Title: The effect of urban ground covers on arthropods: an experiment

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ABSTRACT

Changes to the ground layer in urban areas are extensive, but the effects on arthropod fauna are poorly understood. We undertook a manipulative experiment to examine the response of arthropods to small-scale variation in ground covers commonly found in urban parks and gardens in Australia. The ground covers tested were bare ground, leaf litter, woodchips and grass, with plot sizes of 3.6 m^2. Epigeic arthropods were sampled with pitfall traps and Tullgren funnels over 12 months following establishment

of the treatments. All epigeic arthropods were sorted to order and the ants (Hymenoptera: Formicidae), beetles (Coleoptera), millipedes (Diplopoda) and slaters (Isopoda: Oniscidea) were examined at lower taxonomic levels. Diverse arthropods rapidly colonised previously cleared plots in all four treatments and were most abundant in grass plots. The diversity of ants and beetles was significantly different in different ground cover and tended to be most diverse in grass plots. Despite the treatments providing very different microclimates, the fauna studied did not show strong selection for a particular cover type overall. The abundance of grass cover in the surrounding area may have led to the grass plots having the greatest abundance of arthropods. These results have important implications for developing effective small-scale conservation efforts for arthropods in anthropogenically modified landscapes, especially for species with poor dispersal abilities.

Keywords

Urbanisation, habitat, leaf litter, land use, park, grass.

INTRODUCTION

A common change resulting from urbanisation is the replacement of natural ground coverings with new surfaces (Beard and Green 1994; Paul and Meyer 2001; Pickett et al. 2011). This can include covering the existing ground layer with concrete (Stone Jr 2004), which contributes to the high levels of impermeable surface cover found in urban areas (Angel et al. 2005; Pauleit et al. 2005). However, there can also be more subtle changes. For example, urban green spaces often have mown turf as their dominant ground cover (Beard and Green 1994; Byrne et al. 2008), which replaces leaf litter or low-growing native plant species. Woodchips and mulches are also laid down for purposes such as water retention and weed suppression (Jordan and Jones 2006).

The impact of changes to ground covers in anthropogenically modified landscapes is often overlooked, even though removal of leaf litter is known to have dramatic effects on invertebrate communities (Sayer et al. 2006). For example, ground covers are widely manipulated in agricultural areas by laying mulches with the aim of promoting crop growth (Thomson and Hoffmann 2007) but research on the impacts of these novel ground covers on invertebrates is lacking (Paoletti et al. 2007b). Invertebrates are poorly studied in urban areas generally (McIntyre 2000; Yen 2011) and the effects of novel urban ground covers are particularly poorly understood (Jordan and Jones 2006; Byrne et al. 2008). The effects of turfgrasses and their management on invertebrates has received the most attention, particularly in the United States, where the effects of lawn management on the biodiversity of soil and epigeal arthropods (Rochefort et al. 2006a; Rochefort et al. 2006b; Byrne et al. 2008), the role of invertebrates as indicators of pollution (Cheng et al. 2008) and the effects of lawn management on the presence of beneficial species for pest management (Joseph and Braman 2009) have been studied.

Invertebrates are very important for a wide range of ecosystem functions, including pollination (Steffan-Dewenter et al. 2005; Ricketts et al. 2006), predation (Nash et al. 2008) and decomposition and nutrient cycling (David and Handa 2010; Gessner et al. 2010). Invertebrates are also important food sources for larger animals (Maerz et al. 2005), which are often the more visible and charismatic signs of 'biodiversity'. They are also important, but often neglected, for conservation in their own right (Ponder and Lunney 1999). For these reasons, a greater understanding of how invertebrates respond to urban environments is required (Gaston et al. 2005) and experimental manipulations have been identified as critical in furthering this understanding (Hochuli et al. 2009).

The objective of this research was to experimentally test the effect of four commonly used garden and park ground covers on the diversity, abundance and seasonality of arthropod colonisation. We selected four ground covers commonly used in urban public open spaces and in domestic gardens: lawn grass, woodchips, leaf litter and bare ground. The response of the arthropod community was examined at order level and several groups that play important roles in the ecosystem were examined at lower taxonomic levels. Slaters (Isopoda: Oniscidea) and millipedes (Diplopoda) were examined because of their important role in decomposition and their relationship with leaf litter (Paoletti et al. 2007a; David and Handa 2010), which is often removed in urban areas. The ants (Hymenoptera: Formicidae) were examined at genus level. Ants are a diverse, abundant and dominant fauna, particularly in Australian landscapes (Majer et al. 2004), they are sensitive to environmental changes (Hoffmann and Andersen 2003) and they play important roles in decomposition and soil maintenance (Petal et al. 1977; Folgarait

1998; Choate and Drummond 2011). Finally, we focused on the highly diverse beetle families, which play a wide range of roles in the ecosystem (Lawrence and Britton 1994). The results provide information on the way different arthropod groups respond locally to common park and garden ground cover types.

METHODS

Study site

Experimental plots were established in the field station of the Burnley campus of the University of Melbourne, Australia. The field station is approximately 3 ha in area and is primarily used for horticultural teaching and experiments and has large areas of mown grass. It is bordered on one side by a small botanic garden in the grounds of the University and on three sides by small roads, beyond which are playing fields to the south and south east. To the north east is the Yarra River (less than 100 m away), which is lined with remnant *Eucalyptus camaldulensis* Dehnh. (River Red Gum) grassy woodlands, some examples of which also grow along the borders of the field station. A larger patch of woodland (approximately 1,000 m^2) is located approximately 250 m to the south east of the experimental plot and is continuous with the riverside vegetation. *Eucalyptus camaldulensis* woodlands were once widespread across the northern and eastern regions of Melbourne (Presland 2008) and despite range reductions due to agriculture and urbanisation (Lunt and Bennett 2000; Australian Plants Society Maroondah 2001), both remnant and planted individuals are still common across the city (Australian Plants Society Maroondah 2001).

The soil pH was slightly acidic (μ = 6.2 December 2008, μ = 6.5 January 2010) (Hazelton and Murphy 2007) and did not change over the course of the experiment ($F_{1,14} = 2.32$, $P = 0.150$). The soil bulk density was low to moderately dense (μ = 1.2 g/cm^3 December 2008, μ = 1.3 g/cm^3 January 2010) (Hazelton and Murphy 2007) and did not differ across the course of the experiment ($F_{1,14} = 3.05$, $P = 0.102$). Soils were low in nitrogen (total N: μ = 0.08%. December 2008, μ = 0.09% January 2010) (Hazelton and Murphy 2007).

Plot preparation

The experimental area was a 38 m by 8 m rectangle with a 0.5 m buffer which was managed for weeds (see below). The area was divided into forty-eight 1.8 m by 2 m plots, arranged as a 16 by three plot matrix. Plots were separated by 50 cm of pegged double layer woven black plastic weed mat. The experimental area was initially levelled and scraped free of weeds using a skid loader and remaining weeds were manually controlled and sprayed with Basta®, a broad-spectrum contact herbicide.

Twelve replicates of each of four experimental ground cover treatments commonly used in urban parks were randomly allocated to each plot. The treatments were grass, native leaf litter, woodchips and bare ground. Although concrete is a very common ground cover in urban areas, it is not common in public parks in Australia and was therefore not tested. Bare ground when it is dry has many similar physical properties to concrete (Gluch et al. 2006) but it differs in being a permeable surface (Coutts et al. 2007). It is likely that a concrete treatment would have had lower abundance and diversity of arthropods

as primarily individuals passing through to another area would have been captured, while some taxa live in and on bare ground.

Red Gum woodchips, which are readily available in Melbourne and widely used in ornamental landscapes, were sourced commercially. Leaf litter was collected from the native garden in the Burnley campus grounds, which is dominated by *Eucalyptus camaldulensis*, with a range of native shrubs and small trees in the midstorey. The leaf litter and woodchips were steam sterilised at 60^{o}C for 45 minutes (determined from a pilot study) to remove any pre-existing invertebrate fauna within the fortnight before being applied to the plots. Woodchips were laid to approximately 5 cm depth, a depth commonly used by commercial suppliers and urban park managers. Leaf litter was applied to a depth of approximately 3 cm, which was determined based on the measurements made at remnant *Eucalyptus camaldulensis* sites in Melbourne (Norton 2011). Nothing further was done to the bare plots.

Grass plots were seeded using 500 g of Lawn Pro Kikuyu blend, a mix of kikuyu (*Pennisetum clandestinum* (Hochst. ex Chiov.)) (10%) and turf type perennial rye (*Lolium perenne* L. (Sp. Pl. 1: 83 (1753)) (70%) with a controlled-release fertiliser and granular wetting agent. This was supplemented with five kikuyu runners in each plot. Turf could not be used as it was not able to be sterilised to remove existing invertebrates. Grass plots were top-dressed several days after being sown to avoid competition with weeds and to promote rapid growth of the grass they were watered with approximately 15 L per plot four times in the fortnight after they were established.

A single piece of black bird-netting was laid over the whole plot to avoid interference by birds. Two bricks were laid near the centre of each grass plot to raise the net above the growing grass and to establish a target height for maintenance. The experiment ran for 14 months, from summer (late December 2008) to summer (early January 2010).

Plot maintenance

Throughout the year all plots were maintained to control broadleaf weeds. All plots were regularly hand-weeded, but never less than a week before trapping was undertaken and from March 2009 a herbicide spray was used once a season. Basta® was used on non-grass plots to suppress all weeds and Campbell Sportsground herbicide was used to target broadleafed weeds in grass plots. Both herbicides have very low toxicity for invertebrates (Colin Campbell (Chemicals) Pty. Ltd., Bayer CropScience). Grass plots were maintained at approximately 10 cm height by cutting using hand shears or a brushcutter at least a week before pitfall trapping. Cut grass that fell on the grass plots was left to decompose.

The summer of 2008-2009 (Dec-Jan) was unusually hot in Melbourne, including the hottest and driest days on record (Tolhurst 2009; Cordner et al. 2011). To avoid losing the newly sown grass and to simulate a more typical year, each plot was watered using a hose with approximately 15 L of potable water if less than 1 mm of rain was recorded in a fortnight at the nearest weather station (Australian Government Bureau of Metereology 2009).

Arthropod sampling

Ground-active arthropods were collected in bimonthly wet pitfall trapping and from extractions from leaf litter and woodchips using Tullgren funnels at the end of the experiment. Pitfall trapping was undertaken six times – once per season as well as at the beginning and end of the experiment.

Three pitfall traps were placed in each plot all at least 20 cm from the plot border. Pitfall traps were glass test tubes (diameter 20 mm, length 145 mm) placed in a polyvinyl chloride (PVC) pipe (internal diameter 22 mm, length 170 mm). The PVC pipes were sunk into the ground and the glass tube placed inside it. The upper edge of the pipe was bevelled, so that the test tube opening was flush with the soil surface. Pitfall traps were filled to 5 cm with a 1:1 mixture of absolute ethanol and ethylene glycol. The PVC tubes were dug into the plots in mid-December, two weeks prior to the collection to avoid the 'digging-in effect' (Digweed et al. 1995) and trapping was undertaken in the same locations throughout the experiment.

Traps were left open for seven days each sampling period. Trapping was undertaken in late December 2008 (first collection), late February 2009 (summer), late April 2009 (autumn), August 2009 (winter), October 2009 (spring) and late December 2009 (final collection). Samples were washed through a 90 µm sieve and stored in 70% ethanol in air-tight plastic screw-top vials at 4^{o}C until sorted.

The day after the final pitfall traps were brought in, leaf litter and woodchips were collected from each plot using a 0.1 m^2 ring to define the collection area. One depth measurement was taken from the centre of the ring before all organic matter above the soil level was collected manually and stored in polyester/cotton blend pillowcases with their openings firmly sealed. The samples were kept cool and damp until the following day when they were processed in modified Tullgren funnels. The Tullgren funnels were modified plastic tubs (approx. 40 cm diameter, 10 cm depth), with a cross-hatched grill with holes of size 6 mm x 6 mm and one larger hole. These were placed in sealed wooden chambers and suspended over trays containing water and ethylene glycol (1:1). Heat- and light-producing 120 watt bulbs were suspended above each sample. A temperature gradient between the room and the funnels was maintained with an air-conditioner. Samples were processed over four days, which has been shown to be sufficient time for all the invertebrates to emerge (York 2000). The liquid samples were sieved through plankton mesh and stored in 70% ethanol in plastic vials with air-tight screw-top lids until they were sorted. The litter and wood chip samples could only be taken once, as they represented a significant proportion of cover for each plot.

Environmental monitoring

Soil moisture measurements were taken each time pitfall traps were put in and taken out using a Delta-T Devices ThetaProbe type ML2x in millivolts. Readings were taken in six randomly located positions in each plot, two within 30 cm of each trapping point. The ThetaProbe's millivolt readings were converted to gravimetric soil moisture values, using a series of soil samples with a range of moisture values taken in February 2010, following the protocols in the SENTEK calibration of Sentek Pty Ltd Soil Moisture Sensors manual (2001).

The surface temperature of each ground cover type was measured directly after pitfall traps were removed in winter, spring and the final summer collection. Temperature was logged using Thermacron ibuttons® every 15 minutes for two weeks. Loggers were placed in small, airtight plastic bags placed

directly on the soil surface in the centre of the plot. Forty-six ibuttons that met a set of calibration tests were used, so two plots were randomly excluded from each round of measurements.

Arthropod sorting

All arthropods were initially sorted to order (Harvey et al. 1989), to class where this was the equivalent taxonomic level (Collembola, Symphala) and to superorder in the case of the Acarina. They will be referred to collectively as 'the orders' or 'the order-level community' herein. Samples were sorted in a Petri dish with a Leica binocular microscope with up to 40x magnification. All orders were counted in full, except for Collembola, which were counted in estimated groups of 10's or 100's depending on their density in the trap. Taxa whose primary means of locomotion is flight (e.g. Diptera, Neuroptera) and larvae were excluded from analysis, as these were not targets of the trapping methods. Because the Tullgren samples contained a lot of soil, these were sorted in sub-sampling trays – square, purpose-made trays (10 cm x 10 cm) with ridges built on a 5 x 5 grid pattern. Tullgren samples were first sieved into three fractions (>2 mm, 2 mm-250 µm and 250 µm-90 µm) and spread over several sorting trays. Most taxa were counted in full. Collembola were estimated in these samples based on a random subsample of 10% of the squares in the 90 µm and 250 µm sorting trays. Other taxa (Hemiptera (bugs), Thysanoptera (thrips) and Acarina (mites)) that occurred in very large numbers in some samples were subsampled following the same protocol as for the Collembola.

The Coleoptera (beetles) were further sorted to family level to clarify some of the functional diversity within the order (Lawrence et al. 1999). Beetles were not sorted to species due to insufficient numbers for statistical analysis. The ants (Hymenoptera: Formicidae) were sorted to genus (Shattuck 1999; CSIRO 2011). More than 99% of the Hymenoptera collected were ants, so other Hymenoptera were not analysed. Ants occur in large numbers across Australia and their behavioural responses are reasonably well-understood at the genus level (Andersen 1995; Shattuck 1999; Majer et al. 2004).

The Diplopoda (millipedes) were sorted to genus or species level according to the information available (Sierwald et al. 2007; Mesibov 2011) and the slaters (Isopoda: Oniscidea) were sorted to species using available keys (Green 1961; Green 1978). A reference collection of diplopods was checked by Dr Robert Mesibov, Queen Victoria Museum and Art Gallery, Tasmania and isopod samples were cross-referenced with specimens held by Museum Victoria, Melbourne, Australia.

Data analysis

Temperature and soils data were compared between treatments using ANOVAs, with Tukey's post-hoc analysis. Data were square-root transformed to better meet the distributional assumptions of ANOVA. Differences in soil moisture between ground cover treatments were analysed using one-way ANOVAs with Tukey's post-hoc analysis within each collection month.

Invertebrate abundance data from pitfall trapping were averaged (the mean of the three traps per plot) for each collection to standardise data and account for any missing data points. The Shannon-Weaver diversity index was calculated for the Order level community with and without Collembola, for beetles at family level and ants at genus level for each collection. Repeated-measures ANOVAs were used to examine patterns of diversity between ground covers and collection month. Greenhouse-Geisser

corrections for sphericity were applied where epsilon values were greater than 0.75 (Quinn and Keough 2002). Invertebrate abundance data for each taxon were fourth-root transformed to improve homogeneity of variance and normality (Quinn and Keough 2002) and were analysed using repeated-measures ANOVA. Analyses were undertaken at order level and at family level for beetles and genus level for ants for all groups with approximately 100 or more occurrences and occurring in most seasons and ground covers. Exploratory data analysis was also undertaken using non-metric multidimensional scaling (NMDS) and the results supported the output from the repeated measures ANOVAs. Each taxon was assigned to a functional group for the discussion of results. These groups were determined based on feeding habits (Harvey et al. 1989; Lawrence and Britton 1994; Shattuck 1999; Lassau et al. 2005). The groups were herbivores, predators, omnivores and detritivores.

Most taxa studied fluctuated in abundance seasonally. To obtain a more robust sample for analysis of treatment effects, we examined the collection in which each taxon was most abundant. If there was more than one season in which the taxon peaked in abundance, both seasons were tested. Within the season of greatest abundance, a one-way ANOVA was undertaken, followed by a Tukey's post-hoc analysis to determine which ground covers the taxon was most abundant in. All analyses were performed in R (R Development Core Team 2011).

RESULTS

Variation in the physical environment between treatments

There was a highly significant effect of treatment on temperature in each season (winter $F_{3,61866}$ = 51.807, $P < 0.001$; spring $F_{3,61866} = 660.67$, $P < 0.001$; summer $F_{3,61866} = 387.25$, $P < 0.001$). In each season tested, the woodchips plots were the coolest, bare plots were the hottest and leaf litter plots were generally cooler than grass plots, except in winter when there was no difference between grass and leaf litter (Online Resource 1).

Soil moisture showed significant differences between treatments across months ($F_{3,43} = 24.28$; $P < 0.001$) and a significant interaction with collection month ($F_{15,451} = 5.03$; $P < 0.001$). Within each season of data collection, soil moisture in the woodchips and leaf litter plots was significantly greater than in the grass and bare plots in the two December (summer) collections and in spring (Online Resource 2). In the other seasons the relationships were more mixed, but leaf litter was the only plot type to be consistently significantly moister than the bare plots (Online Resource 2).

Arthropod collections

In total we collected 683,620 organisms from pitfall traps and 17,857 individuals from Tullgren extractions. Nineteen arthropod orders were represented in pitfall traps (Table 1). The Collembola were the most abundant group, composing 90.3% (617,554) of the total. Next were the Hymenoptera (46,141) of which 99.3% were ants (Hymenoptera: Formicidae). Other groups collected in large numbers were the mites (Acarina) (8,957), bugs (Hemiptera) (4,323), earwigs (Dermaptera) (1,525), julid millipedes (1,357) and beetles (Coleoptera) (1,192) (Table 2). The most abundant orders collected from the Tullgren samples

were the Collembola (11,504), Acarina (5,150), Psocoptera (365), Hymenoptera (202; ants were 96.5% of total) and Julida (126, including juveniles).

The total number of arthropods collected differed significantly between treatments ($F_{3,44} = 21.97$, $P < 0.001$) and collection ($F_{5,220} = 256.40$, $P < 0.001$) and there was a significant interaction between the two ($F_{15,220} = 15.25$, $P < 0.001$) (Table 2). The total abundance of the final collection (December 2009) was significantly greater than the first collection (December 2008) both including ($P < 0.001$) and excluding ($P = 0.009$) Collembola. The winter collection (August 2009) had the greatest abundance of arthropods (369,927 individuals) but the majority of these were Collembola. After excluding Collembola, the greatest number of individuals collected was in the final summer collection (December 2009). There was a significant effect of collection for all taxa tested (Table 2).

Differences in the arthropod community between treatments

The diversity of the order-level community, both including and excluding Collembola, was significantly affected by collection but not by ground cover, although there was a significant interaction between ground cover and collection (Table 3). In contrast, there was a significant effect of ground cover on the diversity of both beetle families and ant genera, but there was also a significant effect of collection and a significant interaction term (Table 3). In all except one collection (the first for beetles and the second for ants) the grass plots had the greatest diversity of both ants and beetles (Table 3).

The total abundance of invertebrates in pitfall traps was greatest in bare plots and lowest in woodchip plots, but the differences in abundance were not strong (Figure 1). Once Collembola were excluded, there were significantly more invertebrates collected in grass than any of the other three treatments, which did not differ significantly in total abundances (Figure 1). There was no significant difference in the total abundance of arthropods collected using Tullgren funnels between woodchip and leaf litter treatments ($F_{1,22} = 1.26$, $P = 0.274$).

There was a significant effect of treatment for all taxa tested, except for the Lithobiomorpha (Table 2). There was a significant interaction with collection for all tested taxa except the Lithobiomorpha, Orthoptera, and *Paratrechina* (Hymenoptera: Formicidae) (Table 2).

The abundance of most groups of organisms collected in the Tullgren funnels was not significantly different between woodchip and leaf litter plots (Table 4), with the exception of Dermaptera, which were significantly more numerous in woodchip than leaf litter plots ($F_{1,22} = 12.81$, $P = 0.002$) and Psocoptera, which were significantly more numerous in leaf litter than woodchip plots ($F_{1,22} = 16.34$, $P < 0.001$).

Of the Coleoptera collected in pitfall traps across the experiment, 605 were weevils (Curculionidae), 123 were tenebrionids and there were 93 carabids and 93 anthicids. Other families present in low numbers in the plots were Bostrichidae, Byrrhidae, Chrysomelidae, Coccinellidae, Corylophidae, Elateridae, Erotylidae, Latridiidae, Scarabidae and Staphylinidae. The total abundance of Coleoptera was significantly affected by both ground cover and collection month, with a significant interaction between them (Table 2). This was largely driven by the large numbers of beetles in grass plots (Table 1), with relatively few occurring in the other ground covers. This pattern is driven largely by the numerically dominant Curculionidae (herbivores) family.

Effects of treatment on the omnivores

The Dermaptera and the Hymenoptera were the most abundant omnivores collected. The Dermaptera were most abundant in the summer collections (first and final collections). In the first collection they were more abundant in bare plots although their abundance was not significantly different between treatments. In the final collection they were significantly more abundant in bare plots compared to grass plots (Table 5).

The total number of Formicidae (Hymenoptera) collected in pitfalls was 45,816. Of these, there were 19,550 from the subfamily Dolichoderinae, 502 Ectatomminae, 608 Formicinae and 25,156 Myrmicinae. All but two dolichoderines were from the genus *Iridomyrmex*. The other two were from the genus *Ochetellus*. All Ectatomminae were *Rhytidoponera* and the Formicinae were made up of *Melophorus* (57) and *Paratrechina* (551). Within the Myrmicinae, representatives of the genera *Pheidole*, *Cardiocondyla*, *Monomorium*, *Solenopsis*, *Strumigenys* and *Tetramorium* were detected. *Pheidole* were by far the most numerous of this genus, with 23,800 collected (Figure 2).

Both *Iridomyrmex* and *Pheidole* peaked in abundance in late summer (February 2009) (Figure 2) and both were significantly more abundant in grass than in any other ground cover type. *Pheidole* were significantly less abundant in woodchips than in leaf litter and *Iridomyrmex* were significantly less abundant in leaf litter compared to bare plots (Table 5; Figure 2).

Solenopsis peaked in abundance in late summer 2009 and again in the final summer colletion (December 2009) (Figure 2). In late summer (February 2009) there was no significant difference in its abundance between any of the ground covers, but in the final collection it was significantly more abundant in grass than any other ground cover type (Table 5). Similarly, *Paratrechina* was significantly more abundant in grass than any other plot type (Table 5; Figure 2). *Rhytidoponera* were most abundant in autumn and in the final collection (Figure 2). There was no effect of any particular ground cover in the final collection, but *Rhytidoponera* ants were significantly more abundant in grass compared to bare or woodchip plots in autumn (Table 5).

There was a single additional ant genus collected with Tullgrens that was not detected in pitfall traps – *Hypoponera*, a predatory group. The ants collected from Tullgren funnel samples did not show any statistically different patterns between leaf litter and woodchip plots (Table 4). The genera collected in the Tullgren funnels were *Iridomyrmex* (6 in total), *Pheidole* (19 in leaf litter and 19 in woodchips), *Solenopsis* (134 in total), *Strumigenys* (8 in total, all in woodchips) and *Hypoponera* (9 in total, 8 in woodchips).

Effects of treatment on the herbivores

The weevils (Coleoptera: Curculionidae), bugs (Hemiptera) and Orthoptera (grasshoppers and crickets) were the dominant herbivores collected. The Hemiptera (Table 2) are a large, diverse order, but herbivororous families were particularly abundant in these samples (e.g. Aphidae, Cicadellidae, pers. obs.). The Hemiptera peaked in abundance in late summer (February 2009), when they were significantly more abundant in grass plots than in any other ground cover type (Table 5). There was a weak significant effect of both collection month and ground cover on the Orthoptera (Table 2). The Orthoptera showed

two peaks in abundance – in late summer (February 2009) and in the final collection in summer (December 2009). There was no clear effect of any ground cover type in either of those collections.

The weevils were most abundant in the final summer collection and were significantly more abundant in grass than any other ground cover type (Table 5). In the Tullgren extractions, weevils were the only beetle family numerous enough to analyse, but did not differ in abundance between the leaf litter and woodchip treatments (Table 4).

Effects of treatment on the detritivores

The detritivores collected were the Collembola, the millipedes (class Diplopoda), the slaters and two saprophytic beetle families, the Anthicidae and Tenebrionidae, although the anthicids and tenebrionids only occurred in low numbers. Only 31 slaters were collected across this experiment, which was not enough to analyse. All individuals were the common introduced species *Armadillidium vulgare* (Latreille, 1804).

There were two orders of millipedes collected – the introduced order Julida and the Polydesmida. Only one polydesmid was collected, however and it could not be identified because it was a juvenile. The julids were a mix of *Ommatoiulus moreletii* (Lucas, 1860), *Cylindroiulus* sp. and *Ophyiulus* sp. (Newport, 1843) and were analysed together, as large numbers were not collected. The *Ophyiulus* could be either *O. pilosus* (Newport, 1843) or *O. targionii* (Silvestri, 1898), which are taxonomically but not ecologically distinct. The julids occurred in large numbers in winter (August 2009), spring (October 2009) and in the final summer (December 2009) collection. There was no difference in their abundance in any ground cover type in the final collection. In the winter collection they were significantly less abundant in bare and grass plots, compared to leaf litter and woodchips, which did not differ (Table 5). In spring they were more abundant in leaf litter than bare plots ($P < 0.001$) and in grass compared to woodchips ($P = 0.022$) (Table 5).

The Collembola were the most abundant group of any collected (Table 2); they had a major peak in abundance in winter and a lower peak in the final summer collection. In winter there were extremely large numbers (significantly greater than the other plots) in bare plots and particularly low numbers in woodchip plots (Figure 1). In the final summer collection (December 2009) they were significantly more abundant in grass than in any other plot type (Table 5).

Effects of treatment on the predators

Three orders of predators were collected, mites (Acarina), spiders (Araneae) and stone centipedes (Lithobiomorpha). Low numbers of the predatory beetle family Carabidae were also detected. Mites were most abundant in winter (August) and were significantly more abundant in grass plots (Table 5). Spiders were most abundant in the first and final collections (mid-summer). In both collections they were significantly more abundant in both leaf litter and woodchips than in bare plots and in the final collection they were also more abundant in grass compared to bare plots (Table 5). The stone centipedes were significantly affected by collection month and they were most abundant in spring (October 2009). They were, however, the only order tested where there was no effect of ground cover type (Table 2).

DISCUSSION

Our experimental test of the role of different common ground covers on the arthropod community revealed that arthropods invaded the test plots relatively quickly (i.e., within months) and that grass treatments had the greatest abundance of different taxa. Overall, there were 21 orders of arthropods collected and of these the Collembola, Hymenoptera (mostly Formicidae) and Acarina occurred in the largest numbers. Of the four ground covers tested, grass had the most abundant arthropod community when the Collembola were excluded. This was due to the large numbers of ants in grass plots, although a number of other taxa were also more abundant in grass compared to the other treatments. Both the ant and beetle communities appeared to be most diverse in grass plots, although there was a significant interaction effect with collection.

The response of arthropods to the grass treatment

Grass plots had the greatest abundance of non-Collembolan arthropods overall. This is likely to be because some of the most abundant taxa, including the Hemiptera, mites and beetles, were most commonly found in grass plots in the season in which they were most abundant. The dominant beetle family, the weevils, which are specialist herbivores, reflected this trend, occurring mostly in grass plots. Weevils would be expected to show a relationship with increased vegetation because of their dietary requirements (Schaffers et al. 2008).

Grass plots were also where the ants, which were the second most abundant taxon, were primarily found. This was true of the less abundant genera as well as the dominant *Iridomyrmex* and *Pheidole*. This pattern was reflected in the high diversity of ants in grass plots in all seasons except late summer. Ants are a comparatively well-studied arthropod group in Australia and are also a dominant and highly diverse family (Majer et al. 2004). The ant community structure found in this experiment is common in more open vegetation communities (Hoffmann and Andersen 2003). This makes ecological sense given the experimental plots had no overstorey. It is interesting to note that the very few individuals from the arid-adapted *Melophorus* genus (Andersen 2007) were found mostly in the bare plots in the final, summer, collection. This trend is consistent with a recent study from North Carolina, U.S.A., in which urban ant assemblages in open habitats and industrial areas were found to be similar to communities from hot and dry areas of the country (Menke et al. 2010).The bare plots were the hottest and most open environments in this experiment and are the closest replicate of concrete, which is a common ground cover in urban areas.

Ants are important providers of ecosystem services in Australian landscapes and often perform functions undertaken in the the northern hemisphere by other organisms, for example worms (Choate and Drummond 2011; Evans et al. 2011). Although ants were classified mostly as omnivores in this experiment, they are likely to play other important roles for example by maintaining healthy soil structure (Folgarait 1998). Although the habitat preferences of ant genera are reasonably well-understood in Australia, the ecological function each group undertakes is still being explored (Brown Jr. 2000).

The response of detritivores and leaf-litter arthropods to the experimental treatments

Collembola are important decomposers (Greenslade and Ireson 1986; Kaneda and Kaneko 2007) and were the most abundant group collected. Other research in urban areas has suggested that Collembola are tolerant of urban environments and abundant in a wide range of urban land uses (McIntyre et al. 2001). In our experiment Collembola occurred predominantly in the grass plots in the final summer collection and in bare plots in winter. Their high abundance in grass plots may be due to the availability of decomposing grass material after mowing (Rochefort et al. 2006b). In winter, there was a thin layer of moss on the bare plots (pers. obs.) which may have provided resources for the very large numbers of Collembola collected.

If there were leaf litter-dependent invertebrates in the plots, these should have been detected in the Tullgren extraction collections (York 1999; Andrew et al. 2000). The Tullgren extractions could only be undertaken for woodchip and leaf litter plots. These were the moistest and generally the coolest microhabitats of the four experimental treatments. The Tullgren extractions only added one ant genus to the collections. Only two orders showed treatment effects from this method: the Psocoptera were significantly more abundant in leaf litter compared to woodchips from the Tullgren extractions, whereas Dermaptera were present in larger numbers in woodchip plots. This was consistent with the results of the pitfall traping, where the abundances of different organisms were rarely different between leaf litter and woodchip plots.

There were two groups of macrodetritivores collected in this study, julid millipedes (Order Julida) and slaters (Isopoda: Oniscidea), but slaters occurred in very low numbers. Both taxa require leaf litter for shelter and food. All the macrodetritivores that could be identified were, however, introduced fauna, which are known to have comparatively wide habitat tolerances (Kime and Golovatch 2000; Vilisics and Hornung 2009). The julid millipedes were surprisingly diverse for such a small area and at least three species from three different genera were present. It is also possible that more species of *Cylindroiulus* were present, but the genus is poorly resolved and identification below genus level was not possible. The consequences for litter decomposition of having a largely introduced macrodetritivore fauna in Australia are not well understood (Baker 1979; Paoletti et al. 2007a).

The millipedes were found in significantly lower numbers in bare plots than in other plots and when they did occur in large numbers it was often in leaf litter and grass plots. Jordan and Jones (2006) who examined invertebrates in mulch habitats in the American Midwest and found millipedes to be the most abundant taxa in all the mulch types tested, but there were no millipedes in bare plots. This contrasts with our results, where millipedes were only the fifth most abundant taxa and did occur in the two hottest and driest treatments (grass and bare ground). The difference in results may be due to differences in the lower overall abundance of millipedes in Australia compared to northern hemisphere countries (Paoletti et al. 2007a) and may also be related to the species present in the two studies. In this study, all the species were from the order Julida, which is comparatively tolerant of drier, more open conditions (Kime and Golovatch 2000), but the species in Jordan and Jones' (2006) study may have had more restrictive habitat requirements.

The effects of season and ground cover microclimates on arthropods

The sampling periods in which the most arthropods were collected, after excluding Collembola, were late summer (February 2009) and the final summer collection. This is reflected in the activity of the different dominant groups. Almost all the ant genera were most active in late summer (February 2009) and were most abundant and species rich in grass plots, although grass plots did not have the greatest ant diversity in this season because of lower evenness values. This activity period is consistent with results from a number of other studies from southern Australia (Thomson et al. 2004; Walters 2006; Gibson and New 2007; Sharley et al. 2008). A wide range of different arthropod taxa were most active in summer (December), which corresponds to the other peak in total abundance, although diversity was not especially high in this season as community evenness was often low. Taxa that were notably active in summer were primarily many beetle families, the spiders and the earwigs. These taxa have been shown in the past to be particularly active at this time of year (Thomson et al. 2004; Sharley et al. 2008).

The abundance of the total community at the end of the experiment and the community excluding Collembola, was greater than at the start of the experiment. This may be a colonisation effect, although a study in mid-western United States found no difference in abundance between the start and end of their experiment and a strong effect of season (Jordan and Jones 2006). The weather conditions are likely to have played a role in the different numbers of arthropods collected between the start and end of this experiment. The year the plots were established was the final year of a long drought, while there were heavy rains during the remaining year of the experiment, including during the final summer (December 2009) sampling session (Australian Government Bureau of Metereology 2009) and drought conditions are known to reduce the abundance of epigeal arthropods (Frampton et al. 2000).

We have interpreted these results primarily in terms of the different taxa responding to changes to the ground-layer micro-environment, but it is important to consider the effect of trapping methods on the results. There is not yet a standard protocol for pitfall trapping invertebrates (Neville and Yen 2007). The trap type used in this study was originally designed for trapping ants (Majer 1978) but has been used to trap a wide range of invertebrate groups (Thomson et al. 2004; Thomson and Hoffmann 2007). It has the benefit of being inconspicuous in public places and having a low probability of vertebrate by-catch (Pearce et al. 2005). Some research has suggested, however, that capture in pitfall traps is affected by the ground-layer environment, particularly that trapping in more open environments appears to detect more individuals (Melbourne 1999). Given this, we might expect to have collected the most invertebrates in the bare plots, which was not the case. Once Collembola were excluded, the arthropods collected from bare plots were not significantly different in abundance from the plots with the most complex ground covers – leaf litter and woodchips. Although some interaction between habitat preference and response to traps cannot be entirely ruled out, the low number of new taxa detected in Tullgren funnel extractions did suggest that not too many taxa had been missed in pitfall traps.

Effects of the surrounding land use on colonisation

The experimental ground cover treatments were all rapidly colonised, but there was little difference in the abundance or identity of taxa collected in each treatment apart from the grass treatment. These results suggest that taxa that specialise in the ground covers were not available to readily colonise the plots and that the management of the surrounding landscape may be important for colonisation of similar

small patches. Given the extent of change to the ground surface in urban areas, this research highlights an important potential area of focus for urban biodiversity conservation.

The greater abundance of many arthropod groups in the grass plots is likely to have been affected by the management of the landscape surrounding the experimental plots. The landscape context of a site has been shown to be important in structuring local invertebrate communities (Weigmann 1980; Steffan-Dewenter et al. 2002; Clough et al. 2005; Tscharntke et al. 2005), as different organisms have different abilities to move through fragmented habitats (Ricketts 2001; Baum et al. 2004). In this study, much of the surrounding landscape (i.e., within 100 m) was mown grassy areas, which may be the cause of the high abundance of many groups and diversity of ants and beetles in grassy plots. Urban landscapes are heterogeneous environments, typically highly modified in terms of ground cover type, vegetation structure and composition and the presence of buildings (Sukopp 2004; Grimm et al. 2008). Although there are green spaces for some species to move through, for example private gardens (Gaston et al. 2005; Daniels and Kirkpatrick 2006), median strips (Pećarević et al. 2010) and greenery along street verges (White et al. 2005), this is still a challenge for species that are dependent on continuous or high quality understorey vegetation, such as short-range dispersing invertebrates like millipedes (Paoletti et al. 2007a; Mesibov 2008). Other leaf litter-dependent invertebrates such as slaters and amphipods that are important in litter decomposition are also slower to colonise new areas than winged arthropods (Nakamura et al. 2003).

If this experiment were to be repeated where the plots were surrounded by forest, or over a longer time period, the results may be different. For example in leaf litter addition studies in forests, leaf litter has been shown to attract different invertebrate communities to areas without litter added (Koivula et al. 1999; Magura et al. 2005). It is possible that if the experiment had been run over a longer period of time that a greater range of arthropods would have been able to reach and colonise the leaf litter. This raises some interesting questions about using small-scale land management practices to promote invertebrate conservation. Two other experiments looking at the colonisation success of different habitat features added to urban domestic gardens, found that novel habitat features in urban domestic gardens were often rapidly colonised (Gaston et al. 2005; Sperling and Lortie 2009). However, this was not always the case and Gaston et al. (2005) suggest a realistic assessment of the likelihood of biodiversity gain in small-scale, relatively short-term restoration projects (Gaston et al. 2005). The timescale of this experiment was similar to some of their trials and provides support for this statement in a different microenvironment.

Interest is increasingly being shown in designing or retrofitting urban spaces to promote invertebrate biodiversity and the ecosystem services they provide in urban areas (Bormann et al. 1993; Felson and Pickett 2005; Gaston et al. 2005; Hunter and Hunter 2008). Returning leaf litter to the urban environment might be one way to achieve this, but consideration must be given to the target organisms and where they are in the landscape (Pećarević et al. 2010). This experiment and others with similar aims (Nakamura et al. 2008; Nakamura et al. 2009), show that it is important to understand the local and landscape-scale requirements of the target species when new ground layer environments are created. Developing a landscape-level plan for managing diverse urban green spaces is therefore critical for future efforts for conserving a diversity of species and functional groups (Goddard et al. 2010).

In summary, arthropods rapidly colonised all four treatments of ground covers commonly used in urban parks and gardens. Diversity of the order-level community was not affected by ground cover type, although beetle and ant diversity did respond to ground cover type. The overwhelming abundance of taxa occurred in grass plots due to the strong response of ants to these plots, as well as a diverse range of other taxa. This response may be due to the dominance of open, managed grasslands in the surrounding landscape. While leaf litter and woodchips were colonised, the composition of the arthropod communities were not strikingly different from the other treatments and overall woodchips and leaf litter had lower numbers of organisms. In order to preserve biodiverse arthropod faunal communities in modified landscapes, these results suggest it is important to maintain a diversity of connected ground cover types for organisms dependent on different microenvironments to move through.

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Tables

Table 1: Median, minimum and maximum abundance per plot of each order collected in an experimental test of common garden and park ground covers. Data are average values across six pitfall trapping collections (December 2008, February, April, August, October, December 2009).

Table 2: Results of repeated-measures ANOVA on the abundance of orders collected in an experimental plot. Data are presented for beetle (Coleoptera) families and ant (Hymenoptera: Formicidae) genera. Transformed abundance data were compared across ground cover treatments (bare, grass, leaf litter, woodchips) and six pitfall trap collections (December 2008, February, April, August, October, December 2009). 'GG correction' refers to whether the Greenhouse-Geiser correction was made for sphericity.

Table 3: The mean diversity (Shannon-Weaver) of arthropods in each ground cover and each collection. Results of repeated-measures ANOVA on the Shannon-Weaver diversity index are also presented. The index was compared across ground cover treatments (bare, grass, leaf litter, woodchips) and six pitfall trap collections (December 2008, February, April, August, October, December 2009) for the order-level community with and without Collembola, the beetle (Coleoptera) families and ant (Hymenoptera: Formicidae) genera.

Table 4: Abundance of invertebrates collected from Tullgren extractions from leaf litter and woodchips in experimental plots, in January 2010. Significant differences in abundance ($P < 0.05$) are indicated by asterisks next to the name of the taxa. Orders where there is information for lower taxonomic groups are in bold and the lower taxonomic groups are in italics.

Table 5: The effects of treatment on the abundance of arthropods collected. Each taxon was tested for the collection in which it was most abundant. Differences in abundance were determined using a Tukey's post-hoc analysis after one-way ANOVAs on transformed data. Where the abundance of a taxon is significantly ($P < 0.05$) greater in one treatment type, the treatment of greatest abundance and the *P*-value are provided. LL = leaf litter, WC = woodchips.

Figures

Fig. 1 Box plots showing the median (line), interquartile range (box) and minimum and maximum values (whiskers), with outliers represented by dots, summarising the total abundance of arthropods caught in pitfall traps in an experimental test of different ground covers. Data are averaged across each plot and displayed by a) ground cover (see text); and b) ground cover excluding Collembola. The same letters indicate no significant difference at $P < 0.05$ between ground covers obtained using transformed data

Fig. 2 The proportion of the ant community represented by different genera, in each of four experimental ground covers. The ant community is presented from six pitfall trapping collections: a) first

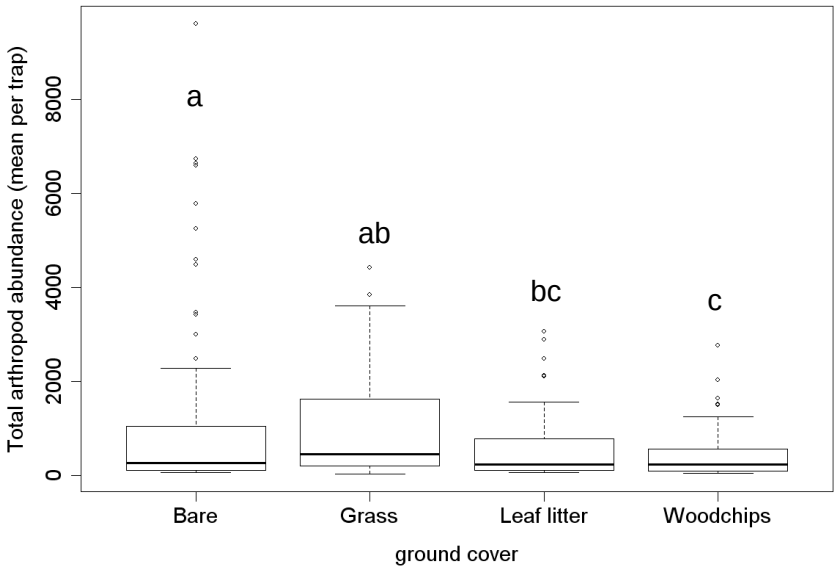
collection (December 2008), b) summer (February), c) autumn (April), d) winter (August), e) spring (October), f) Final, summer collection (December 2009)

Supplementary material

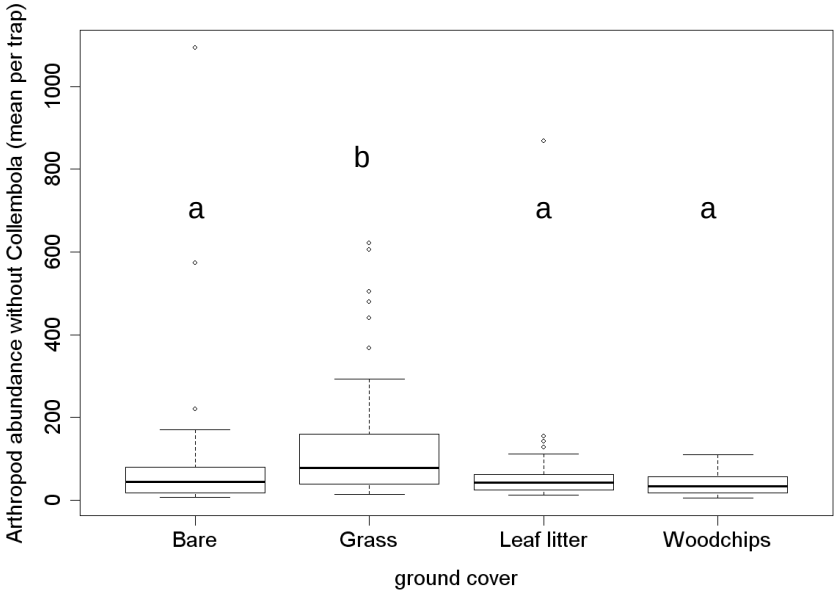
Online Resource 1: Temperature (mean, standard error, range) at the soil surface under four experimental ground cover treatments in three seasons: winter (August 2009), spring (October 2009) and summer (January 2010). All measurements are in degrees Celsius. Superscript letters indicate where there is a significant difference in temperature between ground covers within the season, at $P < 0.05$.

Online resource 2: Soil moisture values from an experiment on different ground covers in an urban environment. Values are the mean ± standard deviation of gravimetric soil moisture values in each ground cover type and for when the traps went in ('start') and when they came out ('end') for each of six pitfall trap collection periods. There were no data for the third pitfall trap collection due to a malfunction in the equipment. Superscript letters indicate significant differences ($P < 0.05$) between soil moisture in different ground cover treatments, within the collection period (row).

a)


Total arthropod abundance (mean per trap)
0
2000
4000
6000
8000
a
ab
bc
c
Bare
Grass
Leaf litter
Woodchips
ground cover

b)


Arthropod abundance without Collembola (mean per trap)
0
200
400
600
800
1000
a
b
a
a
Bare
Grass
Leaf litter
Woodchips
ground cover

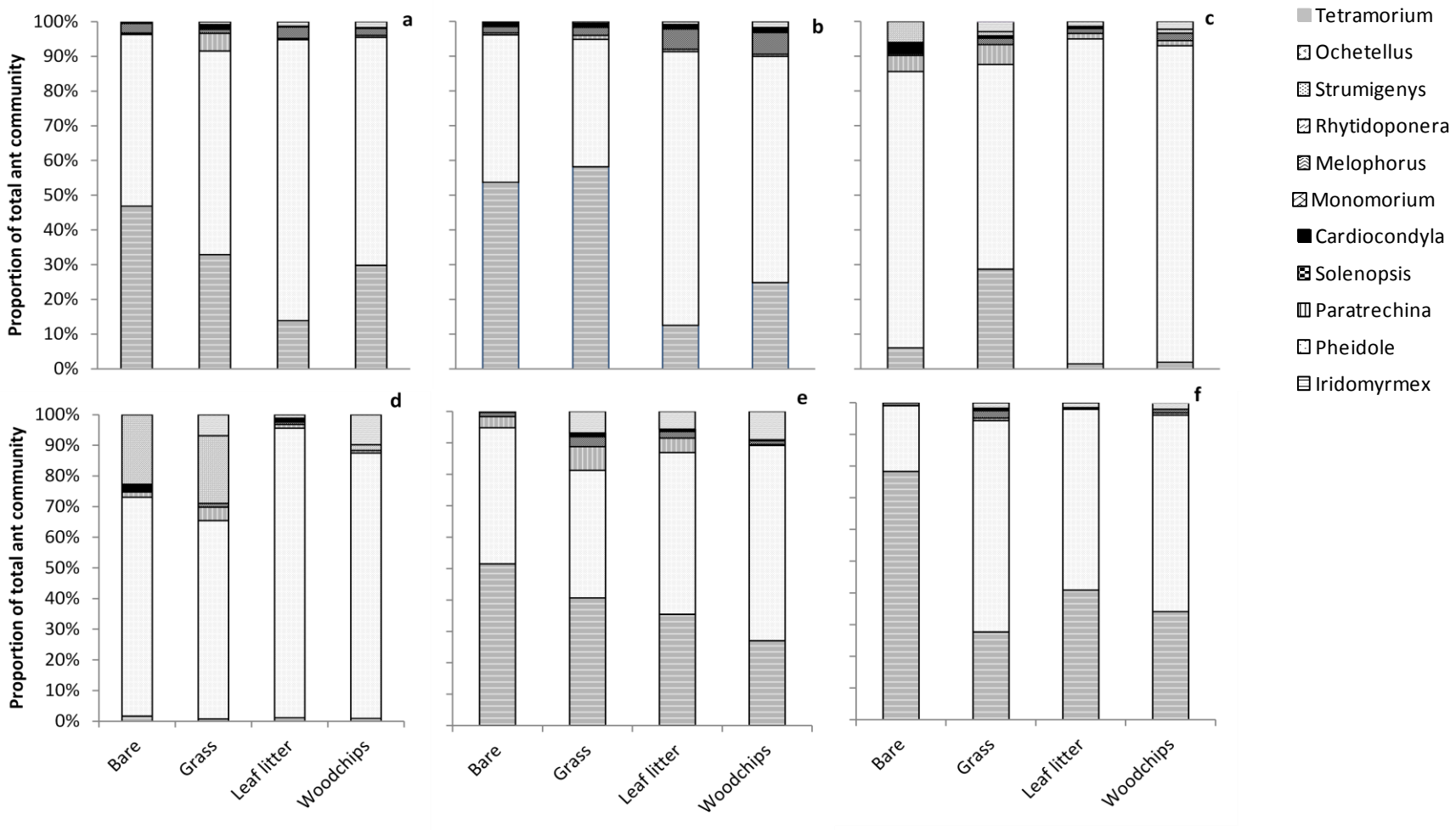

a
b
c
d
e
f
Proportion of total ant community
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Bare
Grass
Leaf litter
Woodchips
Tetramorium
Ochetellus
Strumigenys
Rhytidoponera
Melophorus
Monomorium
Cardiocondyla
Solenopsis
Paratrechina
Pheidole
Iridomyrmex

Table 1: Median, minimum and maximum abundance per plot of each order collected in an experimental test of common garden and park ground covers. Data are average values across six pitfall trapping collections (December 2008, February, April, August, October, December 2009).

	Bare			**Grass**			**Leaf litter**			**Woodchips**		
Order	Median	Min	Max	Median	Min	Max	Median	Min	Max	Median	Min	Max
Collembola	205.17	11.67	9600.00	280.33	13.33	4293.33	195.00	8.67	3046.67	205.50	6.67	2736.67
Hymenoptera	29.83	0.00	1059.33	36.67	0.00	581.67	23.00	1.33	852.33	19.33	0.33	92.67
Acarina	5.17	0.00	38.67	9.33	0.00	128.67	3.33	0.00	49.67	3.83	0.00	74.00
Hemiptera	0.83	0.00	37.00	6.67	0.00	152.67	0.33	0.00	4.00	0.67	0.00	16.67
Dermaptera	2.00	0.00	11.67	1.00	0.00	23.67	0.67	0.00	4.33	1.00	0.00	8.33
Julida	0.17	0.00	2.67	0.42	0.00	12.00	1.00	0.00	18.67	0.33	0.00	13.00
Coleoptera	0.67	0.00	5.67	2.17	0.00	12.67	0.67	0.00	5.67	0.33	0.00	4.33
Araneae	0.33	0.00	1.33	0.67	0.00	3.67	0.67	0.00	4.00	0.67	0.00	22.00
Orthoptera	0.00	0.00	1.33	0.00	0.00	2.00	0.00	0.00	2.33	0.33	0.00	4.00
Lithobiomorpha	0.00	0.00	2.00	0.00	0.00	4.67	0.00	0.00	4.67	0.00	0.00	5.00
Psocoptera	0.00	0.00	1.33	0.00	0.00	1.00	0.00	0.00	1.67	0.00	0.00	0.33
Thysanoptera	0.00	0.00	0.67	0.00	0.00	1.00	0.00	0.00	0.33	0.00	0.00	0.67
Isopoda	0.00	0.00	0.33	0.00	0.00	0.67	0.00	0.00	1.00	0.00	0.00	0.33
Protura	0.00	0.00	0.67	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00
Amphipoda	0.00	0.00	0.33	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.33
Blattodea	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.33
Diplura	0.00	0.00	0.33	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00
Thysanura	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00
Polydesmida	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00

Table 2: Results of repeated-measures ANOVA on the abundance of orders collected in an experimental plot. Data are presented for beetle (Coleoptera) families and ant (Hymenoptera: Formicidae) genera. Transformed abundance data were compared across ground cover treatments (bare, grass, leaf litter, woodchips) and six pitfall trap collections (December 2008, February, April, August, October, December 2009). 'GG correction' refers to whether the Greenhouse-Geiser correction was made for sphericity.

Order	Family	Genus	Ground cover			Collection			Interaction			GG correction
			MS	$F_{(3, 44)}$	*P*-value	MS	$F_{(5,220)}$	*P*-value	MS	$F_{(15, 220)}$	*P*-value	
Acari			2.59	19.72	<0.001	11.98	83.20	<0.001	0.61	4.26	<0.001	YES
Araneae			1.00	8.54	<0.001	1.37	9.25	<0.001	0.39	2.64	0.001	NO
Coleoptera			4.97	22.20	<0.001	0.99	8.09	<0.001	0.47	3.88	<0.001	NO
	Curculionidae		7.21	31.17	<0.001	0.64	4.66	<0.001	0.59	4.35	<0.001	NO
Collembola			5.92	11.90	<0.001	137.61	380.15	<0.001	3.62	10.00	<0.001	YES
Dermaptera			1.20	6.79	0.002	1.68	17.37	<0.001	0.32	3.30	<0.001	YES
Hemiptera			11.69	58.08	<0.001	5.30	31.84	<0.001	0.96	5.75	<0.001	NO
Hymenoptera			2.97	8.42	0.001	20.37	121.35	<0.001	0.84	4.98	<0.001	YES
	Formicidae	*Iridomyrmex*	4.22	11.85	<0.001	38.46	167.87	<0.001	1.09	4.74	<0.001	YES
	Formicidae	*Paratrechina*	4.73	8.54	<0.001	0.88	6.43	<0.001	0.19	1.42	0.138	NO
	Formicidae	*Pheidole*	1.34	5.13	0.015	12.25	100.07	<0.001	0.30	2.48	0.014	YES
	Formicidae	*Rhytidoponera*	3.23	3.16	0.034	0.34	3.83	0.002	0.16	1.76	0.042	NO
	Formicidae	*Solenopsis*	1.38	6.76	0.001	7.10	46.05	<0.001	0.47	3.07	<0.001	NO
Julida			3.68	23.65	<0.001	8.84	65.4	<0.001	0.76	5.63	<0.001	NO
Lithobiomorpha			0.24	1.53	0.221	4.81	42.79	<0.001	0.17	1.48	0.114	NO
Orthoptera			0.60	2.99	0.041	3.53	26.99	<0.001	0.15	1.17	0.297	NO
Total			**10.73**	**21.68**	**<0.001**	**97.69**	**300.13**	**<0.001**	**3.46**	**10.62**	**<0.001**	**YES**
Total (excl. Collembola)			**6.08**	**30.86**	**<0.001**	**11.00**	**76.48**	**<0.001**	**0.76**	**5.27**	**<0.001**	**YES**

Table 3: The mean diversity (Shannon-Weaver) of arthropods in each ground cover and each collection. Results of repeated-measures ANOVA on the Shannon-Weaver diversity index are also presented. The index was compared across ground cover treatments (bare, grass, leaf litter, woodchips) and six pitfall trap collections (December 2008, February, April, August, October, December 2009) for the order-level community with and without Collembola, the beetle (Coleoptera) families and ant (Hymenoptera: Formicidae) genera.

	Collection					
	1	**2**	**3**	**4**	**5**	**6**
Order						
Bare	0.62	1.02	0.58	0.03	0.88	0.46
Grass	0.68	0.85	1.00	0.10	0.90	0.38
Leaf litter	0.60	1.01	0.84	0.13	0.79	0.35
Woodchips	0.52	1.18	0.92	0.09	0.58	0.43
P-values	Ground cover: 0.103; Collection: <0.001; Interaction: <0.001					
Order, excl Collembola						
Bare	0.57	0.69	1.20	1.32	1.24	0.82
Grass	0.68	0.62	1.11	1.18	1.56	1.22
Leaf litter	0.57	0.63	1.00	1.26	1.35	0.99
Woodchips	0.62	0.87	1.12	1.35	1.44	1.02
P-values	Ground cover: 0.308; Collection: <0.001; Interaction: <0.001; Greenhouse-Geiser corrected					
Beetle						
Bare	0.61	0.36	0.51	0.38	0.72	0.21
Grass	0.93	1.17	0.71	0.55	0.85	0.54
Leaf litter	1.02	0.05	0.25	0.41	0.24	0.32
Woodchips	0.91	0.10	0.17	0.11	0.37	0.15
P-values	Ground cover: <0.001; Collection: <0.001; Interaction: <0.001					
Ants						
Bare	0.73	0.82	0.46	0.43	0.77	0.63
Grass	0.86	0.77	0.73	0.70	1.04	0.89
Leaf litter	0.73	0.71	0.31	0.22	0.72	0.80
Woodchips	0.80	0.82	0.34	0.23	0.71	0.76
P-values	Ground cover: <0.001; Collection: <0.001; Interaction: 0.001					

Table 4: Abundance of invertebrates collected from Tullgren extractions from leaf litter and woodchips in experimental plots, in January 2010. Significant differences in abundance ($P < 0.05$) are indicated by asterisks next to the name of the taxa. Orders where there is information for lower taxonomic groups are in bold and the lower taxonomic groups are in italics.

	Woodchips		**Leaf litter**	
Taxon	Median per plot	(min, max)	Median per plot	(min, max)
Acarina	177.0	(85, 495)	166.0	(46, 452)
Araneae	2.5	(0, 7)	1.5	(0, 4)
Coleoptera	1.0	(0, 3)	0.5	(0, 5)
Curculionidae	0.5	(0, 3)	0.0	(0, 5)
Collembola	359.5	(115, 833)	492.5	(198, 1339)
Dermaptera *	1.0	(0, 2)	0.0	(0, 1)
Hemiptera	0.0	(0, 4)	0.5	(0, 4)
Hymenoptera	6.0	(0, 21)	6.0	(0, 37)
Pheidole	0.5	(0, 7)	0.0	(0, 10)
Solenopsis	1.0	(0, 21)	4.5	(0, 36)
Julida	4.0	(1, 15)	3.0	(0, 13)
Lithobiomorpha	3.0	(0, 6)	4.5	(1, 10)
Psocoptera *	5.0	(1, 13)	21.0	(4, 54)

Table 5: The effects of treatment on the abundance of arthropods collected. Each taxon was tested for the collection in which it was most abundant. Differences in abundance were determined using a Tukey's post-hoc analysis after one-way ANOVAs on transformed data. Where the abundance of a taxon is significantly ($P < 0.05$) greater in one treatment type, the treatment of greatest abundance and the *P*-value are provided. LL = leaf litter, WC = woodchips.

Order	Family	Genus	Collection	Grass - Bare ground		Grass - LL		Grass - WC		Bare ground - LL		Bare ground - WC		LL - WC	
				GC most abundant	*P*-value	GC most abundant	*P*-value	GC most abundant	*P*-value	GC most abundant	*P*-value	GC most abundant	*P*-value	GC most abundant	*P*-value
Acarina			Autumn	Grass	<0.001	Grass	0.001	Grass	0.025						
Araneae			Summer ('08)							LL	0.009	WC	0.003		
			Summer ('09)	Grass	<0.001					LL	<0.001	WC	<0.001		
Coleoptera			Summer ('08)												
			Summer ('09)	Grass	<0.001	Grass	<0.001	Grass	0.001						
	Curculionidae		Summer ('09)	Grass	<0.001	Grass	<0.001	Grass	0.001			WC	0.007		
Collembola			Winter	Bare	<0.001		0.149	Grass	0.046	Bare	<0.001	Bare	<0.001		
			Summer ('09)	Grass	0.001	Grass	0.004	Grass	<0.001						
Dermaptera			Summer ('08)												
			Summer ('09)	Bare	0.008										
Hemiptera			Summer(Feb)	Grass	<0.001	Grass	<0.001	Grass	<0.001						
Hymenoptera			Summer(Feb)	Grass	<0.001	Grass	<0.001	Grass	<0.001			Bare	0.034		
		Iridomyrmex	Summer(Feb)	Grass	0.004	Grass	<0.001	Grass	<0.001	Bare	0.034				
		Paratrechina	Summer(Feb)			Grass	0.046	Grass	<0.001						
	Formicidae	*Pheidole*	Summer(Feb)	Grass	<0.001	Grass	<0.001	Grass	<0.001					LL	0.041
		Rhytid.	Autumn	Grass	0.001			Grass	0.035						
		Rhytid.	Summer ('09)												
		Solenopsis	Summer(Feb)												
		Solenopsis	Summ	Gras	<0.	Gras	0.0	Gras							

	psis	er ('09)	s	001	s	1	s					
Julida		Winter Spring Summer ('09)	Grass	<0.001	LL	<0.001	WC Grass	0.002 0.022	LL LL	<0.001 0.001	WC	<0.001	LL	0.008
Orthoptera		Summer(Feb) Summer ('09)										

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