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Rota, E., Caruso, T., Migliorini, M., Monaci, F., Agamennone, V., Biagini, G., & Bargagli, R. (2015). Diversity and abundance of soil arthropods in urban and suburban holm oak stands. *Urban Ecosystems*, *18*(3), 715-728. https://doi.org/10.1007/s11252-014-0425-5

Published in:
Urban Ecosystems

Document Version:
Peer reviewed version

Diversity and abundance of soil arthropods in urban and suburban holm oak stands

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Running title

Soil arthropod diversity in urban stands

Abstract

We investigated the soil arthropod communities of urban and suburban holm oak (*Quercus ilex* L.) stands in a small (Siena) and a large Italian city (Naples) and tested whether the abundance and diversity of higher arthropod taxa are affected by the biotic and abiotic conditions of urban forest soils, including pollution. Acarina and Collembola were the dominant taxa in both cities. In Siena the total number of arthropod individuals collected in the samples was over 1/3 greater than in Naples, but all diversity indices scored higher in Naples than in Siena, probably in response to the higher heterogeneity of microclimatic and pedological conditions found in Naples study area. Oribatids resulted twice more abundant in Siena and so were the total mites with respect to Collembola. While "taxonomic richness" per site increased with distance from road traffic, entropy and evenness indices scored higher at the two ends of the impact gradient in both cities. The overall variation in basic pedological and microbiological soil parameters positively correlated with the total abundance of arthropods, and negatively correlated with their taxonomic richness. At the resolution employed, no significant relation emerged between anthropogenic factors, such as traffic load and soil pollution, and the arthropod fauna density and variety. These results are consistent with conclusions drawn from a previous study on the enchytraeid fauna examined at species level, which is remarkable considering the different taxonomic resolutions of the two studies. CCA results suggest that the higher abundance of Oribatid mites, Protura and Thysanura and the lower abundance of Diplopoda and Symphyla in Siena could depend on a higher fungi/bacteria ratio. This observation can be interpreted in terms of differences in fungi and bacteria between the two cities: Siena is shifted towards the fungal decomposition channel, which supports taxa such as oribatid mites, while Naples is shifted towards the bacterial channel, which supports chiefly detritivorous groups, such as diplopods.

Keywords: Soil arthropods; Acari; Collembola; Mediterranean urban communities; holm oak stands

Introduction

Urban areas are spatially heterogeneous and temporally dynamic systems and differ from their current surroundings and from pristine conditions in terms of imperviousness of surfaces (e.g. due to soil compaction and paving), pollution (light, noise, atmospheric, and aquatic), number of exotic species, and changes of local climate (the urban heat island effect) (Vitousek et al., 1997). Urban agglomerations may be considered ecosystems in their own right, with fluxes and interactions, and feedback mechanisms among both natural and anthropogenic forms of physical and biological components (McIntyre et al., 2001; Liu et al., 2007). Although urbanization has detrimental effects on many animal taxa, there is often greater invertebrate diversity in urban green settings than in the rural surroundings (e.g. Erséus et al., 1999; Magura et al., 2010). This is due to variation in community composition among patches (beta diversity), which in turn is a result of a high variety of habitat types ranging from semi-natural to highly anthropogenic ones (Rebele, 1994). At many individual sites, anthropochorous dispersal and synanthropy mix species that would otherwise never coexist. It is therefore common to find in urban systems communities consisting of "irregular" combinations of species (unprecedented in natural habitats), including not only alien species but also species associated with human habitats, generalists, and native species that can cope with habitat alteration. At moderate levels of urbanization, taxonomic richness may actually be higher than in nearby wild lands, and total numerical abundances can reach high levels (e.g. at roadsides; Jones and Leather, 2012), even without the presence of exotic invaders.

The invertebrate soil fauna has rapid generations times, is easy to sample, and its sampling is not controversial in the public eye. Soil invertebrate communities also play a fundamental role in the cycling of organic matter and nutrients (Bardgett, 2005). Studying these communities in an urban context is therefore doubly suitable: ecologists can acquire basic information on biodiversity and evaluate soil quality and/or the impact of human activities on urban soils and other ecosystem components. Changes in soil community composition can in fact influence the transfer of persistent pollutants along food chains because soil invertebrates are food sources for higher trophic levels.

In Mediterranean regions, the evergreen holm oak, *Quercus ilex* L., has a wide natural distribution and has been traditionally used for landscaping of urban and rural parks. Within the frame of a project addressing the biodiversity of soil-dwelling invertebrates in Mediterranean urban environments, we investigated the community patterns of soil arthropods in urban and suburban *Q. ilex* stands in a small (Siena) and a large city (Naples). This paper describes the composition and abundance of the arthropod communities at high taxonomic levels, focusing on qualitative/quantitative aspects of their diversity at various spatial and temporal scales. The effects of relevant soil variables, including anthropogenic pollutants, on the abundance and distribution of arthropod taxa were also evaluated. We tested the general hypothesis that the two cities differ in terms of the abundance and diversity of soil arthropods and that these differences can be interpreted as an effect of soil abiotic and biotic conditions, and pollution.

Methods

Study areas

The cities of Siena and Naples are located in two different geological settings: sands, clays and calcarenites developed from Pliocene marine deposits, and andisols from pyroclastic volcanic deposits dated at <500 ka BP, respectively. The climate in Siena is temperate and mild, with average min temperature 2–17 °C, average max 8–28 °C; precipitation 750 mm yr^{-1} (min summer, max autumn). The climate in Naples is slightly warmer and moister than in Siena, with average min temperature 4–18 °C, average max 12–30 °C; precipitation 1007 mm yr^{-1} (min summer, max autumn) (data 1961–1990). In 2009 (the year of sampling) the spring in Siena was rainier than the average and the summer and autumn were drier than the average. In Naples the spring temperature was about 3 °C higher and precipitation 3.6 mm lower than typical seasonal average values. In contrast, September and October 2009 were characterized by frequent and heavy rainfall. The population density and the motor vehicle traffic volume are very different between the two cities. The municipality of Siena occupies the same area as the municipality of Naples (117.3 vs 118 km^2), but has $1/17^{th}$ of the Neapolitan population (54 500 vs 957 600). In the province of Naples, whose surface area (1171 km^2) is one third that of the Siena province (3821 km^2), there are many industrial plants and the total motor vehicles are nearly ten times more numerous (2 320 000 vs 247 000) with 1980 vehicles km^{-2} against 65 vehicles km^{-2} in Siena.

Sampling design

In each city, three sampling plots were selected in holm oak (*Q. ilex* L.) stands at increasing distances from a trafficked road, a fourth plot (control) was established in the city outskirts, far away from the urban traffic. In Siena, the three urban plots (named S1, S2 and S3, respectively) were located under large holm oak trees within a 5 ha wide private park dating from the mid-19th century (Villa Patrizia; 346 m a.s.l., 43°20′13″N, 11°18′28″E). The plots were positioned at a distance of 10, 15 and 40 m from the highly trafficked Via Fiorentina. The suburban plot (S4) was located 3.5 km from Siena city centre, where a holm oak forest surrounds the 12th century Castle of Belcaro (350 m a.s.l., 43°18′26″N, 11°17′24″E). Geological, pedological and climatic features are very similar to those of Villa Patrizia but with minimal air pollution and anthropogenic disturbance.

In Naples, the three urban plots were located in Capodimonte Park, one of the largest (130 ha) green areas in Naples, positioned in the northern part of the city on top of a hill (150 m a.s.l., 40°52′18″N, 14°15′07″E). The park houses the former Bourbon royal palace which served as a hunting reserve for the kings of Naples as well as “garden of delights” for the production of fruit for the royal table. The selected locations in Capodimonte Park are part of a much larger (over 200 times larger) and more diversified green area than Villa Patrizia, whose long management history goes back to the early mid-18th century and today the arboreal flora is dominated by holm oaks trees, chestnut trees, magnolias and elm trees although the park overall harbours 400 species of plant. Soil samples (named N1, N2 and N3 respectively) were collected at 10, 160 and 380 m from the highly trafficked via Miano. The differences in sampling distances along the transect at Capodimonte as compared to Villa Patrizia were due to the need to collect samples under the same type of vegetation cover. The suburban plot (N4) was located in Astroni (50 m a.s.l., 40°50′52″N, 14°08′59″E), a State Nature Reserve, 250 ha wide, 8.5 km to the northwest of Naples city centre. The area, an ash-ring crater about 4000 years old, is covered by dense forest vegetation showing a complex zonation pattern (see Rota et al., 2010). Geo-pedological features are similar to those in Capodimonte and the soil samples were collected near the Vaccheria (a former royal hunting lodge), under the canopy of the oldest *Q. ilex* trees surviving in the crater. The overall rationale behind our sampling strategy was that of ensuring comparable length and steepness in the examined pollution gradient. The distance between sampling plots in the two cities was therefore based on this choice and preliminary data on the study areas.

Details of the topsoil features and vegetation at the sampling plots and analytical procedures for soil physico-chemical and microbiological characterization are reported in Rota et al. (2013, 2014). In this paper, we analysed a selection of the parameters measured, as we aimed at obtaining an effective and simple descriptor of environmental variation, which we used to explain variation in diversity indices. The eleven chosen soil parameters were those maximizing the variance explained by main PCA axes (Suppl. Table 1): soil basic properties, such as pH, OM (Organic Matter) and water holding capacity; the total concentrations of Al, Cr, Fe, Ni, accounting above all for soil geochemistry; the extractable fraction of Zn and the total content of PAHs (Polycyclic Aromatic Hydrocarbons), as tracers of the different level of traffic-induced pollution; fungal:bacterial biomass and catabolic evenness, as indicators of the composition and functional diversity of soil microbiological communities.

Faunal sampling and data processing

The faunal sampling was conducted in May–June and October–November 2009. From each plot, five box cores of the top soil layers (10 × 10 × 5 cm) were randomly taken within an area of 5 × 5 m. The animals were extracted using a modified Berlese-Tullgren funnel for 20 days and were preserved in 75% ethanol. Arthropods were identified at the level of Class, Order or Family based on the identification of easily classifiable descriptor taxa with known functional roles (e.g. trophic guild). Abundances of taxa were recorded for each replicate.

Taxon richness and the entropy and evenness of the communities were measured using the following diversity indices: Menhinick's richness index: $S/\sqrt{n}$; Shannon's entropy index: $-\sum pi\ ln(pi)$; Simpson's interspecific encounter probability: $1-\sum(pi)^2$, and Pielou's "relative evenness" index: $H'/ln(S)$, respectively. The significance of these indices was tested by randomization tests, and for Shannon's also by the Hutcheson t-test. A Principal Component Analysis (PCA) of the 11 soil parameters measured at the 8 plots (correlation matrix) was performed to find new variables (components) accounting for at least 70-75% of the variance in the environmental data and to verify their correlation with the observed faunal diversity. To detect the main pattern in the relations between the environment and the abundance of the arthropod taxa at the 8 plots in the two seasons, a Canonical Correspondence Analysis (CCA) was used. Statistical significance of CCA axes was assessed by a permutation approach using 100 iterations. All statistical analyses were performed using the free software PAST version 2.17 (Hammer et al., 2001, available at http://folk.uio.no/ohammer/past). The calculation of diversity indices is consistent with Magurran (2004), while our main reference for the sampling design and statistical analysis was Quinn and Keough (2002)

Results

From the 80 soil samples we extracted a total of 79,634 mesofaunal arthropods. Population densities (Tables 1–2) were much higher (on average one-third higher) in Siena than in Naples. Both in Siena and in Naples the highest total densities of soil arthropods on seasonal and annual bases were recorded at the station most exposed to the vehicular traffic (S1 and N1, respectively).

Community structure

Dominant taxa in the collection were: Acari (56,874 individuals: Oribatida 44%; others 27%) and Collembola (18,195: 23%). The remaining 16% was represented by 21 different taxa, two of which (Diptera and Coleoptera) were separately counted as adults and larvae. Ranked in order of abundance: Diplopoda (0.98%), Diptera larvae (0.85%), Protura (0.84%), Symphyla (0.69%) and Formicidae (0.56%), Diptera (0.43%), followed by smaller percentages of Chilopoda, Pauropoda, Diplura, Coleoptera larvae, Araneae, Thysanoptera, Isopoda, Pseudoscorpiones, Coleoptera, Hemiptera, Hymenoptera, and by occasional Orthoptera, Psocoptera, Dermaptera and Thysanura.

In Siena the total number of soil arthropods in the samples was 48,039 individuals against 31,595 in Naples (Table1), and among mites the Oribatida in Siena were twice more abundant than in Naples (Oribatida/other Acari ratio scored 2.0 in this city, as compared to 1.1 in Naples), and so was the Acari/Collembola ratio (3.9 in Siena, against 2.3 in Naples) (Table 2). Protura were abundant in Siena but not so in Naples; similarly, Diplopoda and Symphyla were more abundant in Naples than in Siena. Thysanura were only collected in Siena, whereas Dermaptera, Orthoptera and Psocoptera were only found in Naples (Table 1).

In Siena, the urban communities consisted of 16–18 taxa in spring, against 15–19 taxa in autumn. S2 and S3 sites were the only locations for Thysanura (in spring), Mecoptera and Hemiptera (in autumn). The S4 control community consisted of 15 taxa in spring and 19 taxa in autumn. In the urban district, Protura, Diplura, Symphyla, Pauropoda, Diplopoda, Araneae, Thysanoptera and Hemiptera increased numerically in the autumn sampling. At the control station, instead, all groups increased in the autumn, except Protura and Diptera. Among Siena sites, the Oribatida/other Acari ratio and

Acari/Collembola ratio were lowest at the control station in both sampling periods (Table 1).

In Naples, the urban communities consisted of 19–22 taxa in spring, against 16–17 taxa in autumn. The N4 control community consisted of 19 taxa in both sampling periods, although Araneae were only collected in spring and were replaced by Hemiptera in autumn. Protura, Diplura, Symphyla and Pauropoda increased in general in autumn, whereas Dermaptera, Orthoptera, Mecoptera and Psocoptera were only found at Capodimonte in spring. Pseudoscorpiones were most abundant at Astroni in spring. N1 yielded the highest number of Diplopoda and Diptera, whereas N2 scored the lowest Oribatida/other Acari ratio and the highest Acari/Collembola ratio, in both sampling periods. Both these ratios remained nearly unchanged and close to the unit for N4 in both sampling periods (Table 1).

Diversity indices

When comparing seasons (Table 1), Menhinick's index (number of taxa per square-rooted individual) ranged within 0.18–0.26 for Siena, and 0.24–0.34 for Naples. At none of the plots, however, we found significant differences of Menhinick's index between spring and autumn. Minimal values were recorded at S1 and N1 in both seasons, maximal values at S3 and S4 and at N3 and N4. Thus, the overall "taxonomic density" per site (regardless of the relative abundance of the various groups) increased in both cities with distance from the traffic road. The seasonal values of Shannon's entropy index (Table 1) were also lower in Siena (1.1–1.3) with respect to Naples plots (1.2–1.6), but they were significantly higher at plots 1 and 4 as compared to the other plots in both cities and seasons. The same trend also applied to evenness, whether expressed as Simpson's interspecific encounter probability, or as Pielou's "relative evenness" index.

At the annual scale (Table 2), values of Shannon's entropy were significantly different ($P < 0.005$) among plots, but not for the couples N2–N3 and N1–N4 in Naples. Significant differences in Menhinick's richness were only found for the whole Naples urban district (Capodimonte plots) between seasons, but not when comparing the two urban districts (Villa Patrizia vs. Capodimonte) or the whole cities (Siena vs. Naples). Shannon's entropy was instead significantly different when comparing the two urban districts or the whole cities, at both seasonal and annual temporal scales (Table 2).

PCA analysis

The selected set of environmental variables (concentrations of Al, Cr, Fe, Ni, e-Zn and total PAHs; soil pH, OM and WHC; fungal:bacterial biomass and catabolic evenness; Suppl. Table 1) measured at the eight sampling plots (Rota et al., 2013) well summarizes expectations on the different environmental settings in which the investigated faunal communities live: volcanic soils from Naples had significantly higher Al and Fe concentrations and those from Siena much higher Cr and Ni concentrations. Soil pH, OM and WHC were on average higher at Siena than at Naples, the water holding capacity was related to soil texture, soil depth and to the OM content which strongly affects the water storage capacity. The soil fungal biomass prevailed over bacterial biomass in Siena, but the overall microbial communities appeared functionally more diverse in Naples (Rota et al., 2013).

The first two PCA components account for nearly 80% of the variance, allowing most of the information to be visualized in two dimensions. The biplot (Fig. 1) shows Siena stations far separate from Naples stations and a clear tendency of the environmental conditions to be less varied in Siena than in Naples. PCA1 accounts for 60% of the variance and reflects the different geological, textural and microbiological properties of the two cities. The two control stations (S4 and N4) are situated at the opposite ends of this axis. The second principal component, PCA2 (18% of the variance), appears strongly related to the anthropogenic impact. The stations closest to the trafficked roads (S1 and N1) and the highly contaminated innermost station N3 (Suppl. Table 1; Rota et al., 2013) appear segregated in the upper half of the PCA biplot.

We analysed the correlation between the annual averages of the arthropod diversity indices at the eight stations and the overall environmental variation as reflected in the first component of the environmental data. PCA1 turned out to be highly (positively) correlated with the total abundance of arthropods ($r = 0.92$, $P = 0.001$) and even more strongly (negatively) correlated with Menhinick's richness index ($r = -0.93$, $P = 0.0007$). No significant correlation was found instead between the annual averages of the diversity indices and PCA2.

CCA analysis

The distribution of the 23 arthropod taxa in the 16 seasonal samples (five replicates cumulated) were analysed by Canonical Correspondence Analysis, with the aim to identify the environmental variables (among the 11 analysed) shaping the local arthropod communities (Fig. 2).The resulting first two ordination gradients, CCA1 and CCA2, accounted for over 84% of the variance in the arthropod data matrix and were both significant at $P < 0.01$. Scaling type 2 was used to emphasize relationships between taxa and sites. Three taxa mark two perpendicular trends: Thysanura contrast with Pseudoscorpionida on the first axis and the latter contrast with Psocoptera on the second one. The CCA1 gradient correlates strongly with the fungal:bacteria ratio and places the urban stations of Siena, in general richer in fungal biomass, on the same side as fungivorous groups such as Thysanura (exclusive of Siena), Protura and Oribatida (more abundant in Siena), all situated on the left side of the graph. Siena control station (S4) is positioned on the right side of the graph, along with all Naples stations. Naples stations are more diversified from one another and on average richer in taxa than Siena urban stations, particularly in spring. Astroni appears best characterised by the lack of pollution and the high numbers of Pseudoscorpiones in spring, whereas the most impacted stations in Naples are best defined by their abundance in Diptera, both adults and larvae, Diplopoda and Isopoda.

Both the Oribatida/other Acari ratio and the Acari/Collembola ratio, as well as Shannon’s index, scored in Belcaro (Siena control station) within the range recorded for Naples stations. Furthermore Belcaro in autumn (2S4) yielded a number of arthropod taxa as high as Astroni (Naples control). These results are consistent with S4 being located in the upper right half of the graph.

Discussion

The holm oak stands of the two targeted cities (Siena and Naples) are supported by soils that differ in basic parameters such as pH, concentrations of major and trace elements and microbiological features (e.g. the fungi/bacteria ratio). Previous studies on oak stands (e.g. Sharon et al., 2001; Sadaka and Ponge, 2003; Moreno et al., 2008) indicated that these parameters are key determinants of the distribution of major arthropod taxa. Accordingly, we found remarkably different arthropod communities between Siena and

Naples, and in each city a comparable number of taxa between urban and periurban control sites. We deem the differences remarkable because we employed a fairly coarse taxonomic level, although it is known that arthropods can in some cases respond to environmental variation already at the level of higher taxa (Caruso and Migliorini, 2006). Oribatid mites, the major Acari taxon, were by far the most abundant taxon in Siena (accounting for over 50% of the collected arthropods), whereas in Naples their numbers were comparable to those of other mites and springtails. Other taxa also showed significant differences: Thysanura were only encountered in Siena, while Dermaptera, Orthoptera and Psocoptera were only sampled in Naples. Protura were well represented in Siena but less abundant in Naples, as much as Diplopoda and Symphyla were well represented in Naples but less abundant in Siena. Diplura, Pauropoda and Araneae were more abundant in Siena, whereas Naples yielded more numerous Pseudoscorpiones, Formicidae, Diptera, Thysanoptera and Coleoptera. Abundances of these taxa were generally very low compared to those of Acari and Collembola, and their relatively poorer representation in the communities might be partly due to a sampling effect. However, the sampling effort in this study was remarkable (a total of 80 sampling units across different locations and two seasons) and some of the observed differences must be due to some genuine ecological process. For example, in soil samples from Siena the fungi/bacteria ratio was much higher and correlates with the high abundance of Oribatid mites, Protura and Thysanura and the low abundance of Diplopoda and Symphyla. Although oribatid mites and collembolans show a variety of feeding habits, ranging from decomposers of low quality organic materials to predators on fungivorous nematodes (Maraun *et al.* 2004, 2011; Schneider *et al.* 2004; Heidemann *et al.* 2011), a large part of Oribatid mites, as well as Protura and Thysanura, are fungivorous while diplopods and symphylans are detritivorous

(Coleman et al., 2004). If the Siena system is shifted towards the fungal decomposition channel, while the Naples system towards the bacterial channel (see Bardgett, 2005 for an exhaustive discussion of these two channels), then we might reasonably expect taxa such as oribatids to be more abundant in Siena. For the same reason, we expect the chiefly detritivorous groups, such as diplopods, to be more abundant in Naples. Higher fungi/bacteria ratios imply a more recalcitrant litter, slower rate of decomposition of organic matter and possibly a more complex soil food web (Bardgett, 2005; Bardgett and Wardle, 2010). Testing our hypothesis will therefore require an assessment of feeding spectra using suitable markers, such as stable isotopes (Scheu, 2002).

As previously observed for the assemblages of enchytraeid species at the same sampling sites (Rota et al., 2013), the different climatic and pedological features, more than the level of urban pollution, seem the main factors affecting the structure of soil arthropod communities, this being true besides trophic ecology. Although in Naples urban soils are much more polluted by heavy metals and PAHs than in Siena, Naples city soils harbour higher numbers of arthropod taxa, similar to those recorded in samples from Astroni State Nature Reserve. Arthropod diversity does not therefore seem related to levels of traffic intensity or to soil pollution, at least at the taxonomic resolution of the present study. In both cities the highest total number of individuals was observed at the stations that were most exposed to the vehicular traffic. This result might be due to the fact that the opportunistic species can take over specialist species under stress/disturbance (e.g. Walker, 2012). Although the overall taxonomic density (regardless of the relative abundance of the various groups) increased with distance from the traffic road, none of the diversity indices correlated with levels of soil pollutants. Some authors have proposed that mites/collembolans ratios should be lower in disturbed soils, whereas in more stable communities there should be a switch from the generally r-strategist Collembola to the K-strategist Oribatida (Acari) (Coleman and Crossley, 1996). In this study, the Acari/Collembola ratio, while scoring higher in the less polluted city (Siena), showed the lowest values at the two control stations, which questions the reliability of this ratio as an indicator of soil pollution or other anthropogenic impacts. The ratio could nevertheless be a valid tool in other systems because effects are context and method dependent (Knoepp et al., 2000).

In Siena and Naples urban parks, the sampling locations were chosen in order to collect under the same type of vegetation cover, underbrush composition and density, and forest floor. It must be noted, however, that the two urban parks are different in size, history, morphology and structure. The woodland at Villa Patrizia offers throughout rather homogeneous habitats for soil arthropods as compared to the interplay of spontaneous and irregular vegetation characterizing Capodimonte Park (La Valva et al., 1996). All this implies that in Naples the microclimatic and pedological differences between the three urban sites and the control are more remarkable than in Siena (see Rota et al., 2013). These differences appear to be reflected by qualitative and quantitative differences in soil higher arthropod taxa, as well as in the enchytraeid fauna examined at species level (Rota et al., 2013).

Conclusions

We investigated the soil arthropod faunas of urban and periurban holm oak stands in two Italian cities (Siena and Naples), representative of different pedological features, levels of environmental pollution and urban park structures. Acarina and Collembola dominated in both cities and although the total number of arthropod individuals and the mites/collembolans ratios were higher in Siena than in Naples (a much more polluted urban environment), in both cities the highest numbers of individuals were observed in soils more exposed to the vehicular traffic. Diversity indices, too, scored higher in Naples than in Siena. In agreement with a previous study on the enchytraeid species communities at same sampling sites (Rota et al., 2013), the results on the arthropod fauna at coarse taxonomic level indicate that soil pollution may exert an indirect and subtle impact on soil invertebrates. An analysis of the arthropod communities at species level will be required to achieve more exhaustive conclusions; nevertheless the present study suggests that basic pedological and microbiological soil features, the trophic ecology of organisms, and the variability of available habitats (resulting from the size, morphology, history, structure and management of parks) are the main factors affecting the diversity and abundance of major arthropod taxa in urban soils.

Acknowledgements

We are grateful to Drs Flavia De Nicola, Paola Iovieno and Ludovica Sessa for assistance with field work in Naples and environmental analyses. Prof. Anna Alfani, University of Salerno, coordinated the grant from the Italian Ministry of Education, University and Research (PRIN-2007AH8KT8) supporting this research.

References

Bardgett RD (2005)The biology of soil. A community and ecosystem approach. Oxford University Press, New York.

Bardgett RD, Wardle DA (2010) Aboveground-belowground linkages. Biotic interactions, ecosystem processes, and global changes. Oxford University Press, New York.

Berardi A (1999) Biophysical modelling of the Astroni Nature Reserve, Naples, Italy. PhD Thesis, University College London.

Caruso T, Migliorini M (2006) Micro-arthropod communities under human disturbance: is taxonomic aggregation a valuable tool for detecting multivariate change? Evidence from Mediterranean soil oribatid coenoses. Acta Oecologica 30:46–53.

Coleman DC, Crossley Jr DA (1996) Fundamentals of soil ecology. Academic Press, San Diego, CA.

Coleman DC, Crossley Jr DA, Hendrix PF (2004) Fundamentals of soil ecology, 2nd edn. Elsevier, London, UK.

Erséus C, Grimm R, Healy B, Lundberg S, Rota E, Timm T (1999) Clitellate diversity in Nationalstadsparken, an urban national park in Stockholm, Sweden. Hydrobiologia 406:101–110.

Hammer Ø, Harper DAT, Ryan PD (2001) PAST: Paleontological statistics software package for education and data analysis. Palaeontologia Electronica 4(1), 9 pp.

Heidemann K, Scheu S, Ruess L, Maraun M (2011) Molecular detection of nematode predation and scavenging in oribatid mites: Laboratory and field experiments. Soil Biol. Biochem. 43:2229–2236.

Jones EL, Leathe SR (2012) Invertebrates in urban areas: A review. Eur. J. Entomol.109:463–478.

Knoepp JD, Coleman DC, CrossleyJr DA, Clark JS (2000) Biological indices of soil quality: an ecosystem case study of their use. For. Ecol. Manag. 138:357–368.

La Valva V, Guarino C, De Natale A, Cuozzo V, Menale B (1996) La flora del Parco di Capodimonte di Napoli. Delpinoa, n.s., 33–34 (1991–1992):143–177.

Liu J, Dietz T, Carpenter SR, Alberti M, Folke C, Moran E, Pell AN, Deadman P, Kratz T, Lubchenco J, Ostrom E, Ouyang Z, Provencher W, Redman CL, Schneider SH, Taylor WW (2007) Complexity of coupled human and natural systems. Science 317:1513–1516.

Magura T, Horvath R, Tóthmérész B (2010) Effects of urbanization on ground dwelling spiders in forest patches in Hungary. Landsc. Ecol. 25:621–624.

Magurran AE (2004) Measuring biological diversity. Blackwell Publ., Oxford.

Maraun M, Erdmann G, Fischer BM, Pollierer MM, Norton RA, Schneider K, Scheu S (2011) Stable isotopes revisited: Their use and limits for oribatid mite trophic ecology. Soil Biol. Biochem. 43:877–882.

Maraun M, Heethoff M, Schneider K, Scheu S, Weigmann G, Cianciolo J, Thomas RH, Norton RA (2004) Molecular phylogeny of oribatid mites (Oribatida, Acari): evidence for multiple radiations of parthenogenetic lineages. Exp. Appl. Acarol. 33:183–201.

McIntyre NE, Rango J, Fagan WF,Faeth SH (2001) Ground arthropod community structure in a heterogeneous urban environment. Landscape Urban Plann. 52:257–274.

Moreno CE, Guevara R, Sánchez-Rojas G, Téllez D, Verdú JR (2008) Community level patterns in diverse systems: A case study of litter fauna in a Mexican pine-oak forest using higher taxa surrogates and re-sampling methods. Acta Oecol. 33:73–84.

Quinn GP, Keough MJ (2002) Experimental design and data analysis for biologists. Cambridge University Press, Cambridge, UK.

Rebele F (1994) Urban ecology and special features of urbanecosystems. Global Ecol. Biogeog. Lett. 4:173–187.

Rota E, De Nicola F, Bargagli R (2010) *Parergodrilus heideri* Reisinger, 1925 (Annelida: Polychaeta) from a holm oak wood in an extinct volcano of southern Italy. Zootaxa 2687:65–68.

Rota E, Caruso T, Bargagli R (2014) Community structure, diversity and spatial organization of enchytraeids in Mediterranean urban holm oak stands. Eur. J. Soil Biol. 62:83–91.

Rota E, Caruso T, Monaci F, Baldantoni D, De Nicola F, Iovieno P, Bargagli R (2013) Effects of soil pollutants, biogeochemistry and microbiology on the distribution and composition of enchytraeid communities in urban and suburban holm oak stands. Environ. Pollut. 179:268–276.

Sadaka N, Ponge J-F (2003) Soil animal communities in holm oak forests: influence of horizon, altitude and year. Eur. J. Soil Biol. 39:197–207.

Scheu S (2002) The soil food web: structure and perspectives. Eur. J. Soil Biol. 38:11–20.

Schneider K, Migge S, Norton RA, Scheu S, Langel R, Reineking A, Maraun N (2004) Trophic niche differentiation in soil microarthropods (Oribatida, Acari): evidence from stable isotope ratios ($^{15}N/^{14}N$). Soil Biol. Biochem. 36:1769–1774.

Sharon R, Degani G, Warburg M (2001) Comparing the soil macro-fauna in two oak-wood forests: does community structure differ under similar ambient conditions? Pedobiologia 45:355–366.

Vitousek PM, Mooney HA, Lubchenco J, Melillo J (1997) Human domination of Earth's ecosystem. Science 277:494–499.

Walker LR (2012) The biology of disturbance ecology. Oxford University Press, New York.

Figure captions

Fig. 1 – Principal Component Analysis of eleven soil properties measured at the eight sampling plots (based on log-transformed data and the correlation matrix). The diagram shows the first two ordination axes, accounting for 59.6% and 18.1% of the variance, respectively. pH based on water extracts. OM = Soil Organic Matter. WHC = Water Holding Capacity (gravimetric). Al, Cr, Fe, Ni = total metal concentrations. Zn-e = EDTA-extractable fraction of Zn. PAHs = total concentration of 16 EPA Polycyclic Aromatic Hydrocarbons. fu:baPLFA = fungal/bacterial PhosphoLipid Fatty Acids ratio. Catab._Ev. = Catabolic Evenness. Siena sites: S1–S4; Naples sites: N1–N4.

Fig. 2 – CCA (Canonical Correspondence Analysis) ordination triplot of arthropod taxa (seasonal counts), environmental descriptors, and Siena and Naples sites at the two sampling times (site codes preceded by 1= spring sampling, by 2= autumn sampling). Total inertia in matrix of arthropod taxa = 0.12643. Eigenvalues are 0.076 ($P = 0.005$), 0.031 ($P = 0.004$) and 0.009 ($P = 0.47$) for first (horizontal), second (vertical) and third axes, respectively. They explain 59.8%, 24.4% and 7.2% of the variance in the matrix of arthropod taxa, respectively. Scaling type 2 was used, to emphasize the relationships among taxa and sites, and the length of the environmental vectors was tripled for clarity of the diagram. For abbreviations of environmental descriptors see Fig. 1, for codes of taxa see Table 1.