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Factors Influencing Arthropod Diversity on Green Roofs

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Green roofs have potential for providing substantial habitat to plants, birds, and arthropod species that are not well supported by other urban habitats. Whereas the plants on a typical green roof are chosen and planted by people, the arthropods that colonize it can serve as an indicator of the ability of this novel habitat to support a diverse community of organisms. The goal of this observational study was to determine which physical characteristics of a roof or characteristics of its vegetation correlate with arthropod diversity on the roof. We intensively sampled the number of insect families on one roof with pitfall traps and also measured the soil arthropod species richness on six green roofs in the Boston, MA area. We found that the number of arthropod species in soil, and arthropod families in pitfall traps, was positively correlated with living vegetation cover. The number of arthropod species was not significantly correlated with plant diversity, green roof size, distance from the ground, or distance to the nearest vegetated habitat from the roof. Our results suggest that vegetation cover may be more important than vegetation diversity for roof arthropod diversity, at least for the first few years after establishment. Additionally, we found that even green roofs that are small and isolated can support a community of arthropods that include important functional groups of the soil food web.

Keywords
Insect diversity, soil arthropod, vegetation cover, pitfall trap, Collembola

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INTRODUCTION

Roofs that are planted with vegetation ("green roofs") are known to provide a variety of benefits to the urban environment. Some benefits of green roofs have been well studied, such as their ability to reduce stormwater runoff and the heat island effect in cities, among other things (reviewed in Getter and Rowe 2006). Green roofs also have the potential to provide habitat for arthropods and birds in urban environments (Baumann 2006; Kadas 2006), as cities generally provide little habitat and resources for wildlife (beyond species that are adapted to living in the human-dominated landscape) (McKinney 2002).

Other green areas in cities, such as parks and brownfields (abandoned industrial sites that are overgrown with vegetation), can provide habitat for some animal species (McKinney 2002; Kattwinkel et al. 2009). However, green roof installations offer a unique opportunity to increase habitat quality and diversity in urban areas. Roofs cover 20-30% of land in non-residential urban areas (Ferguson 2005), so there is a large potential for the conversion of existing space into new habitat. Green roofs could be particularly useful if they provide habitat for bird and arthropod species that are not supported by other urban habitats that experience a higher degree of disturbance by people and mammalian predators, and some studies have examined this possibility. For example, green roof designers in London built green roofs that were intended to serve as habitat for the rare black redstart (*Phoenicurus ochruros*) (Grant 2006), and ground nesting birds were found breeding on green roofs in Switzerland, though unsuccessfully (Baumann 2006). Another study of birds on green roofs in Switzerland found that bird species on the roofs were ones that are more common in natural landscapes with low vegetation cover, rather than species that are common in cities (Brenneisen 2003). Some studies comparing arthropod communities in green roofs and ground-level urban habitats have shown that green roofs often support a different species composition than other urban habitats (Gedge and Kadas 2005, Colla et al. 2009), but another study found that the insect communities on green roofs were composed of a subset of species in nearby non-roof habitats (MacIvor and Lundholm 2011). In general, studies suggest that green roofs may increase urban biodiversity by providing habitat for species, particularly of birds, that are less successful in ground-level environments in the city.

Increasing biodiversity in cities can bring both economic and ecological benefits. For example, arthropods can provide pest arthropod control and decomposition services (Hunter and Hunter 2008), which reduces expenses associated with other pest control and soil enhancement methods. Urban biodiversity may also be important in conservation of rare and endangered species, since increasing development outside cities reduces the availability of wild habitats (Hunter and Hunter 2008). Also, urban environments may provide some stability in arthropods' food supply as the climate changes (Shochat et al. 2004), which may mean that the arthropods, in turn, can serve as a relatively stable food supply to birds and mammals in cities. Soil arthropods, in particular, may represent an important functional group on green roofs. Certain soil arthropods, such as collembolans, can promote soil development through production of feces that control the release of nutrients to plants (Hopkin 1997; Schrader and Böning 2006). Collembolans' contribution to nutrient availability in green roof soil, and their ability to control fungal pathogens (Lartey et al. 1994), may enhance plant growth. Though a diverse arthropod community may benefit green roofs and contribute to urban biodiversity, there have been few studies of arthropod diversity on green roofs.

In this observational study, we measured the diversity and abundance of insect families captured in pitfall traps on a green roof with variable vegetation cover. We also measured arthropod diversity in soil samples on six green roofs. We tested for correlations of arthropod diversity (species richness, family richness, and Shannon diversity index) with: living vegetation cover, plant species richness, roof area, and, as measures of isolation, distance of the roofs from the ground and the nearest vegetated ground-level habitat. One previous study suggests that arthropod diversity on green roofs is correlated with vegetation diversity, and is not correlated with roof area and height (Gedge and Kadas 2005), but we are not aware of any previous study that examined the relationship between vegetation cover and arthropod diversity on green roofs. We hypothesized that arthropod diversity would be positively correlated with vegetation cover and diversity. In addition, we hypothesized that arthropod diversity would positively correlate with roof area, and negatively correlate with a roof's distance to the ground and non-roof habitat.

METHODS

The study was conducted on six green roofs in the Boston, MA area (Tables 1, A1; Figure A1). The roofs were all fairly young (0-6 years old), and were highly variable in plant species composition (Figure 1). To test for correlations of vegetation characteristics with insect diversity, insect samples were collected from WT (the water treatment building at Wellesley College) with pitfall traps, from June through October, 2010. In addition, soil arthropod samples were obtained from all roofs once in June 2010, since access to several of the green roofs was restricted. The sampling across roofs was meant to test the generality of findings on WT and also test for correlations of green roofs' overall physical characteristics with arthropod diversity, at least during one point in the season, when collembolans may be most active (Romero and Harwood 2010).

Data Collection

Ten 0.4 m^2 circular plots on WT were chosen based on existing vegetation cover. Within areas of similar distance from the ground abutting edge, one plot with low vegetation cover (30-33% cover) and one with higher vegetation cover (39-56% cover) were chosen by visual approximation. Five such groups of paired plots were created. Plots were arranged with a spacing of at least 0.6 m between outer edges of neighboring plots, and plots were at least 0.5 m away from any edge of the roof. On each of the other five roofs, five 0.4 m^2 plots were sampled, with a distance of at least 0.6 m between plots and a minimum distance of 0.5 m from the roof edge.

To measure living vegetation cover, plots were photographed from above during June 2010, and were digitally processed using Photoshop (Version 12, Adobe Systems, Inc., San Jose, CA, USA) to highlight only green vegetation (Figure A2). These modified images were used to obtain mean gray values for plots using ImageJ (National Institutes of Health 2010), from which percent cover was calculated. Plant species richness was determined by counting the number of plant species in each plot. The cover of each major plant species, as well as litter, in the plots was measured by selecting the area of each species or of litter in unprocessed images in ImageJ.

Table 1. Summary of roof characteristics. Plant list is a partial list of the species in sampling plots on each roof. See Table A1 for more complete lists of plants, including those outside of plot areas. Area range for CH indicates sizes of three green roof boxes.

Location	Coordinates	Soil characteristics	Soil Depth (cm)	Area (m^2)	Height above ground (m)	Distance to nearest green area (m)	% Vegetation Cover (Mean ± standard deviation)	Plant richness (Mean ± standard deviation)	Plant Species Identified
Water treatment vault, Wellesley College Botanic Gardens (WT)	42.2942°N-71.3039°W	Low organic content, expanded shale and compost	15	55	0-2	0	41±11	4.9±1.2	*Carex pensylvanica*, *Solidago sciaphila*, *Fragaria virginiana*, *Dennstaedtia punctilobula*, *Geum triflorum*, *Aster spp.*, *Campanula rotundifolia*, *Allium sp.*
Massachusetts College of Art and Design (MA)	42.3369°N-71.0985°W	High organic content	30	149	60	16	49±14	7.4±0.9	*Arctostaphylos uva-ursi*, *Prunus maritima* *Linaria vulgaris*
Four Seasons Hotel Boston (FS)	42.3521°N-71.0680°W	High organic content	7.5	326	10	50	99±3	5.8±1.3	*Sedum spp.*, *Talinum calycinum*
Boston City Hall (CH)	42.3606°N-71.0581°W	High organic content	9-18	14-21	30	63	93±15	5.8±1.9	*Trifolium pratense*, *Sedum spp.*, *Hemerocallis sp.*, *Sedum* 'Black Jack', *Nepeta faasenii* 'Dropmore', *Heuchera* 'Palace Purple', *Aquilegia Canadensis*
Campus Center, Wellesley College (CC)	42.2945°N-71.3087°W	High organic content	75	66	18	10	67±11	4.2±1.6	*Carex pensylvanica*
Alumnae Hall, Wellesley College (AH)	42.2947°N-71.3104°W	High organic content	12	37	0.2-1	0	54±13	2.6±0.5	*Yucca filamentosa*

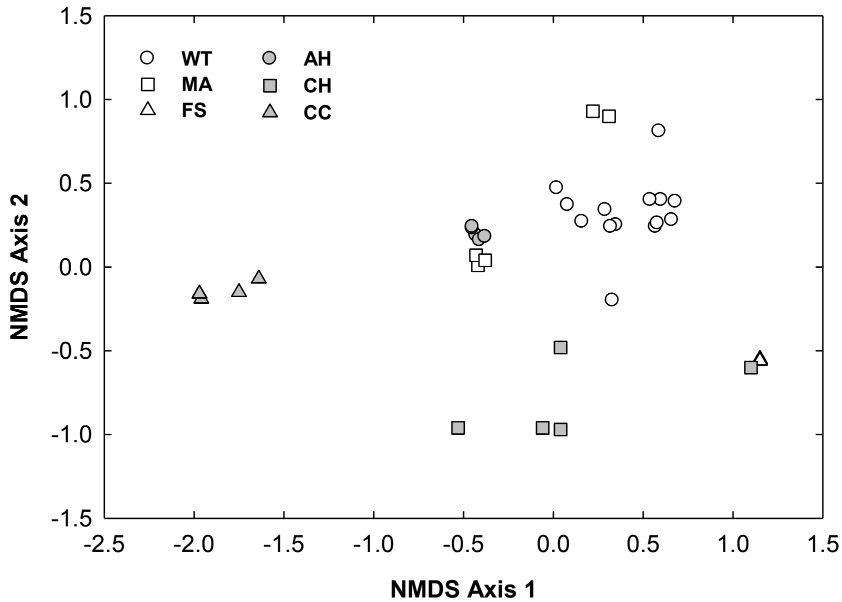

Figure 1. Nonmetric multidimensional scaling (NMDS) analysis of vegetation and litter cover similarity for plots on six green roofs (points closer together are more similar in terms of plant composition). Plots for separate roofs are indicated by different labels. WT- Water treatment vault, MA- Massachusetts College of Art and Design, FS- Four Seasons Hotel Boston, CH- Boston City Hall, CC- Campus Center, AH- Alumnae Hall.

Soil samples were collected once in June at all sites. On each roof, soil samples were collected with a spoon from the top few centimeters of substrate of each plot and refrigerated until sorted. Samples were sifted through a 1 mm sieve and were stored in 70% alcohol to preserve small arthropods. Larger particles that did not go through sieve were sorted through for large arthropods. Soil arthropod species richness was measured by counting morphospecies, based on size, color, shape, and other characteristics of specimens (Oliver and Beattie 1996). The volume of soil samples was measured in a beaker and ranged from 25 to 125 mL, with most (74%) samples between 75-100 mL. There was no correlation between sample volume and the number of arthropods (Spearman's ρ=-0.12) or arthropod species collected (Spearman's ρ=-0.1).

On WT, arthropods were also collected in pitfall traps, which were located in the center of each plot, from June to October 2010. The traps were 7.5 cm tall plastic cups with a surface diameter of 8.7 cm (Chinet Cut Crystal, 266mL, Huhtamaki, Inc., De Soto, Kansas, USA), and were covered with clear plastic roofs that stood about 5 cm above the traps. Each trap was filled with approximately 40 mL of 5% acetic acid (Woodcock 2005). A thin layer of canola oil was used to cover the surface, thereby reducing evaporation of the acetic acid preservative. Contents were collected every 2 weeks. Larger arthropods were removed from preservative and kept as voucher specimens if in good condition. Ants and collembolans were kept as voucher specimens in alcohol. Insects were identified to family, where possible. Unidentifiable insects, which comprised 12% of all samples collected, were excluded from analyses.

For each roof, the distance of the roof from the ground was measured or estimated based on the floor level of the roof in stories converted to meters. The planted area of the roof was also measured. For CH, which consisted of five separate green roof boxes, the area of each of the three boxes where samples were collected was measured, and the area of the three boxes was averaged to obtain one value for the roof. We used an average area instead of the sum because the roof boxes we sampled were separated from each other by at least seven meters, and so were not expected to serve as one continuous habitat for soil arthropods. The horizontal distance of the roof from the nearest ground level vegetated area was measured using Google Maps (Google, Inc., Mountain View, CA, USA).

Data Analysis

Average measures of plant cover, plant species richness, and the plant Shannon diversity index (H') across all 10 (on WT) or 5 (on the other 5 roofs) 0.4 m^2 circular plots on each roof were calculated. These values were tested for correlations with the average, for each roof, of arthropod species richness in soil samples collected from these plots. We also tested for correlations between the average soil arthropod species richness and characteristics of each roof, including distance of roofs from the ground, horizontal distance to ground-level vegetated areas, and green roof area.

On WT only, we also tested for correlations between the cumulative number of insect families collected in each pitfall trap over 10 weeks and attributes of the vegetation in corresponding plots, including cover, H', and number of plant species and families.

For the data on insect diversity collected in pitfall traps on WT, some pitfall traps became filled with rainwater during the collection period, and these traps had significantly fewer insects. Pitfall traps in plots with lower vegetation cover were filled with rainwater more frequently, so that vegetation cover had an indirect effect on the number of insects and insect families collected through vegetation's protection of pitfall traps from rainwater. To remove the effect of water on the total number of insect families per trap, weeks in which any pitfall traps were filled with rainwater were excluded from analyses for all plots. It was necessary to exclude entire weeks from the analysis to find the cumulative number of insect families over the collection period, since there was variation in the number of new families with date of collection. As a result, the analysis is limited to 10 weeks in July-October when all pitfall traps were unaffected by rainwater.

Similarity of vegetation and litter cover across the six green roofs was evaluated by calculating Bray-Curtis similarity values for cover of litter and plant species/type between all plots. Non-metric multidimensional scaling (NMDS) ordination was performed using the similarity values. Overall similarity is displayed graphically on the first two NMDS axes (2D stress=0.04) (Figure 1). Spearman rank correlation was used to test for correlations. Correlations were performed using JMP (Version 7, SAS Institute, Cary, NC, USA) and NMDS was performed using Primer-E (version 6, Primer-E Ltd., Lutton, UK).

RESULTS

Analyses across roofs indicated a correlation between vegetation cover and arthropod diversity. There was a positive correlation between soil arthropod species richness (See Table 2) and vegetation cover across green roofs ($p=0.01$, Spearman's $\rho=0.90$) (Figure 2a). Litter cover, on the other hand, did not correlate with soil arthropod species richness across roofs ($p=0.12$, Spearman's $\rho=-0.71$). The average number of soil arthropod species in soil samples also was not significantly correlated with the average number of plant species ($p=0.93$, Spearman's $\rho=-0.04$) (Figure 2b) in plots on those roofs.

Table 2. Number of arthropods and species collected in soil samples on each roof. *Ten plots were sampled on WT, and five plots were sampled on other roofs.

Location	Identified Orders	Number of arthropods/ soil sample (Mean±SD, total)	Total number of soil arthropods/roof	Number of arthropod species/ soil sample (Mean ± SD)
WT	Collembola, Chilopoda	1.5 ± 2.0	21*	0.8 ± 1.0
MA	Collembola, Hymenoptera (Formicidae)	3.4 ± 1.8	17	1.2 ± 1.1
FS	Collembola	5.8 ± 4.0	29	2.6 ± 1.5
CH	Collembola, Chilopoda	3.2 ± 3.5	16	1.6 ± 1.1
CC	Collembola, Coleoptera (larva)	4.6 ± 2.3	23	1.4 ± 0.9
AH	Collembola	3.8 ± 1.9	19	1.6 ± 0.5

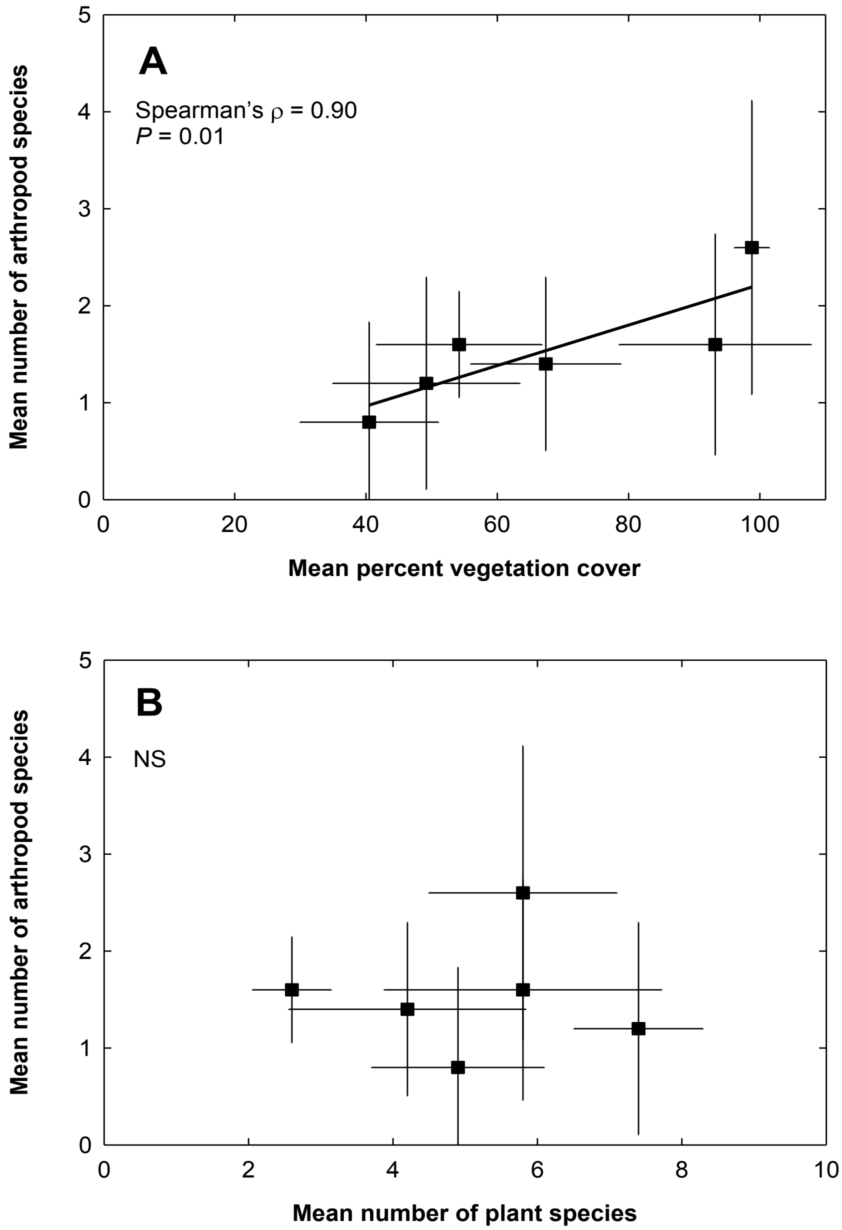

Figure 2 a. Correlation of mean percent vegetation cover with mean number of arthropod species in soil samples on six green roofs. Error bars indicate one standard deviation. . **b.** Correlation of mean number of plant species in plots with mean number of arthropod species in soil. For clarity, figures for soil samples across all roofs are indicated with square data labels throughout the results.

Pitfall trap samples of insects on WT (See Table A2 for list of families) showed similar results for correlation with vegetation characteristics. The cumulative number of insect families collected in pitfall traps on WT over 10 weeks was positively correlated with vegetation cover in their respective plots (p=0.03, Spearman's ρ=0.68) (Figure 3a). However, H' of insect families in pitfall traps was negatively correlated with vegetation cover because of low evenness in some high cover plots (p=0.03, Spearman's ρ=-0.68). Litter cover in WT plots correlated with vegetation cover (p=0.01, Spearman's ρ=0.74), but litter cover did not correlate with insect family richness in pitfall traps (p=0.11, Spearman's ρ=0.53).

The number of insect families collected over 10 weeks in pitfall traps on WT was not correlated with the number of plant species in 0.4 m^2 plots where the pitfall traps were located (p=0.52, Spearman's ρ=-0.23) (Figure 3b). Results were similar for the relationship of insect family richness in pitfall traps with the vegetation's H' (p=0.64, Spearman's ρ=-0.17) and with the number of plant families (p=0.55, Spearman's ρ= -0.22).

In addition to testing for correlations of vegetation cover and richness with arthropod diversity, we also tested for relationships of arthropod diversity with the characteristics of roofs, specifically isolation and size of roofs. Neither the vertical distance of roofs from the ground (Figure 4a), nor the horizontal distance to ground-level vegetated areas (Figure 4b) correlated with average number of arthropod species in soil samples on the six green roofs (p=0.91, Spearman's ρ=0.06, and p=0.30, Spearman's ρ=0.51, respectively). The average number of soil arthropod species on each roof also did not correlate with the size of the green roof (p=0.83, Spearman's ρ=0.12) (Figure 4c).

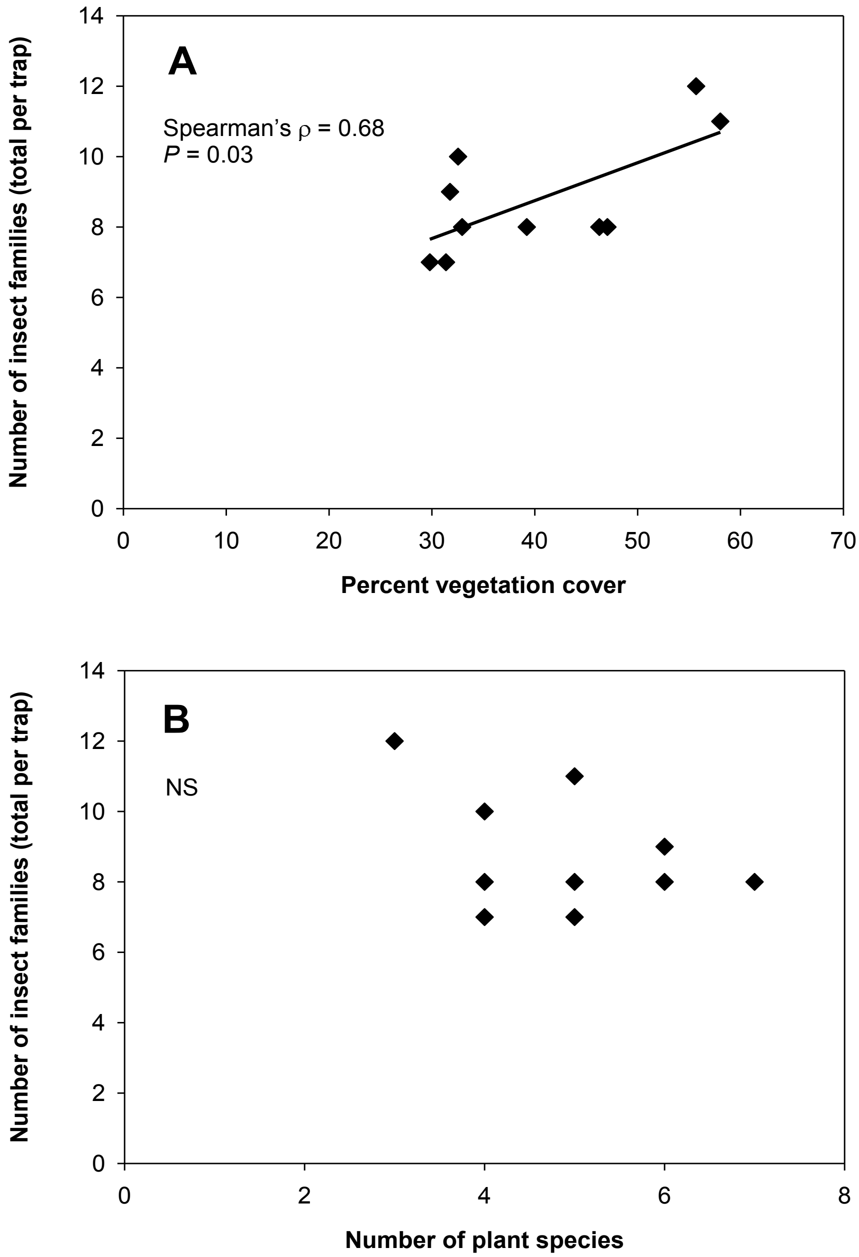

Figure 3. a. Correlation of percent vegetation cover in plots with cumulative number of insect families in their respective pitfall traps, collected over 10 weeks **b.** Correlation of number of plant species in plots with cumulative number of insect families in their respective pitfall traps. For clarity, figures for pitfall traps on WT are indicated with diamond shaped data labels throughout the results.

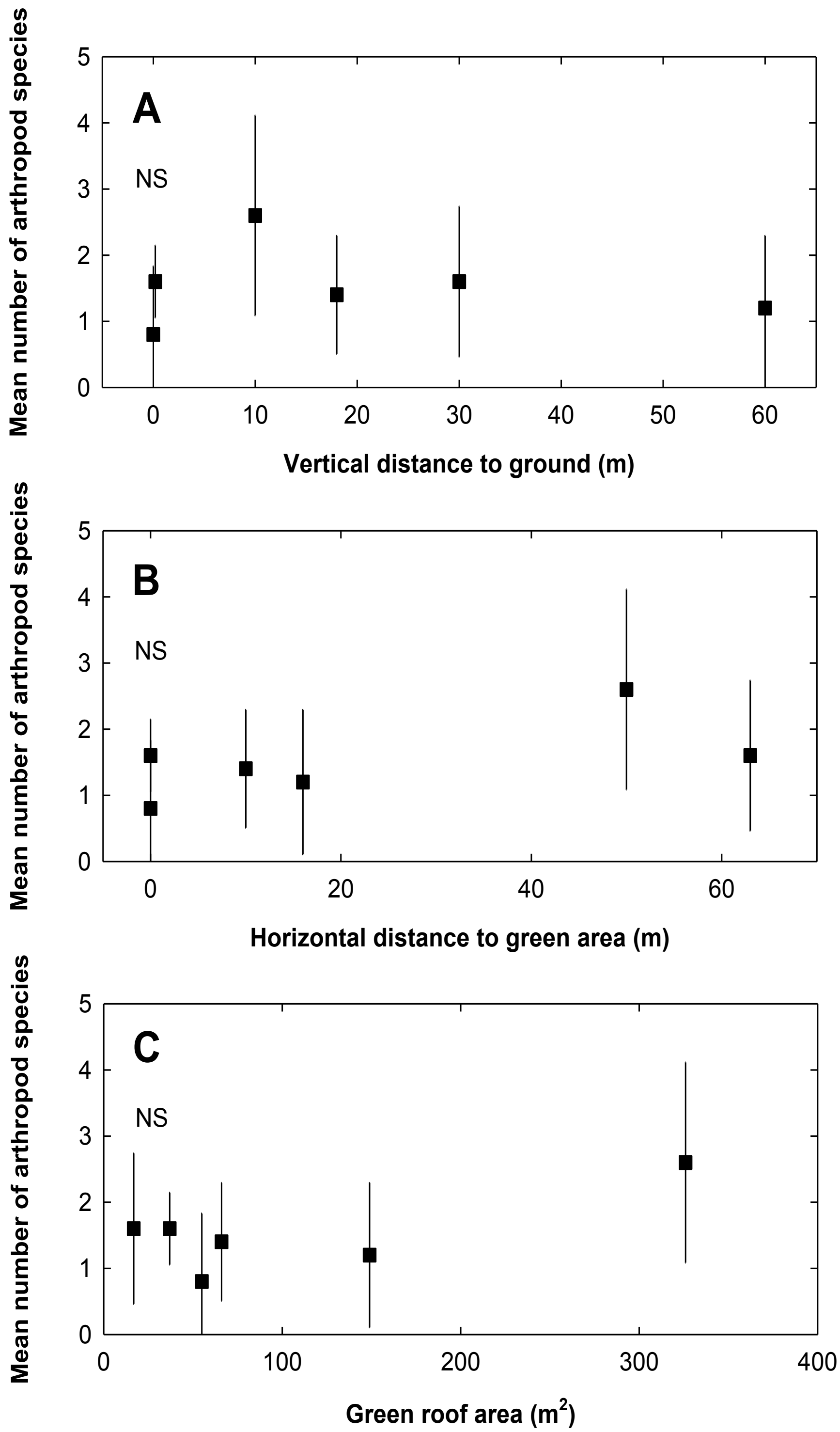

Figure 4 a. Correlation of vertical distance to the ground with mean number of arthropod species in soil samples on six green roofs. Error bars indicate one standard deviation. **b.** Correlation of horizontal distance to the nearest ground-level vegetated area with mean number of arthropod species in soil samples on six green roofs. **c.** Correlation of green roof area with mean number of arthropod species in soil samples on six green roofs.

DISCUSSION

Our data suggest that for arthropod diversity on green roofs, the proportion of vegetation cover can be more important than the diversity of the vegetation, at least for arthropods that are found in soil or that are collected by pitfall traps (Figures 2, 3). A previous study of spiders on green roofs found a correlation of spider diversity with vegetation height (Gedge and Kadas 2005), but we know of no other studies that have tested for a correlation between vegetation cover and arthropod diversity on green roofs or similar urban habitats. Studies of less manipulated habitats suggest that greater plant biomass has a positive effect on the diversity of soil fauna, but plant diversity may not (Hooper et al. 2000). Soil arthropod diversity may be correlated with vegetation cover, and not plant diversity, because the presence or abundance of most arthropod species may depend on the abundance of edible plant species, rather than a range of species, and a plant community with higher plant diversity may include relatively inedible species (Wardle et al. 1999).

The correlation of vegetation cover and arthropod diversity, particularly in the soil, could also be due to positive effects of arthropod diversity on vegetation cover, rather than the other way around. Some of the arthropods found in pitfall traps were predaceous, and high arthropod predator diversity can, in some cases, lead to lower herbivore abundance, which could result in higher vegetation cover (Bruno and Cardinale 2008). Collembola, which comprised most arthropods found in soil samples, can also promote plant growth by controlling pathogens (Lartey et al. 1994), so a diversity of Collembola may have a positive effect on vegetation cover. However, because the studied roofs were young (0-6 years old), it seems likely that arthropod diversity would not have had much time to influence vegetation cover, so the correlation is likely driven by vegetation cover.

Studies of aboveground arthropods have found positive correlations of arthropods with plant diversity (Murdoch et al. 1972), including a study of spiders on green roofs (Gedge and Kadas 2005), while in this study aboveground insect family richness in pitfall traps did not correlate with plant diversity (Figure 3b). However, since the sample size in this study was small and richness was measured with a low taxonomic resolution, the relationship between insect diversity and plant diversity may be stronger than observed. Furthermore, high plant diversity can be useful for other green roof functions, such as cooling and water absorption (Lundholm et al. 2010). It is also possible that at high vegetation cover levels, plant diversity has a positive effect on arthropod diversity aboveground, but that on the roofs in this study vegetation cover was sufficiently variable (range of 40% to 100% cover) to swamp other potential influences on arthropod diversity. Plant diversity may become more important as the vegetation fills in, as long as the roofs achieve a high level of vegetation cover.

Other factors that may affect arthropod diversity on green roofs include the extent to which the plant community is composed of native species, and the proportion of cover of litter. The native status of plants may be important for individual arthropod species that specialize on particular host plants. This study did not address this issue, since the variation in cover of native plants on WT was due only to the cover of one plant species, *Solidago sciaphila*, which is nonnative in the Northeastern United States, but is native in the Midwest and has congeners native to the Northeast; further studies are needed to test for the effect of nonnative vegetation cover on arthropod colonization. Future studies could also determine if litter cover has an effect on abundance or diversity of arthropods, since in this study there was little variation in litter cover among most roofs. Observations in this study suggest that the amount of litter cover on roofs varies with the level of maintenance and the proximity of trees that produce leaf litter. Future experiments could determine whether litter cover is also an important determinant of arthropod diversity, particularly of detritivores, and whether reduced maintenance (e.g. weeding and litter removal) affects diversity.

There may be a tradeoff between vegetation cover and plant diversity on green roofs, as there seems to be a limited number of plant species that can thrive on roofs. Most species that grow well on roofs without added water are low growing Crassulaceae species (Carter and Butler 2008), which offer little in terms of growth form and functional group diversity when planted in monoculture, as they often are. One study that measured a biomass index of green roof assemblages with a varying number of plant life-forms found that, in general, biomass was higher in mixtures of several life-forms, while variation in biomass over time was lower (Lundholm et al. 2010). However, a monoculture of grasses produced the highest level of biomass (Lundholm et al. 2010), suggesting that in some cases higher vegetation cover can be achieved by one species that is optimized for this purpose. In other urban habitats, plant diversity can reach as high as 40 species per square meter (Rebele 1994), whereas the green roof with the highest vegetation cover in this study contained an average of 6 species per 0.4 m^2. However, if both high plant cover and diversity can be achieved, arthropod diversity may be higher than with high plant cover alone. This is suggested by the correlation between plant diversity and arthropod diversity in previous studies at ground-level and on green roofs (Murdoch et al. 1972; Gedge and Kadas 2005).

Though higher vegetation cover may enhance arthropod diversity, the results of this study suggest that many of the insect families found with higher vegetation cover are relatively rare on the roof, so higher vegetation cover does not necessarily lead to higher diversity index values, due to lower evenness in some high cover plots. A green roof manager's motivations for increasing arthropod diversity on green roofs will determine whether high arthropod H' is desirable, or whether high species or family richness is desired, perhaps for biodiversity conservation purposes. Increasing arthropod diversity could be motivated by a desire to maintain a healthy plant community that can support the roofs' primary purposes, or by a desire to increase the suitability of green roof habitats for other animals. Green roofs may also be used as a connecting habitat for arthropods between fragmented ground-level habitats in urban environments. It would be very useful to understand how species richness, H', or abundance of arthropods affects these functions of green roofs.

Aside from biological characteristics, other physical aspects of green roofs could be important in affecting arthropod communities. In this study, roof area did not appear to influence the average soil arthropod species richness at this small scale (Figure 4c), though the effect of roof area on total soil arthropod species richness across all roof samples is unknown. At 14 to 326 m^2, the roofs sampled in this study had a relatively small range of sizes, as green roofs worldwide average 1900 m^2 and can reach up to 100,000 m^2 (Greenroofs.com 2010). Roof size may have an effect on arthropod diversity at a greater range of sizes, as previous studies of arthropod diversity in fragmented urban habitats have found a correlation between fragment size and average arthropod diversity in pitfall traps (Bolger et al. 2000). On the other hand, a study of spiders on green roofs found no correlation of spider H' with roof area or height (Gedge and

Kadas 2005). Our study also found no effect of roof height, or distance to ground level habitat, on soil arthropod species richness (Figure 4a, b). In general, biogeography theory would predict that habitat islands, such as green roofs, would have higher diversity if they are less isolated (MacArthur and Wilson 1963). If plants and soil that are brought to a roof are an important source of arthropods, and particularly soil arthropods, a roof's isolation from the ground may not be an important determinant of soil arthropod diversity. Thus, a diverse arthropod community may be achievable even on green roofs that are small and isolated from ground level habitats, if vegetation cover is high.

Our results indicate that across a range of roof and vegetation types there is a correlation between vegetation cover and arthropod richness on green roofs. Plant diversity was not an important predictor of arthropod richness in this study, but it may be important under other circumstances, such as on roofs with more consistent vegetation cover. Finally, we found that roof size and isolation did not correlate with arthropod species richness, and that even small roofs that were far from other vegetated areas contained several species of soil arthropods.

APPENDIX

Table A1. List of plant species on roofs. WT- full list of plants present on roof, MA- partial list of planted plants, other roofs- list of planted plants.

Location	Plants
WT	*Allium cernuum* *Allium stellatum* *Andropogon scoparius* *Arctostaphylos uva-ursi* *Aster divaricatus* *Aster laevis* *Aster ptarmicoides* *Campanula rotundifolia* *Carex eburnea* *Carex pensylvanica* *Dennstaedtia punctilobula* *Fragaria virginiana* *Geum triflorum* *Hieracium sp.* *Houstonia longifolia* *Mollugo verticillata* *Oxalis stricta* *Opuntia fragilis* *Potentilla norvegica* *Sedum nevii* *Sedum ternatum* *Solidago altissima* *Solidago gigantea* *Solidago graminifolia* *Solidago sciaphila* *Trifolium repens* *Vaccinium angustifolia* *Verbena stricta* *Viola pedata* *Vicia cracca*
MA	*Antennaria Spp.* *Arctostaphylos uva-ursi* *Carex pensylvanica* *Comptonia peregrina* *Deschampsia flexuosa*

Table A1, Continued

Location	Plants
MA	*Eurybia spectabilis* *Ionactis linariifolius* *Liatris scariosa var. novae-angliae* *Potentilla Tridentata* *Prunus maritima* *Schizachyrium scoparium* *Solidago nemoralis* *Vaccinium angustifolium*
FS	*Agastache rupestris* *Allium schoenoprasum* *Cerastium tomentosum* *Dianthus spiculifolius* *Festuca glauca* 'Elija Blue' *Geranium maculatum* *Jovibarba allionii,* Perovskia 'Little Spire' *Orostachys boehmeri* *Phedimus takesimensis* *Phlox subulata* *Sedum album* *Sedum cauticola* *Sedum kamtschaticum* *Sedum floriferum* *Sedum rupestre* *Sedum rupestre* 'Angelina' *Sedum sexangulare* *Sedum sichotense* *Sedum sieboldii* *Sedum spirium* *Sedum spurium* 'Fuldaglut' *Sempervivum* 'Silver Thaw' *Talinum calycinum* *Tradescantia ohiensis* 'Mrs. Loewer'
CH	*Aquilegia canadensis* *Delosperma cooperi* *Dracocephalum argunense 'Fuji White'* *Heuchera 'Palace Purple'* *Iris tectorum* *Nepeta x faasenii 'Dropmore'* *Origanum vulgare 'Herrenhausen'* *Phlox 'Eva Cullum'* *Phlox 'Nicky'* *Pycnanthemum muticum* *Salvia nemerosa* *Salvia officinalis 'Berggarten'* *Sedum album 'Stefco'* *Sedum 'Angelina'* *Sedum 'Black Jack'* *Sedum cauticola 'Lidakense'* *Sedum kampschaticum* *Sedum nevii* *Sedum sexangulare 'Weiss Tetra'* *Sedum spurium 'Fulda Glut'* *Stokesia laevis* *Talinum calycinum* *Veronica allionii* *Viola cornuta 'Jacqueline'*
CC	*Yucca filamentosa*
AH	*Carex pensylvanica*

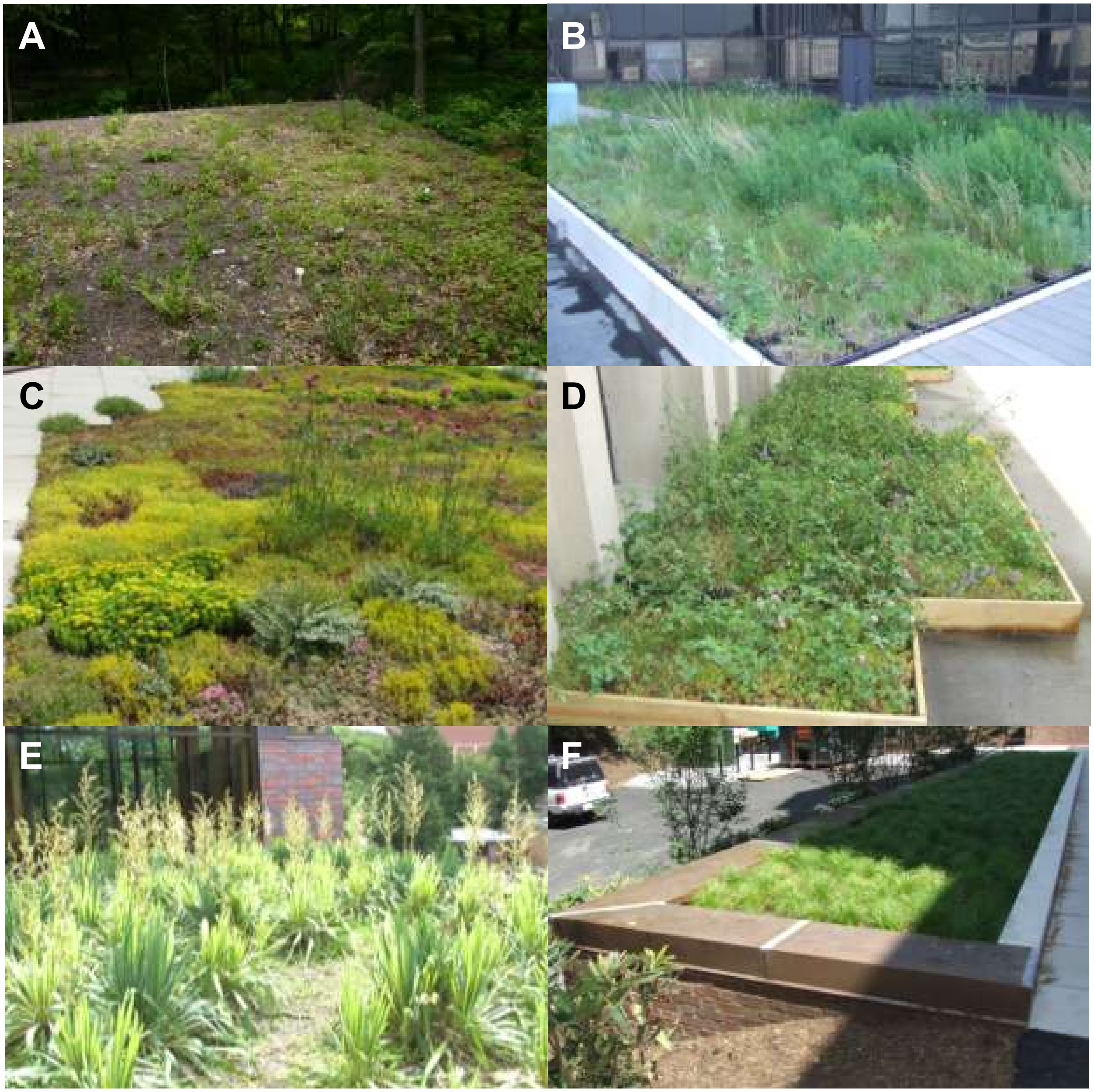

Figure A1. Green roofs sampled in this study: **a.** WT **b.** MA **c.** FS **d.** CH **e.** CC **f.** AH

Figure A2. Photographs of plots on each roof: **a.** WT **b.** MA **c.** FS **d.** CH **e.** CC **f.** AH

Figure A2, Continued. Photographs of plots on each roof: **a.** WT **b.** MA **c.** FS **d.** CH **e.** CC **f.** AH

Table A2. Arthropod families collected in pitfall traps on WT. Collembola outside the family Sminthuridae were not identified and were excluded from analyses.*Observed outside of sampling period.

		Number of insects collected by collection date					
Order	Family	7/19-8/2	8/2-8/16	8/30-9/13	9/13-9/27	9/27-10/11	Total
Blattodea	Blattellidae	1	2	5	2	1	11
Coleoptera	Buprestidae				1		1
	Carabidae		2	3			5
	Coccinellidae		1				1
	Leiodidae					1	1
	Scarabaeidae*						
	Staphylinidae	1			1		2
Collembola	Sminthuridae	1					1
Dermaptera	Forficulidae				1		1
Diptera	Anthomyiidae					1	1
	Chironomidae					1	1
	Chloropidae				1		1
	Culicidae*						
	Dolichopodidae	4	2	1			7
	Empididae		3	1			4
	Milichiidae			1			1
	Muscidae		1				1
	Mycetophilidae			1			1
	Phoridae			1			1
	Psilidae			1			1
	Therevidae		1				1

Table A2, Continued

		Number of insects collected by collection date					
Order	Family	7/19-8/2	8/2-8/16	8/30-9/13	9/13-9/27	9/27-10/11	Total
Hemiptera	Aphididae			3		1	4
	Cercopidae*						
	Cicadellidae		2		2	1	5
	Fulgoroidea				1		1
	Lygaeidae		1		1	1	3
	Reduvidae			1			1
Hymenoptera	Apidae	1		2		1	4
	Bethylidae*						
	Braconidae					1	1
	Ceraphronidae		1	1		2	4
	Diapriidae			1			1
	Formicidae	94	38	80	2	1	215
	Ichneumonidae					1	1
	Proctotrupidae	11	8	10	8	3	40
	Roproniidae			2			2
	Sapygidae*						
	Scoliidae*						
	Sphecidae*						
	Tenthredinidae*						
Lepidoptera	Unidentified species	74	164	21	5	3	267
Neuroptera	Hemerobiidae			1			1
Odonata	Coenagrionidae*						
Orthoptera	Gryllidae	7	2	1	2	2	14
	Rhaphidophoridae*						
	Total families	9	14	19	12	15	36

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