Urban Ecosyst (2006) 9: 337–349
DOI 10.1007/s11252-006-0001-8

# Baseline biodiversity surveys of the soil macrofauna of London's green spaces

**Jo Smith · Anna Chapman · Paul Eggleton**

Published online: 18 October 2006


**Abstract** A serious barrier to our understanding of urban ecosystems is a lack of information on the ecology of soils organisms of green spaces within large cities. This study addresses this gap by providing baseline survey data on the biodiversity of soil macrofauna in urban parks and domestic gardens of London, UK. In April and June 2004, the soil macrofauna were handsorted from soil cores in eleven parks and gardens of various sizes in central London. Five taxa were identified to species (Lumbricidae, Isopoda, Diplopoda, Chilopoda and Formicidae). The biodiversity value of the two main habitats (horticultural borders and mown grass lawns) was assessed and the influence of a range of environmental factors on species density (number of species per unit area) examined. The species densities of the studied soil invertebrates in the urban gardens were comparable with those found in natural ecosystems, although plant borders contained significantly more species than lawns. Borders had higher levels of plant nutrients, higher floristic diversity and lower levels of micronutrients and heavy metals than lawns. Significant predictor variables of species densities in the plant borders were the percentage of leaf litter cover, sampling month and soil pH. Species densities in the lawns were significantly correlated with the distance of the samples from the edge of the lawn.

**Keywords** Urban biodiversity · Soil macrofauna · Domestic gardens

## Introduction

The conservation of soil biodiversity has been recognised as essential for the maintenance of ecological processes such as decomposition and soil formation, as well as for utilitarian reasons such as supporting sustainable agriculture (Stork and Eggleton 1992; Hågvar 1998).

J. Smith (✉) · A. Chapman · P. Eggleton
Soil Biodiversity Programme, Department of Entomology, The Natural History Museum, Cromwell Road, London SW7 5BD, UK
e-mail: joans2@nhm.ac.uk

These services are particularly important in urban environments where the soil biota may enhance the environmental quality of the city through degradation of pollutants and reduction of surface water run-off due to the development and preservation of soil structure. However, urban biodiversity is subject to a number of both natural processes and anthropogenic activities, making it difficult to identify a general conservation strategy.

While there are few data on below-ground taxa, studies on above-ground invertebrates of habitat fragments in urban areas have identified several factors that influence species diversity, including: fragment size, degree of isolation, fragment age, edge effects, disturbance levels, habitat characteristics, and invasion by exotic species (Faeth and Kane 1978; Rebele 1994; Collinge 1996; Bolger et al. 2000; Gibb and Hochuli 2002). These studies have focused on natural habitats fragmented by urban expansion, such as woodlands and coastal scrub. However, in many cities, the majority of urban green spaces are domestic gardens and parks (33% of the surface area of London). These unique environments, although highly modified and disturbed, have recently been identified as an important source of native biodiversity (Gaston et al. 2004).

This paper provides baseline data on soil macrofauna (earthworms, millipedes, woodlice, centipedes and ants) in the parks and gardens of London. These green spaces consist of horticultural borders which often contain a high proportion of alien flora [67% in Sheffield, (Thompson et al. 2003)] surrounding a mown grass lawn. The biodiversity value of these two habitats for native soil invertebrates is assessed and the influence of a range of environmental factors on species density [number of species per unit area, (Rebele 1994)] examined.

## Methods

### Study sites

Eleven study sites were chosen, distributed over an area of 3 $km^2$ in the borough of Kensington and Chelsea, in central London. Each site was a mown grass lawn surrounded by horticultural borders, with predominately small woody perennials (shrubs). These sampling sites were either private shared gardens maintained by the Wellcome Trust on behalf of residents, or public parks managed by the Royal Parks Authority (Green Park and Kensington Gardens), Imperial College estates (Princes Gardens), or the Royal Borough of Kensington and Chelsea local authority (Holland Park). They ranged in area from 0.044 to 250 ha, representing an evenly spaced distribution of size on a log scale (Table 1).

We assumed that the degree of isolation from surrounding areas of semi-natural habitats of the green belt on the periphery of the city (about 25 km south or west) was the same for each of the sites, which at most were 3 km apart. The study sites were separated from other green spaces by at least 50 m of built environment (roads and houses). While different taxa are likely to have different capacities for dispersal, a study has shown that even a single road cutting through a forest seriously restricted Carabid activity (Mader 1984).

The original soil parent material is London clay, although this has been highly modified by human activities such as eutrophication and translocation. Examination of

**Table 1** Sample sites

| Study sites | Area (ha) |
|---|---|
| Onslow Square I | 0.044 |
| Evelyn Gardens I | 0.155 |
| Onslow Gardens I | 0.270 |
| Evelyn Gardens II | 0.322 |
| Lennox Gardens | 0.432 |
| Onslow Gardens II | 0.667 |
| Onslow Square II | 1.011 |
| Princes Gardens | 1.992 |
| Holland Park | 21.912 |
| Green Park | 47.809 |
| Kensington Gardens | 250.000 |

historical Ordnance Survey maps showed that the study sites have been green spaces for at least 130 years.

## Habitat characteristics

Plant borders were generally linear features forming a border between the garden and the surrounding urban area. Common shrub species were *Rhododendron* spp., *Ilex aquifolium*, *Rosa* spp., *Berberis* spp, and *Hydrangea* spp. Herbaceous plants were less abundant and therefore the soil surface tended to have no ground cover. Dominant tree species included the London plane (*Platanus x hispanica*), horse chestnut (*Aesculus hippocastanum*), and large-leafed lime (*Tilia platyphyllos*). Relevant management treatments with potential for influencing the soil biota included the removal of dead vegetation and leaf litter, the application of ericaceous compost around acid-loving species such as rhododendrons, and irrigation during the summer months.

Mown grass lawns accounted for the greatest proportion of the study sites, and consisted of an apparently uniform monoculture. No attempt was made to identify the grass species present due to lack of flowering parts, but a recent survey of the lawn flora in Sheffield, UK, found that over half of the total lawn cover was composed of just three species of grasses (*Agrostis capillaris*, *Festuca rubra*, *Lolium perenne*) (Thompson et al. 2004). In the London lawns, common forb species were White Clover (*Trifolium repens*), Daisy (*Bellis perennis*) and Creeping Buttercup (*Ranunculus repens*). The lawns were cut to roughly 3 cm height on a weekly basis during the growing season (May–October).

## Sampling technique

The parks and gardens were sampled twice, once in April and once in June 2004. To avoid confounding the effects of area and sample size, the same numbers of cores were collected in each garden, regardless of size. During each round of sampling, 10 soil cores, measuring 15 $cm^2$ and 10 cm deep (volume of 2250 $cm^3$), were taken at random points from the plant borders and 10 cores from under the centre of the lawn, at a minimum

distance of 3 m from each other. A depth of 10 cm was deemed to be adequate, as in other soils, invertebrate populations are known to be concentrated within the upper 5–10 cm (Peterson and Luxton 1982). The turf layer was removed from the soil cores taken from the lawn, and the roots searched for macrofauna. The soil cores were hand-sorted for 20 min and any macrofauna encountered were removed using forceps and preserved in 80% ethanol.

## Environmental variables

*Soil variables* Percentage soil moisture of the cores was measured using Time Domain Reflectrometry [TRIME FM, (IMKO)] and soil temperature recorded using a soil thermometer. Soil samples were taken from the April round of handsorted cores and analysed in the lab for pH, and water-soluble (bio-available) concentrations of soil nutrients and metals. Soil pH was measured by mixing 10 g of fresh (undried) soil with 10 ml of distilled water. The samples were shaken for 1 min and left to settle before being measured using a calibrated OAKTRON pH tester. For analysis of concentrations of soil elements, the soil samples were air-dried and crushed to produce 5 g of fine dust per soil core. The soil samples from each sample (i.e., 10 cores from each habitat, in each garden) were combined and two sub-samples analysed for % carbon and nitrogen by combustion analysis in the Electron Microscopy and Mineral Analysis (EMMA) laboratory in the Natural History Museum, London. Two sub-samples were also analysed for water-soluble nutrients and metals. Distilled water (10 ml) was added to 1 g soil and the solution shaken for 24 h before being filtered and acidified for cation analysis using concentrated nitric acid. The solution was then analysed for concentrations (ppm) of Al, Ca, Cu, Fe, K, Mg, Pb, and Zn by inductively coupled plasma atomic emission spectrometry (ICP-AES) in the EMMA labs.

*Other variables* The number of plant species occurring in and over the soil core was recorded to provide a simple measurement of above ground vegetation diversity and the absence or presence of leaf litter was also recorded. For the lawn samples, the distance of the position of the soil cores from the edge of the lawn was measured.

## Species identification and distribution patterns

Initially, the 440 samples were sorted to higher taxonomic units (class or order) and specimens from the five most abundant groups (Oligochaeta, Chilopoda, Isopoda, Diplopoda, and Formicidae) were identified to species. The Coleoptera were not included as insufficient numbers were collected for analysis. Specimens were identified at the Natural History Museum, London, using appropriate keys (Eason 1964; Blower 1985; Hopkin 1991; Skinner and Allen 1996; Sims and Gerard 1999; Barber 2003). These keys were also used to obtain distribution information. A voucher collection is stored at the Natural History Museum, London.

The species were classified as: (1) synanthropic species, found predominantly in gardens and in other highly disturbed sites, (2) widespread species, found in most habitats, but especially in cultivated land, (3) species especially associated with warm south-eastern, especially coastal, areas, (4) myrmecophiles, (5) species predominantly associated with thin calcareous soils, especially grasslands and woodlands, generally with

more restricted ranges. The proportion of species of each taxa found in these urban gardens as a percentage of the total species list for the whole of the British Isles was calculated (Table 3).

## Statistical analyses

### Preliminary analyses

In order to reduce the risk of Type I statistical errors, a principal components analysis (PCA) was performed on the soil nutrient and metal data to identify significantly inter-correlated variables and so reduce the number of variables to be entered for analysis of the species density data. The PCA was performed using Canoco 4.51 (ter Braak and Smilauer, 2003) and identified strong correlations among the macronutrients (Ca, P, K, Mg), and among the micronutrients and heavy metals (Al, Cu, Fe, Pb, Zn) (results not shown). Calcium was chosen to represent the macronutrients in further analyses as it has an important influence on woodlice, earthworm and millipede populations. Zinc was chosen to represent the micronutrients and metals as it has been shown to be toxic for many soil taxa. Total soil carbon, total soil nitrogen and organic carbon were closely correlated with each other [Pearson correlation, all $r$'s $> 0.84$, $P < 0.001$, (MINITAB14 2003)], and % organic C was chosen for further analyses.

### Comparison of habitats

Total species densities (total number of species per sample, i.e., per 10 pooled soil cores taken each month, in each habitat, in each green space) of the lawn and plant borders were compared using analysis of variance [one-way ANOVA, (MINITAB14 2003)]. A significant difference between the species density of the two habitats would indicate that further analysis should be performed separately on lawn and border data.

### Influence of environmental variables

Forward stepwise multiple regression (alpha to enter and remove = 0.15) was used to determine which of the environmental variables measured were significant predictors of total species density in the lawn and plant border habitats (MINITAB14 2003). The environmental (independent) variables included in the analysis were: garden area [log (hectares + 1)], mean vegetation diversity, mean soil moisture (%), mean soil temperature (°C), mean pH, month of sampling (April or June), organic C (%), Zn and Ca (ppm). In addition, an extra variable describing the presence of leaf litter (number of soil cores per sample containing leaf litter) was included in the analysis of the plant border data (there was no leaf litter in the lawn samples), and a variable describing the distance of the lawn samples from the edge of the lawn was included in the analysis of the lawn data. If two independent variables are highly correlated, only one will end up in the regression model, even though either can be regarded as predictors. Therefore, to aid in the interpretation of the regression models, correlations between the significant predictor variables and the remaining environmental variables were identified (MINITAB14 2003).

**Table 2** List of species sampled

| BOTH | BORDER | LAWN |
|---|---|---|
| **Lumbricidae** | | |
| W *Allolobophora chlorotica** | W *Dendrodrilus rubidus* | S *Aporrectodea icterica** |
| W *Aporrectodea caliginosa** | S *Murchieona minuscula* | W *Aporrectodea longa** |
| W *Lumbricus castaneus* | | W *Aporrectodea rosea** |
| W *Lumbricus rubellus* | | W *Lumbricus terrestris* |
| **Chilopoda** | | |
| S *Clinopodes linearis** | S *Cryptops anomalans* | |
| S *Geophilus osquidatum* | S *Cryptops hortensis* | |
| S *Lithobius microps** | S *Haplophilus subterraneus** | |
| W *Necrophloeophagus flavus** | S *Henia brevis* | |
| | L *Henia vesuviana* | |
| | S *Lamyctes emarginatus* | |
| **Diplopoda** | | |
| C *Blaniulus guttulatus** | W *Brachyiulus pusillus* | |
| | W *Cylindroiulus britannicus* | |
| | C *Cylindroiulus caeruleocinctus** | |
| | S *Cylindroiulus vulnerarius** | |
| | C *Macrosternodesmus palicola* | |
| | W *Ophiodesmus albonanus* | |
| | W *Ophyiulus pilosus* | |
| | W *Polydesmus* sp. | |
| **Isopoda** | | |
| | S *Armadillidium nasatum* | M *Platyarthrus hoffmannseggi* |
| | W *Armadillidium vulgare* | S *Androniscus dentiger* |
| | W *Haplopthalmus* sp. | |
| | W *Philoscia muscorum* | |
| | W *Porcellio scaber* | |
| | W *Trichoniscus pusillus* | |
| | W *Trichoniscus pygmaeus* | |
| **Formicidae** | | |
| S *Lasius niger** | W *Stenamma debile* | W *Myrmica rubra* |
| W *Lasius flavus** | | |
| W *Myrmica ruginodis* | | |
| L *Ponera coarctata* | | |

* indicates widespread species sampled in seven or more of the sites; W—widespread, especially in cultivated land and/or pastureland, S—Synanthropic, commonly recorded from gardens and other areas around human habitations, L—found around coastal areas in SE England and in London, C—associated with thin calcareous soils (woodland and grassland), M—Myrmecophilous.

## Results

### Species identification

Over 2,500 invertebrates were identified to 44 species (Table 2, Appendix). Of these, 24 were found primarily in the plant borders, while seven were sampled only in the lawns. The remaining 13 species were present in both habitats. Several species were widespread and found in the majority of the sites (Table 2). A majority of the sampled species are known to

**Table 3** The proportion of species of each taxa found in urban gardens in London as a percentage of the total species list for that group across the whole of the British Isles

| Habitat | Lumbricidae (27 species[a]) | Chilopoda (35 species[b]) | Diplopoda (52 species[c]) | Isopoda (37 species[d]) | Formicidae (42 species[e]) |
|---|---|---|---|---|---|
| Urban gardens, London, UK | 37% | 29% | 17% | 24% | 14% |
| Oak-Beech woodland, Hampshire, UK[f] | 37% | 31% | 12% | 13% | 5% |
| Arable field (winter wheat), Cambridgeshire, UK[g] | 18% | 6% | 8% | 0% | Not Recorded |

Data from a natural and anthropogenic habitat are shown for comparison. Source: [f] Inward, in preparation, [g] Smith, unpublished data. Species lists obtained from: [a] Blakemore 2005, [b] Barber 1985, [c] Blower 1985, [d] Hopkin 1991, [e] Skinner and Allen 1996.

be widespread throughout England within cultivated land. A large minority, however, are recorded as specifically synanthropic, particularly within the centipedes. Only three species appear to be commonly associated with natural ecosystems, and these are all millipedes normally found in calcareous grasslands or woodlands. These calicolous millipedes were all found in borders. Two other species, *Ponera coartaca* (Formicidae) and *Henia vesuviana* (Chilopoda), are species associated with warm SE England sites (coastal and anthropogenic). The sampled species within the study taxa represent a rather variable but generally high proportion of their respective UK species lists (Table 3).

## Comparison of habitats

There was a significant difference in species density between the lawn and plant border habitats (one-way ANOVA, $F = 18.44$, $P < 0.001$, $n = 44$) with higher species densities in

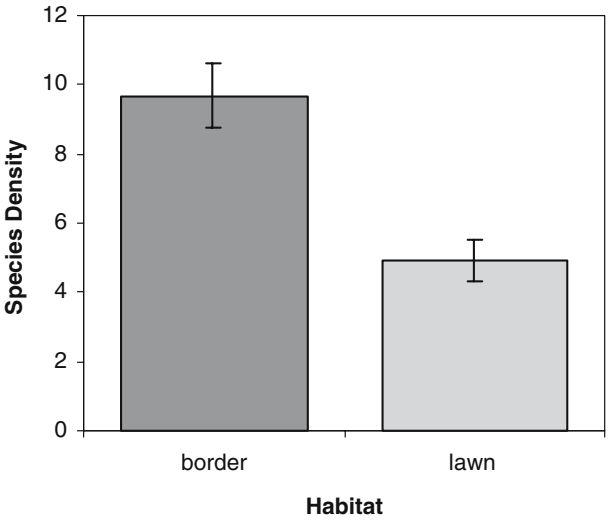


**Fig. 1** Species density and habitat type. Bars are one standard error from the mean

**Table 4** Results of stepwise regression analysis on species density (number of species per sample) of soil macrofauna in the horticultural borders and mown grass lawns of 11 parks and gardens in London, UK

| Model type | Variables in model | Coefficient | *F* | *df* | *P* | $R^2$ |
|---|---|---|---|---|---|---|
| Species density | | | | | | |
| Plant borders | Leaf litter | 0.06* | | | | |
| | Month | −3.20* | | | | |
| | Soil pH | 3.60* | | | | |
| | Vegetation diversity | 4.20† | | | | |
| | | | 7.15 | 4, 17 | 0.001 | 0.6273 |
| Grass lawns | Month | −2.36* | | | | |
| | Distance from edge | −1.73* | | | | |
| | | | 5.56 | 2, 19 | 0.013 | 0.3544 |

For list of independent variables available to be entered into model, see text. Only the variables entered in the model (alpha = 0.15 to enter or remove) are listed, in the order they entered the model. † $P = 0.05$–$0.10$, *$P < 0.05$

the plant borders (Fig. 1). Given this result, we have examined the species density data from each habitat separately in further analyses.

## Influence of environmental variables

In the plant borders, the presence of leaf litter was the best predictor of species density, with more species occurring in samples with more leaf litter (Table 4). Month of sampling and mean soil pH explained significant remaining variance, with higher species densities in

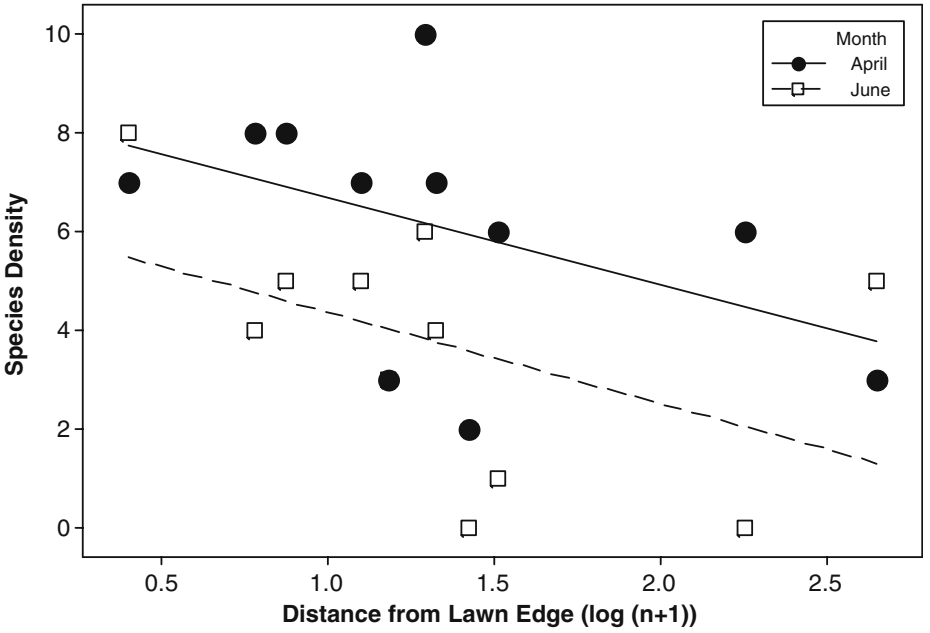


**Fig. 2** Plot of total species density and distance from lawn edge showing regression lines

**Table 5** Pearson correlations between significant predictor variables from regression models in Table 3 and remaining environmental variables

| Variable | Area | Month | Veg | Moist | Temp | pH | Org C | Zn | Ca |
|---|---|---|---|---|---|---|---|---|---|
| Plant borders | | | | | | | | | |
| Leaf litter | 0.440* | 0.254 | 0.006 | 0.469* | −0.309 | 0.247 | 0.408 | −0.680** | 0.343 |
| Month | 0.000 | 1.000 | 0.029 | 0.383 | 0.869** | 0.000 | 0.000 | 0.000 | 0.000 |
| Soil pH | 0.030 | 0.000 | −0.066 | 0.118 | −0.110 | 1.000 | 0.008 | −0.347 | 0.515* |
| Grass lawns | | | | | | | | | |
| Month | 0.000 | 1.000 | 0.113 | −0.772** | 0.768** | 0.000 | 0.000 | 0.000 | 0.000 |
| Distance | 0.924** | 0.000 | −0.281 | −0.012 | 0.002 | −0.522* | 0.234 | −0.526* | −0.008 |

*$P < 0.05$, **$P < 0.001$

April, and at higher soil pHs. Mean vegetation diversity was marginally significant ($P = 0.056$) and so was included in the model, which in total explained 63% of the variance in the data.

Month of sampling was the best predictor of species densities in the lawn samples, again with more species sampled in April (Fig. 2). Distance from the edge of the lawn was the only other significant variable with species densities decreasing as distance increased (Fig. 2). The regression model explained 35% of the variance in species density (Table 4).

### Correlation of environmental variables

In the plant borders, leaf litter was positively correlated with the area of the garden and mean soil moisture and negatively correlated with zinc concentrations ($P < 0.05$) (Table 5). Month of sampling was significantly correlated with mean soil temperatures with higher temperatures in June. Mean pH was positively correlated with water-soluble Ca concentrations. For the lawn data, June samples had higher soil temperatures and lower % soil moisture than the April samples. Distance from the edge of the lawn was highly correlated with size of garden, and negatively with soil pH and water-soluble zinc concentrations (Table 5).

## Discussion

### The biodiversity of soil invertebrates in the parks and gardens of London

Our data demonstrate that, despite its highly modified and disturbed nature, the urban garden is a valuable source of native soil biodiversity, at least for some groups. The proportion of species recorded was as high as 37% of the total UK species list for certain soil invertebrate taxa (Table 3). This compares favourably with other anthropogenic environments such as arable fields, and parallels species diversity in a natural oak-beech woodland (Table 3). Indeed for diplopods, a group traditionally associated with undisturbed woodland habitats (Kime 1997), species diversity was higher in the London gardens than in the Hampshire oak woodland (17% compared to 12%). This agrees with the findings

of other studies (Barber 1985) that recorded peak species diversity of diplopods in urban areas of Denmark. This high level of species richness in urban areas has been attributed to great habitat diversity often over a small area (Rebele 1994; Smith 2003). The urban environment also provides favourable climatic conditions for some taxa, such as centipedes (Barber 1985). The 'heat island' effect, where temperatures in cities may be as much as 5°C higher than the surrounding countryside, favours species from warmer, southern regions. One such species sampled in the London gardens is the centipede *Henia vesuviana*, a widespread species of the Mediterranean region which is at the northern edge of its range in London (Barber 1985). However, with a significant proportion of the soil macrofauna being classed as synanthropic, this raises the question of what is conservationally valuable in such habitats?

In these anthropogenic environments, natural processes of dispersal and extinction are influenced to varying degrees by introductions and local exterminations due to human activities (Rebele 1994). Urban communities are more likely to consist of unique combinations of species that do not share a common evolutionary history, having been brought together as a result of human activities (Rebele 1994). For example, in this study of city gardens, the presence of species usually associated with natural ecosystems may be as a result of translocation of soil and vegetation into these urban habitats. The impact of these unique assemblages on natural processes such as population dynamics and ecosystem functioning is unknown.

## Comparison of plant borders and lawns

Species densities were greater in the plant borders than in the grass lawns (Fig. 1). The borders of London's parks and gardens represent an environment with heterogeneous vegetation diversity and structure, and heterogeneous soil properties such as amount of organic matter and soil moisture, and are subject to regular human disturbance. This environmental heterogeneity and intermediate level of disturbance may be responsible for the higher species richness in the plant borders when compared with the more homogenous nature of the lawn. In any case, the exposed nature of the domestic lawn is likely to result in more extreme environmental conditions. However, seven soil invertebrate species were recorded from the lawn samples only, indicating that this habitat contributes to the overall complementarity biodiversity value of urban parks and gardens.

## Environmental correlates of soil biodiversity

Higher species densities in the plant borders were closely correlated with the presence of leaf litter. This is to be expected, as three of the five taxa sampled are detritivorous (earthworms, millipedes and woodlice). Leaf litter also provides a more structurally complex environment than bare soil (Bultman and Uetz 1984) and can buffer the underlying soil from climatic extremes. We found a correlation between mean soil moisture and amount of leaf litter indicating that a litter layer may reduce water loss from soils. Heavy metal concentrations in the soil were lower in samples with more leaf litter, which may be due either to the litter acting as a barrier, preventing pollutants reaching the soil, or to increased activity of detoxifying soil organisms where leaf litter is present.

Sampling in April recorded higher species densities than in June in both the lawns and borders. Soil organisms such as earthworms and millipedes reach peak abundances in spring

(Hopkin and Read 1992; Spurgeon and Hopkin 1999) and may react to the increased temperatures and decreased soil moisture later in the year by retreating to lower soil layers or entering diapause. Soil temperatures were higher in June in both habitats, but soil moisture was lower only in the lawn samples, probably as a result of regular irrigation in the borders, and higher levels of insolation in the lawns.

Soil pH was found to be a significant predictor of species density in the plant borders and is known to be a major factor influencing the distribution of a number of soil taxa, including the Oligochaeta, Diplopoda and Isopoda (Leadley-Brown 1978; Edwards and Bohlen 1996). Such detritivorous groups rely on enzymes produced by microbes to aid decomposition of plant structural compounds, and these micro-organisms are strongly influenced by decreasing soil pH levels, resulting in decreased population densities of these macrofauna groups (Zimmer and Topp 1997). Soil pH also influences nutrient availability (Dubbin 2001). Availability of calcium increases as soil pH increases and this influences the abundance of groups such as woodlice and millipedes which require calcium for the exoskeleton (Oliver and Meechan 1993). Soil pH and water-soluble calcium levels were strongly correlated in the London soils.

Species densities in the lawns decreased as distance from the edge increased (Fig. 2). This may be evidence of an 'edge effect' which has been found to influence species richness in other studies of habitat fragments (Bolger et al. 2000). Bolger et al. (2000) propose that an increase in species diversity at fragment edges is due either to "an increase in generalist 'edge' species, or the spillover of species that specialise in adjacent habitat types" (i.e., an ecotone effect). In this case, it seems that the latter explanation is the most likely, and where the lawn and plant borders meet, the extension of favourable plant border abiotic characteristics and dispersal of border species increases species densities at the lawn edge.

The size of an urban habitat fragment has been found to be a significant predictor of arthropod species diversity in several studies (Collinge 1996; Bolger et al. 2000). The area of a fragment is thought to influence the population dynamics of a species, with decreases in population sizes in small habitat remnants increasing the probability of local extinctions (Collinge 1996), but the area of the gardens in London was not a significant predictor of species densities. This may indicate that the surrounding urban matrix may not be as impermeable to the soil invertebrate taxa as assumed, and that these green spaces are connected by corridors such as grass verges allowing dispersal, or that human activities have obscured natural patterns. However, garden area appears to have had an indirect influence on species diversity through interaction with other environmental variables. In the plant borders, larger gardens had more leaf litter, suggesting a decrease in management intensity as area increases (less 'tidying up' of dead vegetation and litter). In the lawns, garden area was correlated with distance from the lawn edge implying that lawns in smaller gardens consisted entirely of species rich 'edge' habitat modified by the surrounding plant borders (as discussed above), while lawns in larger gardens had a distinct species-poor 'core'.

**Acknowledgments** We are grateful to Mr. Stephen Preston and the Wellcome Trust Ltd., the Royal Parks Authority, Imperial College estates and the Royal Borough of Kensington and Chelsea for giving us permission to sample in their parks and gardens. Many thanks to Alessandro Giusti, Alex van Holland and Belinda Edwards for field assistance, and thanks also to Alex van Holland for identifying the Chilopoda. We are very grateful to Sarah James of the Electron Microscopy and Mineral Analysis (EMMA) lab at the Natural History Museum, London, for help and advice with the soil analyses. Many thanks to Kelly Inward for providing data on oak-beech woodland. This work was funded by a grant from the Research Fund of the Entomology Department of the Natural History Museum, London.

## Appendix

Total species density of each sampling site

| Sample site (location 51°N 0°W) | Area (ha) | Habitat (border/lawn) | Sampling month (April/June) | Total species density (per sample) |
|---|---|---|---|---|
| Onslow Square I | 0.111 | B | A | 8 |
| 29′32″N 10′18″W | | B | J | 10 |
| | | L | A | 7 |
| | | L | J | 8 |
| Evelyn Gardens I | 0.387 | B | A | 8 |
| 29′20″N 10′46″W | | B | J | 8 |
| | | L | A | 8 |
| | | L | J | 4 |
| Onslow Gardens I | 0.673 | B | A | 15 |
| 29′28″N 10′35″W | | B | J | 7 |
| | | L | A | 7 |
| | | L | J | 5 |
| Evelyn Gardens II | 0.806 | B | A | 8 |
| 29′18″N 10′40″W | | B | J | 2 |
| | | L | A | 8 |
| | | L | J | 5 |
| Lennox Gardens | 1.079 | B | A | 19 |
| 29′45″N 09′48″W | | B | J | 14 |
| | | L | A | 3 |
| | | L | J | 3 |
| Onslow Gardens II | 1.667 | B | A | 10 |
| 29′30″N 10′33″W | | B | J | 9 |
| | | L | A | 10 |
| | | L | J | 6 |
| Onslow Square II | 2.528 | B | A | 16 |
| 29′33″N 10′25″W | | B | J | 7 |
| | | L | A | 7 |
| | | L | J | 4 |
| Princes Gardens | 4.98 | B | A | 6 |
| 29′57″N 10′20″W | | B | J | 5 |
| | | L | A | 2 |
| | | L | J | 0 |
| Holland Park | 54.781 | B | A | 18 |
| 30′10″N 12′15″W | | B | J | 9 |
| | | L | A | 6 |
| | | L | J | 1 |
| Green Park | 119.522 | B | A | 12 |
| 30′15″N 08′40″W | | B | J | 3 |
| | | L | A | 6 |
| | | L | J | 0 |
| Kensington Gardens | 625 | B | A | 9 |
| 30′20″N 10′50″W | | B | J | 10 |
| | | L | A | 3 |
| | | L | J | 5 |

## References


Barber AD (1985) Distribution patterns in British Chilopoda. Bijdr Dierkd 55:16–24

Barber AD (2003) A guide to the identification of British centipedes. AIDGAP Test Version. Field Studies Council, Shrewsbury, UK

Blakemore RJ (2005). British and Irish earthworms - a checklist of species updated from Sims and Gerard (1999). In a series of searchable texts on earthworm biodiversity, ecology and systematics from various regions of the world. Eds. N. Kaneko and M .T. Ho. COE Soil Ecology Research Group, Yokohama National University, Japan. CD publication

Blower G (1985) Millipedes. Synopses of the British Fauna. Bath, Avon, UK

Bolger DT, Suarez AV, Crooks KR, Morrison SA, Case TJ (2000) Arthropods in urban habitat fragments in southern California: area, age and edge effects. Ecol Appl 10:1230–1248

Bultman TL, Uetz GW (1984) Effect of structure and nutritional quality on abundances of litter-dwelling arthropods. Am Midl Nat 111:165–172

Collinge SK (1996) Ecological consequences of habitat fragmentation: implications for landscape architecture and planning. Landsc Urban Plan 36:59–77

Dubbin W (2001) Soils. The Natural History Museum, London

Eason H (1964) Centipedes of the British Isles. William Clowes & Sons, London & Beccles, UK

Edwards CA, Bohlen PJ (1996) Biology and ecology of earthworms. Chapman & Hall, London, UK

Faeth SH, Kane TC (1978) Urban biogeography. City parks as islands for Diptera and Coleoptera. Oecologia 32

Gaston KJ, Smith RM, Thompson K, Warren PH (2004) Gardens and wildlife: the BUGS project. Br Wildl 16:1–9

Gibb H, Hochuli DF (2002) Habitat fragmentation in an urban environment: large and small fragments support different arthropod assemblages. Biol Conserv 106:91–100

Hågvar S (1998) The relevance of the Rio-Convention on biodiversity to conserving the biodiversity of soils. Appl Soil Ecol 9:1–7

Hopkin S (1991) A key to the woodlice of Britain and Ireland. Field Studies Council, Shrewsbury, UK

Hopkin S, Read HJ (1992) The biology of millipedes. Oxford University Press, Oxford, UK

IMKO. Micromodultechnik GmbH. Im Stock 2, D-76275 Ettlingen, Germany http://www.imko.de

Kime RD (1997) Biodiversity and land-use with regard to Diplopods on some West European sites. In Proceedings of the 10th Int. EIS-Coll., 6–7 July, 1995 Saarbrucken

Leadley-Brown A (1978) Ecology of soil organisms. Heineman Educational Books Ltd., London, UK

Mader HJ (1984) Animal habitat isolation by roads and agricultural fields. Biol Conserv 29:81–96

MINITAB14 (2003) MINITAB Release 14 For Windows. Minitab Inc.

Oliver PG, Meechan CJ (1993) Woodlice. Synopses of the British Fauna No.49. The Field Studies Council, Shrewsbury, UK

Peterson H, Luxton M (1982) A comparative analysis of soil fauna populations and their role in decomposition processes. Oikos 39:287–388

Rebele F (1994) Urban ecology and special features of urban ecosystems. Glob Ecol Biogeogr Lett 4:173–187

Sims R, Gerard B (1999) Earthworms. The Field Studies Council, Shrewsbury, UK

Skinner G, Allen G (1996) Ants. The Richmond Publishing Co. Ltd., Richmond, UK

Smith J (2003) Gardening practices and soil macroinvertebrate diversity, MSc Dissertation, Imperial College, University of London

Spurgeon DJ, Hopkin S (1999) Seasonal variation in the abundance, biomass and biodiversity of earthworms in soils contaminated with metal emissions from a primary smelting works. J Appl Ecol 36:173–183

Stork NE, Eggleton P (1992) Invertebrates as determinants and indicators of soil quality. Am J Altern Agric 7:38–47

ter Braak CJF, Smilauer P (2003) Canoco for windows, Version 4.51. Biometris-Plant Research International, Wageningen, The Netherlands

Thompson K, Austin KC, Smith RM, Warren PH, Angold PG, Gaston KJ (2003) Urban domestic gardens (I): putting small-scale plant diversity in context. J Veg Sci 14:71–78

Thompson K, Hodgson JG, Smith RM, Warren PH, Gaston KJ (2004) Urban domestic gardens (III): composition and diversity of lawn floras. J Veg Sci 15:373–378

Zimmer M, Topp W (1997) Does leaf litter quality influence population parameters of the common woodlouse, *Porcellio scaber* (Crustacea: Isopoda)? Biol Fertil Soils 24:435–441