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Can green roofs provide habitat for urban bees (*Hymenoptera: Apidae*)?

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Abstract

Increasing urbanization of many regions of the world has resulted in the decline of suitable habitat for wild flora and fauna. Green roofs have been suggested as a potential avenue to provide patches of good-quality habitat in highly developed regions. In this study, we surveyed green roofs for bee diversity and abundance to determine their potential as quality habitats in an urban area for these important pollinators. By comparing various biodiversity measures between green roofs and ground-level sites, we show that green roofs provide habitat to many bee species. Implications for pollinator conservation and urban agricultural production are discussed.

Keywords

Green roofs; pollinator conservation; urban biodiversity; bee abundance; habitat loss; species richness.

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INTRODUCTION

The increase of human populations in city centres and urban sprawl have resulted in substantial losses of land available for natural habitat and agricultural production globally (e.g. Pimentel et al. 1976; Seabloom et al. 2002). Since large amounts of land area are covered by residential developments, industrial areas and shopping centres, the construction and maintenance of green roofs on buildings has been recommended as a potential solution to habitat loss and food production issues (Orbendorfer et al. 2007). Additionally, green roofs in urban centres provide other benefits such as reduced storm water runoff, energy conservation, cooling of "heat islands", fire prevention, improved air/water quality and aesthetic value (e.g. Getter and Rowe 2006).

The benefit of green roofs for biodiversity is an understudied aspect of urban planning. However, various recent studies in Europe have indicated that green roofs in large cities have high potential as habitat for species negatively impacted by land-use changes (reviewed in Gedge and Kadas 2005; Grant et al. 2003). For example, in Basel, Switzerland, surveys of birds, spiders and beetles on green roofs found high diversity levels for all groups, including many species considered rare or threatened (Brenneisen 2003, 2006). Green roofs were also found to provide suitable habitat for ground-nesting birds (Baumann 2006). Similarly, a study in London, England, on invertebrate populations on green roofs found a high diversity of spiders, beetles, and aculeates compared to brownfield sites (Kadas 2006). Additionally, green roofs in London have been found to provide suitable habitat for the black redstart, a nationally rare avian species (Gedge 2003). Similar biodiversity studies have not taken place in North America, where the ecological benefits of green roofs have only recently gained interest.

Bees (Hymenoptera: Apoidea) are an important group of insects which provide the crucial ecosystem service of pollination of native flora and agricultural crops (Bond 1994; Allen-Wardell et al. 1998; Vamosi et al. 2006, Klein et al. 2007). Recently, substantial declines in both wild and managed bee populations have been documented in North America (reviewed in Berenbaum et al. 2007; Colla and Packer 2008). The causes of these declines are unclear and likely differ between species, but may be attributed to habitat loss, pesticide use, global warming, diseases introduced from managed bees, and competition with introduced species (reviewed in Berenbaum et al. 2007). The sustainability of crop production and native ecosystems requires a diverse and abundant supply of bees (e.g. Cane and Tepedino 2001; Williams et al. 2001). With the presence of suitable plant species and habitat, urban areas have been shown to support high bee diversity (Tommasi et al. 2004; Mcfrederick and LeBuhn 2006; Matteson et al. 2008). Thus, the construction of green roofs in urban areas may aid in the conservation of bees by providing suitable habitat for foraging and nesting where these resources may be otherwise scarce. In this study, we compare bee diversity and abundance between green roofs and non-green roof sites. Our objective was to determine the degree of overlap in bee communities between green roofs and nearby ground level sites and to investigate the utility of green roofs as suitable bee habitat.

METHODS

Study Sites

From 2004–2006, we surveyed bees at a total of six sites located at York University (Keele Campus), Toronto, Ontario, Canada. Of these sites, two were 'extensive' green roofs. The first green roof (hereafter GR1) was constructed on the three-story Computer Science and Engineering building in 1999 and seeded with alpine grasses and a wildflower mix. The total area of the green roof is 1875 m^2 with 270 m^2 vegetated with the wildflower mix. The second green roof (hereafter GR2) was constructed in 2004 on the fifth story of a student residence building. GR2 was not actively seeded but had naturally occurring grasses and flowering species (mostly vetches and clovers) present by 2005. The total area of this second green roof is 3048 m^2. Additional ground level sites (NGR) on the university campus were surveyed for comparison to the bee diversity on the roofs. These sites included a woodlot (W), lawn (L) and two untended grassy areas (F1 and F2).

Data Collection

In 2004, one green roof site (GR1) and non-green roof site (W) were surveyed from the beginning of August to mid-September. In 2005, both green roofs and four non-green roof sites (W, L, F1 and F2) were surveyed from June to September. In 2006, both green roofs and three non-green roof sites (L, F1 and F2) were surveyed from April to September. The woodlot (W) was not sampled in 2006 so that all non-green roof sites were sampled for two years. Between August 2004 and September 2006, we conducted surveys for a total of 21 days. For all years, the sites were surveyed approximately every other week, on warm, sunny days without high winds or precipitation.

Pan traps were used to sample the diversity and relative abundance of bees simultaneously at all sites (Potts et al. 2005). Bees were collected by using coloured pan traps ¾ filled with unscented soapy water. Traps were made from 6 oz. Solo® plastic bowls, either left white or spray-painted fluorescent blue or fluorescent yellow (Krylon® Brand). On each survey day, 30 traps (10 of each colour) were placed in an X-pattern with traps approximately 2 metres apart at each site. Traps were put out at 8:00–9:00 and collected at 15:00–16:00. All bees were then transferred to vials containing 75% ethanol and brought back to the laboratory for identification.

Collected specimens were pinned and identified to genus and species by E. Willis using Mitchell (1960, 1962) and other relevant taxonomic keys (McGinley 1986, Laverty and Harder 1988). Difficult genera, such as *Lasioglossum, Ceratina* and *Andrena,* were verified or identified by L. Packer, A. Taylor, C. Sheffield or J. Gibbs. All specimens are found at the York University Bee Collection.

Data Analysis

Samples were combined by site type to compare the biodiversity of green roof sites (GR1 and GR2) and non-green roof sites (F1, F2,W and L). For each site type [green roof (GR) and non-green roof (NGR)], biodiversity levels were quantified as species richness (*S*), abundance (*A*), the Shannon-Weiner diversity index (*H*') and the evenness index (*J'*) using BioDiversity Pro software (McAleece et al. 1997). Using data from the year with most sampling dates (2006), a clustering dendrogram was produced based on the Bray-Curtis similarity index to determine similarity between sites sampled throughout the spring and summer. These indices were chosen because they are widely used measures in biodiversity studies (Magurran 2003). Finally, qualitative species-level comparisons were made to determine differential occupancy and/or abundance among species at both sites types.

RESULTS

A total of 1542 bees belonging to 79 species and 24 genera were collected at the study sites (Table 1). Of these, five species were not native to the region (Table 1). The most abundant species overall belonged to the genera *Lasioglossum* (24.7% of total sample) and *Halictus* (20.3%). Additionally, 17.7% of the observed species were represented by only one individual.

There were differences found between green roof and non-green roof sites for species richness, abundance, diversity *H*' or evenness *J*', with diversity and richness generally being higher at non-green roof sites (Table 2). Results from the cluster analysis indicate that the two green roofs supported similar bee communities compared to the three non-green roof sites (Figure1). The two green roof sites clustered more closely to each other than any of the other sites when we used the Bray-Curtis Similarity index. Rarefaction curves suggest that more species are present on both green roof and non-green roof sites, than were captured in this study (Figure 2).

Additionally, some differences between site types were noted when comparisons were made at the species level. Despite having fewer numbers of green roof sites than non-green roof sites, at least one native species, *Lasioglossum pilosum* Smith, was found in substantially larger numbers on the roofs than at ground level (Table 1). Species that were much less abundant at green roof sites than at the other sites were the native species *Augochlorella aurata* Smith, *Hylaeus affinis* Smith and *Lasioglossum admirandum* Sandhouse. Both stem-nesting species of the genus *Ceratina* were much more abundant at ground level than on the roofs.

Table 1. Number of individuals per species collected from each site at York University in Toronto, ON, 2004–2006 [(E) indicates species not native to Ontario]. Please see methods section for site details.

Species	GR1	GR2	F1	F2	W	L
Agapostemon virescens	2		3	1		6
Andrena carlini			1			
A. cressonii cressonii						2
A. forbesii						2
A.hippotes			1		1	1
A.miserabilis						2
A. nasonii	2		9	2		11
A. vicina			1			5
A. wilkella	1					1
Anthidiellum notatum	1					1
Anthidium manicatum (E)	3		2		2	1
Anthrophora furcata terminalis			1			2
Apis mellifera (E)	3	2	6	3	1	15
Augochlorella aurata	2	1	8	78	2	5
Bombus bimaculatus	1		2	1		
B. citrinus						3
B. perplexus		1				
B. rufocinctus	3		1	2	1	4
B. vagans	1				1	
Calliopsis andreniformis			1			
Ceratina calcarata	1		41		12	19
C. dupla dupla	2	2	83	10	17	30
Coelioxys rufitarsis						1
C. sayi						1
Halictus confusus	81	14	47	27	15	28
H. ligatus	27	6	9	38	2	4
H. rubicundus	5	2	2	1	1	4
Herides leavitti			7		4	4
Hoplitus producta	1		9	1	6	3
H. affinis	50	1	50	77		57
H. cressoni	2		3			2
H. modestus			1	1		4

Table 1. Continued.

Species	GR1	GR2	F1	F2	W	L
L. cinctipes		2	2			4
L. coeruleum			2	1	1	1
L. coriaceum	4	1	6		5	5
L. cressonii	1		1			1
L.divergens	1			1		1
L. ellisiae	3			2		
L.fattigi	11	3	1	2	2	
L. foxii	1				1	2
L. imitatus	1		1		1	
L. laevissimum	14	8	5	5	9	5
L.leucozonium (E)	14		5	5	4	9
L.lineatulum	4		1	2		2
L. oblongum	17	21	15	8	8	12
L. paradmirandum	7	2	1		2	
L. perpunctatum	1	2		2		
L.perspicuum	2	2	2	2	1	
L. pilosum	25		1		3	1
L. rohweri	1		1			1
L.tegulare	7		1		2	
L.viridatum	1		2	4	1	1
L.zephyrum	1	1			1	2
Megachile brevis brevis	3			2		
M. frigida			1		2	2
M. inermis			1			
M.latimanus	1			1		1
M. mendica			2			
M. pugnata pugnata			1			
M. relativa						1
M.rotundata (E)	25	20	6	5	2	17
M. sculpturalis (E)			1			
M. texana		1	1	1		
Melissodes desponsa		1	1	2	1	
M.denticulata			1			
M.dentiventris		2				
M. illata	2			2		
Nomada bishoppi						1
N.cressonii			2			2
Osmia albiventris						1
O. conjucta			6			
Pepoapis pruinosa		1	2			3
Sphecodes sp.	1					1
Stelis trypetina			1			
Xylocopa virginica	1					
Total Individuals	**342**	**101**	**373**	**309**	**118**	**299**
Total Species	**45**	**54**	**52**	**31**	**24**	**33**

Table 2. Biodiversity measurements for bees collected at both site types [Green roof sites (GR) and non-green roof sites (NGR)] from 2004–2006.

	GR			NGR		
	2004	**2005**	**2006**	**2004**	**2005**	**2006**
Richness (*S*)	19	37	30	17	46	70
Abundance (*A*)	53	246	144	33	393	673
Shannon-Weiner Diversity (*H*')	1.08	1.19	1.16	1.09	1.25	1.37
Evenness (*J*')	0.84	0.76	0.78	0.89	0.75	0.74

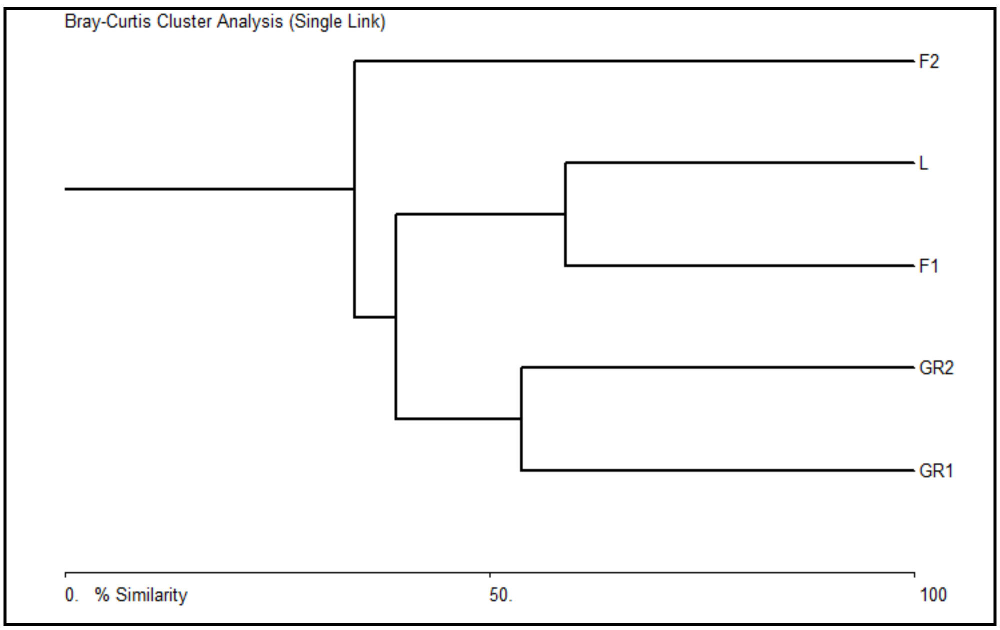

Figure 1. Clustering dendrogram of bee communities using the Bray-Curtis similarity index for green roof (GR1, GR2) and non-green roof (L, F1, F2) sites sampled in 2006 at the York University Campus, Toronto, Ontario, Canada. Figure was generated using BioDiversity Pro software by McAleece et al. (1997).

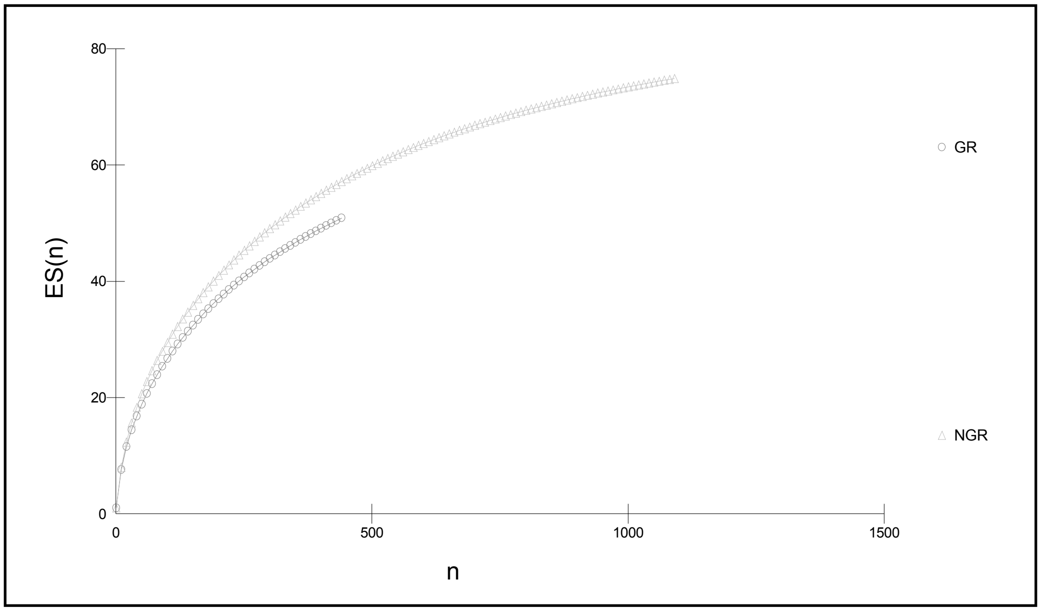

Figure 2. Rarefaction curves for the two site types [Green roof (GR) and non-green roof (NGR)] generated using BioDiversity Pro software by McAleece et al. (1997). Sample sizes are n=443 and n=1099 for GR and NGR respectively

DISCUSSION

Bees on Green Roofs and in Urban Areas

Green roofs are a common sight in many European cities, and interest in them has increased greatly in North America (Emilsson and Rolf 2005). In large cities, green roofs are a potential strategy for dealing with environmental challenges over the next few decades, such as the loss of available habitat for wildlife (Oberndorfer et al. 2007). This is especially important in various regions of southern Canada, where urban sprawl and intensive agriculture replace large amounts of native habitat containing relatively high biodiversity. This study provides evidence that green roofs in urban areas can offer suitable habitat for foraging and/or nesting for a variety of bee species. The composition of the green roof bee communities did not differ substantially from those found at ground level sites based on various biodiversity measures. We noted higher species abundance and richness for the actively seeded GR1 compared to the passively seeded GR2 but were unable to test this statistically. This finding should be verified with a study at a larger scale with more than one green roof of each type.

Despite relatively low sampling at few sites, the species richness of bees found during this study (S =79) is comparable to other surveys in urban North American cities. One study of Vancouver city gardens and urban parks obtained a total of 56 bee species from 25 sites; species richness did not differ significantly among site types (Tommasi et al. 2004). In New York City, a study of the bee diversity in urban gardens found a total of 54 species from 19 sites (Matteson et al. 2008). Both these studies differ from ours in the proportion of larger bees collected (i.e. *Bombus* spp. and *Apis mellifera*), likely as a result of differences in sampling methods. The higher species richness reported in our study may be due to the identification of all specimens belonging to the taxonomically challenging but speciose subgenus *Lasioglossum* (*Dialictus*). Nonetheless, the number of species we found is lower than that known for non-urban habitats in the countryside around Toronto, Ontario (Grixti and Packer 2006; Grixti and Packer unpublished data).

The Potential of Green Roofs for Pollinator Conservation

As our results indicate, a variety of native bee species can use green roofs as foraging and/or nesting habitat. Since our study used only pan traps as a collection method, larger bees such as *Bombus* and *Xylocopa* were likely underrepresented in our surveys (Roulston et al. 2007), despite being common on campus (S. Colla, pers. obs.). Given their ability to fly long distances (Osborne et al. 2008) and withstand cool temperatures and windy conditions (e.g.Bishop and Armbruster 1999), larger bees are expected to use suitable green roofs for foraging. Rarefaction curves also indicate there is likely a higher diversity of bees at both site types (Figure 2). Further surveys with nets and/or malaise traps as collection methods may be useful in determining the presence of a greater diversity of bees.

Green roofs may be able to offset some of the pressures threatening bee populations. Suspected causes for bee decline in North America, as recently reviewed by Berenbaum et al. (2007), include habitat loss, invasive species, pesticide use and pathogen spillover from managed bees. Using green roofs, habitat loss can be minimized by incorporating suitable nesting substrate and native flower species for forage in urban areas where such habitat may be scarce. Our study found differential abundances of some species on green roofs versus ground level sites (and to a lesser extent between the two green roofs) presumably because of differences in provided habitat. Further studies may provide information on habitat requirements; this will allow for the design of green roofs which cater to specific bee taxonomic groups or guilds.

With increasing human population growth and the resulting increase in intensive agricultural practices, habitat free of harmful chemicals and disease will likely be in short supply for dwindling pollinator populations. Urban green roofs can potentially provide native bees with habitat away from agricultural areas with disease spillover (e.g. Colla et al. 2006) and pesticide contamination (e.g. Coupe et al. 2000). In addition, bees in urban areas may suffer less competition for floral resources than those in agricultural areas with managed and/or introduced bee populations (e.g. Huryn 1997). Although the magnitude of each of these threats to native bees is not completely understood, the potential for green roofs to augment declining species by alleviating some of these pressures should be given consideration in future urban planning.

The Importance of Bees for Sustainable Green Roof Ecosystems and Urban Agriculture

The presence of a diverse bee community is likely crucial to permit green roofs to mimic natural ecosystems in a sustainable manner, yet this is an overlooked aspect of green roof design. The pollination services provided by bees allow for the production of seeds from year to year, decreasing the need for active seeding and tending. The presence of bees on green roofs may also allow the persistence of a stable plant community which may attract other wildlife species dependent on bee-pollinated plants for food or shelter. Further research in the stability of pollinator populations and the sustainability of green roof communities is required to gain a better understanding of the potential benefits to other wildlife species.

Urban agriculture has been suggested to be of utmost importance for sustainable cities (Smit and Nasr 1992). The use of space for urban agriculture can help promote greater food security in areas with high population growth (Koc et al. 1999). Increased bee diversity has been shown to increase agricultural production in numerous crops (e.g. Klein et al. 2003; Kremen et al. 2004) including peppers, alfalfa, tomatoes, cucumbers, berries, squashes and tree fruit. The growing of crops on green roofs has proven possible in downtown Toronto, with the production of tomatoes, eggplants and peppers by a local company (Annex Organics). Thus, the diversity of bee species observed in this study suggests that pollination by bees may not be the limiting factor for green roof productivity but crop yield could be increased if the green roof is designed to sustain bee populations.

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