v) in a microwave oven (Milestone-Digestion/Drying Module mls 1200).

The metal concentrations in soil and litter samples were measured using an ICP spectrometer (iCAP duo 6000 Series, Thermo Scientific). Accuracy was checked by a concurrent analysis of standard reference materials from the EU Commission Community Bureau of Reference (BCR no. 142R: sandy loam soil; BCR no. 62: Olea europaea leaves): recoveries ranged from 86 to 98%. The metal analyses were performed in triplicate.

2.4. Litter-leaf trait analyses

Undecomposed *Q. ilex* litter leaves were analyzed for leaf area (LA), specific leaf area (SLA), leaf specific mass (LSM), leaf thickness (LT) and relative water content (RWC).

LA was determined using the programme Image J 1.45 (Image Analysis Software); SLA and RWC were determined according to Cornelissen et al. (2003); LSM was calculated as the ratio of leaf dry mass to area; and LT was estimated according to Vile et al. (2005). These leaf traits were selected as they are widely used as predictors of leaf-litter decomposability. LA provides information on leaf size,