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Responses of functional and taxonomic collembolan community structure to site management in Mediterranean urban and surrounding areas

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ABSTRACT

The aim of this study was to identify the physical and chemical properties of different human-mediated ecosystems (urban, peri-urban/industrial and agricultural – including forested areas as a control) and to evaluate their effects on the taxonomic and functional trait composition and microhabitat preferences of collembolan communities. Soils impacted by different types of land management were sampled in urban and surrounding areas of Naples, Italy. The physical and chemical properties of the soil were measured, and the species distribution, functional traits and microhabitat preferences of its collembolan community were characterized. The results indicated that different types of human activities markedly affect the abiotic properties of soils. We found that agricultural soils were more altered than forest soils, and that collembolan communities in agricultural soil were dominated by few species (mainly *Proisotoma minuta* and *Entomobrya multifasciata*), and that these species showed adaptations to open or disturbed environments. Instead, the collembolan communities in urban soils were comparable to those observed in forest soils. It appears that agricultural activities have a greater effect on the taxonomy and functional traits of collembolan communities than urban impact has.

1. Introduction

The increase in the human population and the growing demand for resources are changing land management practices [1]. It is generally accepted that by clearing forests, intensifying farm production and expanding urban areas, human actions are modifying the world's landscapes in pervasive ways [2]. Many, if not all, above-ground human activities heavily impact below-ground communities, as the two are intimately linked [3]. For example, the changes that occur when a forest shifts to a human-mediated ecosystem force organisms to adapt to the new habitat, with potentially dramatic modifications in species composition and abundance. Agricultural intensification as well as urban and industrial activities have been shown to cause alterations in soil biodiversity [4–10], which in turn modify the soil functioning [11,12]. Therefore, modifications in land use and management are growing concerns on a local and global scale. In this context, urban and surrounding areas are very interesting ecosystems to study as they are mosaics that concentrate different types of human activities and land management in a very small area, ranging from occasional natural and preserved areas such as woodland to artificial and recent human-made ecosystems such as industrial brownfields.

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As invertebrates are highly sensitive to soil habitat changes [7–10,13] they have been used since the early 1960s [14] as indicators of soil quality in managed ecosystems [15]. In particular, given their marked response to different habitat characteristics [16–18] and their ability to provide useful information about land disturbance in dynamic landscapes [15], collembolans have great potential for use in integrated biodiversity monitoring schemes [10,19,20].

Recent ecological research on soil invertebrate communities has focused not only on species identification, but more specifically on functional traits [21–25]. These are properties that influence an organism's performance and are measured at the individual level [26,27]. Functional traits allow us to better understand how abiotic factors drive the species assemblage of a particular soil community and to predict how it will develop according to changes in the habitat [28–30]. Despite the growing interest in the impact of human activities on the environment, little is known about the effects of human activities or land management on soil functioning and species distribution, especially in urban ecosystems. Most studies have examined soil biodiversity in one single human-mediated ecosystem [5,31,32]; studies comparing the communities in soils impacted by different types of land use in urban contexts are rare [33,34].

The aim of this study was to test the hypothesis that soils subjected to different types of human activities or management (agricultural, urban and peri-urban/industrial) show modifications of physical, chemical and biological properties. To investigate this, we: (1) evaluated the main physical and chemical characteristics of the soils in different human-mediated ecosystems in a Mediterranean urban and surrounding area; (2) characterized the collembolan communities in these soils based on taxonomic and functional approaches in order to identify the species and traits representative of different types of anthropic activities or pollution. In the taxonomic approach, the collembolan community was investigated at species level, whereas in the functional approach, the morphological and biological traits within the community were evaluated.

2. Materials and methods

2.1. Site description and soil sampling

The study was carried out in the center and the surroundings of Naples (southern Italy), an area with a typically Mediterranean climate of dry, warm summers and cold, wet winters. The soil was sampled in October 2011, in two consecutive days, at 18 sites characterized by different types of management: forest (F1, F2), urban (U1–U6), peri-urban/industrial (PI1–PI4) and agricultural (A1–A6). The sites were selected on the basis of their similar pedogenetic substrate and of site accessibility. For this reason the four categories of land management did not account the same number of sites. In general, the sites were divided in forest, urban, peri-urban/industrial, agricultural soils. Forest sites are far from any human activities and source of pollution; urban sites are located within the city and mainly subjected to urban pollution; peri-urban/industrial sites are located in surrounding area, near to industries, mainly undergone to industrial pollution; agricultural sites are located far from urban centers and subjected to agricultural practices and pollution. The arable sites are differently farmed, and they were chosen as representative of the agriculture practices made in Naples surroundings. The detailed description of the sites is given in Table 1.

At each site, ten samples of surface soil (depth: 0–5 cm, diameter: 5 cm) were collected, after litter removal, in order to cover the delimited area. Five of the ten samples were kept separate and used to extract the collembolans; the other five samples were mixed together to perform the physical and chemical analyses. A detailed description of the sampling method used is reported in Santorufo et al. [10].

2.2. Physical and chemical analyses of the soil

For each site, the chemical and physical analyses were performed in triplicate. The soil samples were sieved (with 2-mm mesh) and characterized for: bulk density (BD), the ratio of dry soil (at 75 °C) weight to volume [35]; water-holding capacity (WHC), determined by gravimetric analysis after saturating the soil with distilled water and then oven-drying it at 105 °C to reach constant weight; water content (WC), determined by drying fresh soil at 105 °C to reach constant weight; pH (measured in a soil:distilled water suspension of 1:5 = v:v by electrometric method [36]; total nitrogen and carbon content (C, N); organic matter content (OM), calculated on the basis of soil organic carbon content [37]; cation exchange capacity (CEC), measured in a solution of 50 $\text{mmol}^{+}\ \text{l}^{-1}$ of hexamminecobalt(III)chloride [38]; and for three texture fractions (sand: 0.05–2 mm, silt: 2–50 μm and clay: <2 μm) in a soil:distilled water suspension of 1:5 = v:v during the sedimentation process.

We also measured the concentrations of the total and the water-extractable Cd, Cr, Cu, Ni, Pb and Zn, as well as of 16 polycyclic aromatic hydrocarbons (PAHs) designated by the United States Environmental Protection Agency (US EPA).

Total metal concentrations were measured following the US EPA method [39]: an aliquot of 0.5 g of pulverized (250 μm) and dried soil sample was digested with 10 ml of HNO_3 (65%, Sigma-Aldrich, Germany), 5.5 ml of H_2O_2 (AnalaRNormapur, France) and 5 ml of HCl (37%, Carlo Erba, Italy) at 95 °C for 4 h; the solutions were filtered through a 0.45 μm Whatman filter. To evaluate the water-extractable metal concentrations, a soil:distilled water suspension (1:2.5 = v:v) was shaken for 2 h at 200 rpm and filtered through a 0.45 μm filter. Both the total and water-extractable metal concentrations were measured using an ICP spectrometer (iCAP duo 6000 Series, ThermoScientific). Accuracy was checked by a concurrent analysis of standard reference materials from the EU Community Bureau of Reference (BCR No. 142R: sandy loam soil) and the recoveries ranged from 86 to 98%.

To analyze the PAH concentrations, the soils were air dried and sieved at 500 μm. Copper powder and Na_2SO_4 were successively added to the soil to remove, respectively, the molecular sulfur and the remaining water, and then an aliquot of 1 g of soil was placed in the ASE corers of the automated extractor Dionex® ASE 350 [40]. The extractions were performed using dichloromethane at 100 °C and at 130 bars. The recovered extracts were concentrated under a gentle flux of nitrogen (Turbovap automatic evaporator) to reach a volume of 2–3 ml and then diluted with dichloromethane at 20 ml. The organic extracts were analyzed using a gas chromatography–mass spectrometer (GC–MS) with a GC-2010 plus (Agilent) instrument equipped with a DB 5-MS column (60 × 0.25 mm) coupled to a QP2012 Ultra (Agilent) mass spectrometer. The GC oven temperature was programmed from 70 °C (held 2 min) to 130 °C at 15 °C min^{-1}, then from 130 °C to 315 °C (held 2 min) at 4 °C min^{-1}. For the PAH quantification, an internal PAH standard mix (naphthalene-d8, acenaphtene-d10, phenanthrene-d10, chrysene-d12 and perylene-d12) was added to the extract before the injection in the GC–MS, and the recovery ranged from 90 to 98%. The 18 PAH concentrations were expressed as the Σ of PAH concentration.