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Soil invertebrates as bioindicators of urban soil quality

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ABSTRACT

This study aimed at relating the abundance and diversity of invertebrate communities of urban soils to chemical and physical soil characteristics and to identify the taxa most sensitive or tolerant to soil stressors. The invertebrate community of five urban soils in Naples, Italy, was sampled. To assess soil quality invertebrate community indices (Shannon, Simpson, Menhinick and Pielou indices), Acarina/Collembola ratios, and the soil biological quality index (QBS) were calculated. The chemical and physical characteristics of the soils strongly differed. Abundance rather than taxa richness of invertebrates were more affected by soil characteristics. The community was more abundant and diverse in the soils with high organic matter and water content and low metal (Cu, Pb, Zn) concentrations. The taxa more resistant to the urban environment included Acarina, Enchytraeids, Collembola and Nematoda. Collembolans appeared particularly sensitive to changing soil properties. Among the investigated indices, QBS seems most appropriate for soil quality assessment.

1. Introduction

Soil is one of the most heterogeneous ecosystems on the planet. It plays an irreplaceable role in the biosphere: it governs plant productivity and allows organic matter degradation and nutrient cycles (Pietramellara et al., 2002). Human activities, using the soil for agriculture, building and transport, negatively affect soil functionality, leading to alterations of several processes that could weaken the ecosystem. Urbanization is associated with a variety of effects on the soil system, including pollution, conversion of indigenous habitats to various forms of land use, habitat fragmentation and loss, and soil community changes (McIntyre, 2000).

Unfortunately, little is known about the impact of human activity on organisms in urban soils. Soil invertebrates are excellent candidates for studying how human activity impacts the environment (McIntyre, 2000). Foremost of these is the variety of roles played by invertebrates in the soil system (i.e., organic matter degradation, nutrient cycling and bioturbation). Additionally, invertebrates are abundant, relatively easy to sample, and they can quickly respond to soil disturbance (McIntyre et al., 2001). Finally, since soil invertebrates respond to habitat structure, different species assemblages could highlight differences in soil properties and kind and degree of soil pollution (Nahmani and Lavelle, 2002). As invertebrates are sensitive to changes in soil conditions, they can be considered valuable indicators of soil disturbances (Nahmani and Lavelle, 2002).

Urbanization may have several effects on soil invertebrate communities. In particular, in the short term, species diversity and abundance decrease (Battigelli and Marshall, 1993; Eitminaviciute, 2006; Gongalsky et al., 2010), and tolerance to pollution may increase. In the long term, the increase in the number of tolerant individuals in the community and the replacement of pollution-sensitive species by less sensitive ones can lead to a different species assemblage inside the community (Salminen et al., 2001).

Nowadays, the main properties studied to characterize the soil invertebrate communities are abundance and species diversity (Nahmani and Lavelle, 2002; Sattler et al., 2010). Unfortunately, these two community properties by themselves are not exhaustive to explain the effects of pollution. In order to try to solve this lack, several indices have been proposed. Density and diversity can be integrated into synthetic indices, such as Shannon, Simpson, Menhinick and Pielou indices. Unfortunately, these indices do not take into account the ecological role of each taxon. In addition, some of them, affected by highly abundant or very rare species, can provide destroyed information: in many cases, in fact, high values of these indices could derive from the presence of invasive species rather than from the presence of species that are well structured in the community (Parisi et al., 2005). To overcome these hurdles, other synthetic parameters have been proposed in the scientific literature, such as the ratio between the number of species of mites and collembolans, and the soil biological quality index (QBS). High

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values of the ratio Acarina/Collembola suggest high soil quality, because it has been established that in degraded soils the number of Acarina species decreases (Jacomini et al., 2000). Nevertheless, this index is not reliable for all ecosystems, and the values sometimes are not comparable (Jacomini et al., 2000). The QBS index is applied to soil microarthropods separated according to their morphology, and it is based on the assumption that at higher soil quality, the number of microarthropod groups well adapted to soil habitats will be higher (Parisi et al., 2005).

The aim of this study was to relate the quantitative and qualitative species composition of the invertebrate communities (Enchytraeids and Arthropods) of five soils in the city of Naples, Italy, to the chemical and physical soil characteristics (i.e., pH, water holding capacity, organic matter content, total content and water-extractable metal concentrations) in order to identify the taxa most sensitive or tolerant to soil stressors. In order to assess soil quality and species composition data were integrated by calculating several indices. As a measure of traffic-induced pollution, soils were analyzed for Cu, Pb and Zn, because these metals were shown to be most indicative of urban pollution due to traffic (Davis et al., 2001). In addition, earlier studies on urban soils from Naples and other Italian cities showed that concentrations of these metals were most elevated compared to control soils while other metals seemed of little relevance (Manta et al., 2002; Maisto et al., 2004, 2006).

2. Material and methods

2.1. Soil sampling

In September 2010, ten samples of surface soils (0–10 cm depth and 10 cm diameter), after litter removal, were collected at five sites (ACT, MIA, MAD, IOL, CAP) in downtown Naples (Southern Italy). All the sites are filling soils about 200 years old. ACT is a garden near an urban gallery, MAD and IOL are gardens near a motorway, MIA is the external side of an urban park near a roadside and CAP is the internal side of the same urban park. These soils were chosen because they were not fertilised, and the only anthropogenic impact is traffic-related pollution. In order to minimize the influence of different vegetation covers on soil characteristics and to enable assessment of the effect of air deposition, the soils were collected at the stem flow microsites of *Quercus ilex* L. trees.

2.2. Chemical and physical analyses

The following chemical and physical analyses were performed in triplicate, after mixing five of the ten soil sub-samples for each site to obtain homogeneous sample. The soils were characterized for pH, measured in a soil:distilled water suspension (1:2.5 = v:v) by electrometric method, for organic matter content (OM), evaluated by loss of weight after ignition at 500 °C for 8 h, and water holding capacity (WHC), determined by gravimetric method after soil saturation and oven-drying to constant weight at 105 °C. In order to measure Cu, Pb and Zn concentrations, the soils were sieved (2 mm) and oven-dried (75 °C over night). To measure total metal concentrations, 0.1 g oven-dried soil samples were digested with 2 ml of a mixture (4:1 = v:v) of HNO_3 (65%, p.a., Riedel-deHaën, Seelze, Germany) and HCl (37%, p.a., Baker Philipsburg, NJ, USA) at 140 °C for 7 h in a macro destruction oven. The quality of the analysis was checked using ISE sample 989 (International Soil-Analytical Exchange) certified by Wageningen Evaluating Programs for Analytical Laboratories as reference material. Recoveries of Cu, Pb and Zn were always within 10–15% of the certified concentrations. To measure water-extractable metal concentrations, an oven-dried soil:distilled water suspension (1:2.5 = v:v) was prepared, shaken for 2 h at 200 rpm and filtered over a 0.45 μm filter. The total and water-extractable metal concentrations were measured by atomic absorption spectrometry equipped with a graphite furnace (Perkin–Elmer 5100; Cu and Pb) or flame (Perkin–Elmer AAnalyst 100; Zn) unit. The metal concentrations were reported in graphs as $\mu g\ g^{-1}$, and the sum of metal concentrations was expressed as toxic units (TUs) i.e., the ratio between measured and background metal concentrations. The total metal background levels (37.7 μg Cu g^{-1} d.w.; 60.4 μg Pb g^{-1} d.w.; 84.5 μg Zn g^{-1} d.w.; unpublished data) came from an average of metal measurements in four soils collected in the Campania region (Vesuvio, Ottati, Capo D'Orso, and Astroni) near Naples in Italy. The water-extractable metal background contents (0.07 μg Cu g^{-1} d.w.; 0.02 μg Pb g^{-1} d.w.; 0.13 μg Zn g^{-1} d.w.) were measured in the natural standard soil LUFA 2.2.

2.3. Arthropod and enchytraeid community analyses

The analyses of the soil communities were performed on each of the five sub-samples collected at each site. To extract the arthropods, the soil samples were placed in a Tullgren apparatus (VU University, Amsterdam, The Netherlands) for four weeks (Van Straalen and Rijninks, 1982). To extract the enchytraeids, wet Tullgren extraction for one week was performed following Kools et al. (2009). For both the extractions, the air temperature above the samples was 30 °C while that at the bottom of the sample was kept at 5 °C. The arthropods were collected in jars containing a 70% ethanol solution. The Enchytraeids were collected, first in pots containing water, and, successively, placed in jars containing a 70% ethanol solution. In the final step, the animals were counted and identified according the major taxonomic groups.

The results of the invertebrate community analyses are reported, for each soil, as density (i.e., individual number/m^2 soil) and relative abundance (i.e., individual number of each taxon/individual number). For each soil, the taxa richness is also reported.

2.4. Biological indices

For each site, data on the abundance and diversity of soil invertebrate species were integrated to calculate the Shannon (1948) and Simpson (1949) indices:

$$\text{Shannon index} : H = -\sum P_i \ln P_i$$

$$\text{Simpson index} : D = \sum (P_i)^2$$

where P_i = percentage of the individuals represented by species i on the total number of individuals.

High diversity is indicated by high values of the Shannon index and by low values of the Simpson index.

The representation of the individuals in the taxa (evenness) was evaluated through the Menhinick (1964) and Pielou (1969) indices:

$$\text{Menhinick index} : M = \text{number of taxa}/\text{sqrt}(\text{total number of organisms})$$

$$\text{Pielou index} : P = H/\ln(\text{total number of taxa})$$

High relative abundance of taxa is indicated by high values of the Menhinick and Pielou indices.

In addition, the ratio between the total numbers of Acarina and Collembola (A/C) was calculated, and the soil biological quality index (QBS) was evaluated as reported by Parisi (2001). This QBS index classifies soil microarthropods on the basis of morphological characteristics, assigning to each microarthropod group a different weight, represented by a different score, thereby defining the Ecomorphological indices (EMI) shown in Parisi (2001). The QBS is calculated as the sum of EMI values in each soil (Parisi, 2001).

2.5. Statistical analyses

The Kolmogorov–Smirnov test was applied to assess the normality of the distribution of the data sets. Pearson's regression test was performed to evaluate the relationships between the community density or diversity and each soil physical–chemical characteristic. One-way Analysis of Variance (ANOVA), with Holm–Sidak posthoc test was performed to highlight differences among the sites with respect to community density and diversity and soil metal concentrations. The package Sigma-Plot 11.0 (Jandel Scientific, USA) was used for all these analyses.

3. Results

3.1. Soil physical and chemical parameters

All the soils, with the exception of ACT that was slightly acidic, showed pH around neutrality (Table 1). Large differences were observed for the organic matter content that was particularly high at MIA and CAP, where also the highest water holding capacity was measured (Table 1).

The highest total Pb and Zn concentrations were found at IOL, where also high Cu concentrations were found. The highest Cu

Table 1
Mean (±s.e.) pH, water holding capacity (WHC), and organic matter content (OM) of urban soils from the city of Naples, Italy.

Soils	ACT	MIA	MAD	IOL	CAP
pH (water)	5.45 (0.01)	7.11 (0.01)	6.88 (0.00)	7.33 (0.00)	7.27 (0.02)
WHC (% d.w.)	25.2 (3.56)	70.2 (13.6)	21.4 (4.93)	29.9 (2.80)	63.8 (0.36)
OM (% d.w.)	10.1 (0.03)	25.7 (0.48)	10.1 (0.16)	11.1 (0.03)	16.7 (0.06)

concentrations were measured at MIA (Fig. 1). The lowest soil Cu, Pb and Zn concentrations were always detected at CAP (Fig. 1).

The water-extractable metal concentrations in the soils roughly showed the same spatial trend as observed for the total concentrations (Fig. 1). The highest water-extractable Cu concentration was found at MIA, that of Pb at IOL, and that of Zn at MIA and IOL (Fig. 1). The site trend observed when calculating the sum of metal concentrations as toxic units (TUs) was the same for total and water-extractable metal concentrations: IOL > MIA > ACT > MAD > CAP (Fig. 1).

3.2. Analysis of the soil mesofauna community

Soil mesofauna numbers ranged from 240 to 1630 per sample, corresponding with approximate densities ranging from 6000 to 41 000 individuals m^{-2} of soil (Fig. 2a). The highest density was observed for CAP, whereas the lowest values were observed for ACT.

All together, 21 invertebrate taxa were extracted with a minimum of 13 at ACT and MAD, and a maximum of 19 at CAP (Fig. 2b). The most abundant taxa were Acarina, Enchytraeidae, Nematoda, Collembola, Diplopoda and Diptera larvae (Table 2), accounting for approximately 95% of the collected organisms; the next most abundant taxa were Symphyla, Chilopoda, Lumbricidae, Isopoda, Diplura, Blattoptera larvae, Formicidae and Blattoptera adults, which together amounted to 4% of the total number of individuals (Table 2); the remaining taxa were Araneae, Lepidoptera larvae, Tysanoptera, Pseudoscorpiones, Embioptera, Diptera and Pauropoda that accounted for <1% of the individual abundance (Table 2).

Among the taxa, Acarina and Enchytraeidae were ubiquitous, and their relative abundance was similar in all the investigated soils (Fig. 3a), whereas the Collembola and Nematoda numbers differed among the sites: at IOL and MIA the densities and the relative abundance of Collembola were lower than those of Nematoda as

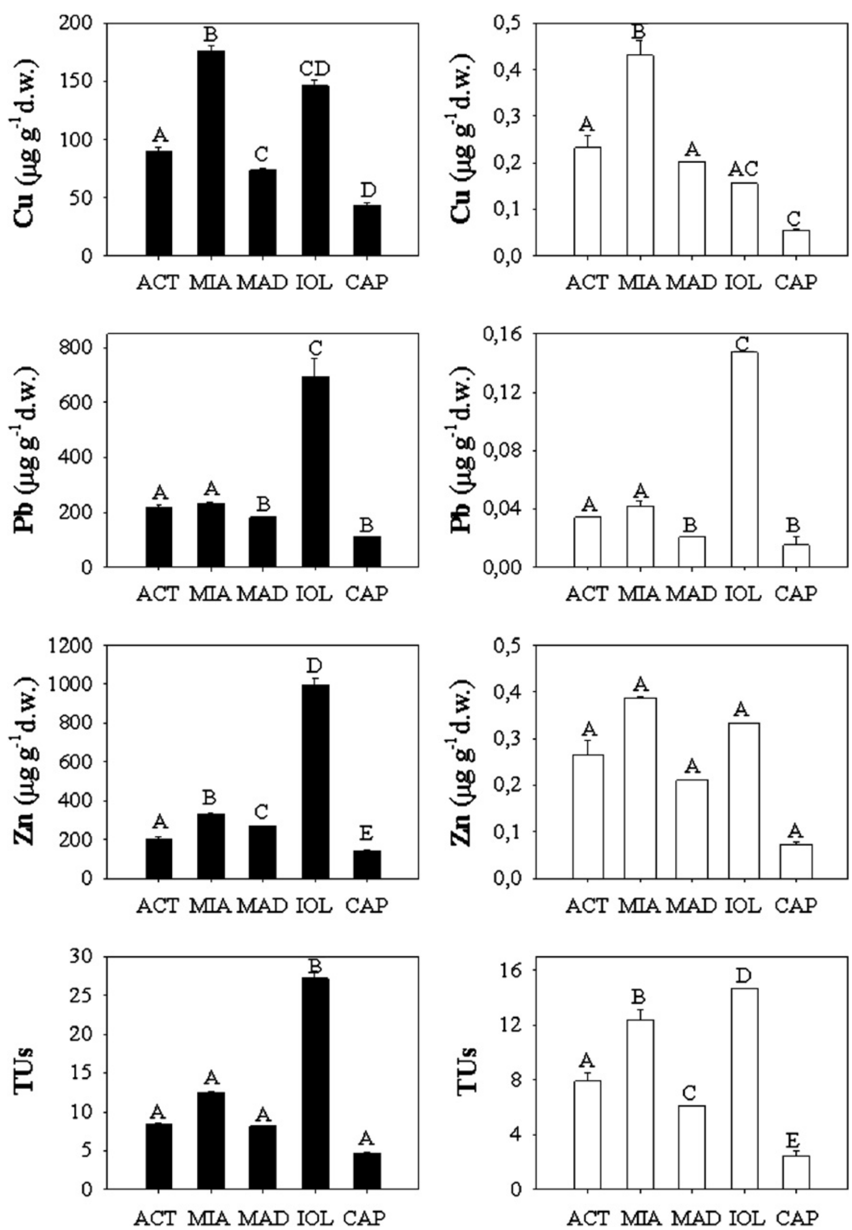

Fig. 1. Mean (±s.e.) total (left) and water-extractable (right) metal concentrations in urban soils from Naples, Italy. Also given are summed metal concentrations calculated as Toxic Units (TUs) using background total concentrations in different Italian soils or water-extractable concentrations in the natural standard LUFA 2.2 soil. Different letters indicate statistically significant differences ($p < 0.05$) among the soils (One-way Analysis of Variance with Holm–Sidak posthoc test).

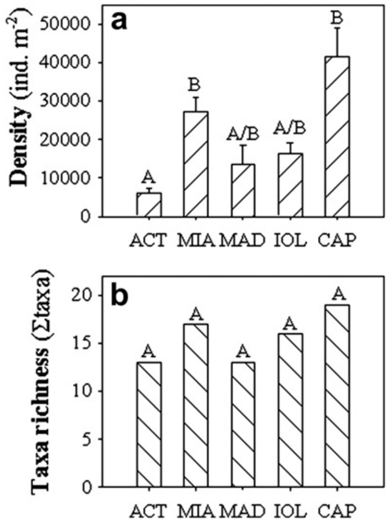

Fig. 2. Mean (±s.e.) density (a) and taxa richness (b) of soil invertebrates in urban soils from Naples, Italy. Different letters indicate statistically significant differences ($p < 0.05$) among the soils (One-way Analysis of Variance with Holm–Sidak posthoc test).

compared to the other soils, in which were higher (Fig. 3a and Table 2). Diplopoda were least abundant at CAP (Fig. 3a). Among the less abundant species, the highest number of Formicidae was measured at CAP, that of Isopoda at ACT, and that of Chilopoda at MAD (Fig. 3b). The highest number of rare species was found at CAP, whereas the lowest number was found at ACT and MAD (Fig. 3c).

3.3. Biological indices

The Shannon and Simpsons indices suggested that diversity was highest at ACT and lowest at MAD (Table 3). The indices of Menhinick and Pielou showed the highest evenness at ACT and the lowest at CAP (Table 3). The highest ratio between Acarina and Collembola was observed for IOL and the lowest for ACT (Table 3). The QBS index indicated soil quality was highest at CAP and lowest at ACT (Table 3).

No correlations were found between the index values and the soil physical–chemical properties and metal contents.

4. Discussion

Although the investigated soils were collected in the same urban area, their chemical and physical characteristics strongly differed. The soils, which cover the greater part of the urban area of Naples, developed on reworked and intercalated pyroclastic deposits of different origins and ages and are characterized by andic properties (Di Gennaro and Terribile, 1999). As the pedogenetic substrates are similar, the differences in metal concentrations of the investigated soils could be attributable to various causes, such as nearness to pollutant emission sources, kind of pollutant emission sources (mobile or fixed) and site management. In particular, the sum TUs based on total metal concentrations at IOL was about 2-, 3-, 3- and 7-fold higher than that at MIA, ACT, MAD and CAP, respectively.

The soils widely differed in invertebrate density (i.e., CAP showed values 7-fold higher than ACT), whereas they slightly differed in taxa richness (maximum difference factor of 1.5). Abundance and density, better than taxa richness, reflected the trend of the soil chemical and physical characteristics. Therefore, it is supposed that individual abundance and density are more affected by soil properties than taxa richness, as also reported by Nahmani and Lavelle (2002). However, both organism density and taxa richness, although no statistically significant correlations were found (Fig. 2), were higher in the soils with high organic matter and water content and lower in the soils with high metal concentrations. These findings agree with those reported by several other authors (Wolters, 2000; Räty and Huhta, 2003; Mulder, 2006; Pižl et al., 2009) who found positive correlations between organism density/taxa richness and soil properties such as pH, organic matter and water content, and negative correlations to soil metal content.

Even though the taxa richness did not significantly differ among the soils, the community composition did differ, causing differences in soil functionality (McIntyre et al., 2001). Organic matter decomposition is greatly facilitated by mites, millipides, earthworms and termites. Also nutrient cycling, closely associated with organic matter decomposition, is determined by small grazers such as protozoa and nematodes. In addition, ants, termites, earthworms and other soil macrofauna create channels, pores, aggregates and mounds that profoundly influence the transport of gases and water in soil, modifying also the microhabitats for other soil organisms (Brussaard et al., 1997). The high relative abundance of Acarina,

Table 2
Mean (±s.e.) densities of each taxon detected in urban soils from the city of Naples, Italy.

	ACT	MIA	MAD	IOL	CAP
Acarina	2268 (479)	11 821 (3471)	7184 (3502)	5273 (1886)	22 343 (5374)
Enchytraeida	1045 (417)	7719 (3070)	2878 (752)	3974 (1599)	6751 (501)
Collembola	968 (404)	1324 (605)	1630 (544)	331 (103)	4840 (2689)
Nematoda	662 (409)	4000 (1396)	840 (491)	4840 (1554)	4152 (433)
Diplopoda	633 (364)	407 (141)	433 (142)	433 (283)	509 (332)
Diptera Larvae	152 (74.3)	662 (198)	50.9 (31.2)	0.00 (0.00)	382 (90.1)
Symphyla	50.9 (31.2)	50.9 (50.9)	25.5 (25.5)	25.5 (25.5)	484 (172)
Chilopoda	0.00 (0.00)	229 (62.4)	229 (116)	101 (47.7)	229 (93.6)
Lumbricidae	50.9 (0.01)	0.00 (0.00)	25.5 (25.5)	76.4 (50.9)	331 (131)
Isopoda	76.4 (31.2)	25.5 (25.5)	0.00 (0.00)	25.5 (25.5)	25.5 (25.5)
Diplura	50.9 (50.9)	331 (131)	0.00 (0.00)	101 (101)	152 (25.5)
Blattoptera Larvae	25.5 (25.5)	306 (95.3)	25.5 (25.5)	0.00 (0.00)	127 (56.9)
Blattoptera	0.00 (0.00)	76.4 (50.9)	50.9 (50.9)	25.5 (25.5)	101 (74.3)
Formicidae	0.00 (0.00)	127 (98.7)	25.5 (25.5)	25.5 (25.5)	687 (656)
Araneae	25.5 (25.5)	76.4 (31.2)	0.00 (0.00)	0.00 (0.00)	76.4 (50.9)
Lepidoptera Larvae	50.9 (31.2)	25.5 (25.5)	0.00 (0.00)	0.00 (0.00)	101 (62.4)
Tysanoptera	0.00 (0.00)	25.5 (25.5)	0.00 (0.00)	25.5 (25.5)	76.4 (76.4)
Pseudoscorpiones	0.00 (0.00)	76.4 (31.2)	0.00 (0.00)	25.5 (25.5)	50.9 (31.2)
Embioptera	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	50.9 (50.9)	0.00 (0.00)
Diptera	0.00 (0.00)	0.00 (0.00)	25.5 (25.5)	0.00 (0.00)	0.00 (0.00)
Pauropoda	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	50.9 (31.2)

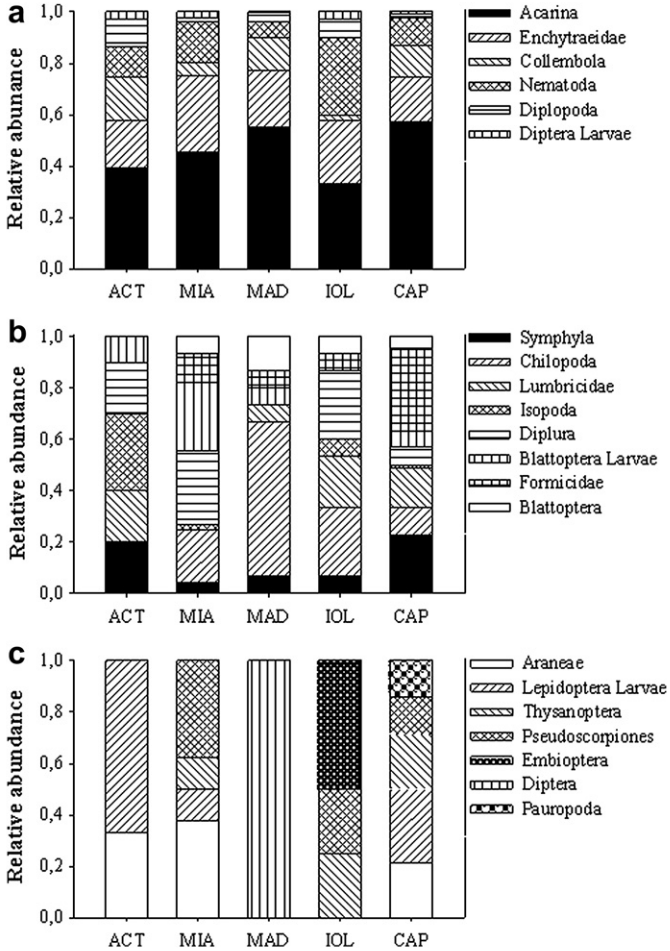

Fig. 3. Relative abundance of the main (a), intermediate (b) and rare (c) soil invertebrate taxa in urban soils from Naples, Italy.

Enchytraeids, Collembola and Nematoda in all soils suggests that these taxa are tolerant to a wide range of soil properties, making them poor indicators of differences in soil conditions (McIntyre et al., 2001). These taxa however, showed variations in individual abundance among the investigated soils, with Collembola being most variable with an 8-fold higher abundance in ACT than IOL. Lower collembolan densities were detected in the soils with the higher metal concentrations (MIA and IOL), both total and water-extractable. Therefore, Collembola, among the ubiquitous taxa, seem most sensitive to soil metal contamination as is well documented by several authors (Filser et al., 2000; Lock and Janssen, 2003; Kuperman et al., 2007; Fiera, 2009; Xu et al., 2009). In addition, it is interesting to note that where collembolans showed low number of individuals, the nematodes presented high individual numbers (Table 2, Fig. 3). This negative relationship could be due to competition for food and to the interaction between the two taxa, as some species of Collembola may prey on Nematoda (Rusek, 1998).

Also Diplopoda can be considered a ubiquitous taxon, since it was present in all the soils with the exception of CAP, where the soil metal contamination was the lowest. Some authors (Read et al., 1998; Vink and Soejono Sastrodihardjo, 1996) report that some Diplopoda species can be more abundant in metal contaminated than uncontaminated soils.

The rare taxa, rather than the ubiquitous ones, can be useful bioindicators of the characteristics of the investigated soils. Formicidae seem to be sensitive to metal contamination and to pH, since they were most abundant in the lowest polluted soil (CAP) and absent in the soil with the lowest pH value (ACT). Some authors (McIntyre et al., 2001; Eeva et al., 2004) report Formicidae tolerance to metal contamination and to urbanization. Therefore, this finding would suggest that, even if Formicidae can also live in polluted soils, they find better conditions to live and to reproduce in unpolluted soils. On the other hand, Isopoda were abundant in the investigated soils with higher metal accumulation, probably for their capability to accumulate metals (Cortet et al., 1999). The presence of the other rare taxa probably is not only linked to soil contamination, but may be affected by the entire set of soil properties, since their distribution is not attributable just to one or few parameters.

In this study, only Cu, Pb and Zn were measured as indicators of urban pollution. Earlier studies have shown that antimony (Sb) and mercury (Hg) also are products of vehicular traffic, but their concentrations in Italian urban soils were rather low and only slightly increased compared to background concentrations (Manta et al., 2002; Maisto et al., 2004). For that reason, these metals were not expected to be a cause of soil invertebrate community differences, and therefore were not included in the analysis. In addition to the metals analyzed, also the content of PAHs in the soil may alter the invertebrate community structure (Blakely et al., 2002). Maisto et al. (2006) and Manzo et al. (2008) found that the total concentrations of PAHs in soils from the urban area of Naples ranged between 0.13 and 5.3 μg g^{-1} dry soil. Manzo et al. (2008) however, also found that the toxicity to bacteria, plants and a crustacean, measured in the Naples urban soils did not correlate with total or extractable PAH concentrations. This seems further supported by Blakely et al. (2002) who only found effects on soil invertebrates in soils contaminated with PAHs at total concentrations >5 μg g^{-1}, with nematodes being more sensitive than arthropods. This, taken together with the fact that collembolans seemed most sensitive in our soils, also seems to confirm that metals rather than PAHs were affecting the invertebrate community structure in the urban soils from Naples.

Overall, the highly variable density of microarthropods in the urban soils from Naples seems to be dependent on several variables and needs appropriate statistical analyses to be correctly assessed (Parisi et al., 2005). In contrast, biological community structure is less variable and can more easily be used to assess soil degradation

Table 3
Mean (±s.e.) of the Shannon (H), Simpson (D), Menhinick (M) and Pielou (P) indices, the Acarina and Collembola ratios (A/C), and the soil biological quality indices (QBS) calculated for the invertebrates collected from urban soils from Naples, Italy. Different letters indicate statistically significant differences among the soils (One-way Analysis of Variance with Holm–Sidak posthoc test at $p < 0.05$).

	H	D	M	P	A/C	QBS
ACT	1.53 A (0.08)	0.31 A (0.04)	1.02 A (0.10)	0.76 A (0.03)	1.98 A (0.71)	78.0 A (16.3)
MIA	1.36 A (0.09)	0.32 A (0.05)	0.78 A (0.04)	0.56 B (0.04)	14.5 AB (4.67)	133 BC (8.87)
MAD	1.23 A (0.04)	0.36 A (0.02)	0.74 A (0.10)	0.66 A (0.04)	4.15 AB (0.81)	83.2 A (8.05)
IOL	1.35 A (0.07)	0.35 A (0.03)	0.73 A (0.08)	0.65 A (0.02)	15.0 B (2.97)	92.2 AC (8.87)
CAP	1.42 A (0.08)	0.34 A (0.03)	0.71 A (0.03)	0.55 B (0.04)	5.21 AB (2.46)	145 B (12.9)

or to evaluate soil maturity level. The soil properties, in fact, define particular ecological niches that could be occupied only by particular organisms. In addition, soils polluted with similar kinds of pollutants could have similarly structured communities, since the contamination could select tolerant species (Salminen et al., 2001). Therefore, the structure of the invertebrate community could highlight peculiar soil characteristics, whereas the presence or absence of particular organisms could show the quality and quantity of pollution (Kuperman, 1996). Further research could be useful to better highlight the sensitivity and the role of single species, since many species belonging to the same taxa can adopt different strategies in a polluted environment (Kamura et al., 2007).

The Simpson and Shannon indices showed high biodiversity in the most polluted soils as confirmed by Nahmani and Lavelle (2002) who found high values of Shannon index in polluted soils. Diversity indices, in addition, are often described as being very sensitive to various factors, such as the sampling unit size, and are thus of limited predictive capabilities (Nahmani and Lavelle, 2002). Finally, Cortet et al. (1999) demonstrated that diversity indices should be carefully used and only in extremely polluted sites.

The Menhinick and Pielou evenness indices agreed with the results of the diversity indices. These two indices showed higher values for soils with both high metal content and low pH, as also reported by Grześ (2009), who found a positive relationship between Menhinick and Pielou index values and soil metal content. Surprisingly, soil metal pollution seemed to cause an increase of invertebrate diversity and evenness, as shown by the values of diversity and evenness indices (Table 3). In contrast with the invertebrate density, strongly affected by soil metal pollution, the taxa richness seemed not proportionally affected by soil metal contamination, showing similar values for all soils. The high taxa richness could be due to a shift in community composition that probably consisted of a high number of tolerant taxa that were more competitive (Grześ, 2009).

Although no significant correlations were found, the A/C ratio seemed positively related to soil metal contamination as confirmed by the significant correlations found with Pb, Zn and the summed metal concentrations (TUs) in the investigated soils. These findings disagree with the higher sensitivity of Acarina to metal contamination compared to Collembola (Menta et al., 2008). In addition, Acarina and Collembola are the two most ubiquitous taxa observed in the investigated soils, suggesting that these taxa are weakly affected by soil metal contamination.

The soil biological quality index (QBS) was highest in the soil with the lowest metal content and the highest density and taxa richness of the invertebrate community. Being a qualitative index (Parisi et al., 2005), QBS takes also into account the role and the adaptation to soil habitats of each taxon of microarthropods found in the community. For this reason, this index seems most appropriate in defining the quality of the investigated soils.

Our study demonstrates that also at the taxa level there are differences in invertebrate communities between soils that can be attributed to pollution stress, and that result in significant differences that can be detected using relatively simple biological indices. It is promising to observe that such simple biological indices can be indicative of urban pollution levels.

5. Conclusions

The investigated soils of the urban area of Naples had highly different chemical and physical characteristics.

Individual abundance, rather than taxa richness, of the invertebrate community seemed more affected by soil characteristics. However, all community parameters were higher in the soils with high organic matter and water content, and lower in the soils with high metal concentrations.

The more resistant taxa to urbanization and most ubiquitous in the investigated soils were Acarina, Enchytraeids, Collembola and Nematoda. Among them, the most sensitive to differences in soil properties seemed to be the collembolans. Formicidae and Isopoda, among the rare taxa, showed contrasting distributions. The former was abundant in soils with low metal content, while the latter seemed to better tolerate metal contamination. The distribution of other rare taxa seemed to depend on various soil parameters.

Among the investigated indices, the Simpson and Shannon diversity indices should be carefully used in order to evaluate soil quality and community structure; the Menhinick and Pielou evenness indices were higher for the soils with high metal content and low pH; the A/C ratio seemed positively related to soil metal contamination.

The QBS index, being highest in the soil with the lowest metal content and the highest density and taxa richness of the invertebrate community, seems most appropriate for soil quality assessment.

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