



HAL
open science

Collembolan Biodiversity in Mediterranean Urban Parks: Impact of History, Urbanization, Management and Soil Characteristics

Vittoria Milano, Jérôme Cortet, Daniela Baldantoni, Alessandro Bellino, Florence Dubs, Johanne Nahmani, Sandro Strumia, Giulia Maisto

► To cite this version:

Vittoria Milano, Jérôme Cortet, Daniela Baldantoni, Alessandro Bellino, Florence Dubs, et al.. Collembolan Biodiversity in Mediterranean Urban Parks: Impact of History, Urbanization, Management and Soil Characteristics. *Applied Soil Ecology*, 2017, 119, pp.428-437. 10.1016/j.apsoil.2017.03.022 . hal-03994216

HAL Id: hal-03994216

<https://hal.sorbonne-universite.fr/hal-03994216v1>

Submitted on 5 Nov 2024

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

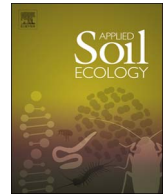


Distributed under a Creative Commons Attribution - NonCommercial - NoDerivatives 4.0 International License



Contents lists available at ScienceDirect

Applied Soil Ecology

journal homepage: www.elsevier.com/locate/apsoil

Collembolan biodiversity in Mediterranean urban parks: impact of history, urbanization, management and soil characteristics

V. Milano^{a,b,*}, J. Cortet^a, D. Baldantoni^c, A. Bellino^c, F. Dubs^d, J. Nahmani^a, S. Strumia^e, G. Maisto^b

^a UMR CEFE 5175, University of Montpellier, EPHE, University Paul-Valéry Montpellier, route de Mende, Montpellier Cedex F-34199, Napoli, France

^b Department of Biology, University of Naples Federico II, via Cinthia, I-80126 Napoli, Italy

^c Department of Chemistry and Biology “Adolfo Zambelli”, University of Salerno, via Giovanni Paolo, II 132, I-84084 Fisciano (SA), Italy

^d IRD – Institute of Ecology and Environmental Sciences of Paris (UMR iEES-Paris), 32, avenue Henri, Varagnat, F-93143 Bondy Cedex, France

^e Department of Environmental, Biological and Pharmaceutical Sciences and Technologies, Second University of Naples, via A, Vivaldi 43, I-81100 Caserta, Italy

ARTICLE INFO

Keywords:

Collembola community
Soil quality
Dominance/diversity analysis
Urban green spaces
Park management

ABSTRACT

Urban parks provide esthetic and recreational services and improve the quality of life in cities. Sometimes considered as biodiversity hot-spots in cities, they are subjected to different management practices which may affect soil biological quality. This is the first study – performed in urban parks of Naples (southern Italy) – aiming to evaluate the effects of park history (age, previous land use of the area and soil origin), urbanization (sealed surface density of park neighborhood), current management (land cover type and litter presence/absence) or soil physico-chemical properties on collembolan communities diversity, as indicators of soil biological quality. Our results showed that the maintenance of specific land cover types and the presence of a litter layer were crucial factors in favoring high collembolan richness in urban parks, likely by ensuring adequate trophic resources and spatial niches. In addition, park age, urban density and previous land use of areas may be involved in shaping collembolan communities. Indeed, the most diverse and structured communities inhabit soils of the oldest urban park, with the lowest surrounding urban density and mild land use change.

1. Introduction

Urbanization is a major driver in the disappearance of green areas (Boyko and Cooper, 2011; Dallimer et al., 2011; Tratalos et al., 2007), disrupts ecosystem integrity and contributes to the degradation of environmental quality (Alberti and Marzluff, 2004). In this context, urban parks provide esthetic and recreational services, improve citizens' health and quality of life (Gómez-Baggethun et al., 2013) and maintain species biodiversity (Francis and Chadwick, 2012; McKinney, 2008). Even though urban parks are considered as biodiversity hot-spots within cities, they are usually still far from reaching this status (Brown, 2003). On the one hand, the conversion of natural areas into man-made ecosystems is accompanied by a decrease in biodiversity with slow recovery, if any (Santorufu et al., 2015). On the other hand, the transformation of urban areas into parks, and land use legacies, may affect ecosystem structure and functioning in the long term.

In order to match people needs and maintain biodiversity in cities, local stakeholders have to plan more green spaces and adopt more conservation programs and urban greening initiatives. Nonetheless,

there is still little information available about the best management methods or vegetation features to maintain biodiversity in urban parks (Politi Bertoncini et al., 2012), especially in the case of soil fauna. For example, as highlighted by Norton (2011), the sanitization of urban parks provokes a decline of ground-dwelling arthropod communities, through the simplification of the vegetation structure and leaf litter and woody debris removal. In addition, urban parks may be constituted by very heterogeneous areas strongly affected by anthropogenic activities (Sarah et al., 2015). For example, picnicking or simply passing visitors cause changes in soil properties (i.e. soil compaction, moisture, organic matter content) and vegetation characteristics (i.e. vegetation height and species diversity) (Politi Bertoncini et al., 2012; Sarah and Zhevelev, 2007; Sarah et al., 2015). The soils of urban man-made green areas, falling into SUITMAs (Soils in Urban, Industrial, Traffic and Military areas; Morel et al., 2015), are often constituted by Technosols (IUSS, 2014), which can affect soil biodiversity. Indeed, these soils are often considered to be almost devoid of life (Leguédou et al., 2016), mainly because of their potential organic and inorganic contamination or their hostile physical properties (Eijsackers, 2010; Hafeez et al.,

* Corresponding author. Tel.: +33 04 67 14 23 15; fax: +33 04 67 14 24 59.

E-mail addresses: vittoria.milano@univ-montp3.fr, vickymilano88@gmail.com (V. Milano).

<http://dx.doi.org/10.1016/j.apsoil.2017.03.022>

Received 5 January 2017; Received in revised form 27 March 2017; Accepted 29 March 2017
0929-1393/ © 2017 Elsevier B.V. All rights reserved.

Table 1

Geographical coordinates, number of sampled plots, park age, urban density of parks, previous land use, park size, as well as number of sampled plots for soil origin and for each land cover type crossed with litter presence/absence of eight public urban parks in Naples (southern Italy).

Park	Total number of sampled plots	Age [‡]	Urban Density [§]	Previous Land Use	Park size (m ²)	Soil Origin		Land Cover [†]			
						native	Technosols	open		closed	
								absent	present	absent	present
Astroni 40° 50' 39.6"N 14° 9' 16.2"E	AST 4	very old	very low	Forest	25,00,000	4	0	0	0	0	4
Capodimonte 40° 52' 25.9"N 14° 14' 25.6"E	CAP 8	old	low	Forest	13,00,000	8	0	4	0	0	4
Virgiliano 40° 47' 55.3"N 14° 10' 46.5"E	VIR 8	old	low	Forest	70,000	2	6	3	1	2	2
Nicolardi 40° 52' 30.0"N 14° 14' 16.3"E	NIC 4	young	low	Tuff quarry	12,000	0	4	4	0	0	0
Poggio 40° 51' 59.0"N 14° 14' 24.8"E	POG 8	young	medium	Tuff quarry	40,000	0	8	2	2	3	1
Scampia 40° 52' 24.2"N 14° 11' 48.6"E	SCA 4	young	medium	Abandoned area	1,40,000	4	0	4	0	0	0
Letizia 40° 50' 20.0" N 14° 19' 21.4"E	LET 4	young	high	Abandoned area	20,000	0	4	0	4	0	0
Troisi 40° 50' 0.7"N 14° 18' 48.6"E	TRO 8	young	high	Agricultural area	1,20,000	6	2	2	2	0	4

[†] In each park, 4 or 8 plots were sampled, depending on the presence of only one - open or closed - or both land cover types. "Open vegetation" means habitats mainly composed by lawn or grassland, whereas "closed vegetation" implies woody and bushy habitats.

[‡] Park age was determined using the date when parks were first opened to the public, and classified as "young" (1–50 years), "old" (51–300 years), and "very old" (> 300 years).

[§] The percentage of urban density was classified as "very low" (< 20%), "low" (21–40%), "medium" (41–60%) and "high" (> 60%), since there was no occurrence in the 80–100% range.

2012; Huot et al., 2014; Lucisine et al., 2015). Nevertheless, it has been reported that Technosols can evolve into biologically active soils even when they are polluted (Frouz et al., 2013; Lucisine et al., 2015).

Even if soils host an extremely rich fauna (André et al., 1994), they are still largely unexplored (Coleman et al., 2004). Some soil invertebrates have been used as indicators of soil quality since the early 1960s (Cortet et al., 1999; Volz, 1962). For example, the use of Collembola is recommended in monitoring programs as they have been selected at the European level as indicators of soil biological quality (Bispo et al., 2010). Nevertheless, their use in biomonitoring of urban ecosystems still remains poorly developed (Fiera, 2009; Santorufo et al., 2015). Collembola are a proxy for soil biodiversity because: (1) they are abundant in many ecosystems and differ in microhabitat preferences and vegetation types (Gillet and Ponge, 2003; Heiniger et al., 2015; Vanbergen et al., 2007); (2) species exhibit different specialization levels, ranging from strictly specialist to generalist species (Auclerc et al., 2009); (3) many soil physico-chemical characteristics are crucial for species survival (Berg et al., 1998; Loranger et al., 2001; Ponge, 1993) and (4) collembolan local biodiversity is inversely related to landscape temporal heterogeneity (Ponge et al., 2003), especially if habitat patches are isolated (Heiniger et al., 2014).

In this study, we aimed to investigate whether collembolan communities diversity was driven by park history (age, previous land use of the area and soil origin), urban density (sealed surfaces in the neighborhood), local management (land cover type and presence of litter), or soil physico-chemical properties, using total metal concentrations as proxies for airborne pollutants (Pouyat et al., 2015). To this end, we compared, using community analysis and different biodiversity metrics, the structure of collembolan communities collected in several urban parks in Naples (southern Italy). We expected vegetation management to be the main factor modifying collembolan structure of communities by affecting niche parameters such as trophic resources and microhabitat quality.

2. Materials and methods

2.1. Study area and sampling design

The study was carried out in eight public urban parks in Naples (40°50'N; 14°15'E), the main metropolis of the Campania region (southern Italy), extending for about 119.02 km² (<http://www.istat.it/storage/urbes2015/napoli>) and representing the third largest metropolitan area in Italy after Rome and Milan. Moreover, Naples is nowadays also one of the most densely populated (8310.23 inhabitants km⁻²) (<http://www.istat.it/storage/urbes2015/napoli>) European metropolises in the Mediterranean area, concentrating in its urban area more than half of the regional population (Scaramella, 2003). The area is characterized by a Mediterranean climate with warm-dry summers, and mild-wet winters (<http://www.dst.unina.it/clima-di-napoli>).

Information on the urban parks (i.e. age, previous land use of the area and soil origin) was obtained from municipality park offices (Table 1). The age of the parks was determined using the date when they were first opened to the public, and they were classified as "young" (1–50 years), "old" (51–300 years) and "very old" (> 300 years). Four classes of previous land use of the park area have been defined: forest, tuff quarry, agricultural or abandoned area. The urban context around each park was also characterized. To this end, the percentage of sealed surfaces (i.e. streets and buildings), in an area extending for 200 m from the perimeter of each park, was calculated with a Geographical Information System platform (QGIS Development Team, 2014), using vector maps of streets, buildings and public parks (<http://sit.regione.campania.it/portal/portal/default/Download>) and aerial Photo 2011 AGEA (Agenzia per le Erogazioni in Agricoltura), at the scale of 1:10,000 (data retrieved June 4, 2014). The calculated percentage was then classified into four classes (Table 1): 1 – "very low" (< 20%), 2 – "low" (21–40%), 3 – "medium" (41–60%) 4 – "high"

Table 2
Mean values \pm standard deviations of pH, bulk density (BD), water content (WC), total C and N concentrations, dissolved organic carbon (DOC), available P and total concentrations of Cu, Ni, Pb and Zn in the soils collected at the eight public urban parks in Naples (southern Italy).

Park [†]	AST	CAP	LET	NIC	POG	SCA	TRO	VIR
pH	6.023	6.285	7.075	6.530	6.736	6.610	6.769	6.740
BD (g cm ⁻³)	0.342	0.593	0.749	0.753	0.644	0.736	0.710	0.494
WC (g g ⁻¹ d.w.)	1.032	0.423	0.234	0.190	0.207	0.296	0.340	0.269
Ctot (g Kg ⁻¹ d.w.)	153.359	95.870	40.680	49.297	44.735	41.337	57.819	39.329
Ntot (g Kg ⁻¹ d.w.)	11.303	7.524	3.539	4.252	3.966	3.809	4.840	2.948
DOC (mg Kg ⁻¹ d.w.)	2262.675	1048.763	424.410	741.675	593.274	393.593	1197.563	725.044
POlsen (g Kg ⁻¹ d.w.)	0.024	0.032	0.005	0.019	0.012	0.023	0.015	0.015
Catot (mg Kg ⁻¹ d.w.)	27.511	36.710	57.791	47.111	26.343	45.493	134.022	18.185
Ntot (mg Kg ⁻¹ d.w.)	5.100	5.350	13.100	4.600	4.850	7.600	12.350	3.350
Pbot (mg Kg ⁻¹ d.w.)	51.944	107.945	61.276	38.753	61.792	56.343	158.991	38.453
Zntot (mg g ⁻¹ d.w.)	92.473	110.146	110.781	79.175	101.243	100.948	187.631	63.202

[†] Park labels are reported in Table 1. Minimum and maximum values of pH, BD, WC, C, N, DOC and P are reported in bold. Total metal concentrations higher than the threshold values defined by Italian law (D.M. 471/99) are also reported in bold.

(> 60%), since there was no occurrence in the 80–100% range. In each park, four or eight plots (4 m² each) were identified, depending on the presence of only one – open or closed – or both land cover types. Each plot was situated in a homogeneous (open or closed) parcel of minimum 225 m². More specifically, habitats composed by lawn or grassland were classified in the “open vegetation” class, whereas woody and bushy habitats were placed into the “closed vegetation” class. Each plot was characterized for soil origin (native or Technosol) and for the presence or absence of a continuous litter layer on the soil when sampling was performed (Table 1). For closed vegetation plots, the continuous litter layer was mainly constituted by *Quercus ilex* leaves, whereas in open vegetation plots, the litter layer was mainly composed by thatch and turf clippings mixed to leaves from tree species in the neighborhood. From each plot, a core of surface soil (0–5 cm depth, diameter 5 cm) was collected after litter removal (if present), according to ISO 23611-2 (2006) as also reported by Cluzeau et al. (2012) and Ponge et al. (2013). For avoiding a potential “edge effect” on collembolan communities, each soil core was sampled at a distance of at least 2 m to parcel borders. To enable data comparisons, samples in closed vegetation plots were always collected under *Q. ilex* L., the dominant native evergreen species in these parks; similarly, samples for open vegetation plots were always collected under turf.

Soil sampling was carried out on April 20th and 21st 2015, as springtime is considered as the period of highest microarthropod species richness in Mediterranean areas (Cortet and Poinso-Balaguer, 1998; Renaud et al., 2004; Sousa et al., 2004). During the week before sampling, mean temperature was 16 °C and relative humidity was 70% (<http://archivio-meteo.distile.it>) (retrieved October 13, 2016). Finally, 48 soil samples have been collected and used for the analysis of collembolan communities, as well as for physical and chemical analyses.

2.2. Collembola identification

Microarthropods were extracted from soil samples, through dry extraction for a week (Macfadyen, 1961). Temperature above the samples was increased during extraction from 35 °C (2 days) to 45 °C (2 days) and then to 60 °C (3 days), while temperature below the samples was kept at 5 °C. Animals were then preserved in 70% ethanol. For each sample, Collembola were counted and identified at morpho-species level under a binocular stereo-microscope (Kyowa optical, SDZ-TR-PL, 7–45 \times magnification). The specimens have been whitened in a Marc André I solution and mounted in a Marc André II solution (André, 1946). Species identification was verified under an optical phase-contrast microscope (Zeiss, Aaxio Scope A1, 200–630 \times magnification) according to various dichotomous keys (Bretfeld, 1999; Dunger and Schlitt, 2011; Hopkin, 2007; Jordana, 2012; Potapow, 2001; Thibaud et al., 2004; Zimdars and Dunger, 1994). When more than 10 specimens were counted for each morpho-species, a subsample of 10 specimens was randomly selected for species identification.

For each sample, collembolan density (number of Collembola per m²) and richness (total number of species, S) were recorded and used to calculate the Shannon diversity index, H' (Shannon, 1948):

$$H' = - \sum P_i \log_2 P_i$$

where P_i is the ratio between the abundance of species i and the total number of organisms.

Moreover, evenness was evaluated according to the Pielou index, J' (Pielou, 1969):

$$J' = \frac{H'}{\log_2 S}$$

Collembola community structure for each urban park was evaluated through Whittaker's curves (Magurran, 2004). The most widely used models of community structure (i.e. brokenstick, pre-emption, log-Normal, Zipf and Zipf-Mandelbrot) were fitted to the data and the best

Table 3
Mean values \pm standard deviations of the Collembola species density (individuals m⁻²) in the eight public urban parks in Naples (southern Italy).

Species [†]	AST	CAP	VIR	NIC	POG	SCA	LET	TRO
Frequency								
<i>Anurida</i> sp.	1	6	0	0	0	0	0	3694 \pm 8668
<i>Brachystomella parvula</i> (Schäffer, 1896)	2	28	764	0	0	0	0	446 \pm 921
<i>Cyphoderus albinus</i> (Nicolet, 1842)	3	2	127	0	0	0	0	0 \pm 0
<i>Ceratophysella denticulata</i> (Bagnall, 1941)	4	2	4841	0	0	0	0	0 \pm 0
<i>Ceratophysella gibbosa</i> (Bagnall, 1941)	5	28	1401	0	0	0	0	828 \pm 1963
<i>Cryptopygus thermophilus</i> (Axelson, 1900)	6	70	0	0	0	0	0	2484 \pm 3216
<i>Desoria tigrina</i> (Nicolet, 1842)	7	4	0	0	0	0	0	191 \pm 540
<i>Entomobrya</i> sp.	8	15	382	0	0	0	0	255 \pm 545
<i>Folsomia fimetaria</i> (Linnaeus, 1905)	9	2	764	0	0	0	0	0 \pm 0
<i>Folsomia inoaltata</i> (Stach, 1946)	10	4	0	0	0	0	0	0 \pm 0
<i>Folsomides parvulus</i> (Stach, 1922)	11	9	255	0	0	0	0	1924 \pm 1621
<i>Folsomia penicula</i> (Bagnall, 1939)	12	6	3694	0	0	0	0	0 \pm 0
<i>Folsomia quadrioculata</i> (Tullber, 1871)	13	6	764	0	0	0	0	0 \pm 0
<i>Folsomia sexoculata</i> (Tullber, 1871)	14	4	0	0	0	0	0	0 \pm 0
<i>Priesea truncata</i> (Cassagnau, 1958)	15	2	0	0	0	0	0	0 \pm 0
<i>Heteromurus major</i> (Moniez, 1889)	16	2	0	0	0	0	0	0 \pm 0
<i>Isotomurus maculatus</i> (Schäffer, 1896)	17	6	0	0	0	0	0	637 \pm 1606
<i>Isotomiella minor</i> (Schäffer, 1896)	18	17	255	0	0	0	0	0 \pm 0
<i>Isotomodes templetani</i> (Bagnall, 1939)	19	30	15,032	0	0	0	0	2420 \pm 6444
<i>Isotomodes trisetosus</i> (Axelson, 1907)	20	2	0	0	0	0	0	0 \pm 0
<i>Lepidocyrtus curvicolis</i> (Boutlet, 1839)	21	2	2293	0	0	0	0	0 \pm 0
<i>Lepidocyrtus lanuginosus</i> (Linnaeus in Gmelin, 1788)	22	4	637	0	0	0	0	0 \pm 0
<i>Lepidocyrtus lignorum</i> (Fabricius, 1775)	23	4	255	0	0	0	0	0 \pm 0
<i>Lathriopyga longiseta</i> (Caroli, 1910)	24	4	382	0	0	0	0	0 \pm 0
<i>Mesaphorura</i> sp.	25	6	0	0	0	0	0	0 \pm 0
<i>Protaphorura armata</i> (Tullber, 1871)	26	6	0	0	0	0	0	0 \pm 0
<i>Protaphorura aurantica</i> (Ridley, 1880)	27	15	0	0	0	0	0	0 \pm 0
<i>Pseudosminella immaculata</i> (Lie-Pettersen, 1896)	28	68	4076	0	0	0	0	8153 \pm 11,073
<i>Pseudosminella caroli</i> (Lucianez Ortega and Simón, 1991)	29	6	1401	0	0	0	0	9873 \pm 11,073
<i>Proisotoma minuta</i> (Tullber, 1871)	30	11	0	0	0	0	0	0 \pm 0
<i>Proisotoma notabilis</i> (Schäffer, 1896)	31	13	6242	0	0	0	0	0 \pm 0
<i>Pseudosminella petterseni</i> (Bömer, 1901)	32	2	0	0	0	0	0	2420 \pm 6846
<i>Proisotoma ripicola</i> (Linmaniem, 1912)	33	2	0	0	0	0	0	0 \pm 0
<i>Sminthurinus elegans</i> (Fitch, 1862)	34	15	0	0	0	0	0	0 \pm 0
<i>Sminthurus viridis</i> (Linnaeus, 1758)	35	9	0	0	0	0	0	255 \pm 545
<i>Tomocerus minor</i> (Lubbock, 1862)	36	2	255	0	0	0	0	0 \pm 0

[†] Park labels are reported in Table 1. Species are labeled by Arabic numerals. Species name information are available on <http://www.collembola.org/taxa/collembola.htm> - Last updated on 2017.03.31 by Frans Janssens.

Table 4

Mean values \pm standard deviations of species richness (S), Shannon (H') and Pielou (J') diversity indices for each Collembola community in the eight public urban parks in Naples (southern Italy).

Park	S		H'		J'	
AST	7.750	± 1.500	1.421	± 0.165	0.702	± 0.081
CAP	4.250	± 1.488	1.021	± 0.389	0.723	± 0.158
VIR	3.429	± 0.787	0.651	± 0.256	0.579	± 0.278
NIC	4.000	± 0.816	0.812	± 0.174	0.617	± 0.233
POG	4.000	± 2.160	0.704	± 0.452	0.566	± 0.154
SCA	3.500	± 1.291	0.791	± 0.290	0.719	± 0.138
LET	4.750	± 1.500	1.113	± 0.178	0.740	± 0.144
TRO	3.750	± 1.669	0.741	± 0.402	0.632	± 0.180

model in each case was chosen according to Akaike and Bayesian Information Criteria (Oksanen, 2016) using the “vegan” package within the R 3.0.1 programming environment (R Core Team, 2013).

2.3. Soil physico-chemical characterization

Water content (WC, g^{-1} d.w.) was gravimetrically determined after soil drying at 105 °C until constant weight. To evaluate soil porosity, bulk density (BD, g cm^{-3}) was calculated as described in Baize (2000) on 100 cm^3 soil cores, taken from the top 5 cm of soil after litter removal (if present). Specifically, cores were dried at 105 °C for 24 h, and BD was calculated as the ratio between dry weight and core volume.

Soils sieved (at 2 mm) and oven-dried (at 75 °C) were characterized for:

- pH (ISO 10390, 2005) with a soil:water ratio of 1:5 v:v;
- total nitrogen (N, g kg^{-1} d.w.) concentration (ISO 13878, 1998);
- total carbon (C, g kg^{-1} d.w.) concentration (ISO 10694, 1995);
- dissolved organic carbon (DOC, mg kg^{-1} d.w.) (Thurman, 1985);
- available phosphorous (P, g kg^{-1} d.w.) according to the Olsen method (ISO 11263, 1994);
- metal concentrations (United States Environmental Protection Agency, 1996).

In particular, total copper (Cu, mg kg^{-1} d.w.), nickel (Ni, mg kg^{-1} d.w.), lead (Pb, mg kg^{-1} d.w.) and zinc (Zn, mg kg^{-1} d.w.) concentrations were measured on an aliquot of 0.5 g pulverized and dried soil sample digested with 10 ml HNO_3 (65%, Sigma-Aldrich, Germany), 5.5 ml H_2O_2 (AnalaR Normapur®, France) and 5 ml HCl (37%, Carlo Erba, Italy) at 95 °C for 4 h. Total metal concentrations were measured using an ICP spectrometer (iCAP duo 6000 Series, ThermoScientific). Accuracy was checked through a concurrent analysis of standard reference material from the EU Community Bureau of Reference (BCR No. 142R: sandy loam soil) and metal recoveries ranged from 86 to 98%.

2.4. Statistical analyses

A multivariate analysis was performed to evaluate the effects of environmental parameters (C, N, DOC, P, BD, pH, WC, Cu, Ni, Pb, Zn, land cover type, soil origin, park age, previous land use, urban density, litter presence) on collembolan communities. In particular, non-metric multidimensional scaling (NMDS) was carried out on the collembolan data set, based on two axes, a Bray-Curtis distance metric and 9999 iterations. NMDS is commonly regarded as the most valuable unconstrained ordination method in community ecology (Minchin, 1987), while Bray-Curtis' algorithm is deemed adequate for the detection of underlying ecological gradients (Faith et al., 1987). To evaluate the effects of these gradients (C, N, DOC, P, BD, pH, WC, Cu, Ni, Pb, Zn), they were fitted, a posteriori, on the NMDS space with generalized additive models (GAMs). To achieve better results in the component

selection within GAMs, the restricted maximum likelihood estimation (REML) method was used as the smoothing parameter estimation, which is in line for unknown scales and preferred when the primary purpose of the analysis is to carry out smooth component selection (Marra and Wood, 2011). To evaluate the effects of the categorical variables (land cover type, soil origin, park age, previous land use, urban density, litter presence), the associated confidence ellipses (for $\alpha = 0.05$) were superimposed on the NMDS biplot, and the significance of the differences between collembolan communities were tested using permutational multivariate analyses of variance (PERMANOVAs) (number of permutations = 999,999) (Anderson, 2001). PERMANOVA is a non-parametric test, extremely robust and applicable to any situation where the simultaneous responses of many dependent variables (i.e. usually abundances of species in an assemblage) have been measured in samples from a one-factor or multifactor ANOVA design (Anderson, 2001). The multivariate homogeneity of group variances for each PERMANOVA model was tested through the PERMDISP test (Anderson, 2006). Since the effect of the different environmental parameters was tested separately through GAMs in the NMDS space or through PERMANOVA, the collinearity among predictors did not affect results, but should be considered in their interpretation. Thus, a correlation matrix (i.e. the Spearman's, interclass' and Cramer's V coefficients of correlation) among the environmental parameters was illustrated in the Supplementary Material. All the analyses were performed with the R 3.0.1 programming environment (R Core Team, 2013) using functions from the “vegan” package.

3. Results

3.1. Park characteristics and soil physico-chemical properties

All parks falling into the “very old” (AST) and “old” (CAP and VIR) classes were built on previously forested areas and are located in “very low” and “low” urban density areas (Table 1). In particular, AST park was characterized by the lowest urban density (9.4%). Among these, AST and CAP had native soil, whereas in six out of eight sampling areas at VIR the soil was a Technosol (Table 1). “Young” parks differed either in previous land use or in the urban density of the surrounding area (Table 1). NIC park is 7 years old and was built with Technosols, as POG and LET parks, whereas in TRO and SCA parks, most or all of the sampling areas were on native soils (Table 1). Among these parks, TRO is located in a densely populated district, reaching the highest urban density value (64.0%).

Soil pH values ranged between 6.023 and 7.075, values measured at AST and LET, respectively (Table 2). The lowest soil water content (0.190 g g^{-1} d.w.) was found at NIC and the highest one (1.032 g g^{-1} d.w.) at AST (Table 2). The soils richest in C, N and DOC were found at AST park, whereas VIR (C and N) and SCA (DOC) parks had the soils with the lowest values of these parameters (Table 2). On average, the highest soil metal concentrations were observed in TRO and LET parks, located in high urban density areas (Table 2).

3.2. Collembolan community

Total collembolan density per sample ranged from 0 to 153,374 individuals per m^2 (detected at POG). A total of 33 taxa have been identified at the species level and 3 at the genus level (Table 3). The most frequently observed species were *Cryptopygus thermophilus* and *Paratullbergia caroli*, with frequencies of 70% and 68% of the total observations, respectively (Table 3). Both species were observed in all the parks (with the exception of *C. thermophilus*, absent from AST) with the highest density in NIC and VIR, respectively (Table 3). Many species have been observed at one site only: *Friesea truncata* at CAP, *Heteromurus major* at VIR, and *Ceratophysella denticulata*, *Cyphoderus albinus*, *Folsomia fimetaria*, *Lathriopyga longiseta*, *Lepidocyrtus lignorum*, *Lepidocyrtus curvicolis*, and *Tomocerus minor* at AST (Table 3).

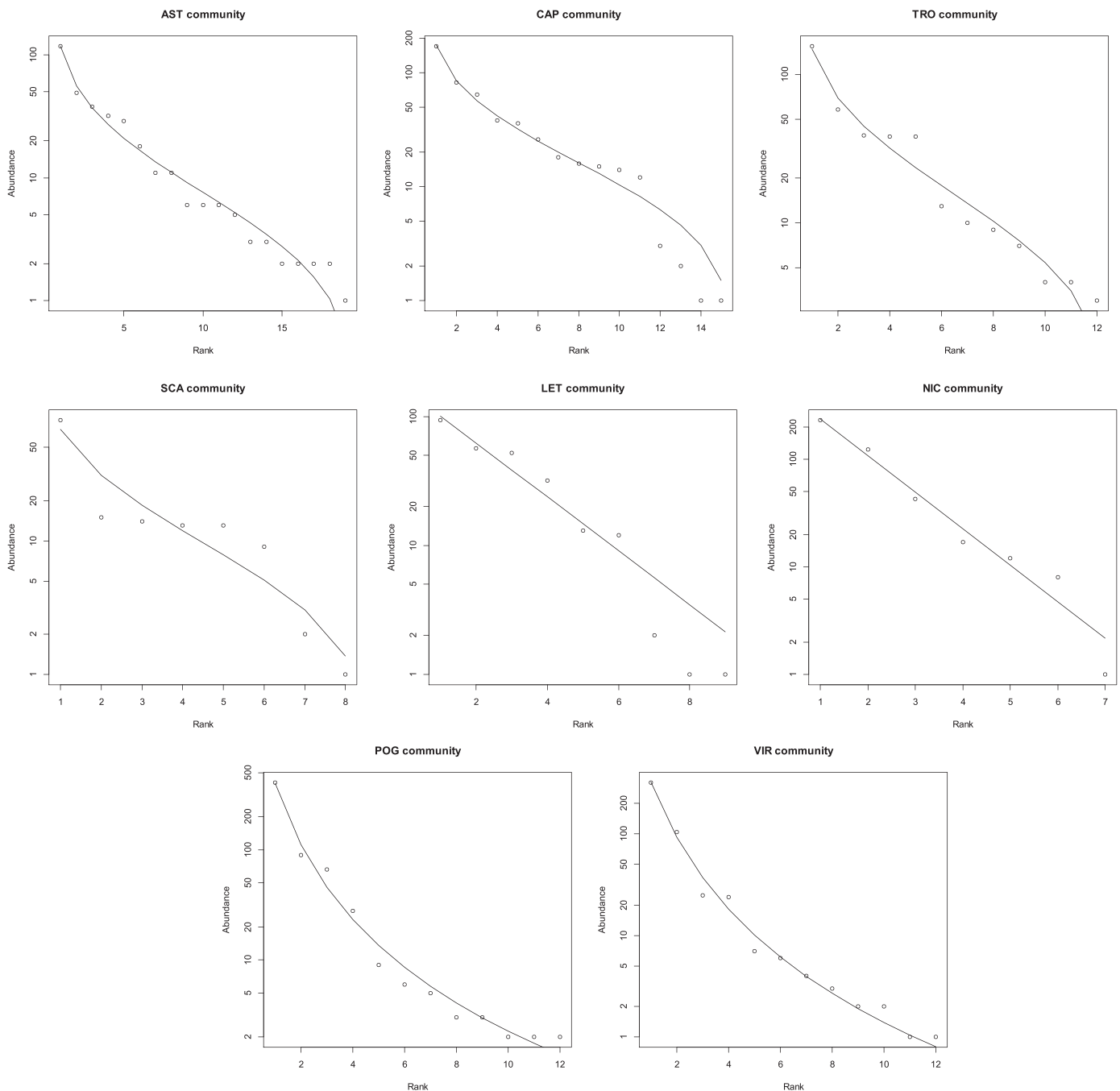


Fig. 1. Whittaker's curves concerning data for collembolans from urban parks in Naples (southern Italy). Species in the rank-abundance space are plotted as circles, whereas predicted abundances based on log-normal (AST, CAP, TRO and SCA), niche preemption (LET and NIC) and Zipf-Mandelbrot (POG and VIR) models are plotted as black lines. Park labels are reported in Table 1.

The least species-rich collembolan communities were observed in VIR soils (3.43), whereas the richest one was found at AST (7.75) (Table 4). The Shannon index per sample ranged between 0.65 (VIR) and 1.42 (AST), whereas the Pielou index ranged between 0.57 (POG) and 0.74 (LET) (Table 4).

Among the abundance-diversity models, the log-normal model was associated to the lowest AIC and BIC (Akaike and Bayesian Information Criteria) values in AST, CAP, SCA and TRO parks (Fig. 1). By contrast, the niche preemption model described better the community structures of LET and NIC, and the Zipf-Mandelbrot model those of POG and VIR parks (Fig. 1).

3.3. Relationships between collembolan communities and physico-chemical variables

Among the physico-chemical variables, GAMs based on soil C, N, DOC, WC and pH were significant ($p < 0.001$; REML scores: 225.75; 110.82; 348.41; -1.64 ; 29.52, respectively) in modeling the distribution of collembolan species in the NMDS space (Fig. 2). In particular, these GAMs explained 46% (C), 44% (WC), 33% (DOC), 30% (N) and 28% (pH) of the observed deviance. All gradients were parallel to the first NMDS axis, although their direction varied, with pH showing a direction of maximum variation opposite to all the others. Overall, a clear species gradient was recognizable, with *P. aurantiaca*, *P. petterseni*, *F. truncata*, *C. thermophilus*, *P. ripicola*, *I. trisetosus*, *B. parvula* and *S.*

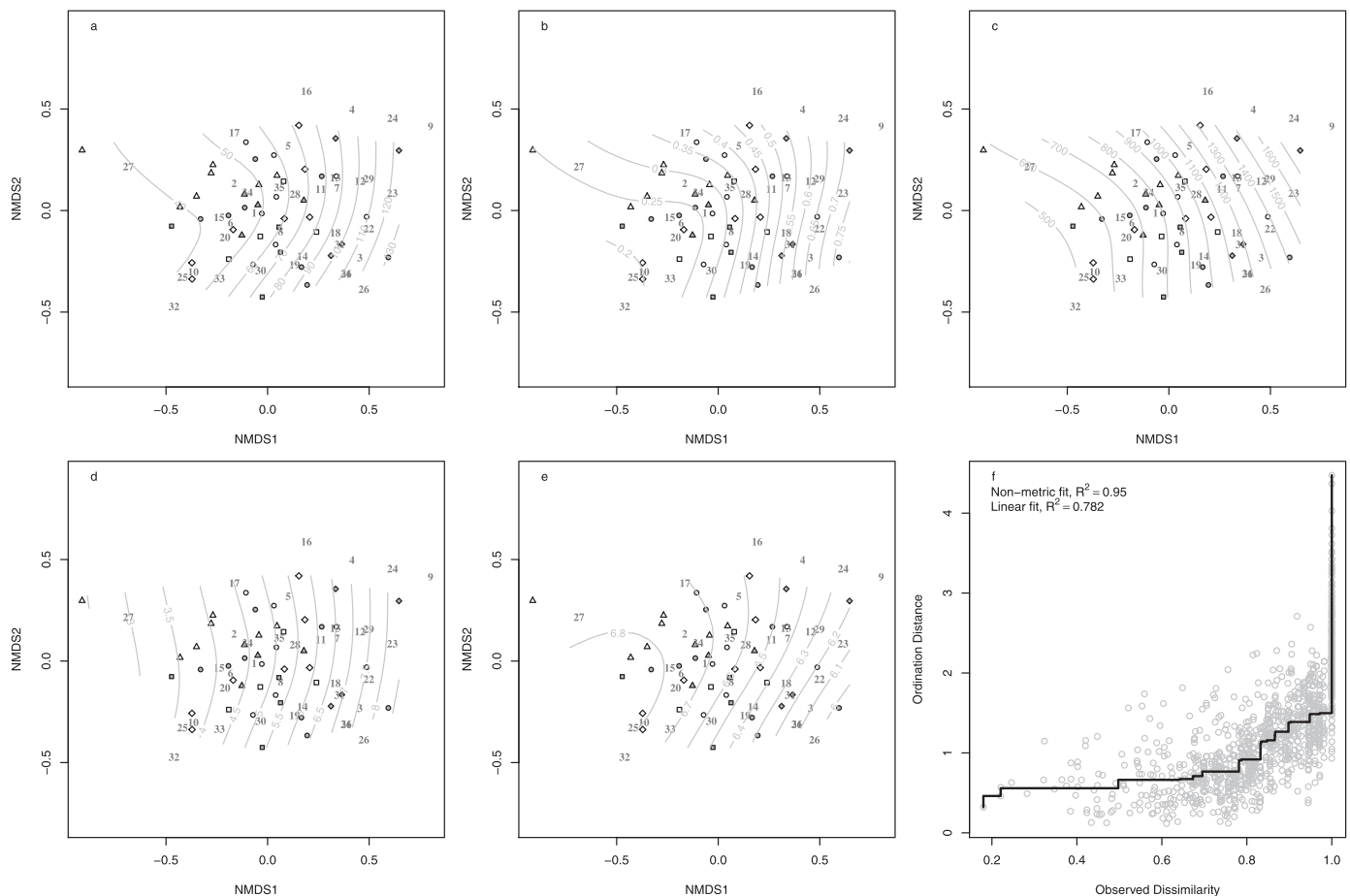


Fig. 2. Gradients, indicated by gray isolines, of soil (a) total C concentration, (b) water content, (c) dissolved organic C, (d) total N concentration and (e) pH on the 2d NMDS space concerning data for collembolans from urban parks in Naples (southern Italy). The stress plot with the linear and non-linear fits is also reported on panel (f). Different parks are coded with different symbols (AST: gray diamonds; CAP: gray circles; LET: gray squares; NIC: gray triangles; POG: white triangles; SCA: white squares; TRO: white circles; VIR: white diamonds). Park labels are reported in Table 1. Species are labeled by Arabic numerals defined in Table 3.

elegans all associated to soils with low C, DOC, N, WC, and with neutral pH values, and *P. immaculata*, *P. armata*, *C. albinus*, *L. curvicollis*, *L. lanuginosus*, *L. longiseta*, *L. lignorum* and *F. fimetaria* on the opposite end of the spectrum for these variables (Fig. 2).

3.4. Relationships between collembolan communities and categorical variables

Collembolan communities significantly differed ($p < 0.001$) between open and closed habitats, although confidence ellipses partially overlapped in the NMDS space (Fig. 3a). Confidence ellipses related to previous land use and the presence or absence of litter overlapped (Fig. 3c, e), but the groups were nevertheless clearly distinguished (both $p < 0.05$) based on PERMANOVA. In particular, parks built on previous tuff quarry sites had different collembolan communities in respect to the others. Finally, urban density and park age showed a similar distribution of confidence ellipses (Fig. 3), with those related to very low urban densities and to the very old park clearly separated from the others and associated to the same species, a differentiation also highlighted by PERMANOVA (both $p < 0.01$). All the categorical variables showed data not overdispersed, except for the litter presence/absence ($p < 0.01$).

4. Discussion

Our study on collembolan communities of Naples urban parks highlighted wide variations in relation to environmental characteristics. Land cover type and litter presence were the main drivers of

collembolan community diversity (even if litter results may be linked to a minor overdispersion of data), probably because they largely contribute to soil DOC, C and N inputs and affect water content and pH. It is well known that litter fall in forest ecosystems is the main pathway of carbon transfer from plant to soil (Berg and McClaugherty, 2014; Campos et al., 2017; Koehler and Tranvik, 2015; Prescott, 2010), mediated by detritivore and decomposer activities. This is evident at AST, a World Wild Fund for Nature reserve established in an ancient volcano, where detrimental management practices such as repeated litter removal and soil poaching are avoided. As a consequence, AST soils were covered by a thick litter layer, partially in an advanced stage of decomposition (personal observation), and exhibited the highest number of rare and forest-specific species. Among these were found: *C. denticulata*, a species commonly living in damp environments and abundant in habitats rich in organic matter (Hopkin, 2007), *F. fimetaria*, a nitrophilous species (Potapow, 2001), and *F. truncata*, *L. curvicollis*, *L. lignorum*, *L. longiseta*, *P. immaculata*, *T. minor* and *H. major*, which are known to live in feces, mosses, roots, under rocks, in dead wood and litter (Fjellberg, 2007; Hopkin, 2007). The maintenance of both canopy cover and litter layer, coupled with an evolution in low anthropogenic pressure conditions, seems thus to positively affect collembolan biodiversity in terms of community composition (Devigne et al., 2016). Conversely, the regular litter removal performed in other parks with closed vegetation or built on previously forested areas may be responsible for the observed substitution of forest-specific species with others, typical of more open habitats (Sattler et al., 2011). The increase in arthropod species richness together with the age of green urban areas was also reported by Sattler et al. (2010); this increase can likely be

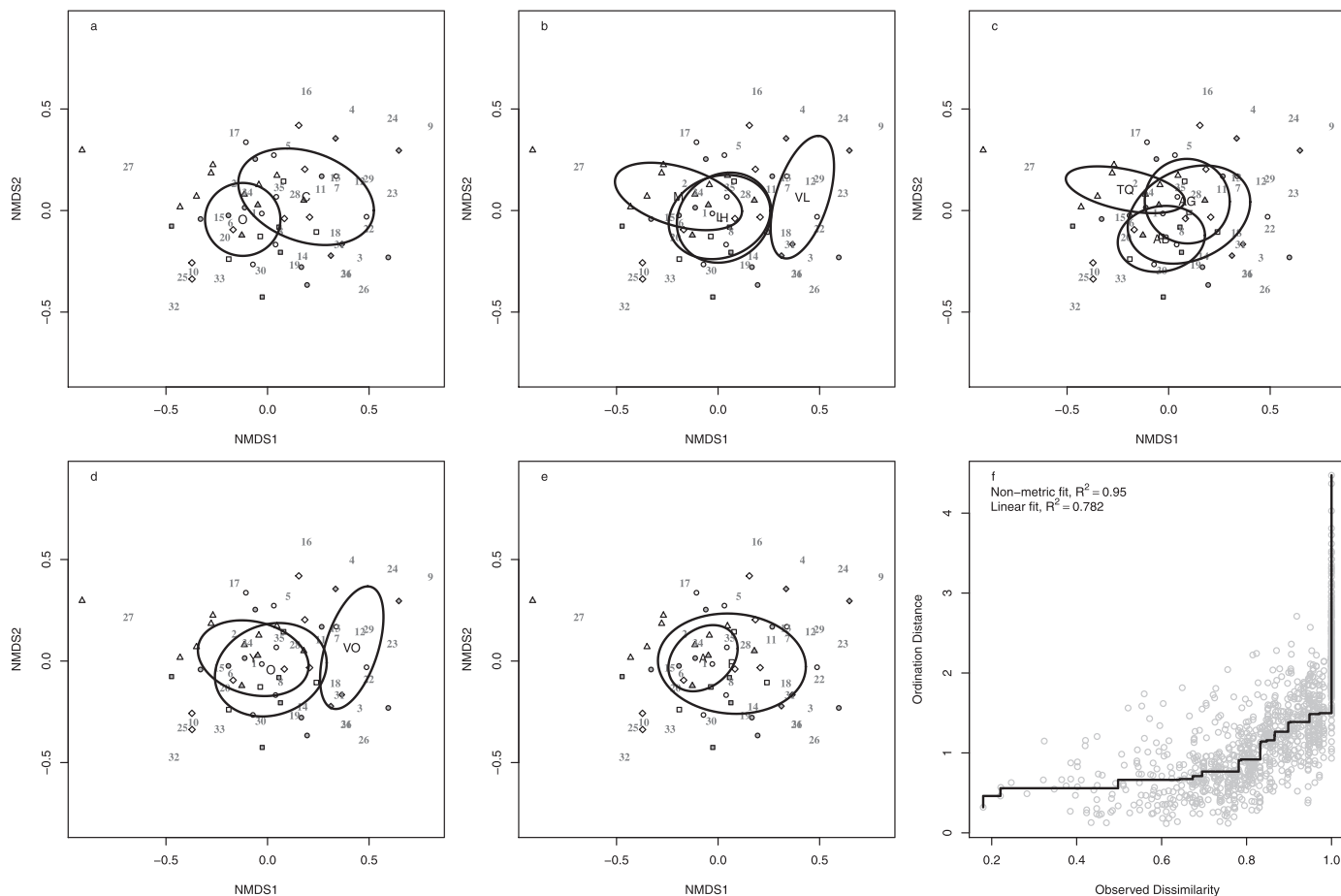


Fig. 3. Confidence ellipses (for $\alpha = 0.05$), relative to (a) land cover (O: open, C: closed), (b) urban density (VL: very low, L: low, M: medium, H: high), (c) previous land use (AB: abandoned area, TF: tuff quarry, F: forest, AG: agricultural area), (d) park age (Y: young, O: old, VO: very old), (e) litter (P: present, A: absent), superimposed on the 2d NMDS space concerning data for collembolans from urban parks in Naples (southern Italy). The stress plot with the linear and non-linear fits is also reported on panel (f). Different parks are coded with different symbols (AST: gray diamonds; CAP: gray circles; LET: gray squares; NIC: gray triangles; POG: white triangles; SCA: white squares; TRO: white circles; VIR: white diamonds). Park labels are reported in Table 1. Species are labeled by Arabic numerals as defined in Table 3.

attributed to the combination of a progressive occupation of new species-specific ecological niches consequently to advancing succession, and a species accumulation over time caused by successful stochastic immigrations.

In our study, AST represents one extreme in the spectrum of the environmental variables measured, the opposite position being occupied by NIC, the youngest park, characterized by the lowest soil DOC, C and N concentrations, as well as by the highest soil compaction. Accordingly, NIC was characterized by species with low resource requirements, which are usually pioneer species, such as *P. minuta*, tolerant to unfavorable conditions (Potapow, 2001), or *C. thermophilus*, *P. caroli*, and *P. notabilis*, which are typically found in early and medium successional stages of decaying soil improvers (Potapow, 2001). Furthermore, many generalist species have been observed in NIC soils. For example, *C. thermophilus* is a nitrophilous species, typically eurytopic in southern Europe; it reaches high densities in various open and closed habitats, usually disturbed ones, such as sites near highways or industries and in metal-polluted soils (Potapow, 2001). *P. caroli* is a species known to live in either open or closed habitats, preferring dryer substrates in southern Europe. *P. notabilis* also generally reached high abundance, but this could be explained by the fact that this species is in fact a complex of different cryptic species, the populations of which may respond differently to their environment (Porco et al., 2012).

The biodiversity indices employed in the present study showed a low sensitivity in detecting differences among collembolan communities, as already pointed out (Devigne et al., 2016; Van Straalen, 1998). Conversely, the Whittaker's curves approach proved to be

especially useful, allowing the analysis of community structure in terms of dominance/diversity (Whittaker, 1965) and its variations among urban parks. The log-normal distribution of species abundance in AST, CAP, SCA and TRO parks suggests complex communities with a dominance structure nearing equilibrium (Wilson, 1991). On the opposite, the communities of LET and NIC, two young parks, described by a niche preemption model of species abundance, appear to be in their early stages of evolution (Motomura, 1932, 1947; Whittaker, 1965). Indeed, the niche preemption model assumes that communities build up sequentially, with incoming species accessing a fraction of the unallocated resources, and has been suggested to be characteristic of resource-poor environments (Whittaker, 1965). Similar to the preemption model, the Zipf-Mandelbrot model, which best described communities in POG and VIR parks, assumes a sequential build-up of the ecological community, although the focus here is on environmental constraints rather than on available resources: early-arriving species are subjected to few constraints and will be more abundant, whereas those arrived later will be rare (Wilson, 1991).

In our study, the absence of any relationship between collembolan biodiversity and soil metal concentrations could be caused by low concentrations in respect to the threshold values defined by Italian law (D.M. 471/99) for urban green areas. Indeed, only CAP and TRO soils exceeded the threshold values (120, 120, 100 and 150 mg kg⁻¹, for Cu, Ni, Pb and Zn, respectively): CAP for Pb and TRO for Cu, Pb and Zn. However, it should be considered that these threshold values have been defined with a view to human health and are probably lower than values really impacting soil fauna. These high Pb and Zn concentrations

were likely due to the high urban density and vehicular traffic along the TRO park borders (El Khalil et al., 2008; Wong et al., 2006), whereas the high Cu concentrations could result from the agricultural practices to which the area had been previously subjected (Belon et al., 2012; Saby et al., 2011). An interesting observation in this context was the exclusive presence in these two parks of *D. tigrina*, a nitrophilous and anthropophilous species (Grinbergs, 1958; Ponge, 1993; Potapow, 2001; Solnzeva, 1967), whose potential use as a bioindicator of metal pollution deserves further investigations.

5. Conclusions

To our knowledge, this is the first study aiming to evaluate the effects of park history, urbanization, management and soil properties on soil collembolan communities in Mediterranean urban parks. Our study clearly shows that maintaining a canopy cover and a litter layer are crucial factors favoring high collembolan biodiversity in urban parks, likely by ensuring adequate trophic resources and spatial niches. Conversely, low soil metal concentrations do not affect collembolan communities. Finally, an array of park characteristics, including park age, the urban context surrounding each park and the previous land use, may be in some way involved in shaping collembolan communities in terms of diversity and structure. The related functional characteristics require further investigations, but this study is one step toward the confirmation that Collembola can also be used as relevant bioindicators of soil biological quality in urban contexts.

Acknowledgments

This work was funded by the University Paul Valéry in Montpellier, France. The authors would like to thank Drs Bruno Buatois and Raphaëlle Leclerc of the PACE platform (Montpellier, France) for facilitating physico-chemical analyses, Dr Francesca Pignataro of Naples municipality for providing cadastral data, the gardeners of Naples parks for kindly sharing precious information, Dr Philippe Chatelet for useful suggestions on the text and Dr Cedric Moisy for comments on earlier versions.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at <http://dx.doi.org/10.1016/j.apsoil.2017.03.022>.

References

Alberti, M., Marzluff, J.M., 2004. Ecological resilience in urban ecosystems: linking urban patterns to human and ecological functions. *Urban Ecosyst.* 7, 241–265.

Anderson, M.J., 2001. A new method for non-parametric multivariate analysis of variance. *Austral. Ecol.* 26, 32–46.

Anderson, M.J., 2006. Distance-based tests for homogeneity of multivariate dispersions. *Biometrics* 62, 245–253.

André, M., 1946. Halacariens marins. Faune de France. Lechevalier, Paris. pp. 46.

André, H.M., Noti, M.I., Lebrun, P., 1994. The soil fauna – the other last biotic frontier. *Biodivers. Conserv.* 3, 45–56.

Auclerc, A., Ponge, J.F., Barot, S., Dubs, F., 2009. Experimental assessment of habitat preference and dispersal ability of soil springtails. *Soil Biol. Biochem.* 41, 1596–1604.

Baize, D., 2000. Guide des analyses en pédologie, 2ème édition revue et augmentée. INRA, Paris.

Belon, E., Boisson, M., Deportes, I.Z., Eglin, T.K., Feix, I., Bispo, A.O., Galsomies, L., Leblond, S., Guellier, C.R., 2012. An inventory of trace elements inputs to French agricultural soils. *Sci. Total Environ.* 439, 87–95.

Berg, M.P., Kniese, J.P., Bedaux, J.J.M., Verhoef, H.A., 1998. Dynamics and stratification of bacteria and fungi in the organic layers of a Scots pine forest soil. *Biol. Fertil. Soils* 26, 268–284.

Berg, B., McLaugherty, C., 2014. Plant Litter: Decomposition, Humic Substances Formation, Carbon Sequestration, Third ed. Springer-Verlag, Berlin.

Bispo, A., Cluzeau, D., Creamer, R., Dombos, M., Graefe, U., Krogh, P.H., Sousa, J.P., Pérès, G., Rutgers, M., Winding, A., Römbke, J., 2010. Indicators for monitoring soil biodiversity. *Integr. Environ. Assess. Manag.* 5, 717–719.

Boyko, C.T., Cooper, R., 2011. Clarifying and re-conceptualising density. *Prog. Plann.* 76, 1–61.

Bretfeld, G., 1999. Synopses on paleoartic collembola *Symphleona* Staatliches Museum

für Naturkunde. Görlitz 2.

Brown, A.L., 2003. Increasing the utility of urban environmental quality information. *Landscape Urban Plan.* 65, 85–93.

Campos, A.C., Lourdes, C.H., Rocha, S.A., 2017. Mass, nutrient pool, and mineralization of litter and fine roots in a tropical mountain cloud forest. *Sci. Total Environ.* 575, 876–886.

Cluzeau, D., Guernion, M., Chaussod, R., Martin-Laurent, F., Villenave, C., Cortet, J., Ruiz-Camacho, N., Pernin, C., Maitelle, T., Philippot, L., Bellido, A., Rougé, L., Arrouays, D., Bispo, A., Pérès, G., 2012. Integration of biodiversity in soil quality monitoring: baselines for microbial and soil fauna parameters for different land-use types. *Eur. J. Soil Biol.* 49, 63–72.

Coleman, D.C., Crossley Jr., D.A., Hendrix, P.F., 2004. *Fundamentals of Soil Ecology*, 2nd ed. Elsevier, San Diego.

Cortet, J., Poinso-Balaguer, N., 1998. Collembola populations under sclerophyllus copices in Provence (France): comparison between two types of vegetation *Quercus ilex* L. and *Quercus coccifera* L. *Acta Oecol.* 19, 413–424.

Cortet, J., Gomot-De Vaulflery, A., Poinso-Balaguer, N., Gomot, L., Texier, C., Cluzeau, D., 1999. The use of invertebrate soil fauna in monitoring pollutant effects. *Eur. J. Soil Biol.* 35, 115–134.

Dallimer, M., Tang, Z., Bibby, P.R., Brindley, P., Gaston, K.J., Davies, Z.G., 2011. Temporal changes in greenspace in a highly urbanized region. *Biol. Lett.* 7, 763–766.

Devigne, C., Mouchon, P., Vanhee, B., 2016. Impact of soil compaction on soil biodiversity – does it matter in urban context? *Urban Ecosyst.* 19, 1163–1178.

Dunger, W., Schlitt, B., 2011. Synopses on paleoartic collembola Tullbergiidae. Senckenberg Museum of Natural History, Görlitz 6/1.

Eijsackers, H., 2010. Earthworms as colonisers: primary colonisation of contaminated land, and sediment and soil waste deposits. *Sci. Total Environ.* 408, 1759–1769.

El Khalil, H., Schwartz, C., Elhamiani, O., Kubiniok, J., Morel, J.L., Boularbah, A., 2008. Contribution of technic materials to the mobile fraction of metals in urban soils in Marrakech (Morocco). *J. Soils Sediments* 8, 17–22.

Faith, D.P., Minchin, P.R., Belbin, L., 1987. Compositional dissimilarity as a robust measure of ecological distance. *Vegetatio* 69, 57–68.

Fiera, C., 2009. Biodiversity of Collembola in urban soils and their use as bioindicators for pollution. *Pesq. Agropec. Bras.* 44, 868–873.

Fjellberg, A., 2007. *The Collembola of Fennoscandia and Denmark*, Brill. Boston.

Francis, R., Chadwick, M., 2012. What makes a species synurbic? *Appl. Geogr.* 32, 514–521.

Frouz, J., Jílková, V., Cajthaml, T., Pižl, V., Tajovský, K., Háněl, L., Burešová, A., Šimáčková, H., Kolaříková, K., Franklin, J., Nawrot, J., Groninger, J.W., Stahl, P.D., 2013. Soil biota in post-mining sites along a climatic gradient in the USA: simple communities in shortgrass prairie recover faster than complex communities in tall-grass prairie and forest. *Soil Biol. Biochem.* 67, 212–225.

Gillet, S., Ponge, J.F., 2003. Changes in species assemblages and diets of Collembola along a gradient of metal pollution. *Appl. Soil Ecol.* 22, 127–138.

Gómez-Baggethun, E., Gren, Á., Barton, D.N., Langemeyer, J., McPhearson, T., O'Farrell, P., Andersson, E., Hamstead, Z., Kremer, P., 2013. Urban Ecosystem Services. In: Elmquist, T., Fragkias, M., Goodness, J., Güneralp, B., Marcotullio, P.J., McDonald, R.I., Parnell, S., Schewenius, M., Sendstad, M., Seto, K.C., Wilkinson, C. (Eds.), *Urbanization, Biodiversity and Ecosystem Services: Challenges and Opportunities*. Springer, Dordrecht, pp. 175–251.

Grinbergs, A., 1958. Forschungen über die Collembolen Lettlands. *Trudy Inst. Biol. Ak. Nauk Latv. SSR* 5, 187–218.

Hafeez, F., Spor, A., Breuil, M.-C., Schwartz, C., Martin-Laurent, F., Philippot, L., 2012. Distribution of bacteria and nitrogen-cycling microbial communities along constructed Technosol depth-profiles. *J. Hazard. Mater.* 231–232, 88–97.

Heiniger, C., Barot, S., Ponge, J.F., Salmon, S., Botton-Divet, L., Carmignac, D., Dubs, F., 2014. Effect of habitat spatiotemporal structure on collembolan diversity. *Pedobiologia* 57, 103–117.

Heiniger, C., Barot, S., Ponge, J.-F., Salmon, S., Meriguet, J., Carmignac, D., Suillerot, M., Dubs, F., 2015. Collembolan preferences for soil and microclimate in forest and pasture communities. *Soil Biol. Biochem.* 86, 181–192.

Hopkin, S.P., 2007. *A key to the Collembola (Springtails) of Britain and Ireland*. Field Studies Council, Telford.

Huot, H., Simonnot, M.O., Watteau, F., Marion, P., Yvon, J., De Donato, P., Morel, J.L., 2014. Early transformation and transfer processes in a Technosol developing on iron industry deposits. *Eur. J. Soil Sci.* 65, 470–484.

ISO 11263, 1994. Soil quality. Determination of phosphorus. Spectrometric determination of phosphorus soluble in sodium hydrogen carbonate solution. International Organization for Standardization, Geneva.

ISO 10694, 1995. Soil quality. Determination of organic and total carbon after dry combustion (elementary analysis). International Organization for Standardization, Geneva.

ISO 13878, 1998. Soil quality. Determination of total nitrogen content by dry combustion (elementary analysis). International Organization for Standardization, Geneva.

ISO 10390, 2005. Soil quality. Determination of pH. International Organization for Standardization, Geneva.

ISO 23611-2, 2006. Soil quality. Sampling of soil invertebrates. Part 2. Sampling and extraction of micro-arthropods (Collembola and Acarina). International Organization for Standardization, Geneva.

IUSS, 2014. World reference base for soil resources 2014. International soil classification system for naming soils and creating legends for soil maps. FAO, Working Group WRB, Rome.

Jordana, R., 2012. Synopses on palaeartic Collembola. *Capryinae & Entomobryini*. Senckenberg Museum of Natural History, Görlitz 7/1.

Koehler, B., Tranvik, L.J., 2015. Reactivity continuum modeling of leaf, root, and wood decomposition across biomes. *J. Geophys. Res. Biogeosci.* 120. <http://dx.doi.org/10.1002/2015JG002444>.

- 1002/2015JG002908.
- Leguédou, S., Séré, G., Auclerc, A., Cortet, J., Huot, H., Ouvrard, S., Watteau, F., Schwartz, C., Morel, J.L., 2016. Modelling pedogenesis of Technosols. *Geoderma* 262, 199–212.
- Loranger, G., Bandyopadhyaya, I., Razaka, B., Ponge, J.F., 2001. Does soil acidity explain altitudinal sequences in collembolan communities? *Soil Biol. Biochem.* 33, 381–393.
- Lucisine, P., Lecerf, A., Danger, M., Felten, V., Aran, D., Auclerc, A., Gross, E.M., Huot, H., Morel, J.-L., Muller, S., Nahmani, J., Maunoury-Danger, F., 2015. Litter chemistry prevails over litter consumers in mediating effects of past steel industry activities on leaf litter decomposition. *Sci. Total Environ.* 537, 213–224.
- Macfadyen, A., 1961. Improved funnel-type extractors for soil arthropods. *J. Anim. Ecol.* 30, 171–184.
- Magurran, A.E., 2004. *Measuring Biological Diversity*. Blackwell, Oxford.
- Marra, G.P., Wood, S.N., 2011. Practical variable selection for generalized additive models. *Comput. Stat. Data Anal.* 55, 2372–2387.
- McKinney, M.L., 2008. Effects of urbanization on species richness: a review of plants and animals. *Urban Ecosyst.* 11, 161–176.
- Minchin, P.R., 1987. An evaluation of relative robustness of techniques for ecological ordinations. *Vegetatio* 69, 89–107.
- Morel, J.L., Chenu, C., Lorenz, K., 2015. Ecosystem services provided by soils of urban, industrial, traffic, mining, and military areas (SUITMAs). *J. Soils Sediment* 15, 1659–1666.
- Motomura, I., 1932. A statistical treatment of associations (in Japanese). *Jap. J. Zool.* 44, 379–383.
- Motomura, I., 1947. Further notes on the law of geometrical progression of the population density in animal association (in Japanese). *Physiol. Ecol.* 1, 55–60.
- Norton, B.A., 2011. The sanitisation of urban ecosystems: simplification of the ground layer in eucalypt woodlands and the effects on arthropod communities. PhD Thesis, Science – Botany, The University of Melbourne.
- Oksanen, J., 2016. Vegan: ecological diversity. Processed with vegan 2.4-1 in R Under development (unstable) (2016-09-06 r71220) on September 7, 2016.
- Pielou, E.C., 1969. *An Introduction to Mathematical Ecology*. Wiley, New York.
- Politi Bertoncini, A., Machon, N., Pavoine, S., Muratet, A., 2012. Local gardening practices shape urban lawn floristic communities. *Landscape Urban Plan.* 105, 53–61.
- Ponge, J.F., 1993. Biocenoses of Collembola in atlantic temperate grass-woodland ecosystems. *Pedobiologia* 37, 223–244.
- Ponge, J.F., Gillet, S., Dubs, F., Fedoroff, E., Haese, L., Sousa, J.P., Lavelle, P., 2003. Collembolan communities as bioindicators of land use intensification. *Soil Biol. Biochem.* 35, 813–826.
- Ponge, J.F., Pérès, G., Guernion, M., Ruiz-Camacho, N., Cortet, J., Pernin, C., Villenave, C., Chaussod, R., Martin-Laurent, F., Bispo, A., Cluzeaud, D., 2013. The impact of agricultural practices on soil biota: a regional study. *Soil Biol. Biochem.* 67, 271–284.
- Porco, D., Potapov, M., Bedos, A., Busmachiu, G., Weiner, W.M., Hamra-Kroua, S., Deharveng, L., 2012. Cryptic diversity in the ubiquitous species *Parisetoma notabilis* (Collembola Isotomidae): long-used chimeric species? *PLoS ONE* 7, e46056.
- Potapov, M., 2001. Synopses of Palaearctic Colembola. III. Isotomidae. *Abhandlungen und Berichte des Naturkundemuseums. Górlitz*.
- Pouyat, R.V., Szlavecz, K., Yesilonis, I.D., Wong, C.P., Murawski, L., Marra, P., Casey, R.E., Lev, S., 2015. Multi-scale assessment of metal contamination in residential soil and soil fauna: a case study in the Baltimore-Washington metropolitan region. *USA. Landscape Urban Plan.* 142, 7–17.
- Prescott, C.E., 2010. Litter decomposition: what controls it and how can we alter it to sequester more carbon in forest soils? *Biogeochemistry* 101, 133–149.
- QGIS Development Team, 2014. *QGIS Geographic Information System 2.2.0 - Valmiera*. www.qgis.org.
- R Core Team, 2013. *R: a language and environment for statistical computing*. R Foundation for Statistical Computing, Vienna.
- Renaud, A., Poinso-Balaguer, N., Cortet, J., Le Petit, J., 2004. Influence of four soil maintenance practices on Collembola communities in Mediterranean vineyard. *Pedobiologia* 48, 623–630.
- Saby, N.P.A., Marchant, B.P., Lark, R.M., Jolivet, C.C., Arrouays, D., 2011. Robust geostatistical prediction of trace elements across France. *Geoderma* 162, 303–311.
- Santorufó, L., Cortet, J., Nahmani, J., Pernin, C., Salmon, S., Pernot, A., Morel, J.L., Maisto, G., 2015. Responses of functional and taxonomic collembolan community structure to site management in Mediterranean urban and surrounding areas. *Eur. J. Soil Biol.* 70, 46–57.
- Sarah, P., Zhevelev, H.M., 2007. Effect of visitors' pressure on soil and vegetation in several different micro-environments in urban parks in Tel Aviv. *Landscape Urban Plan.* 83, 284–293.
- Sarah, P., Zhevelev, H.M., Oz, A., 2015. Urban park soil and vegetation: effects of natural and anthropogenic factors. *Pedosphere* 25, 392–404.
- Sattler, T., Duelli, P., Obrist, M.K., Arlettaz, R., Moretti, M., 2010. Response of arthropod species richness and functional groups to urban habitat structure and management. *Landscape Ecol.* 25, 941–954.
- Sattler, T., Obrist, M.K., Duelli, P., Moretti, M., 2011. Urban arthropod communities: added value or just a blend of surrounding biodiversity? *Landscape Urban Plan.* 103, 347–361.
- Scaramella, M., 2003. *Urban Slums Reports: The Case of Naples, Italy*. (retrieved 13 October 2016).
- Shannon, C.E., 1948. A mathematical theory of communication. *Tech. J.* 27, 379–423.
- Solnzeva, E.L., 1967. The species composition and seasonal population dynamics of Collembola in arable soils of non-chernozem zone of the European part of the USSR. *Zool. Zhurn* 46, 1058–1061.
- Sousa, J.P., da Gama, M.M., Pinto, C., Keating, A., Calhoa, F., Lemos, M., Castro, C., Luz, T., Leitao, P., Dias, S., 2004. Effect of land-use on Collembola diversity patterns in a Mediterranean landscape. *Pedobiologia* 48, 609–622.
- Thibaud, J.M., Schulz, H.J., da Gama Assalino, M.M., 2004. Synopses on palaeartic Collembola Hypogastruridae. *Staatliches Museum für Naturkunde Górlitz* 4.
- Thurman, E.M., 1985. *Organic Geochemistry of Natural Waters*. Junk, The Hague.
- Tratalos, J., Fuller, R.A., Warren, P.H., Davies, R.G., Gaston, K.J., 2007. Urban form, biodiversity potential and ecosystem services. *Landscape Urban Plan.* 83, 308–317.
- United States Environmental Protection Agency, 1996. Acid digestion of sediments, sludges, and soils, in: *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods (SW-846)*. United States Environmental Protection Agency, Washington, D.C. pp. 1–12.
- Van Straalen, N.M., 1998. Evaluation of bioindicator systems derived from soil arthropod communities. *Appl. Soil Ecol.* 9, 429–437.
- Vanbergen, A.J., Watt, A.D., Mitchell, R., Truscott, A.M., Palmer, S.C.F., Ivits, E., Eggleton, P., Jones, T.H., Sousa, J.P., 2007. Scale-specific correlations between habitat heterogeneity and soil fauna diversity along a landscape structure gradient. *Oecologia* 153, 713–725.
- Volz, P., 1962. Beiträge zu einer pedozoologischen Standortslehre. *Pedobiologia* 1, 242–290.
- Whittaker, R.H., 1965. Dominance and diversity in plant communities. *Science* 147, 250–260.
- Wilson, J.B., 1991. Methods for fitting dominance/diversity curves. *J. Veg. Sci.* 2, 35–46.
- Wong, C.S.C., Li, X., Thornton, I., 2006. Urban environmental geochemistry of trace metals. *Environ. Pollut.* 142, 1–16.
- Zimdars, B., Dunger, W., 1994. Synopses on palaeartic Collembola, Volume 1, Tullbergiinae. *Staatliches Museum für Naturkunde. Górlitz*.